Polycyclic Aromatic Hydrocarbons from Waste Incineration

A

Thesis submitted for

the Award of the Degree of

Doctor of Philosophy

by

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Dedicated

To my Parents, my wife Ritu, my brother Ravi Prakash, Sister Vandana and very especially to that unborn baby, affection with whom to play make me to do all prior to her/ his birth.

Thank you for your patience, support and prayers. I love you all.

CERTIFICATE

This is certified that the thesis entitled *"Polycyclic Aromatic Hydrocarbons from waste Incineration"* being submitted by Mr. Vinit Prakash to the School of Chemistry and Biochemistry, Thapar University, Patiala for award of the degree of DOCTOR OF PHILOSOPHY, is a bonafide research work carried out by him under our guidance and supervision and has fulfilled the requirements for the submission of this thesis which, to our knowledge, has reached the request standard.

The results contained in this thesis have not been submitted, in part or in full, to any other University or Institute for the award of any degree or diploma.

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(Vinit Prakash)

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Abstract

This thesis reports the emissions of total 16, 2A and 2B Polycyclic Aromatic Hydrocarbons (PAHs) from the incineration of biomedical waste (BMW)/ industrial hazardous waste (HW) and the effects of combustion parameters (temperature and airflow rate) on their emissions in a specially designed laboratory scale vertical quart tube incinerator. The investigation of management practices followed by ten hospitals, a common biomedical waste treatment facility and two largest acrylic fiber producing industries of India has been under taken with a view to study emerging scenario of biomedical/ hazardous waste management.

Waste samples were collected from Govt. Rajendra hospital, Patiala (blood contaminated blood bag and blood contaminated cotton) and Indian Acrylics limited, Sangrur (acrylic waste solution and cellulose waste filter). Vertical quartz tube incinerator was designed and fabricated for study of PAHs emissions in the laboratory. The collected samples were incinerated at different temperatures and air flow rates in the laboratory scale incinerator.

Studies on Blood contaminated blood bag, Blood contaminated cotton, Acrylic waste solution and Cellulose waste filter has shown that there is no definite trend on PAHs distribution with combustion temperature and airflow rate. Similar findings were also reported by Mastral et al. (1999) on PAHs emissions from coal atmospheric fluidized bed combustion in the pilot scale study. The effect of temperature and airflow rate towards sum of 2A and 2B PAHs has been studied on the collected samples. Blood contaminated blood bag showed lower values of 2A and 2B PAHs at 700ºC or between 900-1000ºC with air flow rate of 1-4 L min^{-1}. Blood contaminated cotton showed the lower values of sum of 2A and 2B PAHs at 700-800ºC with airflow rate of 1-4 L min^{-1}. Acrylic waste solution showed the sum total of 2A and 2B PAHs to be lowest at 700-900ºC with airflow rate of 2-4 Lmin^{-1}. Cellulose waste filter showed the sum total of 2A and 2B PAHs to be less at 700-900ºC with airflow rate of 1-2 L min^{-1}.

There has been increase in number of hospitals/ industries resulting into increase in BMW/ HW. The management of these waste become significant due to risks associated with the health of individuals. Ministry of Environment and Forest Government of India has made BMW/ HW (Management & Handling) Rules. A case study approach has been used for an in-depth analysis of BMW/ HW management practices.

There are 2382 and 181 health care facilities in Punjab and Patiala district and the BMW generated is 6483.76 and 424.3 Kg day^{-1} respectively during 2007. 98% of the BMW waste is treated in Punjab according to BMW management rules. 16% of health care facilities violated these rules and 78% health care facilities utilize common BMW treatment facilities for disposal of waste. The hospitals of Patiala district under study supply their BMW to common BMW treatment facilities whereas Post Graduate Institute - Medical Education and Research has its own incinerator for treatment of BMW. These health care facilities are found to obey BMW (Management & Handling) Rules.

In Punjab, the numbers of hazardous waste producing industries are 3023 which generate HW approximately 323 ton day^{-1} during 2008. Out of this 37 ton waste is disposable; 245 ton is recyclable while 41 ton waste is incinerable. It has been observed that the contribution of Indian Acrylics Ltd., Sangrur (Punjab) and Pasupati Acrylon Ltd., Muradabad (Uttar Pradesh) towards the generation of total HW in respective states is only 0.2 and 0.1 % respectively. Indian Acrylics Ltd. has its own incinerator while Pasupati Acrylon Ltd. supplies the HW to common treatment facility. These industries seem to obey HW (Management & Handling) Rules.

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List of Abbreviation

Abbreviation	**Name**
Acp	*Acenaphthene*
AcPy	*Acenaphthylene*
ACW	*Animal Carcase Waste*
A_{es}	*area of external standard*
AH	*Amar Hospital*
AIDS	*Acquired Immuno Deficiency syndrome*
AIIMS	*All India Institute of Medical Sciences*
Ant	*Anthracene*
APCDs	*Air Pollution Control Devices*
A_{ua}	*Area of Analyte of Unknown Concentration*
AWS	*Acrylic Waste Solution*
BaA	*Benzo(a)anthracene*
BaP	*Benzo(a)pyrene*
BbF	*Benzo(b)Fluoranthene*
BCC	*Blood Contaminated Cottons*
BghiP	*Benzo(g,h,i)perylene*
BkF	*Benzo(k)fluoranthene*
BMW	*Biomedical Waste*
BMW (M&H)	*Bio-Medical Wastes (Management and Handling) Rules*
BWIs	*Biomedical Waste Incinerators*
CBB	*Blood contaminated blood bags*
CBMWTF	*Common Bio-Medical Waste Treatment Facility*
C_{es}	*concentration of external standard*
CHC	*Community Health Centre*
CHR	*Chrysene*
CPCB	*Central Pollution Control Board*
CWF	*Cellulose Waste Filters*
DBA	*Dibenzo(a,h)anthracene*
DCW	*Diesel Component works Hospital*
EG	*Emission Guidelines*
ENVIS	*Environmental Information System*
ENVIS	*Environmental Information System*
EPA	*Environmental Protection Agency*

ESP	*Electrostatic Precipitator*
FID	*Flame Ionization Detector*
FL	*Fluoranthene*
Flu	*Fluorene*
GC	*Gas Chromatography*
GHMH	*Garg Hospital and Maternity home*
GLSMH	*Giani Lal Singh Memorial Hospital*
GRH	*Govt. Rajendra Hospital*
HBr	*Hydrogen Bromide,*
HCFs	*Health Care Facilities*
HCl	*Hydrogen Chloride*
HF	*Hydrogen Fluoride*
HIV	*Human Immuno Deficiency*
HIWIs	*Hazardous Industrial Waste Incinerators*
HPC	*High Powered Committee*
HSWA	*Hazardous and Solid Waste Amendments*
HW	*Hazardous Wastes*
HW (M&H)	*Hazardous Waste (Management and Handling) Rules*
HWC	*Hazardous Waste Combustors*
IAL	*Indian Acrylics Limited*
IARC	*International Agency for Research on Cancer*
ID	*Inner Diameter*
IND	*Indeno(1,2,3-c,d)pyrene*
KH	*Kamal hospital*
MER	*Medical Education and Research*
MG	*Mecanical Grate*
MKH	*Mata Kaushalya Hospital*
MMTA	*Metric Million Tones per Annum*
MoEF	*Ministry of Environment and Forestry*
MS	*Mass Spectroscopy*
MSPCB	*Maharastra State Pollution Control Board*
MSW	*Municipal Solid Waste*
N.T.P.	*National Toxicology Program.*
Nap	*Naphthalene*
NOx	*Nitrogen Oxides*
NRC	*National Research Council*

NSPS	*New Source Performance Standards And*
NTP	*National Toxicology Program*
PA	*Phenanthrene*
PAHs	*Polycyclic Aromatic Hydrocarbons*
PAL	*Pasupati Acrylon Limited*
PCBs	*Polychlorinated Biphenyls*
PCDD/Fs	*Polychlorinated Dibenzo Dioxins/Furans And*
PE	*Polyethylene*
PGI	*Post Graduate Institute*
PIC	*Products Of Incomplete Combustion*
POPs	*Persistent Organic Pollutants*
PPCB	*Punjab Pollution Control Board*
PS	*Polystyrene*
PSCST	*Punjab State Council Of Science And Technology*
PVC	*Polyvinyl Cloride*
Pyr	*Pyrene*
RCRA	*Resource Conservation And Recovery Act*
RF	*Response Factor*
SCOT	*Support-Coated Open Tubular*
SDNP	*Sustainable Development Networking Programme*
SH	*Singla Hospital*
SOx	*Sulphur Oxides*
SREMPL	*Sembramky Environmental Management Pvt. Ltd.*
TCDD	*Tetrachlorodibenzo-P-Dioxin*
TDF	*Tire Derived Fuel*
TEDDY	*Teri Energy Data Directory And Yearbook*
TEQ	*Toxic Equivalents*
TGA	*Thermo Gravimetry Analysis*
TPA	*Tone Per Annum*
TSDF	*Treatment, Storage and Disposal Facility*
UNEP	*United Nations Environment Programme*
UV	*Ultra Violet*
VOCs	*Volatile Organic Compounds*
WCOT	*Wall Coated Open Tubular*
WHO	*World Health Organization*
WMG	*Waste Management Guidelines*

WMG	*Waste Management Guidelines*
WSB	*Wet Scrubber*
1-HOP	*1-Hydroxypyrene*

Chapter – I

Introduction

This chapter highlights the status of environment regarding contamination with PAHs. Incineration, considered to be the best available technology to treat the hazardous components of waste, results into the emission of organic (including PAHs) and inorganic releases to the environment. It has been shown that the study of PAHs emissions from waste incineration is of special environmental concern.

The health status of an individual, a community or a nation is determined by the interplay and integration of two ecological factors i.e., the internal environment of man himself and the external environment of man which surrounds him. The increased standard of living is creating a great threat to both the environments by generating a huge amount of waste. The term ‘waste’ generally, refers to materials, which ceases to be useful to the person who is producing it. Depending upon the source of generation, it may be hospital waste, industrial waste, municipal solid waste or agricultural waste. The ability of the land, water and air to absorb these wastes is limited. Man’s relentless exploring of natural resources is undoubtedly successful but unfortunately adding poisoned rivers, darkened sky and wastelands to our universe. The scientists, climatologists, and environmentalist have alarmed the modern man against devastating impact of unscientific and reckless exploitation of natural resources and pleaded to save the life existing on the earth. The world faces a wide variety of complex environmental threats: the loss of biodiversity, the depletion of ozone layer, global climate change, degradation of soil and water resources, and accumulation of wide spread health threatening pollutants (Corwin et al., 1997). Hence, proper disposal of waste is necessary to avoid human injuries and environmental pollution.

Waste may be classified into hazardous and non-hazardous waste (Bruner, 1994) depending upon its nature. Although no precise definition of ‘hazardous wastes’ has received wide acceptance, hazardous substances are considered to be those substances which may cause adverse or chronic effects on human health or on environment. Hospital and industrial wastes constitute a larger part of what is known as ‘hazardous wastes’ (HW). In India, the HW from hospitals which is infectious in nature is known as Bio-medical waste. The production of these wastes is and will continue to be an on going phenomenon as long as human civilization persists. The health impacts of direct and indirect exposure to HW include: carcinogenic, mutagenic and teratogenic effects, reproductive system damage, respiratory and central nervous system effects etc. (Mato and Kaseva, 1999).

There is increasing concern with the disposal of hospital/ HW due to the large increase in volume of waste from the growing trend of single-use disposable goods and plastics, the continued expansion and construction of new facilities/industries, and the hazards of handling and disposing of HW (Stegemann et al., 1995). HW has become a serious health hazard in many countries, including India. Careless and indiscriminate disposal of the waste by healthcare establishments and research institutions can contribute to the spread of serious diseases such as hepatitis and AIDS (HIV) among those who handle it and also among the general public (Gupta, and Boojh, 2006). In order to sustain our earth, it is necessary to minimize the negative influence of hazardous components of waste through proper disposal methods, so that it renders minimum damage to the environment. In addition to physical and chemical treatment, incineration appears to be viable option (Saxena and Jotshi, 1996).

1.1 Incineration

Incineration is an engineered process that employs thermal decomposition via thermal oxidation at high temperatures (usually 800°C or greater) to destroy organic fraction of the waste (Saxena and Jotshi, 1996). On-site incineration is becoming an increasingly important alternative for the treatment and disposal of hazardous waste (Brewer, 1993). Lee and Hoffman (1996) indicated that hospital waste incineration has potential to be continuously used in future as it is quite safe method for the neutralization of toxic and hazardous components of waste. It is today’s potentially viable, but controversial technology. Currently it is used for destroying contaminated hospital wastes, reducing municipal waste volumes, substantially cutting amounts of chemical and biological waste (HW) and producing energy (Mckone and Hammond, 2000). It is an important and commonly used method for the treatment of waste due to reduction in both the mass, about 70%, and volume, about 90%, of waste subjected to final disposal, as well as the possibility of energy recovery.

Generally, combustible wastes or wastes with significant organic content are considered most appropriate for incineration. However, any waste with a hazardous organic fraction is a functional candidate for incineration. Even significant amount of contaminated water and contaminated soils are being incinerated (Oppelt, 1987). Under flame oxidizing conditions, the organic compounds can be destroyed totally in a few milliseconds. Conventionally, it is the ratio of oxidizer to fuel which just leads to complete combustion (Mukunda, 1989). The important elements are carbon and hydrogen for fuel and oxygen for oxidizer and the complete products are CO_2 and H_2O. But in the real world situation, even under good combustion conditions, products of incomplete combustion (PIC) as by-products are emitted. These may be organic or inorganic in nature. Organic may include polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo dioxins/furans (PCDD/Fs) and polychlorinated biphenyls (PCBs). In reality, what appears outwardly to be straightforward, simple combustion process, is actually an extremely complex one involving thousands of physical and chemical reactions, reaction kinetics, catalysis, combustion aerodynamics, and heat transfer. This complexity is further aggravated by the complex and fluctuating nature of the waste feed to the process (Zheng, 1997). The vast majority of species formed, combines with oxygen and are converted into CO_2 and H_2O, and some other compounds depending upon the elemental composition of the fuel. However there is always some trace amounts of organic PIC remaining in any flue gas. Incineration of waste is not without its own environmental hazards as it has to be carried out under appropriate thermal conditions. It has been seen that the residue from hazardous waste incineration are still hazardous, unless proved otherwise. However the advantage of waste incineration is that the volume and mass of the waste is drastically reduced (Rao and Garg, 1994; Stegemann, 1995).

1.2. Organic Pollutants

Intensive development of civilization together with evolution of industry has caused deep changes in the quality of the environment in which human beings live. Human activities have introduced many kinds of chemical components into the atmospheric environments through industry, automobiles, combustion and many other activities. These chemical components contribute to many environmental problems, such as photochemical smog and asthmatic disease. Generally, most of the processes which add organic pollutants to the environment are combustion related. Since combustion is the dominant cause of air pollution, the various combustion sources emit the same pollutants to a large extent but only in varying proportions. Organic substances can also be brought to the atmosphere due to their evaporation from the earth's surface or emission from the human activities and subsequently transported with the masses of air over long distances (Grynkiewicz et al., 2002).

The class of volatile organic compounds (VOCs) includes species with different physical and chemical behaviors. Pure hydrocarbons containing carbon and hydrogen as the only elements (e.g., alkanes, alkenes, alkynes, aromatics and PAHs) are important VOC classes. The class of persistent organic pollutants (POPs) includes chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment. With the evidence of long-range transport of these substances to regions where they have never been used or produced and the consequent threats they pose to the environment of the whole globe (UNEP, 2001).

There is a growing concern about pollution by POPs including PAHs. In May 2001, a global treaty for the regulation of POPs was signed: the "Stockholm Convention" which includes instruments for the total elimination of 12 POPs on a global scale. Large-scale programs are conducted in relation to the long-range transboundary atmospheric pollution or their discharge into the sea (Gaga, E.O. (2004). To these 12 POPs, the United Nations-European Community has added the PAH viz., benzo(a)pyrene which is considered to be the most toxic. The main objective is to control, reduce or eliminate discharges, emissions and losses of POPs (Garban et al., 2002).

1.3. PAHs and their sources

PAHs are two to eight-ring semi-VOCs formed mainly during incomplete combustion from natural and anthropogenic sources. Natural sources of PAHs are such as forest fires and volcanic eruptions while anthropogenic sources of PAH can be divided into stationary and mobile categories. The stationary category encompasses a wide variety of combustion processes including residential heating, industrial activities (e.g. aluminum production, coke manufacture etc.), incineration of waste and power generation which result in high concentrations of atmospheric PAHs in the vicinity of the major sources. Within the mobile category, the major contributors are vehicular petrol and diesel engines.

In any fuel combustion, PAH formation and emission mechanisms are classified into two processes: pyrolysis (Mastral et al., 1996) and pyrosynthesis (Bjorseth and Ramdahl, 1985; Williams et al., 1986; Barbella et al., 1990; Bonfanti et al., 1994). Organic compounds are partially cracked to smaller and unstable fragments upon heating (pyrolysis). These fragments, mainly reactive free radicals lead to more stable PAH formation through recombination reactions (pyrosynthesis). During thermal decomposition of organic fractions of waste, propargyl ($C_3H_3^{\bullet}$) and cyclopentadienyl ($C_5H_5^{\bullet}$) radicals also play significant role in the formation of first aromatic rings (Richter and Howard, 2000). PAH formation and sequential growth of PAH take place by reactions with stable and radical species, including single-ring aromatics, lower molecular weight PAH and acetylene, followed by the nucleation or inception of small soot particles, soot growth by coagulation and mass addition from gas phase species, and carbonization of the particulate material.

1.4. Toxicity and carcinogenicity of PAHs

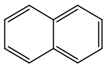
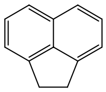
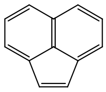
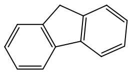
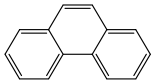
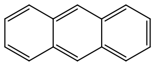
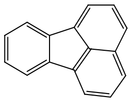
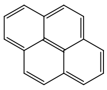
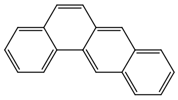
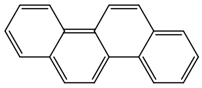
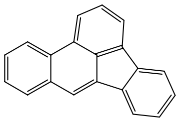
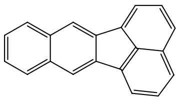
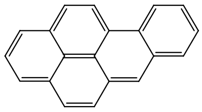
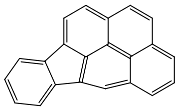
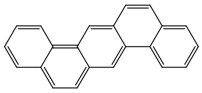
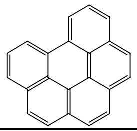
Emissions of PAHs from incomplete combustion are of special environmental concern because of their possibility of interacting with biological nucleophiles, such as proteins, inhibiting the regular metabolic functions of the cells and causing carcinogenesis (Williams, 1990; Lee, 1981; Longwell, 1983; and Barfnedit et al., 1980). The chronic exposure to carcinogenic PAHs concomitant with exposures to multiple chemicals or biological agents in indoor-air (respireable suspended particulate matter) could be an attributable risk factor for acute/chronic pulmonary illnesses, asthma, pulmonary tuberculosis and lung cancer (ICMR, 2001).

The differences in carcinogenic activity of many of these compounds are related to the structure of compound (Ortiz, 2002). The US Environmental Protection Agency (US EPA, 1997) has fixed 16 PAHs as priority pollutants. These compounds are: naphthalene (Nap), acenaphthene (Acp), acenaphthylene (AcPy), fluorene (Flu), phenanthrene (PA), anthracene (Ant), fluoranthene (FL), pyrene (Pyr), benzo[a]anthracene (BaA), chrysene (CHR), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), benzo(g,h,i)perylene (BghiP), dibenzo(a,h)anthracene (DBA) and indeno(1,2,3-c,d)pyrene (IND). The molecular structures of 16 PAHs, physical properties and their toxicology and carcinogenicity are given in Tables 1.1 - 1.3. BaP, DBA and BaA have been classified as probable human carcinogens (2A) while BbF, BkF and IND have been classified as possible human carcinogens (2B) (IARC, 1983; 1987). Nap has been evaluated and reclassified as possible human carcinogens (IARC, 2002). Moreover, in 2005, the Joint (Food and Agriculture Organization/World Health Organization) Expert Committee on Food Additives (JECFA) and Scientific Committee on Food have classified 16 PAHs as priority compounds in food (EFSA, 2007).

Since some PAHs are carcinogenic as well as mutagenic so their identification and minimization are imperative in the combustion process (Chien and Shih, 2006). These PAHs may be transformed to even more toxic compounds by chemical reactions such as sulfonation, nitration or photo oxidation. Traces of nitric acid are known to transform some PAHs into nitro-PAHs (Marce and Borrull, 2000).

Organic compounds released from their sources in gas phase or can be associated with particles by nucleation and condensation, forming particulate matter. The particulate form of PAHs are initially in the gaseous phase at high combustion temperature, however when the temperature decreases, gaseous phase PAHs adsorb or deposit on fly ash particles. Nap has been found 100 % in gas phase, while BaP and other compounds with 5 and 6 rings are adsorbed on particulate matter. However, Nap was also found at high levels in the ash from pulverized coal power generation (Mastral and Callen, 2000).

Table 1.1: Molecular structures of 16 PAHs fixed by US EPA (1997) as priority pollutants

S. No.	**PAHs**	**Abbreviations**	**Structure**
1	Naphthalene	Nap	
2	Acenaphthene	Acp	
3	Acenaphthylene	AcPy	
4	Fluorene	Flu	
5	Phenanthrene	PA	
6	Anthracene	Ant	
7	Fluoranthene	FL	
8	Pyrene	Pyr	
9	Benzo[a]anthracene	BaA	
10	Chrysene	CHR	
11	Benzo[b]fluoranthene	BbF	
12	Benzo[k]fluoranthene	BkF	
13	Benzo[a]pyrene	BaP	
14	Indeno(1,2,3-c,d)pyrene	IND	
15	Dibenzo(a,h)anthracene	DBA	
16	Benzo(g,h,i)perylene	BghiP	

PAHs are regarded as POPs in the environment. This persistence increases with ring number and condensation degree (Henner et al., 1997). Moreover, National Toxicology Program (NTP, 2004) has evaluated Nap and classified it as "reasonably anticipated to be a human carcinogen". Since some PAHs are carcinogenic as well as mutagenic so their identification and minimization are imperative in the combustion process (Chien and Shih, 2006).

Table 1.2: Chemical formula and physical properties of 16 PAHs fixed by US EPA (1997) as priority pollutants

S.No.	PAHs	Formula	Molecular Weight	Melting Point (°C)	Boiling Point (°C)	Vapor Pressure (kPa)
1	Nap	$C_{10}H_8$	128.18	80.2	218	$1.1x10^{-2}$
2	Acp	$C_{12}H_{10}$	154.20	90-96	278-279	$2.1x10^{-3}$
3	AcPy	$C_{12}H_8$	152.20	92-93	265-280	$3.9x10^{-3}$
4	Flu	$C_{13}H_{10}$	166.23	116-118	293-295	$8.7x10^{-5}$
5	PA	$C_{14}H_{10}$	178.24	96-101	339-340	$2.3x10^{-5}$
6	Ant	$C_{14}H_{10}$	178.24	216-219	340	$36x10^{-6}$
7	FL	$C_{16}H_{10}$	202.26	107-111	375-393	$6.5x10^{-7}$
8	Pyr	$C_{16}H_{10}$	202.26	150-156	360-404	$3.1x10^{-6}$
9	BaA	$C_{18}H_{12}$	228.30	157-167	435	$1.5x10^{-8}$
10	CHR	$C_{18}H_{12}$	228.30	252-256	441-448	$5.7x10^{-10}$
11	BbF	$C_{20}H_{12}$	252.32	167-168	481	$6.7x10^{-8}$
12	BkF	$C_{20}H_{12}$	252.32	198-217	480-471	$2.1x10^{-8}$
13	BaP	$C_{20}H_{12}$	252.32	177-179	493-496	$7.3x10^{-10}$
14	IND	$C_{22}H_{12}$	276.34	162-163	530-560	$1x10^{-11}$
15	DBA	$C_{22}H_{14}$	278.35	266-270	524	$1.3x10^{-11}$
16	BghiP	$C_{22}H_{12}$	276.34	275-278	525	$1.3x10^{-11}$

1.5. Distribution of PAHs

The PAHs are universally distributed in our ecosystem. The distribution of PAH in the atmosphere between the gas and particulate phases is determined by several factors, such as the vapor pressure of the PAH (as a function of temperature), the amount of fine particles (in terms of available surface area for adsorption of PAHs), the ambient temperature, PAH concentration and the affinity of individual PAH for the particles organic matrix (Baek et al., 1991). Low molecular weight PAHs (two- and three-rings) are primarily in the gas phase while high molecular weight PAHs (five-rings) are primarily found in the particulate phase. Intermediate molecular weight PAHs (four-rings) are partitioned between the vapor and particulate phases, depending on atmospheric temperature (Howsam et al. 2000, 2001). Gas phase percentages were generally higher in summer than in winter due to increasing temperature which increases the vapor pressure of the compounds (Odabasi, 1998, Kaupp and MacLachlan, 1999).

Table 1.3
Toxicological profile of 16 PAHs

PAHs	**PP** (US EPA, 1997)	**GT** (WHO, 1998)	**CG** (WHO, 1998)	**TP** (US ATSDR, 1995)	**PC** (EFSA, 2007)	**P/PC** (IARC, 1987; 2002)	**POPs Protocol** (UNECE, 1998)
Acp	√	?	?	√	….	….	….
AcPy	√	?	….	√	….	….	….
Ant	√	….	….	√	….	….	….
BaA	√	√	√	√	√	2A	….
BbF	√	√	√	√	√	2B	√
BkF	√	√	√	√	√	2B	√
BghiP	√	√		√	√	….	….
BaP	√	√	√	√	√	2A	√
CHR	√	√	√	√	√	….	….
DBA	√	√	√	√	√	2A	….
FL	√	√	√	√	….	….	….
Flu	√	….	….	√	….	….	….
IND	√	√	√	√	√	2B	√
Nap	√	….	?	….	….	2B	
PA	√	?	?	√	….	….	….
Pyr	√	?	?	√	….	….	….

√ *-Classified*
? *-Questionable*
PP -Priority Pollutants
GT -Genotoxic
PC -Priority Compounds
CG -Carcinogenic
TP -Toxic Profile
P/PC -Probable/Possible Carcinogenic
POP -Persistent Organic Pollutants

The vapor pressure of a PAH molecule determines to a large extent, the phase (particulate or vapor) in which it will be found. Junge (1977) showed for urban particulate matter that compounds with vapor pressures above 1x10^{-5} kPa occur almost entirely in the gas phase, whereas compounds with vapor pressures less than 1x10^{-9} kPa exist predominantly in the particulate phase. Any compound with a vapor pressure between these approximate limits would be expected to occur in both the vapor and particle phase.

Two and three-rings PAHs estimated to be contributed most from combustion activities (60%), vehicular emissions (22%), diesel combustion (11%), and from miscellaneous sources (7%) (Singh et al., 2008). The four-rings PAHs were contributed most by natural gas, wood, coal/coke combustion (50%) and vehicular emissions (41%). The five-rings PAHs were mainly contributed by the combustion activities (54%) and vehicular emissions (44%). Contributions of the higher members (6-ring) PAHs from combustion processes and diesel based activities were 58 and 41%, respectively. Most PAH adsorbed onto fine particles (< 2.5 μm), which depending on atmospheric conditions and chemical reactivity, may be transported over long distances and pollute even remote areas. PAHs on particles < 1 μm are from combustion and other high temperature sources (Sheu et al. 1997; Kiss et al. 1998). Ingestion of PAH contaminated air, water and soil is considered to be a major exposure route. Health risk assessment is based on extrapolations from data obtained via various studies of PAHs exposure.

1.5.1. Indoor and ambient air

Indoor air quality is of particular interest in the world. With the different functions and ventilation conditions, the concentrations of PAHs in indoor air are: kitchen > living room > balcony. Indoor air of kitchen is polluted by PAHs that come from not only outdoor air but also indoor emission sources such as cooking, gas home appliances (Liu et al. 2001). Except for cooking practice, cooking oil-fumes make a significant contribution to PAHs concentrations of indoor air (Moret and Conte, 2000). Biofuels, including wood, dried animal-dung cake and crop waste, are used extensively for cooking energy and are main contributors of indoor PAHs. In India, high concentrations of particulate PAH compounds have been reported in indoor environments, during biofuel combustion for cooking (Raiyani et al., 1993a, 1993b, 1993c; Smith, 1987; Toqan et al., 1984). Low-temperature biofuel combustion has the potential to result in higher emissions of PAH than high-temperature industrial sources. High concentrations of PAHs have been measured in smoke from solid-fuel stoves burning wood, coal and dried cattle manure (Raiyani et al., 1993b) which along with kerosene stoves (Saksena et al., 1996) are used as the primary cooking device by urban slum residents.

The risk associated with human exposure to atmospheric PAHs is also highest in cities, considering the density of population, increasing vehicular traffic and scarce dispersion of the atmospheric pollutants (Rockens et al. 2000). In India, ambient concentrations of particulate BaP have been measured in Mumbai (Mohan et al., 1983) and Ahmedabad (Aggarwal et al., 1982). Studies of PAHs concentrations in ambient aerosol in Ahmedabad, Mumbai, Nagpur and Kanpur show that total PAH concentrations in Indian cities are 10-50 times higher than those reported internationally and range 23-190 µg m^{-3} (Raiyani et al., 1993c; Pandit et al, 1996; Vaishali et al., 1997). Mass concentrations of PAHs have also been reported for Indian cities including Mumbai, Ahmedabad, and Nagpur. Total PAHs concentrations measured at two locations in Mumbai and were found to be 38.8 µg m^{-3} at Saki Naka and 24.5 µg m^{-3} at IIT (Kulkarni and Venkataraman, 2000). Sharma et al. (2007) reported that concentrations of total PAHs in air were 0.667 ± 0.399 and 0.672 ± 0.387 µg m^{-3} (Delhi, India) in the years 2002 and 2003, respectively.

Available data reveals that the concentrations of PAHs are higher in the winter months (Zhou et al., 2005) than in the monsoon and summer months. The concentration of total PAHs were found to be greater in winter (0.47-2.77 µg m^{-3}) as compared to summer (0.70-1.82 µg m^{-3}) in ambient air and were greatest in breathing zone (0.69-9.18 µg m^{-3}) during winter. Maximum concentrations of indoor air BaP (>1.5 mg m^{-3}) has been found in breathing zone in winter in Indian study (Bhargava et al., 2004). Bacskay et al. (2008) recently determined the seasonal variations of PAHs in air particulate extracts and found the mean concentrations of BaP ranged from 1.05 to 3.50 ng m^{-3}. Zhang et al. (2008) studied transport pattern of PAHs in different particle-size fractions of sandy soils. Exposure levels of on-duty traffic police in Beijing to gaseous and particulate PAHs were found to be 1.525 ± 0.759 and 0.148 ± 0.118 µg m^{-3}, respectively (Liu et al. (2007). Presently, limit values of BaP recommended or mandatory in countries like Italy or Germany in air is 0.001 or 0.01 µg m^{-3}. The PAHs from atmospheric air get distributed to plants, food, water, soil and sediments. Kuo et al. (2003) have shown the exposure dose of 22 PAHs per day ranged from 3.18 to 18.0 µg day^{-1} and the personal inhalation BaP_{eq} levels were in the range of 0.4 to 1.55 µg day^{-1} from particulate matter.

1.5.2. Plants

The large surface area of many plants is covered with waxes that facilitate the accumulation of hydrophobic chemicals. The plants work as passive samplers of organic compounds in the atmospheric (Niu et al. 2003; De Nicola et al. 2005; Lodovici et al. 1998; Muller et al. 2001). Schreiber and Schonherr (1992) reported that the main factor affecting the absorption of volatilized PAHs through the cuticle is the extent of leaf area exposed to the atmosphere. PAHs from a polluted atmosphere are generally transferred to plants by particle-phase deposition on the waxy leaf cuticle or by uptake in the gas phase through stomata (Kipopoulou et al. 1999; Lehndorff and Schwark 2004). Leaf features (surface, cuticular waxes, hairs, number of stomata) play an important role in PAH uptake and accumulation (Jouraeva et al. 2002). PAHs can also enter plant tissues by partitioning from contaminated soil to the roots and translocation into the shoot.

1.5.3. Food

Food pollution is due to deposition of PAHs from air or water or results from precipitation, drying and cooking procedures (Zebek, 1980; Lawrence and Weber, 1984; Yang et al., 1998). Humans who are not occupationally exposed to PAH may be exposed to them by intake of food. Consumers could be exposed to PAHs by eating grilled or charred meats, contaminated cereals, flour, bread and vegetables (Grova et al. 2006). Kishikawa et al. (2003) have reported the average concentrations of total PAHs in commercial milk, infant formula and human milk were 0.99, 2.01 and 0.75 μg kg^{-1} respectively. Several studies achieved in environmental conditions have shown the presence of PAHs in the milk of ruminants (Grova et al. 2000, 2006). Fiedler et al. (2002) have found the total PAH concentrations in green tea leaves ranges from 497 - 517 μg kg^{-1} and in brick tea leaves ranges from 1,048 - 1,162 μg kg^{-1}. These concentrations are comparable to those in vegetation grown along the motorway (772 μg kg^{-1}) and an urban area (1,901 μg kg^{-1}) at North West Italy (Ardito et al. 1999). Lodovici et al. (1995) determined average PAHs in tomato and cauliflower to be 0.064 μg kg^{-1} and 2.79 μg kg^{-1} respectively. The PAHs content in tomato, apple and grape were found to be 14.62, 4.05 and 3.87 μg kg^{-1} respectively (Camargo, 2003).

Janska (2006) found the varying PAH concentration from 3.75 - 25.14 μg kg^{-1} in various fruits and vegetables.

Among different congeners of PAHs, two-ring and three-ring PAH were found in higher concentration in fish muscles (Cheung et al. 2007). Malik et al. (2008) studied total PAHs in the fish muscles from Gomti River in India and found these in the range of 12.85 - 34.89 μg kg^{-1}. Vyskocil et al. (2000) shown that food consumption is the main source of PAH exposure for the children even in the big cities that are not heavily polluted by PAH from industrial sources. Butler et al. (1993) measured personal exposure to BaP in 15 adult individuals living in a town in New Jersey (USA) having population of 17,000. Concentration of total PAHs in different brands of tea and coffee samples varied from 18.79 - 31.37 μg L^{-1} and from 16.47 - 18.24 μg L^{-1}, respectively (Bishnoi, 2005). Ziegenhals et al. (2008) observed total PAH in tea samples and found in the range 14 - 2,662 μg kg^{-1}.

The risk associated with dietary PAHs is assessed by European Food safety Authority (Janska, 2006). The concentrations of BaP in meat and meat products is being restricted to 1μg kg^{-1} in Germany, and for food and beverages to 0.03 μg kg^{-1} in Italy. The maximum daily BaP intake from food can be extrapolated to be 1 μg (Jacob and Seidel 2002).

1.5.4. Water

PAHs enter surface waters mainly via atmospheric fallout, urban run-off, municipal effluents, industrial effluents, cleaning of air pollution control devices and oil spillage or leakage. Atmospheric fallout includes wet and dry deposition of particles and vapors. PAHs exist in both gaseous and particulate phase in air and are washed out from the atmosphere during precipitation. Atmospheric deposition is considered to be an important input of PAHs to surface waters. It has been estimated that 10–80% of PAH inputs to the world's oceans is from atmospheric sources. Higher concentrations of PAHs in urban runoff were found during autumn and winter, due to the high incidence of vehicles in the streets, coupled with the use of heating systems (Manoli and Samara 1999).

1.5.5. Soil

Accumulation of PAHs in soils may lead to further potential contamination of vegetables and food chains (Kipopoulou et al. 1999; Mueller and Shann

2006), and cause direct or indirect exposure to human. Moreover, leaching, evaporation and migration are possible PAHs sources of atmospheric or groundwater contamination. Sorption and degradation are key processes that affect the fate and transport of PAHs in the environment (Magee et al. 1991). Sorption also plays a key role in controlling transport of PAHs during leaching, as well as in transformation and bio-accumulation processes (Reeves et al. 2004).

Studies showed the presence of PAHs in soils (Wild et al. 1990; Weiss et al. 1994; Nam et al. 2003). PAHs with three rings or more tend to be very strongly adsorbed to the soil matrices (Knox et al. 1993), preferentially to small aggregates (< 50 µm), which also contain the most humified organic matter (Quantin et al. 2005). Strong adsorption coupled with very low water solubility render PAH loss by leaching insignificant. Lichtfouse et al. (1997) reported that soil PAHs were mainly of pyrolytic origin, e.g. exogenous (airborne) contributions of fossil fuel combustion products and (old) vegetation fires, with a small contribution of uncombusted fossil fuels.

Zhang et al. (2008) studied transport pattern of PAHs in different particle-size fractions of sandy soils. Street dust and surface soil samples in urban areas of Dalian (a coastal city in Liaoning Province, China) showed the concentrations of total PAHs in street dust to be 1890 - 17,070 µg kg^{-1} (dry weight) while in surface soil from 650 - 28,900 µg kg^{-1}(Wang et al., 2008).

The highest concentration of PAHs was detected in the chemical area of Tarragona (476.2 µg kg^{-1}), which was 2 - 4 times higher than those of the urban/residential (206.9 µg kg^{-1}) and the petrochemical zones (119.7 µg kg^{-1}), respectively. The lowest concentration was from soils samples in the unpolluted area (52.8 µg kg^{-1}) (Nadal et al. 2007). Wilcke and Amelung (2000) reported that the total of 20 PAHs in the soils from North America Great Plain ranges from 60 - 180 µg kg^{-1}. The total PAHs concentrations in soils from the paddy fields at Hunpu wastewater irrigation areas in Shenyang (China) were between 950 and 2,790 µg kg^{-1}.

Chen et al. (2003) reported total PAHs in the range 3,000–5,000 µg kg^{-1} for agricultural soil within the wastewater irrigation region in Tianjin (China). PAH contents ranged from 450 µg kg^{-1} of dry material at Honfleur to 5,650 µg kg^{-1} at Notre-Dame de Gravenchon (France) (Motelay-Massei et al. 2004).

Maliszewska-Kordybach (1996) found 264 µg kg^{-1} of 16 PAHs in agricultural soils in Poland. Aamot et al. (1996) found 144 µg kg^{-1} of PAHs (low values) in forested soils of Norway. However, in Estonian urbanized areas, the high levels reported were from 2,200 - 12,300 µg kg^{-1} (Trapido 1999). Mielke et al. (2001) found concentrations of 3,700 µg kg^{-1} in the soil of urban centre of New Orleans (USA). The concentration range of 16 PAHs varied by over two orders of magnitude from 0.016 µg kg^{-1} in rural to 3.884 µg kg^{-1} in suburban soils of Beijing (China) (Ma et al., 2005). Total PAH concentrations ranged from 0.144 to 0.308 µg m^{-3} and 0.239 to 0.537 µg m^{-3} for Chenlou and Meteorological tower sampling, respectively (Wu et al. 2006). Pies (2007) found total PAHs up to 81 mg kg^{-1} dry weight in the soil samples in floodplain soils of the Mosel and Saar River (Germany).

1.5.6. Sediments

Sediments are deposited material consisting of organic matter in various stages of decomposition, particulate mineral matter and inorganic material of biogenic origin. They have been proven an efficient tool to identify environmental impacts (Evans et al. 1990). Due to the exposure time to industrial effluents, they are valid for long-term studies. Sediments constitute a pollutant trap and are an important factor to establish the assimilative capacity of the environment. Sediments may contain a high level of pollutants ready to pass on to the food chain or be mobilized by anthropogenic or natural means. Therefore, sediments can act as indicator of the relationship between natural and anthropogenic variables (Salomons 1995; Calmano et al.1996). PAHs entering the aquatic environment, due to their hydrophobicity, rapidly become associated with sediments and suspended particles. Sediment retention capacity may be related to physico-chemical properties such as grain size and organic matter. The sorption of hydrocarbons is related to the organic matter of the sediments. Viguli et al. (2002) studied the distribution of PAHs in surface sediments of the Santander Bay, Cantabric Sea (Spain) and found the concentration of PAHs were strongly dependent on the organic matter, with sediments below 2% of organic matter always below 10 µg of total 16 PAHs per gram dry weight. The left side of the Bay, where the main urban and industrial activities take place, showed sediment samples with very high concentrations (355 µg g^{-1} dry weight) of the sum of the 16 PAHs. Rao (2003) found 10 PAHs in Sediments from Kolleru Wetland in India. Wayland et al. (2008) determined levels of PAHs and dibenzothiophenes in wetland sediments and aquatic insects in the oil sands area of Northeastern Alberta, Canada. The extent of exposure to PAHs can be usually determined by measuring 1-Hydroxypyrene(1-HOP) in urine samples. The biological monitoring of PAH enables the best way to assess the internal dose of PAH.

1.6. 1-Hydroxypyrene (1-HOP) - biological monitoring

The assessment of environmental exposure to PAH requires the measurement of levels present in each pathway of possible contact. van Schooten et al. (1997) examined the absorption and excretion of PAH in rats orally exposed either to industrially contaminated soils or pure model compounds like Ant, PYR and BaP. The model compounds and the metabolites, *1-HOP* and 3-hydroxy BaP, were measured in blood, feces or urine. Only low levels of the compounds were excreted unchanged in feces whereas the levels of the metabolites were considerably higher in feces and urine.

Higher concentrations of 1-HOP in the urine of municipal workers indicated exposure to elevated levels of PAHs (Angerer, 1990). 1-HOP in human urine was examined as a potential biomarker for the assessment of human exposure to PAHs (Viau et al. 1995). Generally 1-HOP levels are influenced by factors such as diet, industrial pollution, and cigarette smoking. Most studies showed the concentrations of urinary 1-HOP are correlated with cigarette smoking in a non-occupational population (Van Rooij et al. 1994; Levin 1995). A statistically significant correlation between the levels of 1-HOP in human urine and those of PYR and BaP in ambient air was observed (Jongeneelen et al. 1986). Smoking has little influence on this correlation when persons smoke less than 20 cigarettes daily in an environment with a relatively high baseline concentration of air-borne PAHs. These observations support the use of 1-HOP as a potential biomarker of PAH exposure. According to Li et al. (2000) the average concentrations of urinary 1-HOP were 0.04, 0.20, 0.46 and 1.16 μmol mol^{-1} creatinine in non-smokers, light smokers, medium smokers and heavy smokers respectively. The urinary 1-HOP levels of light, medium and heavy smokers were 5, 11 and 28 times higher than those of nonsmokers, respectively. Suzuki and Yoshinaga (2007) reported exposure level for PYR (diet/inhalation: 757/1.2 ng day^{-1}), BkF (diet/inhalation: 25/1.7 ng day^{-1}) and BaP (diet/inhalation: 91/2.1 ng day^{-1}).

The concentrations of 1-HOP and 1-, 2-, 3-, and 4-hydroxyphenanthrene as metabolites of PYR and PA were measured by Gundel et al. (1996) in urine samples collected from 124 housewives (27 smokers and 97 nonsmokers) living in Bottrop (an industrial city located in the Ruhr area in Germany). Smokers had significantly higher urine concentrations of 1-HOP (median 0.487g g^{-1} creatinine), 3- hydroxyl PA (median 0.617g g^{-1} creatinine), 2- hydroxyl PA (0.417g g^{-1} creatinine) and 4- hydroxyl PA (median 0.107g g^{-1} creatinine) than non-smokers (median 0.157g g^{-1} creatinine, 0.317g g^{-1} creatinine, 0.317g g^{-1} creatinine and 0.047g g^{-1} creatinine, respectively).

There is a growing interest in PAH emissions (Williams et al., 1995; Mastral et al., 1997 and Srogi, 2007). One way to abate their emissions could be control of different variables that affect combustion (Mastral et al., 1997). Other way is to minimize their formation by study of PAH formation in relation to combustion process conditions (Bonfanti et al., 1994). Some of the variables, such as the nature of combusting material (Akers et al., 1994), are difficult to modify while others, such as combustion temperature (Mastral et al., 1996) and airflow rate (percentages of excess oxygen) (Mastral et al., 1999), could be controlled to avoid higher emissions.

1.7. Determination of PAHs

Gas Chromatography (GC) is a very popular technique in organic analytical research, because of its very high selectivity and resolution, good accuracy and precision, wide dynamic range and high sensitivity. Capillary GC was first applied to analyse PAHs in the early 1960's and its use has progressed to the point that it now comprises one of the standard methods for determination of these compounds in environmental matrices. For *analyzing PAHs,* open tubular capillary column coated with liquid 5% (phenyl) methyl polysiloxane (non-polar stationary phase) is used. Flame ionization detector (FID) is normally adequate for sensitive detection of PAHs (Santos and Galceran, 2002).

More polar analytes need to be removed from the extract by column chromatography (solid-phase extraction or liquid chromatography) in order to obtain best chromatographic conditions with GC–FID. A wealth of literature is available on the use of this method for the determination of PAHs in all types of environmental samples. GC-FID is a component of national standard methods (in Italy, Greece, Germany, Denmark etc.) for the determination of PAHs in air (EC, 2001) and in solid waste (US EPA, 1980). Use of GC–FID for determination of PAHs in environmental samples include the analysis of air particulates (Lung, 2004; Sharma, 2007), water (Bagheri and Mohammadi, 2003), and sediment (Hyotylainen and Oikari, 1999; Jaouen-Madoulet, 1996). Poster et al. (2006) critically reviewed the analysis of polycyclic aromatic hydrocarbons (PAHs) in environmental samples by GC methods.

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Chapter – II

Review of Literature

This chapter presents an account of available literature on the status of incineration of biomedical waste and hazardous waste along with salient features of Biomedical Waste (Management and Handling) Rules and Hazardous Waste (Management and Handling) Rules. The potent toxic releases (both organic and inorganic) to environment from incineration of these wastes are being described.

2.1 Waste and its incineration

The problem of environmental pollution started with the advent of man on earth and now has become extremely acute both in developed and developing countries. Waste management has become a crucial problem and major concern in most countries (Saxena and Jotshi, 1996). Industrial and technological advances lead to the extensive release of wastes, as solids, liquids and gases into air, soil, rivers etc. Various techniques have been used to reduce human exposure to the toxic and infectious components of wastes (WMG, 1993). For secure disposal of hazardous waste (HW), it is impressive that the wastes must be first treated to render it less toxic and for rendering HW less toxic various treatment technologies being used are : thermal (incineration, detonation, pyrolysis, open burning); physical treatment (carbon adsorption, distillation, stream stripping, solvent extraction, solidification); chemical treatment (neutralization, wet oxidation, UV/ozonation, photolysis, chlorinolysis, dechlorination); biological treatment (activated sludge, anaerobic digestion, aerated lagoon, trickling filter) and the disposal techniques being employed are landfilling, landfarming and deep well injection.

The most commonly used techniques include internal segregation, containment and incineration (MWD, 1994). Incineration seems to be one of the best available technologies for disposing various types of waste (Jang et al., 2006) and is considered one of the four primary ways to manage solid wastes, in conjunction with source reduction and reuse, recycling-composting, and land filling (Lee et al., 2000). Due to loss of self-cleaning capacity of the air, developed countries have laid stringent, safe standards particularly in the area of biomedical waste (BMW) and HW management.

2.1.1 Types of Incinerators

The main goal of incinerators is to develop a sustainable waste management by reducing volume of non-avoidable and non-recyclable waste to be disposed, and to decrease its post depositional reactivity due to its organic matter inventory. Incinerators are divided into three categories on the basis of waste burning capacity: small (less than or equal to 90 kg h^{-1}), medium (between 90 and 225 kg h^{-1}) and large (greater than 225 kg h^{-1}) (Gochfeld 1995).

Lee and Huffman (1996) described two types of incinerators: Modular and Rotary kilns. Modular incinerator can be starved air or excess air type. Starved air incinerator contains two furnace chambers, primary and secondary. In primary chamber, the waste is fired with less air than the stoichiometric requirement and the off gas is allowed to burn in secondary chamber with 100–140% of the stoichiometric air requirement (Fig. 2.1). In excess air incinerators, waste is fired in the primary chamber and the secondary chamber provides the residence time, temperature and supplementary fuel for combustion of the unburned organics. The incinerator contains multiple internal baffles to guide the combustion gases through 90° turns in both lateral and vertical directions. At each turn, ash drops from the gas stream. The air is injected into the primary and secondary combustion chambers through the supplementary fuel burners (Fig. 2.2).

The rotary kiln is a horizontal refractory lined cylinder that rotates about horizontal axis. Waste is charged directly into the kiln. Air, typically in excess of the stoichiometric requirement, is provided to the kiln to burn the waste. A secondary combustion chamber is part of the kiln system. Off-gas from the kiln contains volatiles from the waste that have not burnt out and their burning is completed in secondary chamber (Fig. 2.3).

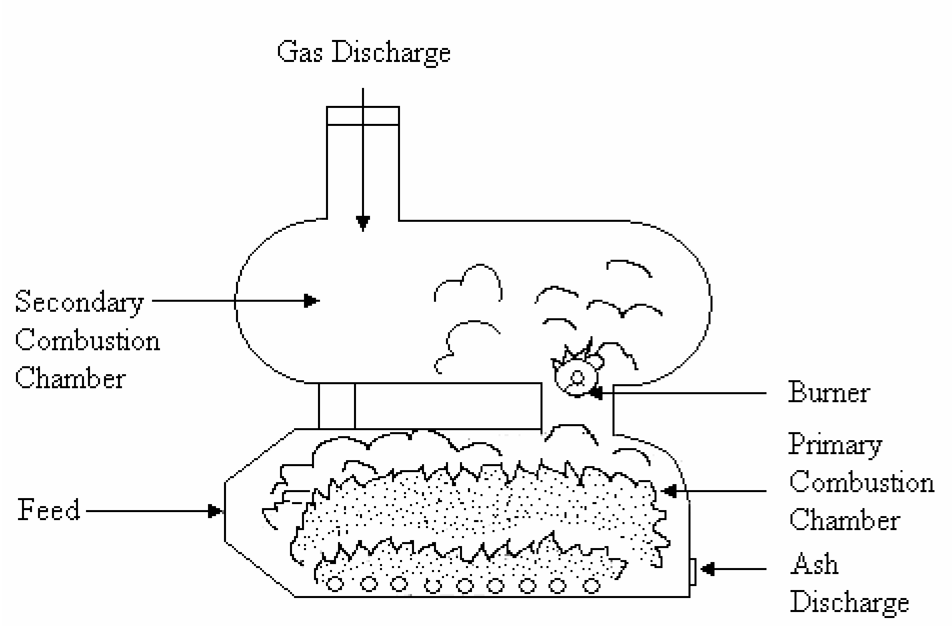

Fig. 2.1: Starved air incinerator (**Source:** Lee and Huffman, 1996)

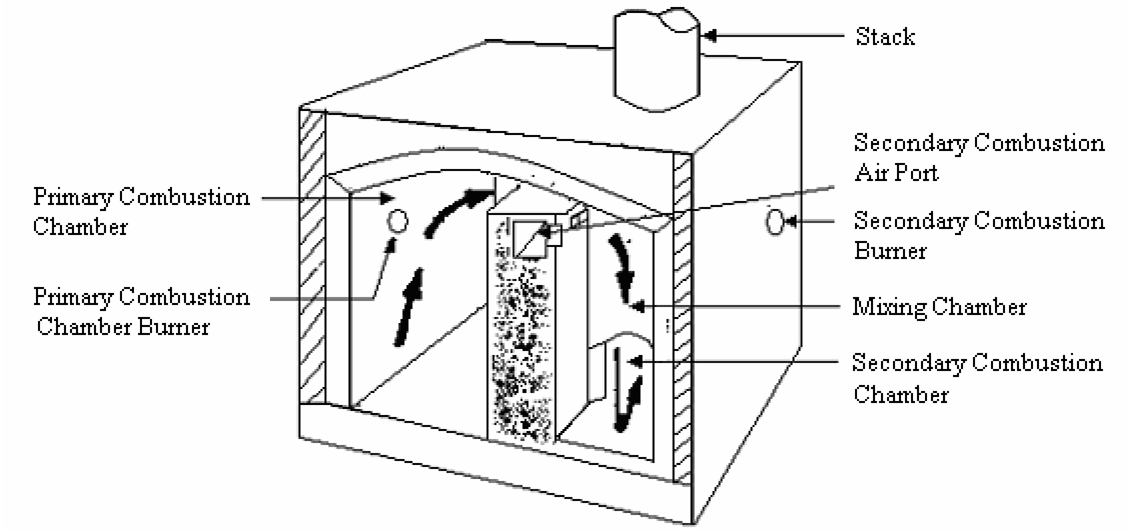

Fig. 2.2: Excess air incinerator (**Source:** Lee and Huffman, 1996)

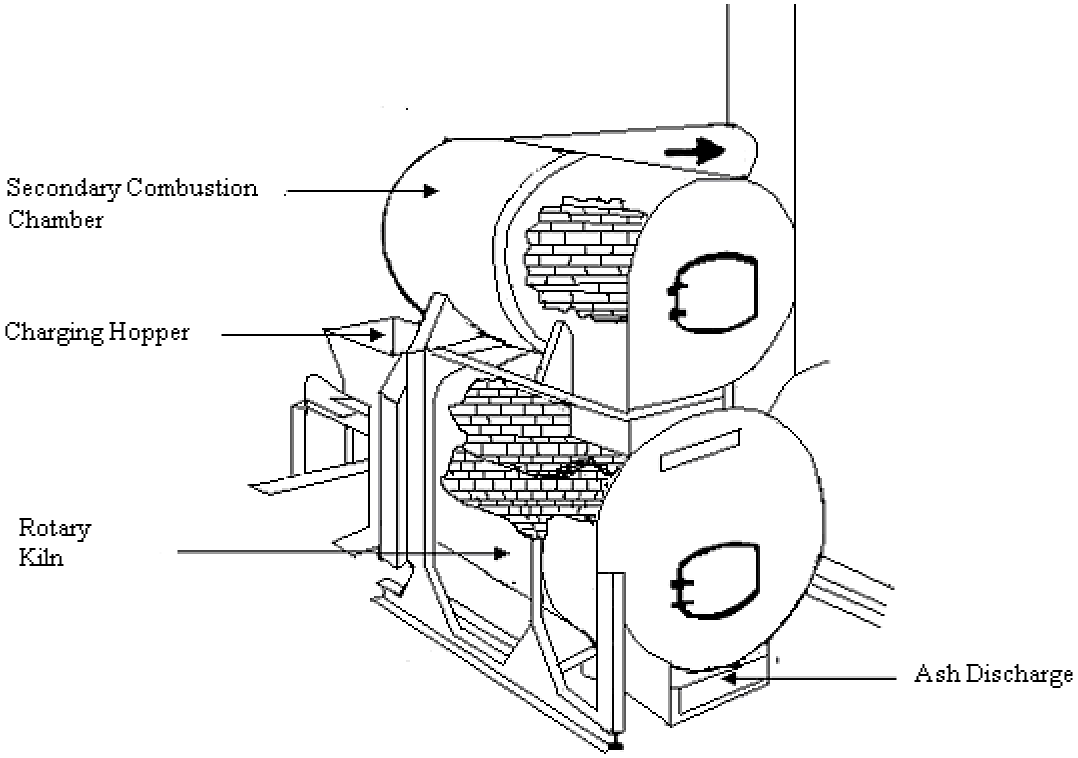

Fig. 2.3: Rotary kiln Incinerator (**Source:** Lee and Huffman, 1996)

2.1.2 Incinerators releases

The emission of products of incomplete combustion in trace quantity occurs in all combustion process (Oppelt, 1987). The combustion process produces three byproduct streams: stack emission, ash residue and residues from pollution control equipment (Mckone and Hammond, 2000). Incineration of BMW as well as HW results into organic and inorganic releases to the environment in the form of stack gases, bottom ash and fly ash.

2.1.2.1 Organic Releases from biomedical waste

2.1.2.1.1 Polycyclic Aromatic hydrocarbons

Most of the studies concerning emissions in combustion in energy generation have been aimed to abate inorganic emissions, CO_x, NO_x and SO_x, mainly due to strict legislation. Although there seems no definite legislation concerning organics emission (PAHs, PCDD/Fs and PCB) abatement. However, EPA has fixed sixteen PAHs as priority pollutants (Masteral and Callen, 2000). PAHs are two- to eight-ring semi-volatile organic compounds and are widespread environmental contaminants, formed mainly during incomplete combustion from natural and anthropogenic sources such as vehicles, tobacco smoking, refuse burning and industrial waste incineration (Singh and Prakash, 2007). Many of these PAHs are highly toxic and build up (bioaccumulate) in the tissues of humans as well as animals (Sahu et al., 2004). Higher concentrations of hydroxypyrene in the urine of municipal workers indicate exposure to elevated levels of PAHs (Angerer, 1992).

Liow et al. (1997) investigated PAHs from two biomedical waste incinerators (BWIs), a mechanical grate incinerator (MG-BWI) for infectious waste and a fixed-bed incinerator for pathological waste. The total PAHs concentration in stack flue gas from mechanical grate (MG) BWIs (1,290 $\mu g\ m^{-3}$) was two times higher than that from fixed-bed incinerator, mainly due to large amount of plastic in infectious waste. Chen et al. (2003) investigated PAH emissions from two batch-type animal carcass waste incinerators, one in a hog farm and the other in a livestock disease control center, along with a fixed grate (FG) BWI for the disposal of biological medical waste in Taiwan. Lee et al. (2002, 2003) investigated emission of PAHs from two batch-type BWIs, one MG-BWI and the other FG-BWI for the disposal of general BMW and special BMW, respectively.

Wang et al. (2002) conducted laboratory experiments in a two-stage horizontal muffle furnace to monitor emissions from batch combustion of polystyrene, a dominant component of BMW and MSW streams and identified conditions to minimize them. Levendis et al. (2001) explored PAH and soot emissions from burning components of surgical gloves and cotton pads in a laboratory scale horizontal muffle furnace. The batch combustion of shredded latex gloves in fixed beds resulted in higher magnitude of PAHs comparable to those emitted from batch combustion of tire-derived fuel, a little higher than those emitted from batch combustion of fixed beds of a pulverized, bituminous coal and soot than those from batch combustion of cotton pads. The condensed phase PAH from latex and cotton was about 1 of 10 and a few percent of the particulate mass, respectively. The gas-phase PAHs from the combustion of cotton were high relative to those in the condensed phase, with the three-membered ring PAHs (PA and Ant) reaching values even higher than those from latex.

The concentrations of 21 PAHs in the stack flue gas, bottom ash and WSB effluent from two batch type animal carcass waste incinerators and a FG-BWI were analyzed. In addition to 16 priority pollutants (US EPA 1997a), various other PAHs determined were cyclopenta(c,d)pyrene, benzo(e)pyrene, perylene, benzo(b)chrycene and coronene. The mean total-PAHs concentrations of the stack flue gas for hog farm and livestock disease control center incinerators were 1.5 and 1.4 times higher than BWI (391 g m^{-3}), respectively. The emissions of total-PAHs and carcinogenic potencies, the mean benzo(a)pyrene, benzo(b)fluoranthene and benzo(b)fluoranthene exceeded 226.2 and 2.3 kg day^{-1}, respectively, during the outbreak of foot and mouth disease among pigs in Taiwan (Chen et al. 2003). PAHs emissions from various BWIs and effect of APCDs are shown in Table 2.1.

Lee et al. (2002) determined the concentrations of 21 PAHs contained in the stack flue gas, electrostatic precipitator (ESP) fly ash, WSB effluent, and incinerating ash of two batch-type BWIs, one MG-BWI and the other FG-BWI sharing same APCDs for the disposal of general BMW and special BMW, respectively. Total PAHs contained in stack flue gas were dominated by low molecular weight containing two to three-ringed PAHs. The effect of the afterburner in reducing PAH concentrations from batch combustion of polystyrene was observed by Wang et al. (2002). Lower molecular weight PAHs were having a higher fraction in liquid phase than that in the solid phase. The efficiency of PAHs removal was found to be higher for WSB than for ESP (Liow et al. 1997). Lee et al. (2003, 2002) showed that BWIs sharing the same APCDs (ESP and WSB) results in reduction of the total PAHs and the overall BaP + B(b)F + B(k)F concentrations or total BaP equivalent emission of BWIs suggesting that the use of proper APCDs during incineration results in significant reduction of carcinogenic potencies associated with PAHs emissions.

Table 2.1: Polycyclic Aromatic Hydrocarbons releases from biomedical waste incinerators

No. and type of sources	No. of PAHs studied	APCDs	BaP+BbF+DBA emission in µg m^{-3}	Total PAHs in µg m^{-3}	Remarks	Reference
2 BWIs:					Efficiency of WS was higher than ESP.	Liow et al. (1997)
1 MG	...	ESP, WS	...	$1,290^{a}$		
1 FG	...	ESP, WS	...	635^{a}		
2 BWIs:					Total PAHs in ash:	Lee et al. (2002)
1 MG	21	ESP, WS	0.118b	$1,290^{a}$	17,132 ng g^{-1}	
1 FG	21	ESP, WS	0.107b	587^{a}	50,480 ng g^{-1}	
2 ACWIs:					Total PAHs in ash:	Chen et al. (2003)
1 HF	21	WS	8.95	592^{a}	737 ng g^{-1}	
1 LDCC	21	WS	5.46	527^{a}	470 ng g^{-1}	
1 BWI (FG)	21	WS	1.18	39^{a}	421 ng g^{-1}	
2 BWIs:					Carcinogenic potency significantly reduced.	Lee et al. (2003)
1 MG	21	ESP, WS	30.2c	$1,510^{d}$		
1 FG	21	ESP, WS	19.8c	707^{d}		
1 BWI (CWI)	11	...	...	...	Total PAH in ash were 499.3 µgkg^{-1}	Wheatley and Sadhra (2004)

ACWIs Animal carcass waste incinerators
CWI clinical waste incinerator
HF in a hog farm
InWIs infectious waste incinerator
LDCC in a livestock disease control center

a In flue gas
b Gram per day
c BaPeq. Total conc. for individual PAH in flue gases, ESP and WS
d In flue gases, ESP and WS
... not reported

The total PAHs concentrations in bottom ashes of hog farm incinerator (737 ng g^{-1}) were 1.6 and 1.8 times higher than the livestock disease control center (470 ng g^{-1}) and BWI (421 ng g^{-1}). The total PAHs concentration in WSB effluents for hog farm incinerator and BWI was 45.3 and 10.5 µg L^{-1} (Chen et al. 2003). Lee et al. (2002) reported total PAH concentration in ESP fly ash, front bottom ash and bottom ash for MG-BWI as 13,800, 3,170 and 162 ng g^{-1}, respectively. However, the total PAH concentration for FG-BWI in ESP fly ash and bottom ash was 47,000 and 3,480 ng g^{-1}, respectively. Wheatley and Sadhra (2004, 2007) studied 11 PAHs in solid residues from clinical waste incineration and their total concentration was found to be 449.3 µg kg^{-1}.

Most of the incinerator pollutants are released as stack emissions to the atmosphere. Hence, workers at the incinerator and people living close by can be exposed directly through inhalation of airborne emissions. Due to the presence of more persistent pollutants such as PAHs, dioxins, furans, polychlorinated biphenyls, mercury and cadmium, there can be indirect exposure at the regional levels by ingestion of locally produced foods or water contaminated by pollutant deposition to soil, vegetation and surface water (Mckone and Hammond, 2000). It is expected that air quality would be improved if the emission of these PAHs, PCDD/Fs and PCB are controlled.

PAHs are generated along with a variety of other airborne products and are present both in particle as well as in gas phase of the emissions. Concentrations of indoor PAHs are reported in the literature (Wilson and Chuang, 1991; Nguyen et al., 1999; Chuang et al., 1990, 1991; Raiyani et al., 1993a; Risner and Conner, 1991; Shuguang et al., 1994; Nguyen et al., 2002) and described to be highest at the cooking spots where biomass is burnt (Nguyen et al., 2002). The concentration of total PAHs were found to be greater in winter (0.47-2.77 $\mu g\ m^{-3}$) as compared to summer (0.70-1.82 $\mu g\ m^{-3}$) in ambient air and were greatest in breathing zone (0.69-9.18 $\mu g\ m^{-3}$) during winter (Bhargava, 2004). Biofuels, including wood, dried animal-dung cake and crop waste, are used extensively for cooking energy in India and high concentrations of particulate PAH compounds have been reported in indoor environments, during biofuel combustion for cooking (Raiyani et al., 1993a,b,c). Low-temperature biofuel combustion has the potential to result in higher emissions of PAH than high-temperature industrial sources. High concentrations of PAHs have been measured in smoke from solid-fuel stoves burning wood, coal and dried cattle manure (Raiyani et al., 1993b) which along with kerosene stoves (Saksena, 1996) are used as the primary cooking device by urban slum residents. In India, ambient concentrations of particulate BaP have been measured in Mumbai (Mohan Rao et al., 1983) and Ahmedabad (Aggarwal, 1982), with a view to evaluate the carcinogenic risk from PAH exposure. Studies of PAH concentrations in ambient aerosol in Ahmedabad, Mumbai, Nagpur and Kanpur, show that total PAH concentrations in Indian cities are 10-50 times higher than those reported internationally and range 23-190 ng m^{-3} (Raiyani et al., 1993c; Pandit et al., 1996; Vaishali et al., 1997; Kulkarni et al., 1997). Mass concentrations of PAHs have also been reported for Indian cities including Mumbai, Ahmedabad, and Nagpur. Total PAHs concentrations were measured at two locations in Mumbai and was found to be 38.8 ng m^{-3} at Saki Naka and 24.5 ng m^{-3} at IIT (Kulkarni and Venkataraman, 2000).

2.1.2.1.2 Polychlorinated dibenzo dioxins/ Furans

Polychlorinated dibenzo dioxins/ furans (PCDD/Fs) are mainly formed during anthropogenic activities and are usually referred to as dioxins. These are extremely potent toxic chemicals, producing effects in humans and animals at extremely low doses. Being persistent in the environment, these chemicals accumulate in the food chain and are distributed globally. Every member of the human population is exposed to them, primarily through the food supply and mother's milk. PCDD/Fs are carcinogenic and affect the development, reproduction and immune system (Thornton et al. 1996). Olie et al. (1977) were the first to discover the presence of these chemicals in the flue gases and fly ashes of incinerators. Since then their emission from various sources became a serious issue. The primary cause of "iatrogenic" PCDD/Fs produced by the incineration of BMW was organically bound chlorine in polyvinyl chloride (Thornton et al. 1996).

The emissions from most combustion processes contained mixtures of 75 PCDD and 135 PCDF congeners (Buekens et al. 2000). The most toxic and human carcinogen congener is 2,3,7,8-tetrachlorodibenzo-pdioxin (TCDD). The amount of PCDD/Fs is presented as toxic equivalents (TEQ) relative to 2,3,7,8-TCDD. PCDD/Fs emission factors depend on composition, type, classification, segregation practice, and management methodology of incinerated waste (Alvim-Ferraz et al. 2003a, b, c).

Pandompatam et al. (1997) compared PCDD/Fs emissions from medical waste incinerators (BWIs) and hog fuel boilers. The 2,3,7,8-TCDD/Fs emission followed the same trend as in case of bark combustion and BMW incineration. In Taiwan, 18 BWIs treated a total of 61.2 ton of BMW daily and released 260 ng TEQ of PCDD/Fs year^{-1}. An average emission factor of 37,400 ng TEQ ton^{-1} obtained from a study of PCDD/Fs stack emissions of BWIs, and used for the calculation of 16 BWIs (Chen 2004). Seventeen PCDD/Fs like compounds and three coplanar polychlorinated biphenyls were studied from fly ashes of BMW, municipal solid waste (MSW) and electrical power plant incinerators by Ling and Hou (1998). The TEQ values of fly ashes from BWIs (13.9 ng g^{-1}) and small MSW Incinerator (29.3 ng g^{-1}) were much higher than those from large MSW incinerator (2.1 ng g^{-1}) and electrical power plant (0.3 ng g^{-1}) incinerators**.** Bennett et al. (1998) calculated the characteristic travel distance of 2,3,7,8-TCDD to be in the range 100 - 1,000 km on assuming a mean wind speed of 4 m s^{-1}. Van Pul et al. (1998) obtained residence times for TCDD and octachloro-dibenzofuran corresponding to travel distances of 1,900 and 370 km, respectively. Travel distance of 810 km for TCDD and 460 km for octachloro-dibenzodioxin has been calculated (Beyer et al. 2000). Baker and Hites (1999) suggested that a large fraction of the PCDD/Fs emissions settle close to the source because most of PCDD/Fs are associated with large particles that settle to the ground rapidly.

The PCDD/Fs emission rates for the crematory source were found to be ~ 9.1, 1 - 35 and 1.3 - 3.8×10^{9} ng TEQ year^{-1}, in US (US EPA, 2001), UK (Eduljee and Dyke 1996) and Japan (Takeda et al. 2001), respectively. The estimated PCDD/Fs emission rate for all crematories in Taiwan was found to be 0.838×10^{9} ng TEQ year^{-1} accounting for 227 and 112% of the annual emissions from all BWIs and MSWIs, respectively (Wang et al. 2003a). The PCDD/Fs like potencies and extractable organohalogens in BMW, MSW and domestic waste incinerator ashes in Japan have been studied (Matsui et al. 2003). The PCDD/Fs in the ashes ranged between 2.33 and 12.29 ng TEQ g^{-1} (dry weight). Relative ranges estimated by ethoxyresorufin-O-deethylase assay in the medical incinerator ashes were 3.8 - 17.6 times higher than the results of conventional chemical analysis. The mean PCDD/Fs emission from the crematory without air pollution control devices (APCD) and the crematory with a bag filter were 2.36 and 0.322 ng TEQ

Nm^{-3}, respectively (Wang et al. 2003a). The PCDD/Fs emissions from various BWIs and effect of APCDs have been summarized in Table 2.2.

Table 2.2: Polychlorinated dibenzo dioxins/ furans releases from biomedical waste incinerators

No. of sources studied	Type of sources	APCDs	PCDD/Fs, (ng I-TEQ Nm^{-3})	Total PCDD/Fs (ng m^{-3})	Remarks	Reference
18	5 BWIs	LE	9.7–32	...	At temperature from 500–1,000°C, PCDD/Fs	Grochowalski (1998)
	8 BWIs	VES	0.015–0.09	...	in bottom ash varies 8.5–45 µg TEQ kg^{-1}	
	5 BWIs	NVE	0.13–3.9	...		
16	1 BWIs	B-WS-BF	5.86	132	PCDD/Fs in fly ash 179 ng g^{-1}	Oh et al. (1999)
	11MSWIs	...	0.07–36.5	8.56–2,100		
	3 SIs	...	0.25–43.3	16.5–1,700		
	1 IWIs	...	0.03	1.51		
1	1 BWI	CFS	<0.1	...	CFS destroys PCDD/Fs to form CO2,H2O and HCl with RE of 98.4%.	Fritsky et al. (2001)
17	2 BWIs	QC-VS-PBS	...	...	The formation of PCDD/Fs influenced by	Wang et al. (2003b)
	1 BWIs	DSI-FF	...	...	the chlorine content in the feeding waste.	
	1 BWIs	...	...	...	Threshold chlorine content is 0.8-1.1%.	
	1 BWIs	WS-BF-FF	...	...		
	8 MSWIs	...	...	...		
	2 VFS	...	...	...		
	2 PVC	...	...	...		
2	1 C1	...	2.36	...	...	Wang et al. (2003a)
	1C2	BF	0.322	...	The RE of BF 55.1%.	
1	1 NPTE	...	<0.1	...	NPTE obeys the emission standard	Yufeng et al. (2003)

B Boiler
BF bag filter
C crematory
CFS catalytical filter system
DSI dry sorbent injection
FF fabric filter
IWI industrial waste incinerator
LE low efficient
NPTE new pyrolysis technology and equipment
NVE not very efficient

PBS packed bed scrubber
PVC polyvinylchloride vent combustors
QC quench chamber
RE removal efficiency
VES very efficient system
VFC vehicle fuel combustion
VS venturi scrubber
SIs small size incinerators
WS wet scrubber
... not reported

BWIs were found to be major source of PCDD/ Fs followed by MSWIs into the atmosphere (Brzuzy and Hites 1996; Pandompatam et al. 1997). These generate relatively large amounts of PCDD/F due to lack of optimal APCDs and high fraction of chlorine containing combustibles (Brzuzy and Hites 1996). The concentrations of PCDD/Fs in combustion gas were much higher than the legal limit (0.1 ng TEQ Nm^{-3}) for the BWIs having no or efficient APCDs (Alvim-Ferraz et al. 2000, 2003a). However, BWIs having very efficient APCDs emit the exhaust fumes containing PCDD/Fs at levels below 0.1 ng TEQ Nm^{-3} (Grochowalski 1998). APCDs needed to be made compulsory for BWIs in developing countries (Brent and Rogers 2002). Linder et al. (1990) studied PCDD/Fs emissions from eight BWIs in California and reported that wet scrubbers (WSB) achieved an emissions control efficiency of 95% while bag house less than 30% in removing PCDD/Fs. To comply with the PCDD/Fs regulations, Fritsky et al. (2001) developed a catalytic filter system for BWIs which destroy PCDD/Fs without adsorption. Yufeng et al. (2003) developed a new pyrolysis technology and equipment for treatment of BMW and municipal household. Singh and Prakash (2007) have shown that organic emissions from medical waste incineration are much higher as compare to the recommended limit in the legislations.

2.1.2.2 Inorganic Releases from biomedical waste

2.1.2.2.1 Gases

Inorganic acidic gases, notably HCl, HF, HBr, SO_x and NO_x are formed as a consequence of the elements chlorine, fluorine, bromine, sulphur and nitrogen being present in waste and are emitted by incinerators (Allsopp et al., 2001). NO_x are also formed as a result of the direct combination of nitrogen and oxygen, a process that is accelerated at high temperatures. HCl is emitted in greater quantities from incinerators due to chlorine in the waste, notably in the form of plastics such as PVC.

Batch combustion of cotton resulted in CO yields, comparable to those from latex gloves and 10 times as much as those from tire derived fuel (TDF). However, CO_2 yields were higher than those form latex gloves but lower than those from TDF. No SO_2 emissions were detected, indicating the conversion of sulfur to H_2S or sulfates in the soot (Levendis et al., 2001). The emission factor for CO, SO_2, NO_x and HCl, associated to the incineration of BMW according to the classification of the Portuguese legislation were studied by Alvim-Ferraz et al.

(2003). The concentrations of CO, SO_2, and HCl were higher than the legal limit, however concentration of NO_x was within limit. Zandaryaa et al. (2001) carried out a full-scale selective non-catalytic reduction on a BWI in Italy by by injecting anhydrous NH_3 for NO_x reduction into the first pass of the boiler. Reduction efficiency of NO_x was found within a molar ratio of 0.9 - 1.5 for NH_3/NO. The fraction of NH_3 used in NO_x removal was found to decrease with rising NH_3/NO molar ratio. Alvim-Ferraz et al. (2003) recommended the control of CO, SO_2, and HCl emissions by the use of APCDs for protecting human health. Incineration of segregated wastes, lead to the smallest amount of SO_2 and reduction of NO_x by 93%, CO and HCl by more than 99%.

2.1.2.2.2 Metals

Heavy metals are emitted from all types of incinerators. Many heavy metals are known to be toxic at low concentrations and some are persistent and bio accumulative. Heavy metals enter the incinerator as components of various materials in the raw waste. A proportion of these toxic trace metals is emitted in the stack gases of incinerators to atmosphere. The major proportion is generally present in fly ash and bottom ash with the exception of mercury where the greater proportion is vented via the flue stack. Mostly the toxic metals associated with BMW incineration are cadmium, lead, mercury, chromium and arsenic. National research council (NRC, 2000) describes various types of toxicity and health effects in humans for these metals.

Trace element samples obtained from a BWI, a coal-fired cement kiln operation and a MSW incinerator were monitored for mercury (Stevenset al., 1996) and measured by the speciated Hg emission (US EPA, 1996). Significant amounts of soluble Hg(II) species were measured in the emissions from waste incineration point sources with the Hg(II)/Hg(total) ratio ranging from 0.75 to 0.95. The BWI emitted nearly 95% of its emissions as Hg(II). Krivanek (1996) found that some facilities in US meet the standards for Hg emissions from BWIs without additional controls (e.g. refuse derived fuel combustors) whereas most of the facilities did not conform to the standards. Mercury control technologies viz., activated carbon injection, sodium sulfide injection and wet scrubbing have been described with their disadvantages. Dvonch et al. (1999) studied the use of elemental tracers to source apportion mercury in South Florida precipitation. An emission reconciliation found that local BWIs, emitted Hg(II) that could account for the Hg wet deposition. The emissions from local urban point sources played the dominant role in the wet deposition of Hg to south Florida and Everglades.

An analytical survey for the concentration of 22 elements in the ashes of incinerators located at veterinary colleges/animal disease diagnostic laboratories in seven states of US was conducted by Thompson et al. (1995). The variation in elemental composition of ashes collected over time from the same veterinary college incinerator at Cornell University in Ithaca (New York) was reported for 24 elements (Thompson et al. 1996). There was an indication that burned plastic wastes were a source of Pb in the ashes. Alvim-Ferraz et al. (2003c) reported the emission factors estimated for particulate matter, As, Cd, Cr, Pb, Mn, Hg, and Ni by segregation of BMW in different types according to Portuguese legislation. Comparison of results of the usual practice of segregation and rigorous practice of segregation, suggested that rigorous segregation practices and adequate management methodologies allowed reduction of 80% amount of the waste for incineration, thereby eliminating Hg and Pb emissions and reducing those of As, Cd, Cr, Mn, and Ni.

In India (Kumar et al., 2004) analyzed nineteen trace elements in the incinerator ash from four major hospitals, one municipal waste incinerator and two R&D laboratories engaged in animal experiment in Lucknow city and found the concentration of toxic metals much higher than recommended limit. Racho and Jindal (2004) determined the relationship between particle size and heavy metal concentrations in bottom ash and simulated leachate from a BWI. Average Pb, Ag, Fe and Zn concentrations in bottom ash were 765.3, 327.9, 314, 121.2 and 18,710.7 mg kg^{-1}, respectively. The mean concentrations of heavy metals for bottom ash samples from three BWIs ranged between 192-5,866 μg g^{-1} of Pb, 100-2000 μg g^{-1} of Cr, 138-1,988 μg g^{-1} of Cu, 31-928 μg g^{-1} of Mn, 21-141 μg g^{-1} of Ni and 1-56 μg g^{-1} of Cd (Abdulla et al., 2001). Chen et al. (2004) found that the pig carcasses treating incinerator (PTI) and animal (including pigs) carcasses treating incinerator (ATI) had much higher metal concentrations in stack flue gases than BWI.

On the basis of absolute concentration of heavy metals such as Cd, Cr, Cu, Ni, Pb, and Zn these metals in slags of BMW, Santarsiero and Ottaviani, (1995) suggested that the landfilling of solid residues from BWI having these metals in slags need not to be classified as toxic and harmful. However, Echegaray et al. (2002) observed that the ash and slug fraction of BMW incineration represent a potential risk to human health due to heavy metal content (Cd, Cr, Pb, Hg, and Cu) and need to be categorized as hazardous waste.

2.1.2.3 Releases from hazardous/ Industrial waste

Hazardous waste (HW) generated by the industries are required to be managed as per the HW (M&H) rules, 1989, amended in 2003. About 4.4% of HW generated in the country is of the nature, which has to be incinerated (CPCB, 2005a). Besides, segregated organic residues, highly concentrated effluents such as mother liquors and toxic effluents not feasible for physico-chemical, biological treatment also require proper disposal through incineration.

Hazardous waste is the inevitable unwanted by product of our industrialized society. Many physical, chemical and biological processes can be used to treat HWs. The treatments can destroy, convert, or detoxify HW or can simply concentrate and isolate that for disposal. Much emphasis has been placed on prevention and waste minimization (making the changes in the industrial process itself to produce fewer or smaller amounts of HW). Physical processes for HW treatment include separation and concentration to reduce HW volume and make it easier or mare economic to treat. Filtration, centrifugation and flotation are all physical separation processes that operate on heterogeneous mixtures. Ion exchange, reverse osmosis, ultra filtration, carbon adsorption, liquid absorption and air stripping are the examples of physical processes that operate on an ionic or molecular scale (Stephen et al., 1998). Chemical treatments include thermal processes (incineration, calcinations, volatilization, catalytic oxidation etc.), wet processes (clorinolysis, hydrolysis, neutralization, electrolysis, chemical oxidation/reduction) and precipitation processes. Biological processes include activated sludge, soil vapor aeration and extraction, in situ bioremediation, aerated lagoons, anaerobic digestion, composting etc. The Resource Conservation and Recovery Act was enacted in 1976 and amended in 1984 by Hazardous and Solid Waste Amendments to handle the problems of toxic and HW disposal. Commensurate with these statutes, the US EPA regards incineration as one of the principal technology candidates for the ultimate safe disposal of wastes and promulgated the standards in the Federal Register, Volume 46 (15) January, 1981.

In acrylic industries during the production of acrylic fiber, two types of wastes are generated; (i) Acrylic waste solution and (ii) Cellulose waste filters. To dispose of these industrial wastes the process of incineration is being employed. There is a recent report by Singh and Prakash (2007) on the emissions from the Acrylic industrial waste incineration where 16 PAHs emissions from incineration of acrylic waste solution at laboratory scale quartz tube vertical incinerator were studied.

2.2 Emission standards

In May of 1993, US EPA introduced a draft waste minimization and combustion strategy to reduce reliance on the combustion of HW and encourage reduced generation of these wastes. Among the key objectives of the strategy is the reduction of health and ecological risks posed by the combustion of HW. New Source Performance Standards and Emission Guidelines for BWIs were issued by US EPA in August of 1997. Proposed air emission standards under Clean Air Act for new and existing hazardous waste combustors (HWCs) were issued by EPA's 2004. In India BMW/Industrial waste needed to be treated and disposed of in accordance with BMW (management and handling) rules, 1998/HW (management and handling) rules, 1989 (MoEF, 1998; CPCB, 2005a). Comparison of incinerators emission standard for biomedical waste incinerators, hazardous waste incinerators and hazardous waste combustors is shown in Table 2.3.

Table 2.3: Comparison of incinerators emission standard for biomedical waste incinerators, hazardous waste incinerators and hazardous waste combustors

Standards for Incinerators:	**BMW (M&H) (MoEF, 1998)**	**HW (M&H) (CPCB, 2005a)**	**BMW (M&H) (US EPA, 1997b)**	**HW (M&H) (US EPA, 2004b)**	
Operating Standards:					
CE	99.00%.	…….	………	…………….	
1º Chamber Temp.	800±50ºC.	………	………	…………	
2º Chamber Temp.	1050±50ºC	1100ºC	………	…………..	
Residence Time	One second	Two seconds	………	…………..	
Stack height	30 meter	30 meter	………	…………	
Emission Standards:				Existing Units	New Units
PM	150 mg Nm^{-3}	50 mg Nm^{-3}	34 mg dscm^{-1}	34 mg dscm^{-1}	1.6 mg dscm^{-1}
NOx	450 mg Nm^{-3}	400 mg Nm^{-3}	250 ppmv	……	…..
HCl	50 mg Nm^{-3}	50 mg Nm^{-3}	≤100 ppmv	1.5 ppmv	0.18 ppmv
HF	…..	4 mg Nm^{-3}	……..	……	…….
VOCs/TOC	≤ 0.01% [a]	20 mg Nm^{-3} [b]	……	…..	……
CO	….	100 mg Nm^{-3}	40 ppmv	100 ppmv	100 ppmv
PCDD/Fs	….	0.1 ng Nm^{-3}	1.76 ng Nm^{-3}	0.40 ng TEQ dscm^{-1}	0.20 ng TEQ dscm^{-1}
SO_2	….	200 mg Nm^{-3}	55 ppmv	…….	…..
POHCs:	….	…..	….	……	……
i) PAHs	…	……	….	99.99 % [c]	99.99 %[c]
ii) PCBs	…..	……	…..	99.9999 % [c]	99.9990 % [c]
Toxic Metals:					
Cd	0.05 mg Nm^{-3}	…….	160 µg dscm^{-1}	59 µg dscm^{-1}	6.5 µg dscm^{-1}
Pb	0.5 mg Nm^{-3}	0.5 mg Nm^{-3}	1200 µg dscm^{-1}	59 µg dscm^{-1}	6.5 µg dscm^{-1}
Hg	0.05 mg Nm^{-3}	0.05 mg Nm^{-3}	550 µg dscm^{-1}	130 µg dscm^{-1}	8 µg dscm^{-1}
Cr	0.5 mg Nm^{-3}	0.5 mg Nm^{-3}	…….	84 µg dscm^{-1}	8.9 µg dscm^{-1}
As	0.5 mg Nm^{-3}	0.5 mg Nm^{-3}	…….	84 µg dscm^{-1}	8.9 µg dscm^{-1}
Be	……..	………	…….	84 µg dscm^{-1}	8.9 µg dscm^{-1}
Cd + Th + Their Compounds	……..	0.05 mg Nm^{-3}	……..	………..	………..
Sb + As + Pb + Cr + Co + Cu+ Mn + Ni + V + their compounds	……..	0.5 mg Nm^{-3}	……..	………..	………..

[a] volatile organic compounds in ash

[b] Total organic carbon in ash

[c] destruction removal efficiency standard

CE - Combustion efficiency

$$\text{C.E.} = \frac{\%\text{CO2 X } 100}{\%\text{ CO2} + \%\text{ CO}}$$

MACT- Maximum achievable control Technology

PM - Particulate matter

POHCs- Principal organic hazardous constituents

ppmv - parts per million by volume

dscm - dry standard cubic meter

…. Not reported

2.3 Biomedical/ hazardous waste management

2.3.1 Biomedical waste

Hospitals are one of the complex institutions which are frequented by people from every walk of life in the society without any distinction between age, sex, race and religion. Patients and staff are over and above the normal inhabitants of hospitals. All of them produce waste which is increasing in its amount and type due to advances in scientific knowledge, and is creating its impact (Rao and Garg, 1994). Hospital waste generally refers to all wastes, biological or non biological that is discarded and not intended for further use. The waste generated in hospitals can be classified into two types based upon health effects; general waste and infectious or potentially infectious waste. The general waste is similar to the domestic waste and can be directly disposed off through municipal waste disposal methods. It is the infectious or potentially infectious waste which is of special concern and in India, it is known as Bio-Medical Waste.

The BMW, in addition to the risk for patients and personnel who handle these wastes poses a threat to public health and environment (Singh and Sharma, 1996). It is a subset of hospital waste; in turn infectious waste is subset of BMW. BMW originates from human or animal health care, medical research, medical teaching facilities, funeral establishments, laboratories and other facilities. A portion of this waste stream is infectious or potentially infectious and presents a potential hazard to the public health and the environment.

For many years, healthcare workers, hospital administrators, sanitarians, and other health-related professionals have understood the necessity to protect themselves and the public from exposure to wastes that might be reservoirs of disease-transmitting organisms. However, efforts to manage such wastes have differed between developed and developing countries (Askarian et al., 2004). BMW is the second most hazardous waste after radioactive waste. The term “hazardous waste” means a solid waste or a combination of solid wastes, which because of its quantity, concentration, or physical, chemical or infectious characteristics may:

i) Cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness or

ii) Pose a potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed (US-EPA, 1986).

Applying more comprehensive waste management approach will help to ensure environmentally sound and economically feasible waste practices. At a minimum, it should be noted that (as with most waste problems), there is no single management scenario that can “solve” all BMW problems; rather, each BMW management problem must be assessed independently to develop a viable and sound solution.

2.3.1.1 Classification

Each country has its own set of regulations defining and setting standards for handling, treatment and disposal of regulated medical wastes. Handling, segregation, mutilation, disinfection, storage, transportation and final disposal are vital steps for safe and scientific management of BMW in any establishment (Rao et al., 2004). World Health Organization released the first global and comprehensive guidance document on safe management of wastes from health-care activities in 1999 (WHO, 1999). It addresses aspects such as regulatory framework, planning issues, waste minimization and recycling, handling, storage and transportation, treatment and disposal options, and training. The wastes from health-care activities include immunizations, diagnostic tests, medical treatments and laboratory examinations.

Almost 80% of total wastes generated by health-care activities are comparable to domestic waste and can be disposed through regular municipal waste methods. The remaining 20% of wastes are considered hazardous (CPCB, 2000) and have been classified into nine categories: infectious waste, pathological waste, sharps, pharmaceutical waste, genotoxic waste, chemical waste, waste with high contents of heavy metals, pressurized containers and radioactive waste (WHO, 2003a, b). Generally, BMWs represents HW (including low level radioactive wastes), all infectious waste that are generated from all types of healthcare institutions, including hospitals, clinics, doctor (dental and veterinary) offices, and medical laboratories. Infectious waste is the one capable of producing an infectious disease.

US Environmental Protection Agency (US EPA, 2004a) defines BMW as any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals, including but not limited to: blood-soaked bandages, culture dishes and other glasswares, discarded surgical gloves, discarded surgical instruments, needles, cultures, stocks, swabs used to inoculate cultures, removed body organs and lancets.

In 1989, the Government of India, in exercise of powers conferred under Section 6, 8 and 25 of the Environment Protection Act, 1986 formulated the Hazardous Waste (Management and Handling) Rules, 1989 which did not cover hospital wastes, despite of the fact that India was a party to Basel Convention of medical wastes management and therefore is bound to implement the same (Patnaik, 2001). In consonance with the same draft watch notification on biomedical wastes (management and handling) [BMW(M&H)] rules, 1995 was issued in April 1995 and objections were invited from public. After duly considering necessary amendments in the Draft Rules, the BMW (M&H) Rules, 1996 finally came into operation with effect from 20th July, 1998. The amendments of principal rules have further been notified on March 06, 2000; June 02, 2000; September 17, 2003 to ensure effective BMW management and are applicable to all persons who generate, collect, receive, store, transport, treat, dispose, or handle BMW in any form.

In India, BMW refers to as any waste, generated during the diagnosis, treatment or immunization of human beings or animals or in research activities pertaining thereto or in the production or testing of biologicals, and is classified into 10 categories: human anatomical waste, animal waste, microbiology and biotechnology waste, waste sharps, discarded medicines and cytotoxic drugs, soiled waste, solid waste, liquid waste, incineration ash and chemical waste (MoEF, 1998). Although not included in the standard definition, the BMW is also generated at the domestic level in the form of sanitary pads, diapers, cotton swabs and gauges, disposable razors, diabetic patient syringes and needles etc. In many cases, the patient is given treatment in his or her own house when the hospitalization is not possible due to some reason. Such “domestic BMW” has not been given any consideration so far.

2.3.1.1.1 Generation and Segregation

Hospital is a place, where an individual is examined by the doctors, diagnosis is made and an appropriate treatment plan is worked out. Depending upon the extent or the intensity of illness, the patients are either treated in/ out patient department or are admitted in the hospital for treatment and follow up. In both the cases, greater amount of waste is generated during this procedure. The quantum of waste thus generated varies according to the site and the nature of treatment. According to BMW (M&H) rules, it will be the duty of every occupier of an institution generating BMW which includes a hospital, nursing home, clinic, dispensary, veterinary institution, animal house, pathological laboratory, blood bank by whatever name called, to take all steps to ensure that such waste is handled without any adverse effect to human health and the environment. BMW should not be mixed with other wastes. It should be segregated into colored containers/bags at the point of generation in accordance with BMW (M&H) rules - Schedule II (Table 2.4) prior to its storage, transportation, treatment and disposal. It is not possible to segregate it thereafter without any undue risk.

Segregation means “separation of different types of BMW by sorting or the systematic separation of BMW into designated 10 categories. It is the most important step in the entire process of BMW management as it needs special attention to be given to the relatively small quantities of infectious and HW, there by reducing not only the risks but the cost of handling, treatment and disposal. For example if general waste gets mixed with infectious waste, the whole waste has to be incinerated which may prove to be costly. It is universally accepted fact that segregation of BMW is and should be the responsibility of the generator of the waste. During segregation special emphasis should be given to infectious, hazardous and sharp wastes. From amongst all categories of waste, the “sharps” which include syringes, needles, trocar, canula, guide wires, broken glasswares, scalpel, blades etc. have the highest disease transmission potential. Almost 85% of sharp injuries are caused between their usage and subsequent disposal and more than 20% of those handle them encounter “stick” injuries (Khan et al., 2005).

Table 2.4: Color coding and type of container for disposal of BMW (Schedule II) (**Source**: MoEF, 1998)

Color Coding	**Type of Container**	**Waste Category**[*]	**Treatment options**
Black	Plastic Bag	Categories 5, 9, 10	Disposal in secured landfill.
Red	Plastic Bag	Categories 3, 6, 7	Autoclaving/Micro-waving/Chemical Treatment
Yellow	Plastic Bag	Categories 1, 2, 3, 5 & 6.	Incineration/deep burial
Blue/White/ Opaque	Plastic Bag /puncture proof containers	Categories 4 & 7	Autoclaving/Micro-waving/ Chemical Treatment & Destruction / shredding

[*] Waste categories are given in table 2.7

The ideal system for segregation would be to use different colored garbage bags or liners in waste storage bins at the point of generation of BMW in accordance Schedule II. There are four major color codes as per the notification:

(i) Black Bag: Used for collecting general waste (Non infectious waste) i.e., paper, non-infectious plastics, cardboard boxes, and other dry waste generated in hospital office or in the wards. For kitchen waste, a separate, preferably a green colored container is highly recommended.

(ii) Red Bag: To be used for segregated plastics collected from operation theaters, intensive care unit and from the wards. One has to be very careful and strict about proper segregation of this waste component.

(iii) Yellow Bag: Used for highly infectious items like pathological waste, human anatomical waste such as body parts, amputed parts/ organs, tumors, placentas,

aborted or otherwise abnormal or dead fetuses etc. In addition, blood soaked cotton bandages, animal tissues, organs, carcasses and other wastes.

(iv) Blue or White or Opaque Bag: This bag is used for collecting the segregated metal and /or glass sharps such as needles, blades, saws, scalpels and all such similar type of waste. These bags must be puncture proof as the metal sharps or broken glass wastes are to be collected in these. It is, strongly recommend to the hospital staff that even metal sharps and broken glass articles are to be segregated.

2.3.1.1.2 Transportation

Transportation means "movement of BMW from the point of generation or collection to the final disposal." When BMW is not treated on site, untreated waste must be transported from the generation facility to another site for treatment and disposal. The containers shall be labeled according to Schedule III (Table 2.5):

i) If a container is transported from the premises where BMW is generated to any waste treatment facility outside the premises, the container shall, a part from the label prescribed in Schedule III.

ii) If a container is transported from the premises where BMW is generated to any waste treatment facility outside the premises, the container shall, a part from the label prescribed in Schedule III, also carry information prescribed in Schedule IV (Table 2.6).

iii) Untreated BMW shall be transported only in such vehicle as may be authorized for the purpose by the competent authority as specified by the Government.

iv) No untreated BMW shall be kept stored beyond a period of 48 hours. If for any reason it becomes necessary to store the waste beyond such period, the authorized person must take permission of the prescribed authority and take measures to ensure that the waste does not adversely affect human health and the environment.

Table 2.5: Label for Biomedical Waste Containers/ Bags (Schedule III)
(**Source**: MoEF, 1998)

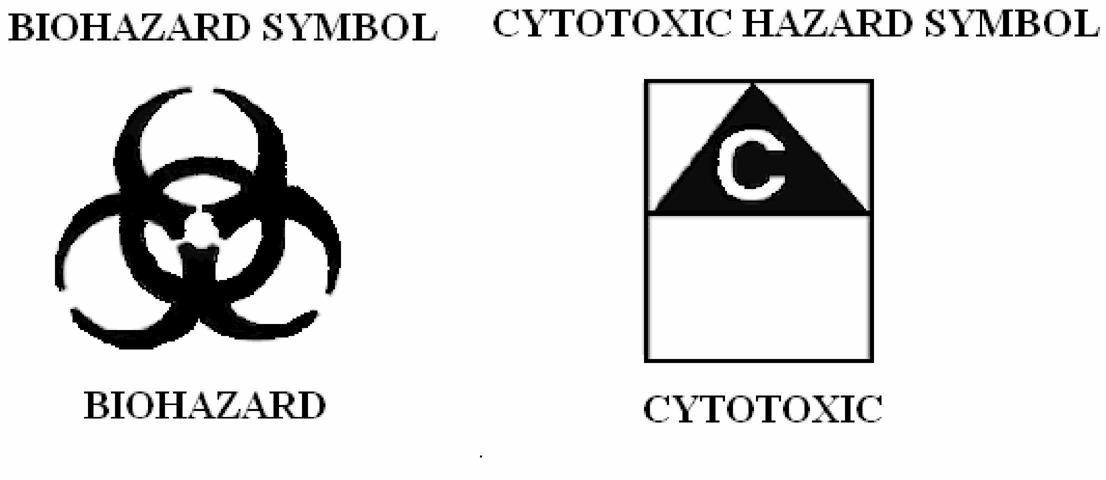

Table 2.6: Label for transport of Biomedical Waste Containers/ Bags (Schedule IV)
(**Source**: MoEF, 1998)

Day .... Month ....Year ....
Date of generation ....

Waste category No ....
Waste class
Waste description

Sender's Name & Address Receiver's Name & Address
Phone No .... Phone No ....
Telex No .... Telex No ....
Fax No .... Fax No ....
Contact Person .... **Contact Person** ....
In case of emergency please contact
Name & Address :

Phone No.

2.3.1.1.3 Treatment

Treatment means “any method, technique or process for altering the biological, chemical or physical characteristics of waste to reduce the hazards it presents and facilitate, or reduce the costs of disposals.” The term 'treatment' may also refer to the process that modifies the waste in some way before it is taken to its final resting place. Treatment is mainly required to disinfect or decontaminate the waste, right at source so that it is no longer the source of pathogenic organisms. After such treatment, the residue can be handled safely, transported and stored. BMW should be treated and disposed off in accordance with Schedule I (Table 2.7) and in compliance with the standards prescribed in Schedule V (Table 2.8). Every occupier where required shall set up in accordance with the time schedule in Schedule VI, requisite BMW treatment facilities like incinerator, autoclave, microwave system for the treatment of waste, or ensure requisite treatment of waste at a common waste treatment facility or any other waste treatment facility. The following treatment methods should be applied to the segregated waste (Joshi, 2006):

Waste from black bags: The common practice was to collect and throw the entire waste in common municipal refuse collector. This ultimately results in creation of large volume of garbage ultimately causing overburdening of the landfills. However, when segregated in this way, the ‘dry’, non-infectious waste can be reused after recycling it at a recycling facility. The ‘wet’, non-infectious and bio-degradable waste from the hospital kitchens can be used for making good quality compost within the hospital premises only and can be effectively used for a healthy garden of the hospitals.

Waste from red bags: The common practice was to mix the waste with general waste after improper disinfection or even in some places, disinfection is not carried at all. This thus enters a common municipal refuse collection bins. The rag pickers segregate these and sell these for a small price. These plastics are then repackaged imitating the original and resold thus causing serious health problems to the concerned people. This waste needs to be disinfected by applying an authorized, scientific methodology. The best way to disinfect is to autoclave this waste. After autoclaving, all the plastic should be shredded or mutilated to avoid unauthorized use. Such plastic can then be recycled and reused for good cause of the community.

Table 2.7: Categories of Bio-medical waste (Schedule I)
(**Source**: MoEF, 1998)

Option	Waste Category	Treatment & Disposal
Category No. I	**Human Anatomical Waste** (human tissues, organs, body parts)	Incineration/deep burial
Category No. II	**Animal Waste** (Animal tissues, organs, body parts carcasses, bleeding parts, fluid, blood and experimental animals used in research, waste generated by veterinary hospitals colleges, discharge from hospitals, animals houses).	Incineration/deep burial
Category No. III	**Microbiology & Biotechnology Waste** (Wastes from lab. Cultures, stocks of specimens of micro-organisms live or attenuated vaccines, human and animal cell culture used in research and infectious agents from research and industrial laboratories, wastes from production of biologicals, toxins, dishes and devices sued for transfer of cultures)	Incineration/ Autoclaving/ micro-waving.
Category No. IV	**Waste Sharps** (Needles, syringes, scalpels, blades, glass etc. that may cause puncture and cuts. This includes both used and unused sharps)	Chemical/ disinfection autoclave/ micro-waving and mutilation/shredding
Category No. V	**Discarded Medicines & Cytotoxic drugs** (Wastes comprising of outdated contaminated and discarded medicines)	Incineration/destruct & drugs disposal in secured landfills
Category No. VI	**Soiled Waste** (Items contaminated with blood, and body fluids including cotton, dressing, soiled plaster casts, lines, beddings, other material contaminated with blood)	Incineration/ autoclave micro-waving
Category No. VII	**Solid Waste** (Waste generated from disposable items other than sharps such as tubings catheters, intravenous sets, etc.)	Chemical disinfection autoclave/micro-waving and mutilation/shredding
Category No. VIII	**Liquid Waste** (Waste generated from laboratory and washing, cleaning house-keeping and disinfecting activities)	Disinfect-chemically & discharge into drains
Category No. IX	**Incineration Ash** (Ash from incineration of any bio-medical waste)	Disposal in municipal landfill
Category No. X	**Chemical Waste** (Chemical used in production of biologicals, chemicals used in insecticides etc.)	Chemically treatment disinfection and discharge of drains for liquid and secured landfill for solids

Note:

1. Chemicals treatment using at least 1% hypochlorite solution or any other equivalent chemical reagent should ensure disinfection.
2. Mutilation/shredding must be such so as to prevent unauthorized reuse.
3. There will be no chemical pretreatment before incineration. PVC shall not be incinerated.

Table 2.8: Standards for treatment and disposal of bio-medical wastes (Schedule V) (**Source**: MoEF, 1998):

STANDARDS FOR INCINERATORS

All incinerators shall meet the following operating and emission standards

A. Operating Standards

Combustion efficiency (CE) shall be at least 99.0%

The compustion efficiency is computed as follows:

$$C.E. = \frac{\%CO_2 \times 100}{\% CO_2 + \% CO}$$

1. The temperature of the primary chamber shall be 800 ± 50 ºC
2. The secondary chamber gas resistance time shall be at least one second at 1050 ± 50ºC, with a minimum of 3% Oxygen in the stack gas.

B. Emission Standards

Parameters	**Concentration** (mg Nm^{-3} at 12% CO_2 correction)
1. Particulate matter	150
2. Nitrogen Oxide	450
3. HCl	50

4. Minimum stack height shall be 30 meters above ground.
5. Volatile organic compounds in ash shall not be more than 0.01 %

Waste from Yellow bags: In many hospitals, most of the human anatomical wastes are buried in the soil. However, this practice is dangerous and causes serious social and environmental problems. As per the Central Pollution Control Board (CPCB) regulation, deep burial of this type of waste is not acceptable for towns or cities above a population of 5 lakhs. The best solution that is available these days is to incinerate this type of waste. In this technology, the contents of the yellow bag are burned in an incinerator at extremely high temperature (800-1100ºC). The contents of the yellow bag are thus turned completely into residual ash, which can be safely buried in the soil. The alternative technologies that are available include use of microwaves, hydroclaves, plasma pyrolysis etc.

Waste from Blue or White or Opaque Bag: This waste also should be disinfected by applying an authorized, scientific methodology like autoclaving, micro-waving or Chemical Treatment. The best way to disinfect is to autoclave this waste. After the proper treatment of needles, blades, saws, scalpels and all such similar type of waste, these metals should be shredded to avoid unauthorized use. Such metals can then be recycled and reused for good cause of the community.

2.3.1.1.4 Disposal

Disposal of BMW means “burial, deposit, discharge, dumping, or release of any BMW into or on any air, land, or water”. After treatment of the BMW, it becomes non infectious or non hazardous and depending upon the quantity of the waste generated the disposal and state of waste the following options can be opted: For disposal of solid waste by either method landfill or use of pills or composting or biogas while for the disposal of liquid waste can be done by either discharge into sewers or waste stabilizing pond or soakage pits. The waste disposal methods vary in their capabilities, cost, availability to generation and impacts on the environment. The various disposal methods include incineration, autoclaving, chemical methods, thermal methods (low and high), ionizing radiation process, microwaving and deep burial. Patil and Shekdar (2001) have prescribed pathways to segregate, treat and dispose of BMW in accordance to Biomedical Waste (Management and Handling) Rules, 1998 (Fig. 2.4).

2.3.1.1.5 Common Biomedical Waste Treatment Facility

A common biomedical waste treatment facility (CBMWTF) is a set up where BMW, generated from a number of healthcare units, is imparted necessary treatment to reduce adverse effects that this waste may pose. The treated waste may finally be sent for disposal in a landfill or for recycling purposes. Installation of individual treatment facilities by small healthcare units requires comparatively high capital investment. In addition, it requires separate manpower and infrastructure development for proper operation and maintenance of treatment systems. The concept of CBMWTF not only addresses such problems but also prevents proliferation of treatment equipment in a city. In turn it reduces the monitoring pressure on regulatory agencies. By running the treatment equipment at CBMWTF to its full capacity, the cost of treatment of per kilogram gets significantly reduced. Its considerable advantages have made CBMWTF popular and proven concept in many developed countries.

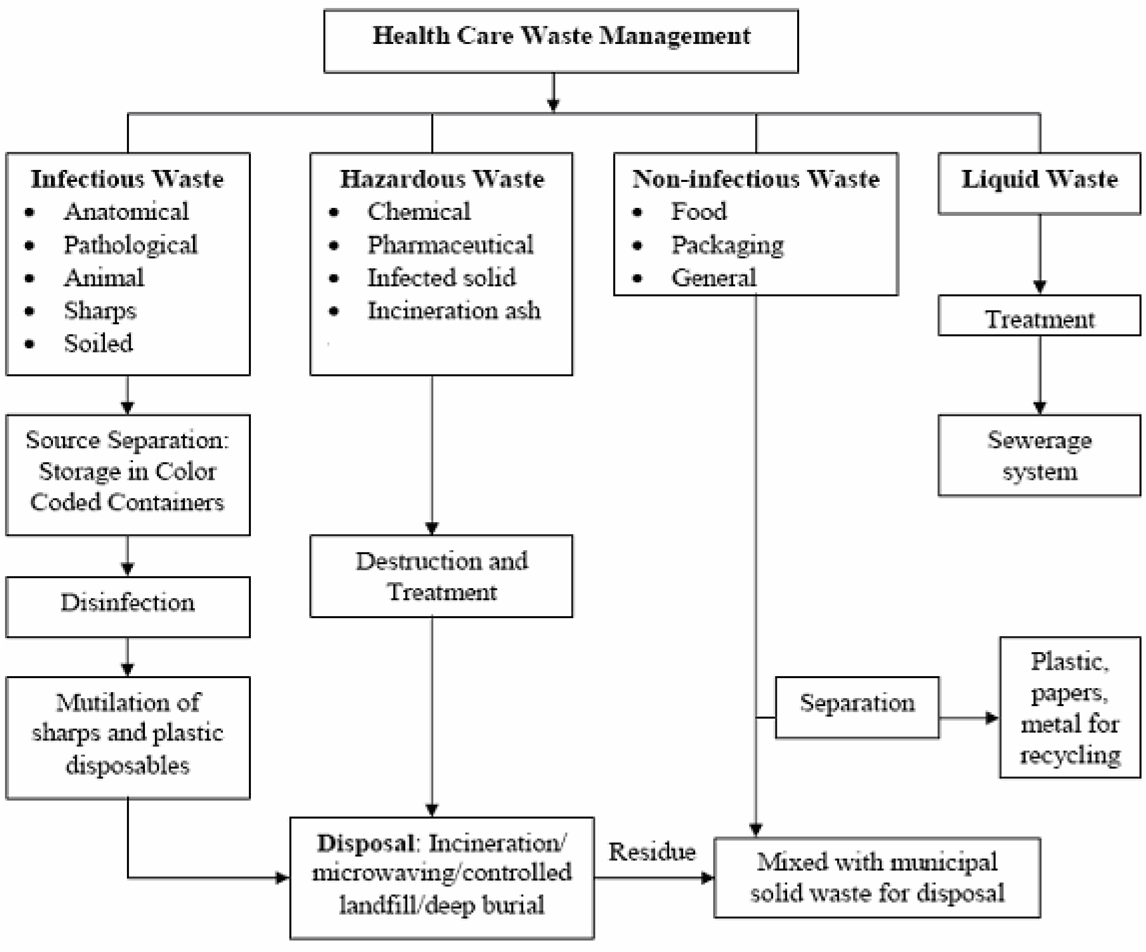

Fig. 2.4: Representation of Biomedical Waste (Management and Handling) Rules, 1998 (**Source**: Patil and Shekdar, 2001)

CBMWTF as an option for waste generators is legally introduced in India. The BMW (M&H) Rules, 1998, gives an option to the BMW generator that such waste can also be treated at the CBMWTF. The Second Amendment of the Rules in June, 2000, further eased the bottleneck in upbringing the CBMWTF by making Local Authority responsible for providing suitable site within its jurisdiction. The concept of CBMWTF is also being widely accepted in India among the healthcare units, medical associations and entrepreneurs.

A CBMWTF should be located at a place reasonably far away from residential and sensitive area so that it has minimal impact on these areas. Sufficient land should be allocated for CBWTF to provide all requisite systems, preferably, a CBMWTF be set up on a plot size of not less than one acre. In any area, only one CBWTF can cater up to 10,000 beds from healthcare units situated within radius of 150 Km at the approved rate by the Prescribed Authority.

2.3.1.1.6 Occupational hazards

The hazardous nature of health care waste may be due to one or more of the following characteristics:

i) It contains infectious agents.
ii) It is genotoxic (waste with mutagenic, teratoxic or carcinogenic properties).

This kind of waste includes certain cytotoxic drugs (those drugs with the ability to kill or stop the growth of certain living cells), vomit, urine or faeces from patients treated with cytotoxic drugs, chemicals and radioactive materials which contains toxic or hazardous chemicals or pharmaceuticals or radioactive materials or sharps. Infectious waste contains a wide variety of pathogenic micro-organisms. Pathogens in infectious waste may enter the body through a number of routes:

a) Through a puncture, abrasion or a cut in the skin.
b) Through the mucous membrane.
c) By inhalation.
d) By ingestion.

There is a particular concern about infection with the Human Immunodeficiency Virus (HIV) and Hepatitis Viruses B and C for which there is strong evidence of transmission via health care waste. These viruses are generally transmitted through injuries from syringe needles contaminated with human blood. Hospital staff and waste handlers in the hospital run the highest risk of contracting disease following improper BMW management.

France: In 1992 (SMWHCA, 2000), 8 cases of HIV infection were recognized as occupational infections. Two of these cases, involving transmission through wounds, occurred in waste handlers.

USA: In June 1994 (SMWHCA, 2000), 39 cases of HIV infection were recognized by the Centers for Disease Control and Prevention as occupational infections, with the following pathways of transmission; 32 from hypodermic needle injuries, 1 from blade injury, 1 from glass injury (broken glass from a tube containing infected blood), 1from contact with non-sharp infectious item and 4 from exposure of skin or mucous membranes to infected blood.

Different pathogenic micro-organisms have varying abilities to survive in the environment. Hepatitis B virus is very persistent in dry air, can survive for several weeks on a surface and is resistant to brief exposure to boiling water. It can also survive to an exposure to some antiseptic chemicals and remains viable for up to 10 hours at a temperature of 60ºC.

Dumping of heaps of hazardous medical wastes consisting of bandages, syringes, plastic and aluminum equipment etc. outside the hospitals create a lot of health problems. At the waste dump sites, several rag pickers try to salvage any discarded material to sell them and make a living. These rag pickers are exposed to the risk of injuries from contaminated needles and other sharp objects and to various infectious diseases. The stagnant waste and unsanitary conditions serve as potential breeding ground for flies, mosquitoes, rodents and insects, which maintain the already existing disease cycle. Due to these acts, diseases like hepatitis, tetanus and dengue fever, HIV infection, etc. are spreading in addition to affecting water, soil and environment at large in the state. In 2003, 353 dengue fever/ dengue hemorrhagic fever cases have occurred in the state of Punjab and seven confirmed deaths have been reported (PSCST, 2003). The burning of plastic and untreated pharmaceuticals produce extremely toxic gases like dioxin and furans, which further add up to the environment pollution.

2.3.1.1.7 Status of Biomedical waste

Implementing effective BMW management programmes require multisectoral cooperation and interaction at all levels. In India, many hospitals violate the BMW (M&H) rules 1998, amended in 2003 (PPCB, 2007). Approximately 20 - 40% of hospital waste can be recycled, but many hospitals recycle only 10% leaving tremendous scope for improvement (Mukherjee, 2001). However it depends upon type and nature of the waste. Gupta and Boojh (2006) have reported that at least 20% of syringes sold, are from recycled sources whose use may harbour deadly virus such as of those Hepatitis B and C. In Punjab, out of 2382 hospitals 372 (16%) violates the BMW (M&H) rules and only 98% of BMW is treated per day (PPCB, 2007). Many hospitals hand over the BMW to waste treatment facilities without disinfecting it. In Meghalaya, 129 hospitals, having bed capacity of 4161 beds employ no CBWTF. Seven incinerators work without air pollution control devices (APCDs) and only 96 % of BMW is treated per day (MSPCB, 2007).

In Punjab, about 6500 Kg BMW is being generated per day from about 34000 beds in hospitals/clinics, etc. in the state (PPCB, 2007). However, It does not include BMW generated by small clinics and dispensaries which do not require authorization from PPCB. Sometime, data regarding BMW generated from veterinary centers is also not available with Pollution Boards (Tiwana, 2007). The BMW generation rate in various districts of Punjab is given in Table 2.9 (ENVIS, 2003a).

Das et al. (2001) reported that only 24% of the waste generated in the Tata Main Hospital (in Jamshedpur city of Bihar State, India) per day was segregated properly and only 45% of the staff generating and handling waste were aware of proper waste disposal. The theoretical health risk to BMW handlers from pathogens may be aerosolized during the compacting, grinding or shredding process that is associated with certain BMW management or treatment practices (Veda et al., 2007). It was found that home-generated medical waste i.e. consisted mainly of sharps and pharmaceuticals are improperly disposed off (Subratty and Nathire, 2005). The risk is further aggravated due to improper handling and disposal of waste. El-Hamouz (2002) reported that medical waste generated in West Bank hospitals and medical centers is collected in plastic bags and then dumped together with other domestic waste without any separation. This malpractice usually leads to air pollution and the danger of spreading viruses and bacteria widely

Table 2.9: Biomedical waste generated in various districts of Punjab
(**Source:** ENVIS, 2003a)

District/ Regions	Total No. of Beds	Total BMW Generated, Kg day^{-1}	Total BWM Treated, Kg day^{-1}
Sangrur	1439	366	….
Patiala	3744	3769.5	1641
Ludhiana-I	3689	4830	4015
Chandigarh	1075	195	190
Faridkot	3357	679	245
Bathinda	….	353	….
Batala	1549	1890	….
Jalandhar	6015	720	530
Amritsar	6666	6020	1530
Ludhiana-II	1828	3420	1268
Hoshiarpur	984	1068	444
Total	**30346**	**23936**	**9863**

Expenditure: The cost of construction, operation and maintenance of system for managing waste represents a significant part of overall budget of a hospital if BMW (M&H) rules have to be implemented in their true spirit. Self contained on site treatment methods may be desirable and feasible for large healthcare facilities (Veda et al., 2007). Rao et al. (2004) determined the amount of hospital waste, BMW produced, and capital cost for their disposal for five hospitals from various sectors like Govt, Private, Charitable institutions etc. It was found that capital cost incurred by benchmarked hospital of 1047 beds was Rs.3,59,000/- excluding cost of incinerator. Out of five only one hospital sells the plastic waste without shredding or Mutilation.

Patil and Pokhrel (2005) suggested that the infectious wastes should be collected separately from the Laboratory, Operation Theater and Intensive Care Unit, and should go directly to the incinerator and should not be transported through the patient area. Rather replacing the polyethylene bags in the respective bins (with periodic disinfections of the bins); the bins should be collected each time and replaced with clean bins with the polyethylene bags already in them.

2.3.2 Hazardous/ industrial waste

Man has disposed of wastes on or into land since the beginning of recorded history and the form of waste varies depending on location and country. The term ‘hazardous waste’ has crept into our vocabulary during the past decades which denotes the waste that presents risk to human life and health (Ortego, 1995). Industries are the second greatest producer of HW after hospitals but the waste from industries must be treated in accordance to Hazardous Waste (Management and Handling) (HW (M&H)) rules 1989, amended in 2003 while the BMW should be treated in accordance to BMW (M & H) rule 1998 amended 2003. *Acrylic industries also produce wastes which are hazardous in nature.*

In practice, the hazards presented by the wastes may be classified as radiological, biological and chemical. The term chemical waste refers to industrial or laboratory chemicals having corrosive, toxic, flammable or explosive properties. Among all the developments in HW regulation, the restriction on land disposal exerts the most profound and widespread impact on waste management practices. Many industrial wastes were disposed off in unregulated landfills (Hanson, 1989). These landfills were having an average useful life of 20 year. During this time and often for many years (up to 200 year or so), the chemicals from the wastes may leach into the aquifer below the landfill and be transported away from the landfill site. The same aquifers may serve as a source of drinking water for people living within a few miles of the landfill site. If the concentrations of toxic chemicals in water are below their taste-odor threshold, then people are likely to suffer prolonged exposure to the chemicals by drinking such water (Schwarzenbach and Westall, 1981; Ahlert and Kosson, 1990). Corrosive chemicals are quite harmful to animal and plant tissue; they dissolve metals and affect plastic materials and ceramics. Once within the landfill, they may react vigorously with other materials producing leachates and gases which may be highly toxic. Toxic chemicals can enter into the human body in four ways: (a) ingestion, (b) injection, (c) skin absorption and (d) inhalation. Of these, the possibility of absorption by skin contact is a potential hazard to those who work on landfills. Safety precautions in the form of protective clothing to the operator are needed in such situations and this hazard can be minimized by a judicious choice of polymeric protective clothing material (Jamke, 1989). A survey showed that about 80 organic chemicals may be present in the atmosphere near a landfill (Daugherty et al., 1992).

The fundamental policy for HW management should include the 4-R concept, i.e. reduction, recover, reuse and recycle of wastes, i.e. waste minimization always first. The ordering option of techniques that can be used in the management are: a) the reduction of waste generation at every source, b) the recovery of resources at each process step, c) the reuse of resources at the point of recovery, d) the recycling of recovered wastes to other processes and to other users, and e) the treatment of unavoidable wastes to reduce waste toxicity and volume and to immobilize the hazardous constituents so as to limit human and environmental exposure when the residues are sent to a secure HW land disposal facility (Haq and Chakrabarti, 1997).

2.3.2.1 Classification

The Government of India has promulgated the HW (M&H) in 1989 through the MoEF under the aegis of Environment Protection Act, 1986. Under the HW (M&H) Rules, the HWs are divided into 18 categories (Table 2.10) in its Schedule-I and the state regulatory agencies are required to identify the HW generators for issue of authorization for collection, storage, treatment and disposal of HW and also the State Government to identify the sites and conduct environmental impact assessment for disposal of HWs. In order to encourage the effective implementation of these rules, the MoEF has further brought out the Guidelines for HW (M&H) rules in 1991 (Maudgal, 1995; Ramakrishna and Babu, 1999) giving the technical details of the principles of HW management covered under the HW (M&H) Rules, 1989, amended in 2000 and further in 2003.

Ministry of environment and forestory has defined hazardous waste as any waste which by reason of any of its physical, chemical, reactive, toxic, flammable, explosive or corrosive characteristics causes danger or is likely to cause danger to health or environment, whether alone or when in contact with other wastes or substances, and shall include wastes listed in column (3) of Schedule I or wastes having constituents listed in Schedule II and Schedule III (MoEF, 2003). Under the HW (M&H) rules amendments 2003, the HWs are divided into 124 types from 36 processes (Table 2.11) in its Schedule-I. These amended rules had following basic modifications:

- Identified the types of HWs likely to be generated from different categories of industries. Such wastes are listed in Schedule-I and are to be deemed as 'hazardous' irrespective of concentrations / constituents.
- Identified concentrations of constitutes waste in Schedule - II (sub-categories A-E). Wastes which are not covered in Schedule - I are to be classified 'hazardous' only if they exceed the threshold concentration limits given in Schedule - II (Table 2.12).
- Schedule-III lists the waste applicable for import and export. Its Part A highlights those wastes which contain Hg and are permitted for import and export while Part B gives the details of those wastes which contain Hg but are not permitted for import and export.
- Schedule IV provides the information about Authorities / Duties and corresponding rule.

2.3.2.2 Identification and Transportation

During the past decade, production of HW has increased alarmingly high in India, and poses a major environmental problem. To identify the HW generating industries is the first step. The HWs were classified under 18 categories under HW (M&H) rules, 1989 and this information (Table 2.10) may be used to preliminary screening of the wastes to classify them as HWs. However there were few observations that- there are probabilities of occurrence of wastes in more than one category; and the above classification system did not give any information to understand the toxic characteristics of HW (Babu and Gupta, 1997). A few suggestions were also provided to improve the classification system by Babu and Gupta (1997). Due the weaknesses in HW (M&H) rules, 1989 these rules were further amended in 2003 and 36 processes of HW generation were identified which generates HW of 124 type. To identify the category of HW, Schedule I (Table 2.11) and Schedule II (Table 2.12) can be effectively used.

Table 2.10: Categories of hazardous Waste under HW (M&H) rule, 1989

Waste Category	Waste Type	Regulatory Quantities
1	Cyanide wastes	1 kg per year as cyanide
2	Metal finishing wastes	10 kg per year the sum of the specified substance calculated as pure metal
3	Waste containing water soluble chemical compounds of lead, copper, zinc, chromium, nickel, selenium, barium and antimony	10 kg per year the sum of the specified substance calculated as pure metal
4	Mercury, arsenic, thallium, and cadmium bearing wastes	5 kg per year the sum of the specified substance calculated as pure metal
5	Non-halogenated hydrocarbons including solvents	200 kg per year calculated as non-halogenated hydrocarbons
6	Halogenated hydrocarbons including solvents	50 kg per year calculated as halogenated hydrocarbons
7	Wastes from paints, pigments, glue, varnish, and printing ink	250 kg per year calculated as oil or oil emulsions
8	Wastes from Dyes and dye intermediates containing inorganic chemical compounds	200 kg per year calculated as inorganic chemicals
9	Wastes from Dyes and dye intermediates containing organic chemical compounds	50 kg per year calculated as organic chemicals
10	Waste oil and oil emulsions	1000 kg per year calculated as oil or oil emulsions
11	Tarry wastes from refining and tar residues from distillation or pyrolytic treatment	200 kg per year calculated as tar
12	Sludges arising from treatment of wastewater containing heavy metals, toxic organics, oils, emulsions, and spent chemicals, incineration ash	Irrespective of any quantity
13	Phenols	5 kg per year calculated as phenols
14	Asbestos	200 kg per year calculated as asbestos
15	Wastes from manufacturing of pesticides and herbicides and residues from pesticides and herbicides formulation units	5 kg per year calculated as pesticides and their intermediate products
16	Acid/alkali/slurry wastes	200 kg per year calculated as acids/alkalies
17	Off-specification and discarded products	Irrespective of any quantity
18	Discarded containers and container liners of hazardous and toxic wastes	Irrespective of any quantity

Table 2.11: List of Hazardous Waste **(**Schedule I) (**Source**: MoEF, 1989)

S.No. 1	**Processes** 2	**Hazardous Wastes** 3
1.	Petrochemical processes and pyrolytic operations	1.1 Furnace/reactor residue and debris* 1.2 Tarry residues 1.3 Oily sludge emulsion 1.4 Organic residues 1.5 Residues from alkali wash of fuels 1.6 Still bottoms from distillation process 1.7 Spent catalyst and molecular sieves 1.8 Slop oil from wastewater 1.9 ETP sludge containing hazardous constituents
2.	Drilling operation for oil and gas production	2.1 Drill cuttings containing oil 2.2 Sludge containing oil 2.3 Drilling mud and other drilling wastes*
3.	Cleaning, emptying and maintenance of petroleum oil storage tanks including ships	3.1 Oil-containing cargo residue, washing water and sludge 3.2 Chemical-containing cargo residue and sludge 3.3 Sludge and filters contaminated with oil 3.4 Ballast water containing oil from ships.
4.	Petroleum refining/re-refining of used oil/recycling of waste oil	4.1 Oily sludge/emulsion 4.2 Spent catalyst 4.3 Slop oil 4.4 Organic residues from process 4.5 Chemical sludge from waste water treatment 4.6 Spent clay containing oil
5.	Industrial operations using mineral/synthetic oil as lubricant in hydraulic systems or other applications	5.1 Used/spent oil 5.2 Wastes/residues containing oil
6.	Secondary production and/or use of zinc	6.1 Sludge and filter press cake arising out of zinc sulphate production 6.2 Zinc fines/dust/ash/skimmings (dispersible form) 6.3 Other residues from processing of zinc ash/skimmings 6.4 Flue gas dust and other particulates*
7.	Primary production of zinc/lead/copper and other non-ferrous metals except aluminium	7.1 Flue gas dust from roasting* 7.2 Process residues 7.2 Arsenic-bearing sludge 7.3 Metal bearing sludge and residue including jarosite 7.4 Sludge from ETP and scrubbers
8.	Secondary production of copper	8.1 Spent electrolytic solutions 8.2 Sludges and filter cakes 8.3 Flue gas dust and other particulates*
9.	Secondary production of lead	9.1 Lead slag/Lead bearing residues 9.2 Lead ash/particulate from flue gas
10.	Production and/or use of cadmium and arsenic and their compounds	10.1 Residues containing cadmium and arsenic
11.	Production of primary and secondary aluminium	11.1 Sludges from gas treatment 11.2 Cathode residues including pot lining wastes 11.3 Tar containing wastes 11.4 Flue gas dust and other particulates* 11.5 Wastes from treatment of salt slags and black drosses*
12.	Metal surface treatment, such as etching, staining, polishing, galvanising, cleaning, degreasing, plating, etc.	12.1 Acid residues 12.2 Alkali residues 12.3 Spent bath/sludge containing sulphide, cyanide and toxic metals 12.4 Sludge from bath containing organic solvents 12.5 Phosphate sludge 12.6 Sludge from staining bath 12.7 Copper etching residues 12.8 Plating metal sludge 12.9 Chemical sludge from waste water treatment

S.No. 1	Processes 2	Hazardous Wastes 3
13.	Production of iron and steel including other ferrous alloys (electric furnaces; steel rolling and finishing mills; Coke oven and by product plant)	13.1 Process dust * 13.2 Sludge from acid recovery unit 13.3 Benzol acid sludge 13.4 Decanter tank tar sludge 13.5 Tar storage tank residue
14.	Hardening of steel	14.1 Cyanide-, nitrate-, or nitrite-containing sludge 14.2 Spent hardening salt
15.	Production of asbestos or asbestos-containing materials	15.1 Asbestos-containing residues 15.2 Discarded asbestos 15.3 Dust/particulates from exhaust gas treatment.
16.	Production of caustic soda and chlorine	16.1 Mercury bearing sludge 16.2 Residue/sludges and filter cakes* 16.3 Brine sludge containing mercury
17.	Production of acids	17.1 Residues, dusts or filter cakes* 17.2 Spent catalyst*
18.	Production of nitrogenous and complex fertilizers	18.1 Spent catalyst* 18.2 Spent carbon* 18.3 Sludge/residue containing arsenic 18.4 Chromium sludge from water cooling tower 18.5 Chemical sludge from waste waster treatment
19.	Production of phenol	19.1 Residue/sludge containing phenol
20.	Production and/or industrial use of solvents	20.1 Contaminated aromatic, aliphatic or napthenic solvents not fit for originally intended use 20.2 Spent solvents 20.3 Distillation residues
21.	Production and/or industrial use of paints, pigments, lacquers, varnishes, plastics and inks	21.1 Wastes and residues 21.2 Fillers residues
22.	Production of plastic raw materials	22.1 Residues of additives used in plastics manufacture like dyestuffs, stabilizers, flame retardants, etc. 22.2 Residues of platicisers 22.3 Residues from vinylchloride monomer production 22.4 Residues from acrylonitrile production 22.5 Non-polymerised residues
23.	Production and/or industrial use of glues, cements, adhesive and resins	23.1 Wastes/residues (not made with vegetable or animal materials)*
24.	Production of canvas and textiles	24.1 Textile chemical residues* 24.2 Chemical sludge from waste water treatment
25.	Industrial production and formulation of wood preservatives	25.1 Chemical residues 25.2 Residues from wood alkali bath
26.	Production or industrial use of synthetic dyes, dye-intermediates and pigments	26.1 Process waste sludge/residues containing acid or other toxic metals or organic complexes 26.2 Chemical sludge from waste water treatment 26.3 Dust from air filtration system
27.	Production or industrial use of materials made with organo-silicone compounds	27.1 Silicone-containing residues 27.2 Silicone oil residues
28.	Production/formulation of drugs/ pharmaceuticals	28.1 Residues and wastes* 28.2 Spent catalyst / spent carbon 28.3 Off specification products 28.4 Date-expired, discarded and off-specification drugs/ medicines 28.5 Spent mother liquor 28.6 Spent organic solvents
29.	Production, use and formulation of pesticides including stock-piles	29.1 Wastes/residues containing pesticides 29.2 Chemical sludge from waste water treatment 29.3 Date-expired and off-specification pesticides
30.	Leather tanneries	30.1 Chromium bearing residue and sludge 30.2 Chemical sludge from waste water treatment

S.No. 1	Processes 2	Hazardous Wastes 3
31.	Electronic Industry	31.1 Residues and wastes* 31.2 Spent etching chemicals and solvents
32.	Pulp & Paper Industry	32.1 Spent chemicals 32.2 Corrosive wastes arising from use of strong acid and bases 32.3 Sludge containing adsorbable organic halides
33.	Disposal of barrels / containers used for handling of hazardous wastes / chemicals	33.1 Chemical-containing residue from decontamination and disposal 33.2 Sludge from treatment of waste water arising out of cleaning / disposal of barrels / containers 33.3 Discarded containers / barrels / liners used for hazardous wastes/chemicals
34.	Purification processes for air and water	34.1 Flue gas cleaning residue* 34.2 Toxic metal-containing residue from used-ion exchange material in water purification 34.3 Chemical sludge from waste water treatment 34.4 Chemical sludge, oil and grease skimming residues from common industrial effluent treatment plants (CETPs) and industry-specific effluent treatment plants (ETPs) 34.5 Chromium sludge from cooling water treatment
35.	Purification process for organic compounds/solvents	35.1 Filters and filter material which have organic liquids in them, e.g. mineral oil, synthetic oil and organic chlorine compounds 35.2 Spent catalyst* 35.3 Spent carbon*
36.	Waste treatment processes, e.g. incineration, distillation, separation and concentration techniques	36.1 Sludge from wet scrubbers 36.2 Ash from incineration of hazardous waste, flue gas cleaning residues 36.3 Spent acid from batteries 36.4 Distillation residues from contaminated organic solvents

* Unless proved otherwise by the occupier based on sampling and analysis carried out by a laboratory recognized under the Act not to contain any of the constituents mentioned in Schedule 2 to the extent of concentration limits specified therein.

Among the 1440 industries identified (as on 31 March, 1996) in the country with a high potential for pollution, 203 industries are recorded as not having adequate facilities to comply with the regulatory standard for treatment and disposal of wastes (TEDDY, 1998). The data on HW quantities generating from 13011 industries show approximately 4.41 metric million tones per annum (MMTA) in India (HPC, 2001; Babu and Ramakrishna, 2003).The HW generation in Indian States is given in Table 2.13 (HPC, 2001; SDNP, 2003). The data shows that the HW generation is maximum in Maharashtra (45.47%) followed by Gujarat (9.73%). Minimum HW is reported in Chandigarh (0.0069%). The number of industries that generate HW are maximum in Maharashtra (30.38%) followed by Gujarat (22.93%). The data shows that, 13011 industries are generating 4415954 TPA of HW in India.

Table 2.12: List of Hazardous Wastes above the particular concentration (Schedule II) (**Source**: MoEF, 1989)

S.No.	Class A	Class B	Class C	Class D	Class E
	≥ 50 mg kg^{-1} (Concentration limit)	≥ 5, 000 mg kg^{-1} (Concentration limit)	≥ 20, 000 mg kg^{-1} (Concentration limit)	≥ 50, 000 mg kg^{-1} (Concentration limit)	At all concentrations
1.	Sb & its compounds	Cr (III) compounds	NH_3 & ammonium compounds	Total Sulphur	Flammable substances
2.	As & its compounds	Co compounds	Inorganic peroxides	Inorganic acids	which generate hazardous quantities of flammable gases
3.	Be & its compounds	Cu compounds	Ba compounds except $BaSO_4$	Metal hydrogen sulphates	
4.	Cd & its compounds	Pb & its compounds	Fluorine compounds	Oxides & OH^- except those of H, C, Si, Fe, Al, Ti, Mn, Mg, Ca	
5.	Cr (VI) compounds	Mo compounds	P compounds except phosphates of Al, Ca & Fe	Total CH other than those listed under A12 to A18	
6.	Hg	Ni	Bromates, (hypo-bromites)	Organic oxygen compounds	
7.	Se & its compounds	Inorganic Sn compounds	Chlorates, (hypo-chlorites)	Organic nitrogen compounds expressed as nitrogen	
8.	Te & its compounds	V compounds	Aromatic compounds other than A12 to A18	Nitrides	
9.	Tl & its compounds	Tungsten compounds	Organic silicone compounds	Hydrides	
10.	Inorganic CN compounds	Ag compounds	Organic sulphur compounds		
11.	Metal carbonyls	Halogenated aliphatic compounds	Iodates		
12.	Nap	Organo phosphorus compounds	Nitrates, nitrites		
13.	Ant	Organic peroxides	Sulphides		
14.	PA	Organic nitro-& nitroso-compounds	Zinc compounds		
15.	CHR, BaA, FL, BaP, BkF, IND & BghiP	Organic azo-& azooxy compounds	Salts of per-acids		
16.	halogenated compounds of aromatic rings	Nitriles	Acid amides		
17.	Halogenated aromatic compounds	Amines	Acid anhydrides		
18.	Benzene	(Iso-& thio-) cyanates			
19.	Organo-chlorine pesticides	Phenol & phenolic compounds			
20.	Organo-tin Compounds	Mercaptans			
21.		Asbestos			
22.		Halogen-silanes			
23.		Hydrazine (s)			
24.		Flourine			
25.		Chlorine			
26.		Bromine			
27.		White & red phosphorus			
28.		Ferro-silicate & alloys			
29.		Manganese-silicate			
30.		Halogen-containing compounds which produce acidic vapours on contact with humid air or water			

Handling of Hazardous Waste (in India). Generator of the HW should pack the waste in a manner suitable for safe handling, storage and transportation. Labeling on packaging should be readily visible and material used for packaging shall withstand physical and climatic conditions. Generator shall ensure that information regarding characteristics of wastes particularly in terms of being corrosive, reactive, ignitable or toxic is provided on the label. To transport HW, the HW generator has to prepare six copies of the manifest in *Form 9* comprising of color code indicated (all six copies should be signed by the transporter).

Table 2.13: Total hazardous waste generation in various states of India (**Source**: SDNP, 2003)

State / Union Territory	**Total Districts**	**Districts in which HW units located**	**Total units**	**Total HW generation TPA**
Andhra Pradesh	23	22	501	111098
Assam	23	8	18	166008
Bihar	55	12	42	26578
Chandigarh	1	1	47	305
Delhi	9	9	403	1000
Goa	2	2	25	8742
Gujarat	24	24	2984	430030
Haryana	17	15	309	32559
Himachal Pradesh	12	6	116	2159
Karnataka	27	25	454	103243
Kerala	14	11	133	154722
Maharashtra	33	33	3953	2007846
Madhya Pradesh	61	38	183	198669
Orissa	30	17	163	341144
Jammu & Kashmir	14	5	57	1221
Pondichery	1	1	15	8893
Punjab	17	15	700	22745
Rajasthan	32	26	332	122307
Tamil Nadu	29	29	1100	401073
Uttar Pradesh	83	65	1036	145786
West Bengal	17	9	440	129826
India	524	373	13011	4415954

The HW generator have to forward copy number 1 (white) to the State Pollution Control Board or Committee and in case the HW is likely to be transported through any transit State, the occupier should prepare an additional copy each for such State and forward the same to the concerned State Pollution Control Board or Committee before he hands over the HW to the transporter. No transporter shall accept HWs from an occupier for transport unless it is accompanied by copy numbers 2 to 5 of the manifest. Copy numbers with color codes for HW handling and treatment are given in Table 2.14. The transporter shall return copy number 2 (yellow) of the manifest signed with date to the occupier as token of receipt of the other four copies of the manifest and retain the remaining four copies to be carried and handed over to respective agencies. In case of transport of HW to a facility for treatment, storage and disposal existing in a State other than the State where HWs are generated, the occupier shall obtain 'No Objection Certificate' from the State Pollution Control Board or Committee of the concerned State or Union Territory Administration where the facility is existing.

Table 2.14: Copy numbers with color codes for HW handling and treatment (**Source**: MoEF, 1989)

Copy number with color code	Purpose
Copy 1 (white)	To be forwarded by the occupier to the State Pollution Control Board or Committee
Copy 2 (yellow)	To be retained by the occupier after taking signature on it from the transporter and rest of the four copies to be carried by the transporter
Copy 3 (pink)	To be retained by the operator of the facility after signature
Copy 4 (orange)	To be returned to the transporter by the operator of facility after accepting waste
Copy 5 (green)	To be returned by the operator of the facility to State Pollution Control Board/Committee after treatment and disposal of wastes
Copy 6 (blue)	To be returned by the operator of the facility to the occupier after treatment and disposal of wastes.

2.3.2.3 Quantification and Storage

The HWs are quantified based on their individual characteristics. The several options of compatibility of wastes with different characteristics should be studied and segregated. The quantity of HWs will be expressed in terms of each category for disposal (e.g. recyclable, incinerable, or disposable etc). The wastes that are recyclable are used e.g. waste oil, lead wastes, zinc wastes etc. (HPC, 2001). The quantity of HW generation reported in India in 2003 was 44,15,954 TPA from 373 districts out of 524 districts (Babu and Ramakrishna, 2003). According to an estimate (SDNP, 2003), the land required to dispose 5.3 million tones of HW in an engineered landfill, assuming the average density of waste to be around 1.2 tones m^{-3} and the depth of the landfill 4 m, would be around 1.08 km^2 every year.

Storage of HW means storing waste for a temporary period, at the end of which the HW is treated and disposed off. Separate area should be earmarked for storing the waste and storage area may consist of different cells for storing different kinds of HWs. Ignitable, reactive and non-compatible wastes shall be stored separately. No open storage is permissible and the designated HW storage area shall have proper enclosures, including safety requirements. In order to have appropriate measures to prevent percolation of spills, leaks etc. to the soil and ground water, the storage area may be provided with concrete pavement and/ or welded iron sheet depending on the characteristics of the waste handled. Storage area shall be designed in such a way that the floor level is at least 150 mm above the maximum flood level. Proper stacking of drums with wooden frames shall be practised. In case of spills/ leaks, cotton shall be used for cleaning instead of water. Signboards showing precautionary measures to be taken, in case of normal and emergency situations shall be displayed at appropriate locations. To the extent possible, manual operations with in storage area are to be avoided. In case of personnel use, proper precautions need to be taken, particularly during loading/ unloading of liquid hazardous. Waste in drums. A system for inspection of storage area to check the conditions of the containers, spillages, leakages etc. shall be established and proper records shall be maintained.

2.3.2.4 Disposal

After quantifying the HW and assessing the probable area requirements for its treatment and storage, the sites are to be identified for disposal. For this purpose, toposheets and/or remote sensing images of the study region may be used. The sites are to be physically verified in the field and to draw observations pertaining to the four different types of attributes (viz., Receptor related-, Pathway related-, Waste characteristics related-, and Waste management practices related-) available for ranking the sites. The site with a minimum score out of the available sites for ranking should be chosen as the site for establishing Treatment, Storage and Disposal Facility (TSDF) (Babu and Ramakrishna, 2003). TSDF are those facilities, which handle HW from more than one industry either installed as an integral part or located elsewhere. Various concerned components of TSDF include proper transportation, storage, analytical laboratory facilities, feeding mechanism, incineration system (rotary kiln & post combustion chamber), gas cleaning system, tail gas monitoring facilities with automatic on-line monitoring and control facilities, ash/ slag management, bleed/scrubber liquor management and measures for health protection of workers.

Physical models are available in literature (Ramakrishna and Babu, 1999; Babu and Ramakrishna, 2000; Babu and Ramakrishna, 2003) that give accurate results than the approximate methods available in Guidelines (1991) for ranking the sites for TSDF. The Environmental Impact Assessment should be conducted in the site identified in the above step. The impacts from the project should be identified and public acceptance should be obtained for clearing the site for TSDF. As per the ideal industrial siting criteria in India, the industry should have enough land available within its premises for the treatment and disposal and or reuse/recycling of the wastes generated from it (Murali Krishna, 1995). However, very few industries in India own proper treatment and disposal facilities (Jeevan Rao, 1999). Mostly the large-scale industries and a few medium-scale industries (Ramakrishna and Babu, 1998), and none of the small-scale industries own the above facilities. Among the 1440 industries identified (as on 1996) in the country with a high potential for pollution, 203 industries (i.e., ~ 14 %) were recorded as not having adequate facilities to comply with the regulatory standards for treatment and disposal of wastes (TEDDY, 1998). Financial, administrative, and infrastructural facilities were some of the reasons attributed for the above limitations. It was surprising to note that, till 1997, there is no secured landfill facility available in the country to dispose of HW (HPC, 2001).

HWs are disposed off at TSDF, a centralized location catering to the HW generated from the waste generators in the near vicinity. The TSDF helps the small and medium scale industries generating HW in disposing their wastes efficiently. The site selection criteria for a TSDF depend upon Receptors and Pathways of likely waste movement, waste characteristics and waste management practices (Guidelines, 1991). The planning for HW management comprises of several aspects ranging from identification and quantification of HW to development and monitoring of TSDF.

Industrial waste is a major component of the waste stream. There are many ways to reduce waste in an industrial setting. Waste minimization includes any source reduction and/or recycling activity undertaken by a waste generator (i.e. any business that produces waste through their operations). These activities result in a reduction of waste produced and/or a reduction in the toxicity of the waste. Estimated waste generated by the industry in Punjab was about 36,000 TPA, out of which Ludhiana alone contributed 40 %. (iGovernment, 2007). According to a report in national news paper (Tribune, 2006a), from Chaba village (Amritsar), the ground water in the entire area has got contaminated due to untreated industrial waste being released into the Chohal drain by paper mills. Residents of the area allege that allergies, jaundice and other diseases have spread in the area due to the contamination of the water. Air pollution caused due to stagnant untreated waste is causing respiratory problems. Industrial waste was being released into the drain despite the PPCB authorities recommending the closure of industrial units spreading untreated waste in the area. The district administration assessed the damage to the crops of the farmers about Rs 1.4 lakh. Majority of the tanning industries are processing through mineral tanning, using chromium, instead of vegetable tanning (The Tribune, 2006b). Chromium is posing a serious health risk to all those working. The carcinogenic chemical has the tendency to settle in the environment and cause lung diseases, including cancer, besides skin ailments. The horror of unbearable foul stench, open channels of effluent discharge, heaps of discarded animal skin and bundles of wet, blue-colored chrome-tanned hides show clear violations of the pollution norms, posing a serious risk to lives of hundreds of workers employed inside these units.

The hazardous water from Punjab was being used for drinking in a vast area of western Rajasthan. The Rajasthan Government in 2004 urged the PPCB to check pollution in the Sutlej, which was affecting people of the desert state, who receive water from Indira Gandhi Canal. Government of Rajasthan, stated that polluted water, including industrial waste, from Ludhiana city was being discharged into the Sutlej through Buddha Nullah. Similarly, sewer water and industrial waste of Jalandhar, Nakodar and Phagwara were being released into the Kali Bein, a tributary of the Sutlej (The Tribune, 2004). District wise generation of HW in Punjab is given in Table 2.15 (ENVIS, 2003b).

Table 2.15: District wise hazardous waste generation rate in Punjab (**Source:** ENVIS, 2003b)

S. No.	District	Total (TPA)
1.	Amritsar	1120.624
2.	Bathinda	29.87
3.	Mansa	Nil
4.	Muktsar	14.00
5.	Gurdaspur	52.10
6.	Ropar	313.36
7.	Faridkot	9.40
8.	Moga	Nil
9.	Ferozepur	18.75
10.	Hoshiarpur	126.73
11.	Nawan Shahar	77.85
12.	Jalandhar	114.804
13.	Kapurthala	41.650
14.	Ludhiana	5691.79
15.	Sangrur	326.565
16.	Patiala	1357.766
17.	Fatehgarh Sahib	491.97
	Total	9787.202

2.4 Gaps in present study

Literature survey has suggested some of the areas for further research:

i) Knowledge of mechanism of products of incomplete combustion (PIC) formation and abatement through the control of combustion conditions is important due to its unknown impact on human and environment, and hence needs thorough investigation. Emission of PIC occurs from all combustion sources. Currently available data indicate that there is inherently no difference between PIC emission from burning hazardous wastes and burning fossil fuel. More research is needed to clarify this point.

ii) A complete study on the influence of different variables (fuel ratio, combustion temperature, percentage of excess oxygen, air flow etc.) on combustion emissions relating to PAHs have not yet been reported.

iii) More experimental work is needed concerning combustion byproducts/ emissions because few tests have examined the level and chemical character of emission for periods of time facilities operating under upset conditions (transients or failure modes).

iv) Literature survey showed various studies at laboratory scale on PAH emissions from incineration of PVC, PS, PE etc. Work has been done on ambient air/ inhouse air in India so as to determine various PAHs. A study on contribution of each of 16 PAHs from coal fluidized bed combustion showed that there is no definite trend on PAH distribution with combustion temperature and air flow rate (Mastral et al., 1999). More studies are needed to verify this trend in real world samples

v) The distribution of 16 PAHs during combustion of biomedical waste/ hazardous waste, PVC, PS, PE has not been reported.

vi) There seems no study regarding the emission of 2A and 2B PAHs from incineration of biomedical/hazardous waste. Apart from this, there is no report regarding management of biomedical/hazardous waste in Punjab state of India.

2.5 Objectives of the proposed work

i) *To analyse the formation of 16 PAHs from incineration of waste from local hospital/ Acrylic industry.*

ii) *To analyse waste management practices followed by local Hospitals/ Acrylic industry and the problems faced by them in complying with the environmental regulations.*

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Chapter - III

Laboratory Scale Incinerator

In this chapter, various types of laboratory scale incinerators used to study emissions from incineration are described. The need for fabrication of a special type of laboratory scale incinerator capable of providing fluidized conditions to the waste before incineration and other features of fabricated electrically heated laboratory scale vertical quartz tube incinerator along with furnace for holding the tubular system are discussed.

In order to study combustion by-products and effects of combustion parameters on their emissions, many laboratory scale incinerators/ reactors are reported. As it is quite difficult to vary combustion parameters in commercial scale incinerators (Wikstrom et al., 1998) so there is a need to construct laboratory scale incinerator. The main advantage of a laboratory-scale incinerator, due to its simplified operation, is that it facilitates elaborate studies on formation/degradation reactions of selected compounds.

3.1 Laboratory Scale Incinerators

Many research experiments have been conducted to study emissions from combustion processes at laboratory scale. Literature survey suggests the need of emission studies from waste to be carried out in an incinerator capable of working at higher temperature in metal and fuel free atmosphere because the composition of fuel as well as nature of waste results into the formation of other by-products catalyzed by the presence of metals. Wey et al. (2001) has shown that Chromium is the main metallic element which influences the formation of PAHs.

Font et al. (2004) studied emission of semi-volatile and volatile compounds in combustion of polyethylene in a lab scale horizontal furnace (Fig. 3.1). Four combustion runs at 500 and 850ºC with two different sample mass/ air flow ratios and two pyrolytic runs at the same temperatures were carried out.

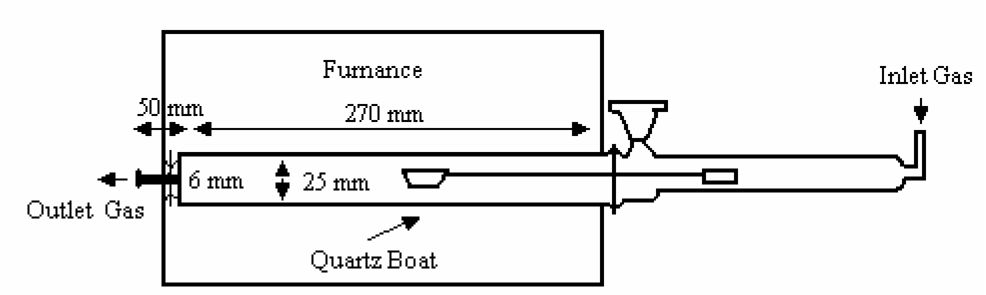


Fig. 3.1: Schematic of lab scale horizontal furnace
(**Source:** Font et al., 2003; 2004)

PAHs emissions have been reported from various laboratory scale studies from the incineration of polyvinyl chloride, polyethylene, polystyrene, latex gloves and cotton pads. The partitioning of PAHs between the particulate and gaseous phases resulting from the combustion of polystyrene was studied by Durlak et al. (1998). The polystyrene combustion experiments were conducted using a vertical, laminar flow, tubular furnace with a maximum temperature of 1200°C (Fig. 3.2). Dry, particle free air was mixed with small polystyrene spheres and fed through the furnace reactor. An average of about 130% (by mass) excess air was used for the combustion.

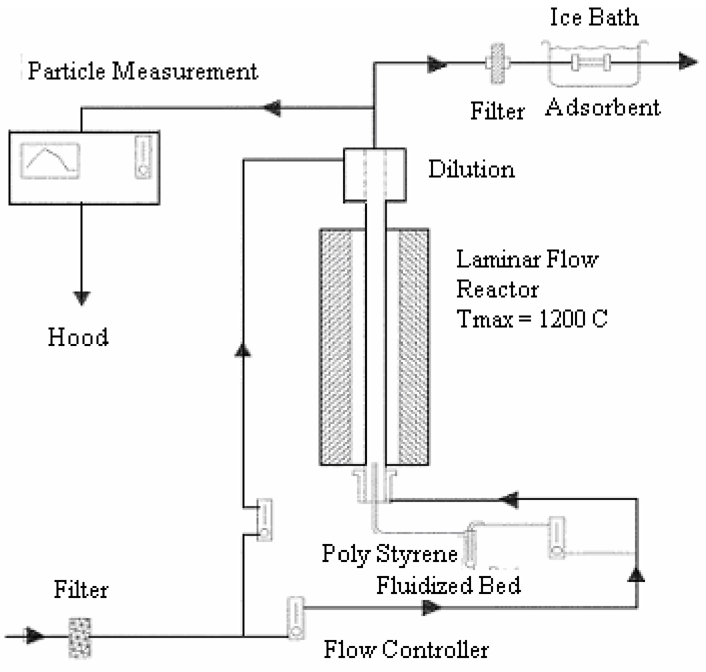


Fig. 3.2: Schematic of vertical laminar flow tubular furnace (**Source:** Durlak et al., 1998)

Wang et al. (2003a) studied CO, CO_2, light hydrocarbons, PAH and particulates emissions from incineration of polyethylene, polystyrene and polyvinyl chloride in a horizontal laminar flow reactor (Fig. 3.3). The temperature of the primary furnace was varied over a range of 500-1000°C, to identify its influence on the emission of pollutants. The combustion effluent was mixed with additional preheated air, channeled to a secondary muffle furnace (afterburner), which was operated at 1000°C. The effect of temperature on polyvinyl chloride combustion using a downstream tubular furnace (Fig. 3.4) was investigated for the formation of PAHs and chlorinated compounds by Kim et al. (2004). It was observed that as the temperature increases, higher amount of PAHs were formed. Chlorinated compounds reached a peak at 600°C, with low emissions recorded at 300 and 900°C. Levendis et al. (2001) investigated the emissions of CO, CO_2, NO_x, particulate and PAHs from batch combustion of representative biomedical waste components, such as medical examination latex gloves and sterile cotton pads in a horizontal, split cell electric furnace (1 kW max.) fitted with a quartz tube, 4 cm in diameter and 87 cm long as shown in Fig. 3.5.

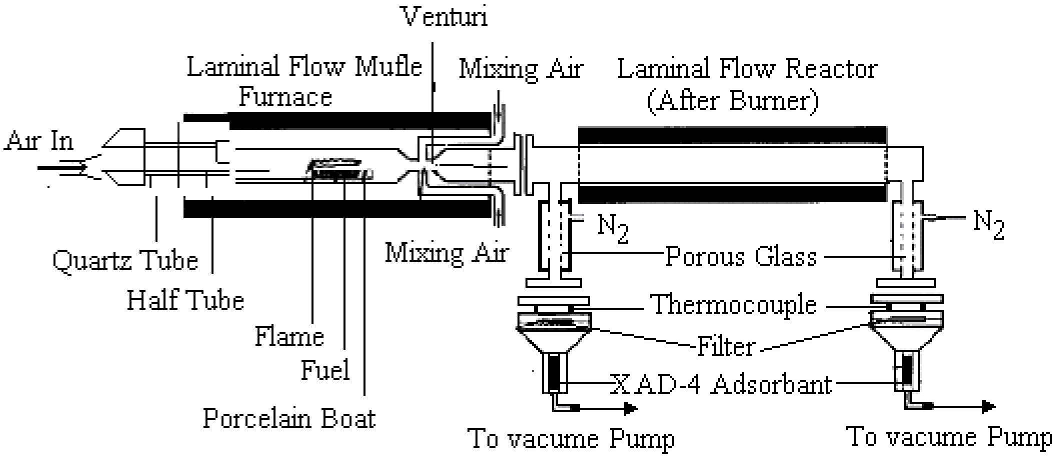


Fig. 3.3: Schematic of the experimental two-stage laminar-flow reactor
(**Source:** Wang et al., 2003a)

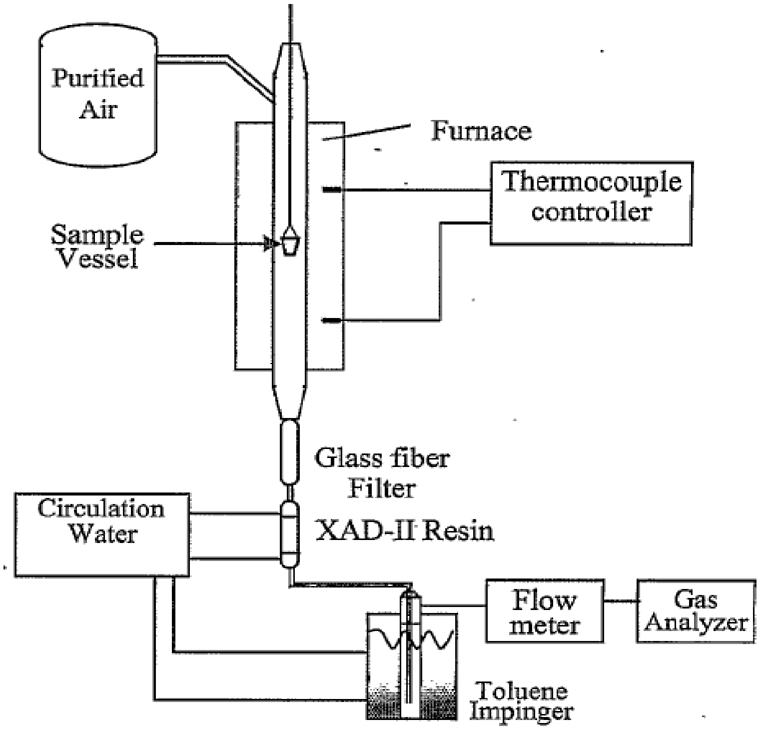


Fig. 3.4: Schematic of downstream tubular furnace (**Source:** Kim et al., 2004)

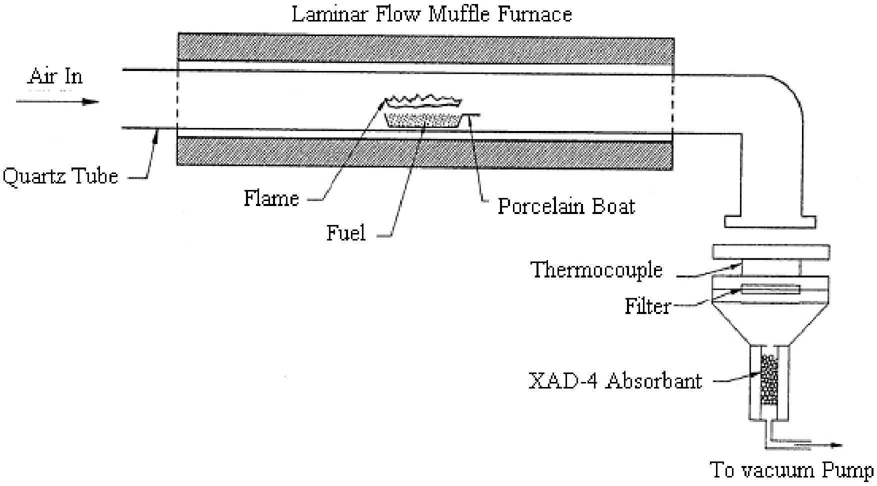


Fig. 3.5: Schematic of the laminar flow, horizontal muffle furnace
(**Source:** Levendis et al., 2001)

Chlorinated PAHs released from combustion of PVC at different furnace temperatures were investigated by Wang et al. (2003b) in a laboratory-scale tube-type furnace with electric heating (Fig. 3.6). At the beginning of a test, the tube furnace was first heated up to the test temperature (600-900ºC), and then air was introduced into the quartz tube at a 2 L min^{-1} flow rate. The quartz boat containing about 1 g of PVC was pushed into the combustion zone of the furnace. The emissions were collected with glass wool, glass fiber filter (pore diameter 0.2 µm), and an adsorption cartridge filled with 7 g of XAD-2.

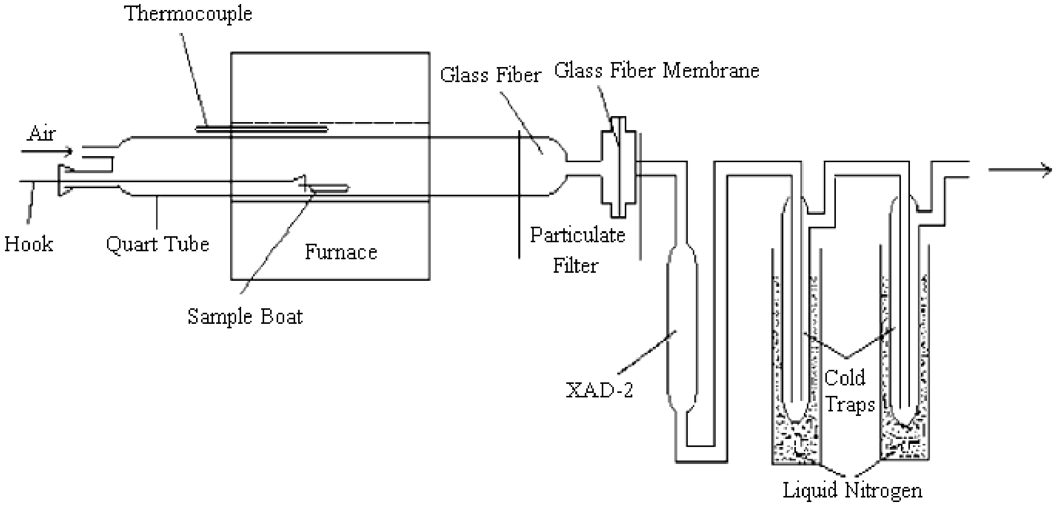


Fig. 3.6: A schematic diagram of a laboratory-scale tube type furnace (**Source:** Wang et al., 2003b)

Stieglitz et al. (1989, 1996) performed studies on de novo and catalytic formation reactions of organic micro pollutants from fly ash in laboratory scale reactor with the gas flow of about 5 ml min^{-1}. Gullet et al. (1990) investigated the effect of metal catalysts on the formation of PCDD/Fs in a quartz tube reactor as shown in Fig. 3.7. One gram of catalyst (copper/ iron compounds) was placed in the center of the quartz tube reactor with a total gas flow of 1 L min^{-1}. Parameters such as residence time, temperature conditions, O_2 and HCl concentrations were varied in this reactor. Sakai et al. (1991) used a laboratory reactor with a fuel capacity of 260 g h^{-1} to know how combustion parameters influence the formation of PCDD/Fs. The reactor consisted of a fluidized bed section and a secondary combustion chamber that was divided into three independent chambers. The combustion air supply was split into two streams and then introduced into the primary and secondary chambers.

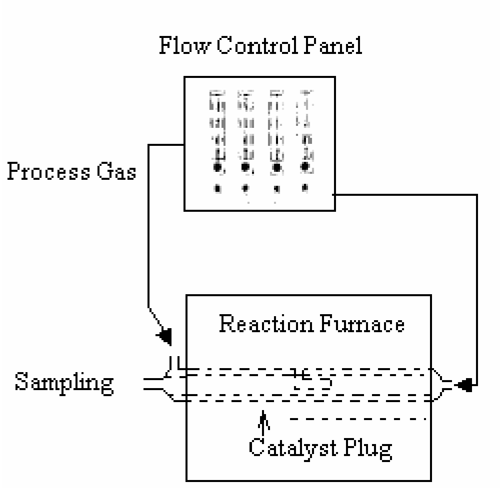


Fig. 3.7: Laboratory scale reactor (**Source:** Gullet et al., 1990)

Combustion experiments in a laboratory-scale fluidized bed reactor (Fig. 3.8) were performed by Hatanaka et al. (2001) to elucidate the effects of combustion temperature on PCDD/Fs formation during incineration of model wastes with polyvinyl chloride (PVC) or NaCl as a chlorine source and $CuCl_2$ as a catalyst. Each temperature of primary and secondary combustion zones in the reactor was set independently to 700, 800, and 900°C using external electric heaters.

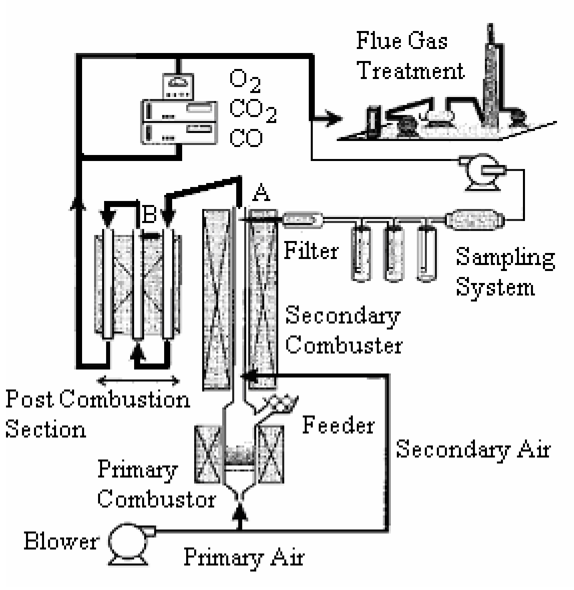


Fig. 3.8: Schematic diagram of lab scale fluidized bed reactor (**Source:** Hatanaka et al., 2001)

Khalfi et al. (2003) described the high temperature (800-1077°C) incineration of wood waste furniture in a tubular quartz reactor (as shown in Fig. 3.9) by weighing about 1 g of sample and have analyzed CO_x and PAHs emissions. A thermocouple was placed a few mm above the center of the sample to get a measure of the temperature of gases. A total air flow rate of 360 NL h^{-1} was passed through the reactor, 350 NL h^{-1} were introduced at the entrance of the fused silica reactor. A complement of 10 NL h^{-1} of air was added through a blowpipe to the sample.

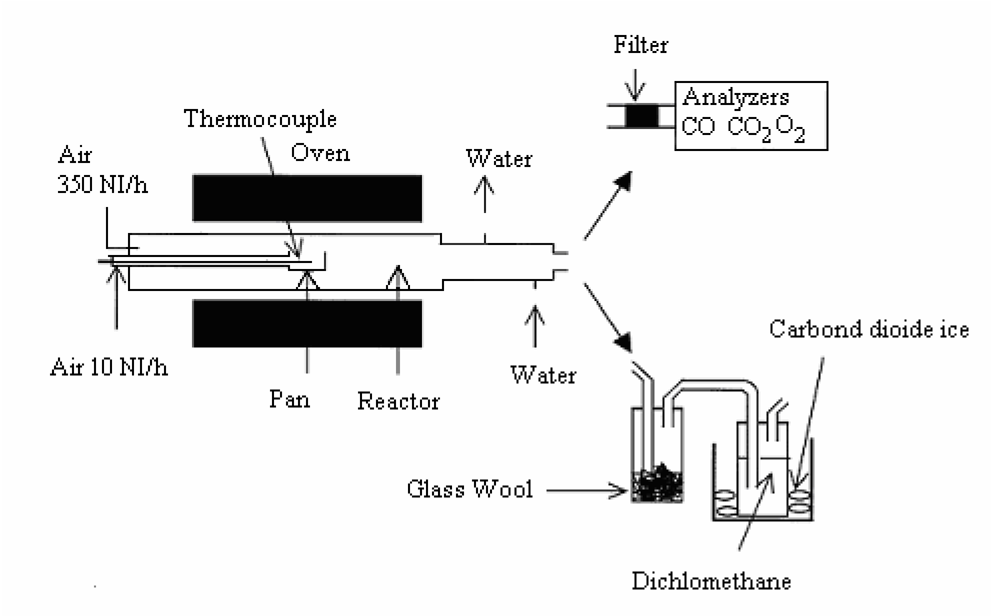


Fig. 3.9: Lab scale tubular quartz reactor (**Source:** Khalfi et al., 2003)

Ryan et al. (2004) investigated the pathways of PCDD/Fs formation from an ethylene diffusion flame in a four stage reactor as shown in Fig. 3.10. The first stage consisted of a double-tube quartz reactor (ID_{inner} = 2.2 cm, ID_{outer} = 4.6 cm, L = 122 cm), kept at 1000ºC by electric heating, with an ethylene diffusion flame at the inlet side. The exhaust from this combustion stage entered a cooling stage (Stage 2, L = 122 cm) with wall temperatures maintained at 260-470ºC to bring total flow to the soot filter stage temperature (third stage). The combustion gas, minus the soot, was then passed to a similar filter in which a 2 g bed of oxidized fly ash, held against a coarse-grain ground quartz frit with glass wool (Stage 4) was placed.

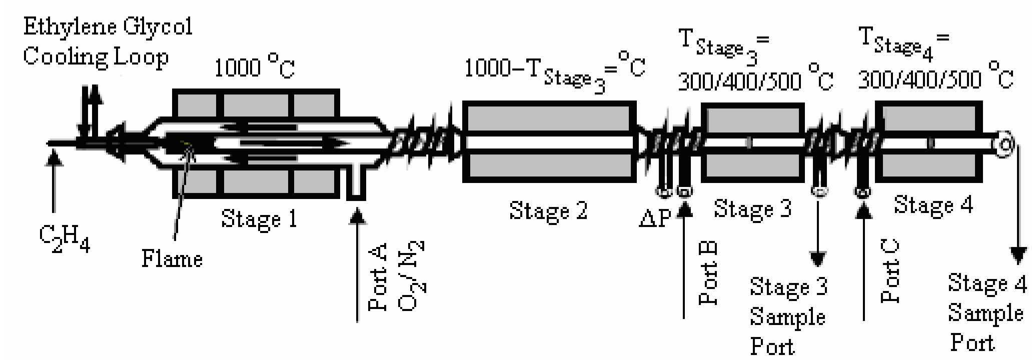


Fig.: 3.10 Schematic diagram of four stage reactor (**Source:** Ryan et al., 2004)

Literature showed that these laboratory scale 'non-flame' reactors are used to study the effect of various combustion parameters on emissions from the incineration. The incinerators used for PAHs studies are either horizontal tubular or do not contain one or more of the followings:

i). Fluidization of the sample for maximizing contact with air
ii). Non supply of preheated air
iii). Thermocouple not placed inside incineration chamber just above the point of burning of sample

So, vertical tubular laboratory scale incinerator capable of fluidizing the sample was designed and fabricated.

3.2 Fabrication of laboratory scale incinerator

The laboratory scale quartz tube vertical incinerator was fabricated to study the PAHs emissions from waste incineration under various conditions. The fabricated incineration system consisted of two parts: tubular system (Fig. 3.11) and electrically heating furnace system (Fig. 3.12). The tubular system of laboratory scale incinerator is made up of quartz tube. There are two electrical heating systems, one for air preheater (air preheater heating system) and other for incineration chamber (incineration chamber heating system) Air preheater heating system consists KANTHAL A-1 heating wire capable to sustain temperature up to 1400ºC coiled over ceramic tube of 4 cm outer diameter. High temperature furnace cement was pasted over the coils. These coils were insulated with ceramic wool in order to reduce the heat loss.

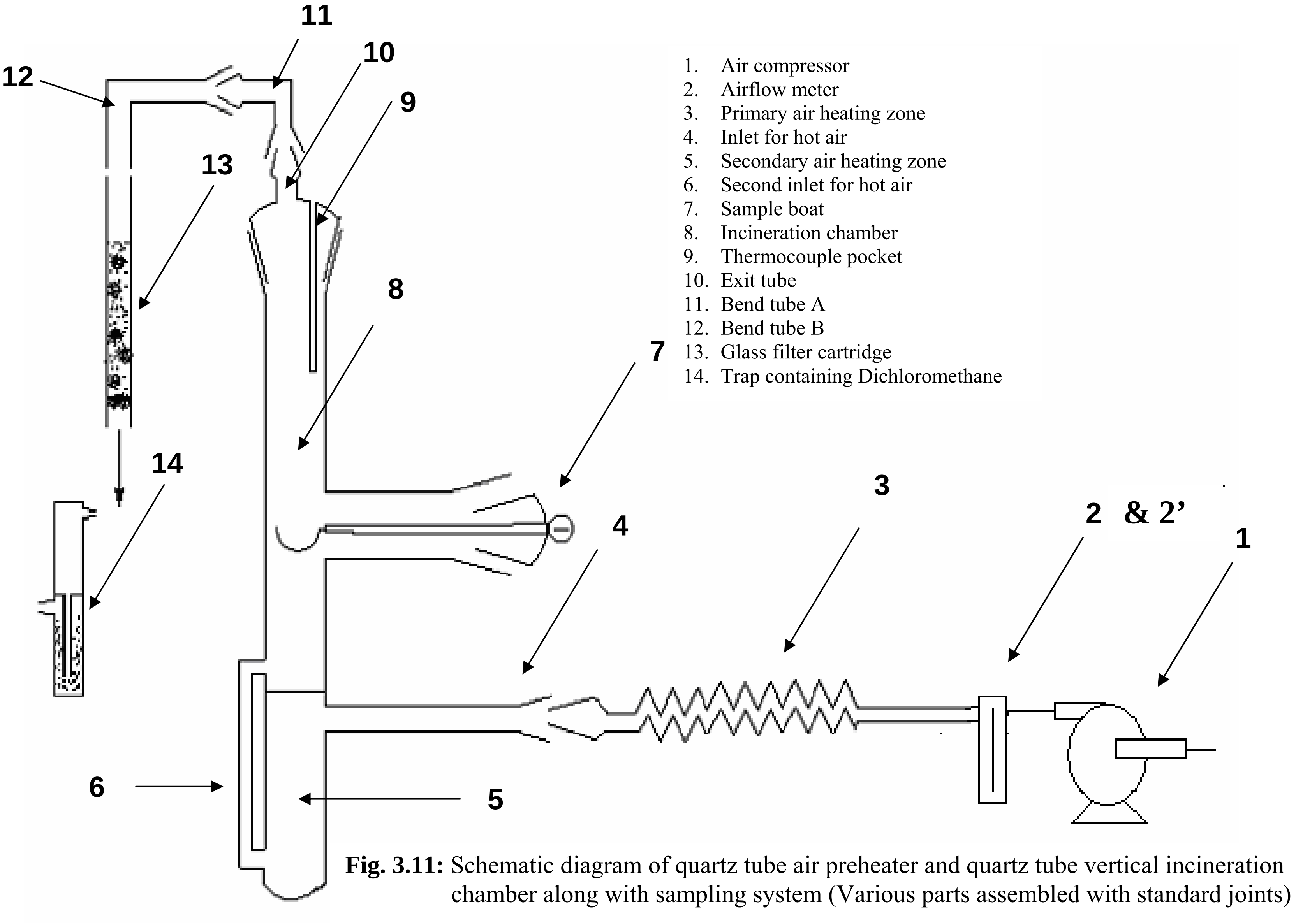
Incineration chamber heating system is made up of two separate parts: still part and other foldable one. Both parts contain electrically heating elements (KANTHAL A-1) fitted on ceramic horizontal plates (Figs. 3.12-3.13). Foldable heating part helped to open/ close the incinerator in order to place or remove the vertical quartz tube (Figs. 3.14-3.15). Heating zone was well insulated with ceramic wool packing of 12 cm thickness.

Inside the ceramic tube of air preheater heating system, quart tube of 8 mm diameter and of 150 cm length was kept. A type R thermocouple (Rhodium/ Platinum capable to work up to 1600ºC) was placed at the center of quartz tube. In incineration chamber heating system, a vertical quartz tube was kept at the center of two half's of the heating system and incinerator was closed. Vertical quartz tube further consists of two chambers: secondary air heating zone and incineration chamber. A thermocouple (Type R) was placed in thermocouple pocket located just above the sample burning zone. Exit gases were allowed to pass from incineration chamber to glass filter cartridge containing XAD resin having G-2 filter.

3.2.1 Details of incineration system

Air compressor **1** was used for passing air through coiled quartz tube of air pre-heater, secondary air heating zone, incineration chamber, exit of incineration chamber, air condenser, glass filter cartridge and traps containing dichloromethane. **2** and **2'** are airflow meters used to measure and adjust the airflow rate. These flow meters were calibrated and have the capacity to pass air up to 5 L min^{-1}. **3** is a coiled quartz tube of 8 mm diameter whose length is ~ 1400 mm. This coiled tube is kept in **26** air preheater heating system having a temperature sensor **24** thermocouple. The temperature of air preheater heating system can be adjusted up to 1000ºC. **4** is inlet for hot air of 8 mm diameter and is made up of quartz. This tube passes the air to secondary heating chamber **5** made up of quartz with a height of 270 mm and diameter of 32 mm. The air from **5** goes to **8** through a narrow quartz tube **6** (8 mm diameter). Part **8** is the main incineration chamber of 432 mm height having diameter 32 mm.

Sample of known weight can be loaded into quartz boat **7**. Part **7** has B-29 cone having quartz road (~ 265 mm) fitted with the boat. It is present in the middle of incineration chamber. The overall height of vertical tube is ~ 700 mm. Incineration chamber **8** has provision to insert boat rod up to the center of vertical quart tube of **8**. Part **9** is a thermocouple pocket used to keep thermocouple (part **25**) which is used to measure the inner temperature of incineration chamber, just above the point of burning of waste. **10** is exit for emission gases from 8 to quart tube **12**. From **12** these emissions pass to **13**, a glass filter cartridge for XAD resin having G-2 filter via air condenser. The emission gases were further allowed to pass through DCM containing traps **14**. The temperature of **8** is increased by Kanthal wire heating elements fitted in ceramic horizontal heater plates **20** and **20'**. Quartz tube **8** along with other parts **5 - 10** is kept in highly insulated ceramic wool. There are spaces **15** and **16** for two quartz tubes, one required for sample feeding and another for passing hot air. **21** represents cross sectional view of vertical tubular furnace. The thermocouples **24**, **25** are attached to PID temperature controllers **22**, **23** respectively. These controllers can read both the set and the actual temperatures of the heating zones. The power supply of this tubular laboratory scale incinerator is 4 KW while current requirement is 8 ampere.



1. Air compressor
2. Airflow meter
3. Primary air heating zone
4. Inlet for hot air
5. Secondary air heating zone
6. Second inlet for hot air
7. Sample boat
8. Incineration chamber
9. Thermocouple pocket
10. Exit tube
11. Bend tube A
12. Bend tube B
13. Glass filter cartridge
14. Trap containing Dichloromethane

Fig. 3.11: Schematic diagram of quartz tube air preheater and quartz tube vertical incineration chamber along with sampling system (Various parts assembled with standard joints)

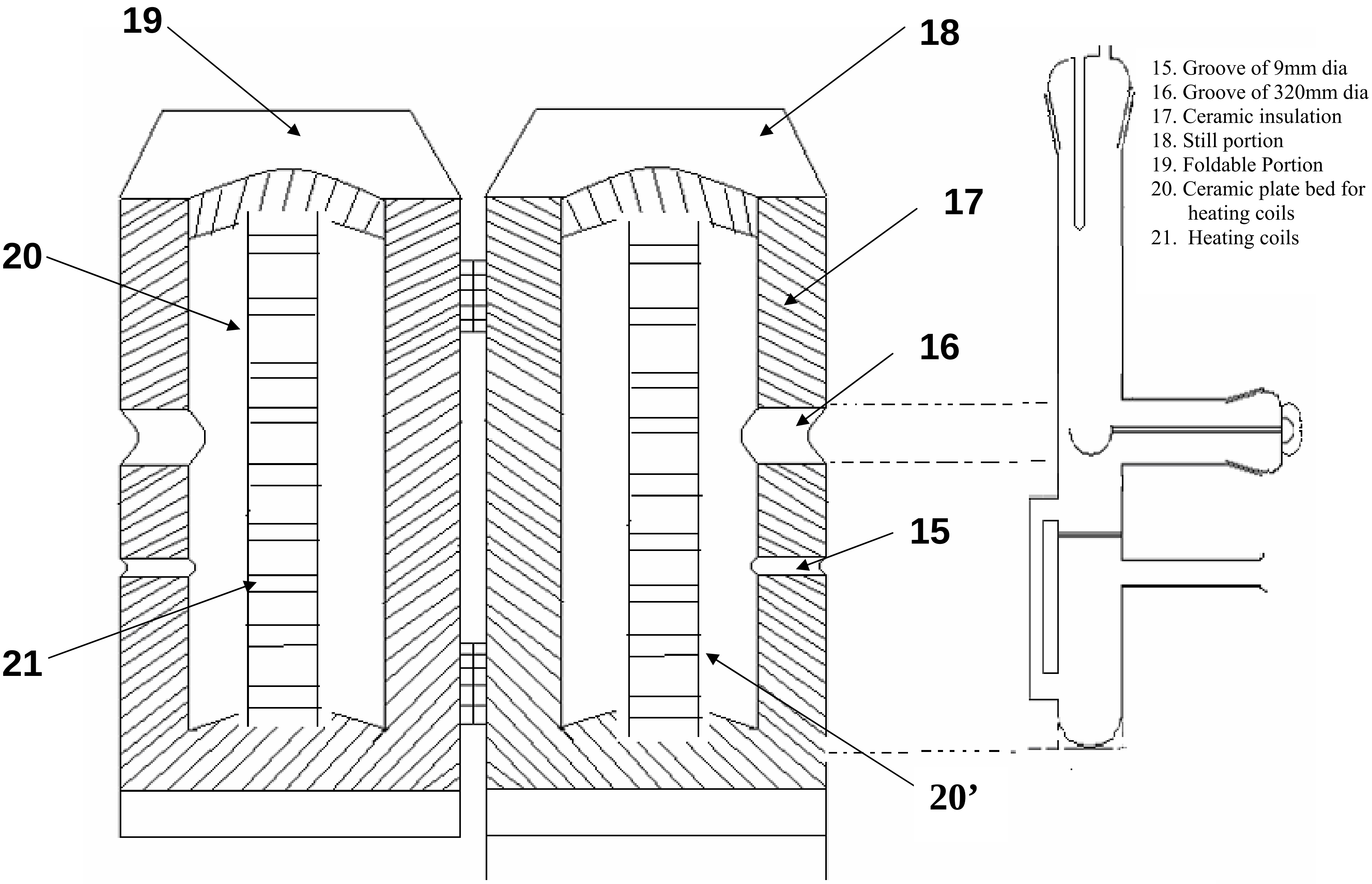
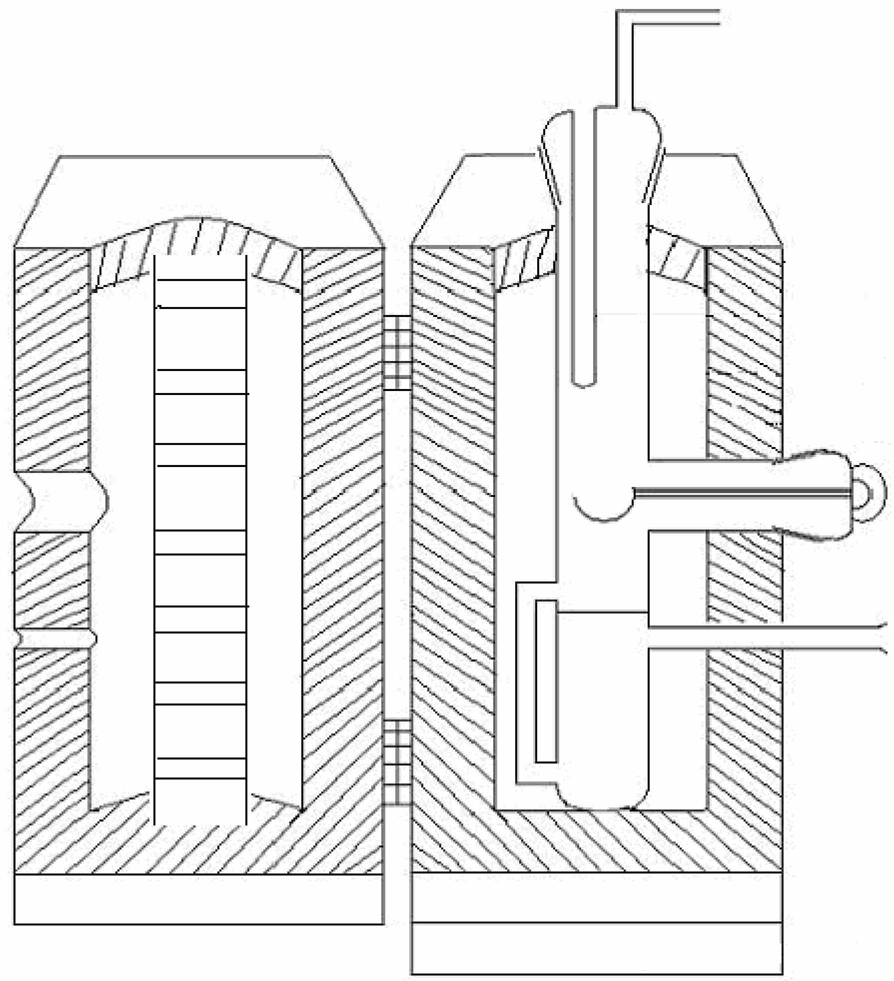
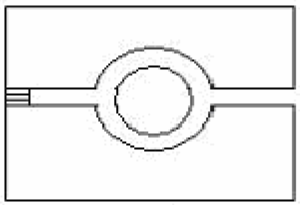


Fig. 3.12: Schematic diagram of quartz tube of vertical incineration chamber along with heating system





(b): Cross sectional view
of closed heating system

Fig. 3.13 (a): Schematic diagram of quartz tube of vertical combustion chamber with heating system

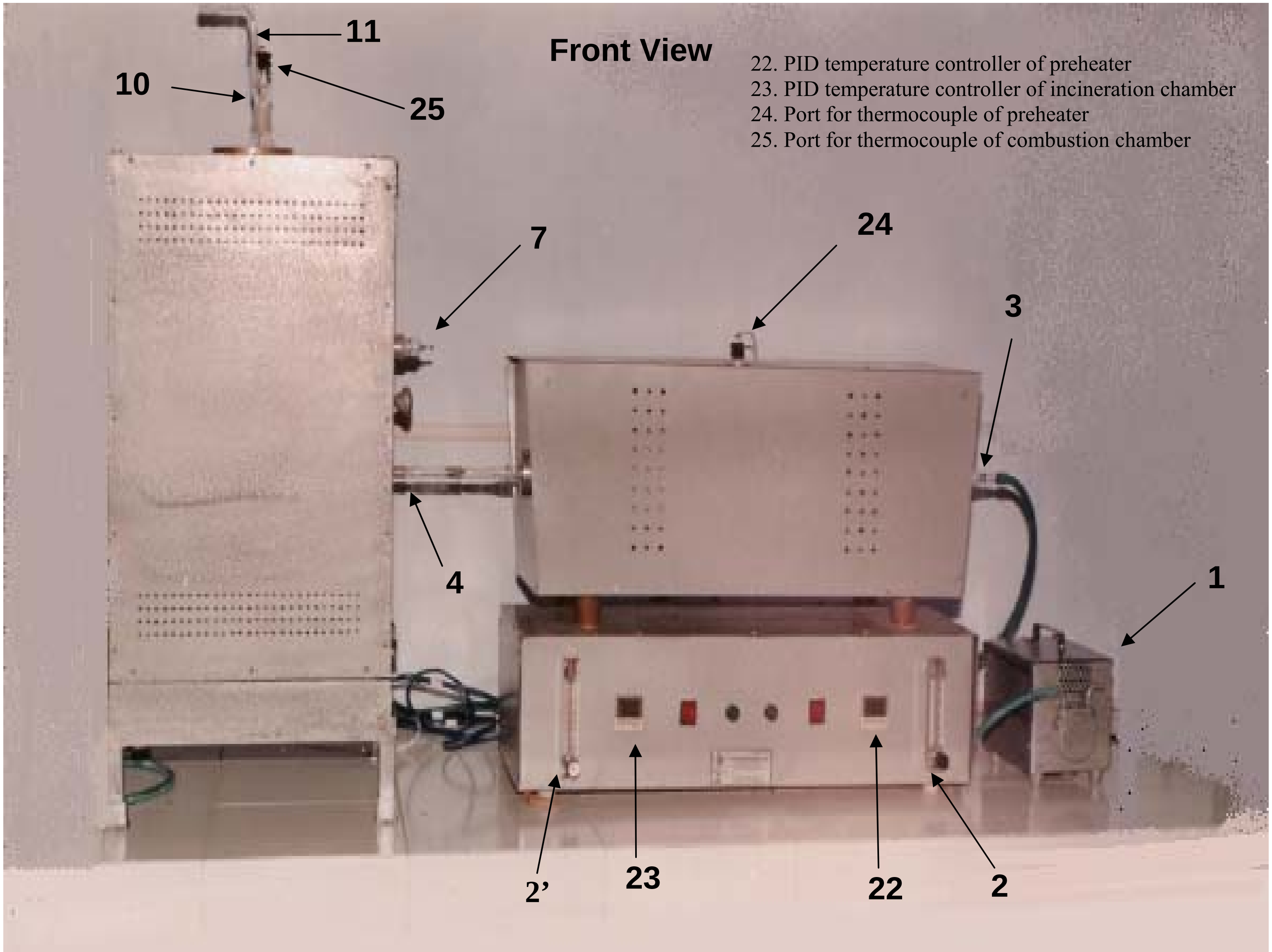


Fig. 3.14: Front view of quart tube vertical laboratory scale incinerator along with accessories

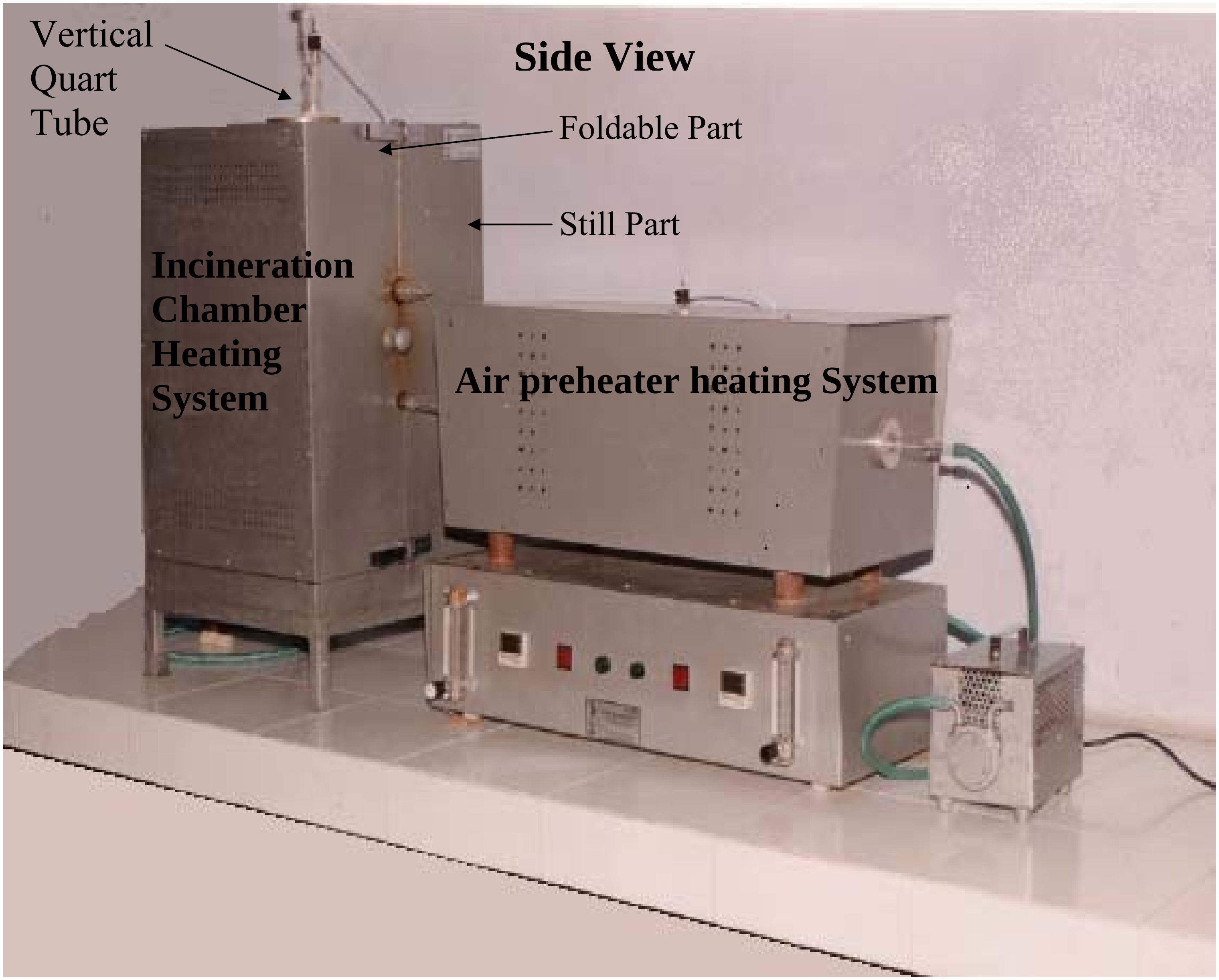


Fig. 3.15: Side view of quart tube vertical tubular laboratory scale incinerator along with accessories

Chapter – IV

PAHs from waste incineration of local hospital/ acrylic industry – A laboratory scale study

Incineration process is generally employed to get rid of hazardous components present in waste but it also leads to harmful organic and inorganic releases to the environment. This chapter presents the studies on the emissions of 16 PAHs from waste incineration in specially designed laboratory scale incinerator and the effect of combustion parameters like temperature and airflow rate on their formation.

4.1. Materials and Methods

The waste samples were collected from Govt. Rajendra Hospital, Patiala (local hospital) and Indian Acrylics Pvt. Ltd., Sangrur (acrylic industry), pre-pre-weighed samples of waste were incinerated in the laboratory scale incinerator. Emission gases were passed through XAD-4 and PAHs were extracted in dichloromethane with soxhlet apparatus and analyzed for PAHs on GC. GC used for PAHs was Nucon - 5765 (India). Elemental analysis (C, H) was recorded on *Elemental analysis Analytic Gena* and TGA were recorded on *TGA Mettler Toledo*.

4.1.1. Experimental Procedure

Incineration of various samples was conducted at different temperatures (700-1000°C) and airflow rates 1-4 L Min^{-1} (measured at atmospheric pressure and room temperature) in a specially designed electrically heated laboratory scale incinerator equipped with a quart tube vertical combustion chamber, quartz tube air pre-heater, an air blower and XAD-4 contained in glass cartridge. Quartz tube of incinerator was cleaned thoroughly after each experiment to avoid any contamination. The temperature of air pre-heater was kept at 700°C for each experiment while the emission gases were passed through XAD -4 cartridge kept at room temperature.

For an incineration experiment, all parts of incinerator were put in place as per Fig. 3.11. The quartz tube furnace and air-preheater were switched on. The temperature of furnace was selected as per requirement of the experiment and temperature of preheater was set at 700ºC. Air flow was adjusted from 1-4 L Min^{-1}. The desired temperature of furnace and preheater was attained in about 3-4 hours. When the temperature stabilized to the selected value, weighed amount of sample was introduced inside the quartz tube incinerator through a boat (made up of quartz and attached to standard joint stopper) to the hot combustion zone and the standard joint stopper was rotated so that the boat turns upside down resulting in the fall of sample inside the hot zone. The emission gases were passed through a trap containing XAD-4 resin and were allowed to pass through another three traps containing dichloromethane (DCM) for about 10 minutes. The apparatus was switched off. Airflow was stopped and parts of apparatus outside heating zone were dismantled. The XAD-4 resin along with its cartridge was extracted with 250 ml fresh DCM in a soxhlet apparatus for 24 hrs. DCM so obtained was mixed with DCM of three traps and was removed under vacuum in rotary evaporator. The sample was concentrated to 1 ml and stored in teflon lined glass vial at 4ºC. In order to compare samples containing PAHs in DCM with standard solution of PAHs in cyclohexane, DCM of some samples was replaced with cyclohexane.

4.1.2. Waste samples

The waste samples were collected from a local hospital and acrylic fiber producing industry from Punjab state of India.

4.1.2.1. Biomedical Waste: The biomedical waste (BMW) samples were collected from Govt. Rajendra Hospital, Patiala, Punjab (India), which comprises; blood contaminated blood bag (CBB) and used blood contaminated cotton (BCC). Currently, both these wastes are supplied to CBMWTF for incineration. The elemental analysis of CBB and BCC showed carbon as 78.65 and 45.47%; and hydrogen as 11.63 and 7.68%, respectively. The CBB was homogenized with liquid nitrogen before incineration. The representative samples of CBB and BCC (~0.5 g) were subjected to incineration at pre-determined temperatures and airflow rates.

4.1.2.2. Acrylic Industrial Waste: The waste samples were collected from Indian Acrylics Limited Sangrur, Punjab (India), which comprises; (i) acrylic waste solution (AWS) and (ii) cellulose waste filters (CWF). These wastes are being disposed off by industry through incineration. The elemental analysis of AWS and CWF showed carbon as 69.72 and 84.20 %; and hydrogen as 11.93 and 14.80 % respectively. The AWS was homogenized with liquid nitrogen before incineration. The representative samples of both AWS and CWF (~ 0.5 g) were subjected to incineration at pre-determined temperatures and airflow rates.

4.1.3. Emission sampling

Incineration experiments of the samples were conducted at temperatures higher than the decomposition temperature of the sample which was determined by *Thermal Gravimetric Analysis.* All waste samples showed complete decomposition get decomposed below 600°C. The temperature of air pre-heater kept at 700°C, airflow rate of 1-4 L min^{-1} was maintained during each experiment. The vertical quartz tube was heated to the pre set temperature of 700-1000^{o}C. A quartz boat loaded with exactly weighed sample (~ 0.5 g) was introduced through the inlet tube of the incinerator. The boat was turned upside down to have fluidized condition. The theoretical mean residence time (chamber volume/gas volumetric flow rate) of the gases in combustion chamber was calculated to be ~ 12, 6, 4, 3 seconds at air flow rate of 1, 2, 3, 4 L Min^{-1} respectively (IRDE, 2006). The emissions were allowed to pass for several minutes through 7 g of XAD-4 resin (Sigma-Aldrich) kept at room temperature, and then allowed to pass through trap containing 250 ml DCM. Both XAD-4 and the glass filter cartridge were extracted with DCM in soxhlet apparatus for 12 hours before these were used for experiments.

4.1.4. Sample preparation

The glass filter cartridge, outlet tubes having soot and XAD-4 resin were removed after each experiment and were extracted along with soot with 500 ml of DCM in soxhlet apparatus for 24-hour. The DCM from the soxhlet and traps was mixed together, concentrated with rotary vacuum evaporator to 1 ml. The final extracts of incinerated sample were stored in glass vials having teflon-lined caps and were stored at 4°C. Special care was taken to eliminate any contamination. Glassware was properly cleaned and dried before use. All the extractions were performed in well ventilated fume hood.

4.1.5. Optimization of GC-FID parameters

GC-FID parameters were optimized prior to analysis of samples. PAHs solution was prepared by suitable dilution of stock solution (standard solution from Sigma-Aldrich, 1 ml of which contains 10 μg of each of 16 PAHs) with cyclohexane. Calibration graphs at several dilutions of standard solution were used for determining the retention time and for studying the linearity of detector. All the PAHs were well resolved. Blanks for DCM were checked for contamination of PAHs by concentrating 500 ml DCM to 1 ml and injecting 1 μl of it to GC. No contamination of PAHs was observed.

A calibration curve was prepared by running 4 - 5 different concentrations of the standard solution. The calibration curve is prepared by plotting area response against concentrations of analyte(s) in the standards. Linearity was found in all cases. Injection port was kept at 280°C. The optimum conditions of GC were obtained after a series of experiments so that PAHs were well resolved (Table 4.1). These conditions were used for determination of 16 PAHs from the waste incineration.

Table 4.1

Operating GC-FID conditions

Parameters	**Specifications/ operating conditions**
GC column	30 m L, 0.25mm i.d., 0.25 mm film thickness 5% Phenyl methyl siloxane, ZB - 5MS,
Liner	Liner Splitless glass liner
Carrier gas	Ultra purified Nitrogen gas, 99.999% pure, (35 ml min^{-1})
Injection type	Split (1:9)
Injection port temperature	280°C
Oven temperature	50°C (hold 5 min) to 275°C @4°C min^{-1} to 320 @5°C min^{-1}
Injection volume	1 μL
Detector (temperature)	FID (325°C)
Fuel gas and flow rate	Hydrogen gas (30 ml min^{-1})
Oxidant gas and flow rate	Air (300 ml min^{-1})

4.1.6. Calibration curve

The calibration curve was prepared by external standard method in which a sample containing a known amount of analyte was injected and the peak area was recorded. Then a response factor (RF) was calculated by using equation (i). The amount of analyte of unknown concentration was calculated by applying equation (ii).

$$RF = A_{es}/C_{es} \quad ....(i)$$

$$\text{Amount of analyte} = A_{ua}/RF \quad ……………..(ii)$$

Where A_{es} is area of external standard i.e. analyte of known amount while C_{es} is concentration of external standard and A_{ua} is the area of analyte of unknown concentration.

4.1.7. PAHs analysis

The identification and quantification of 16 PAHs was accomplished by using a gas chromatograph (Nucon-5765) with ZB-5 MS (Zebron) capillary column and FID. The chromatogram of 16 PAHs (Sigma-Aldrich) under operating conditions is given in Fig. 4.1 and, their retention times, standard deviation and detection limits are given in Table 4.2. The retention time of each PAHs component in sample was compared with the standard solutions of individual 16 PAHs. PAHs were quantified by response factor method.

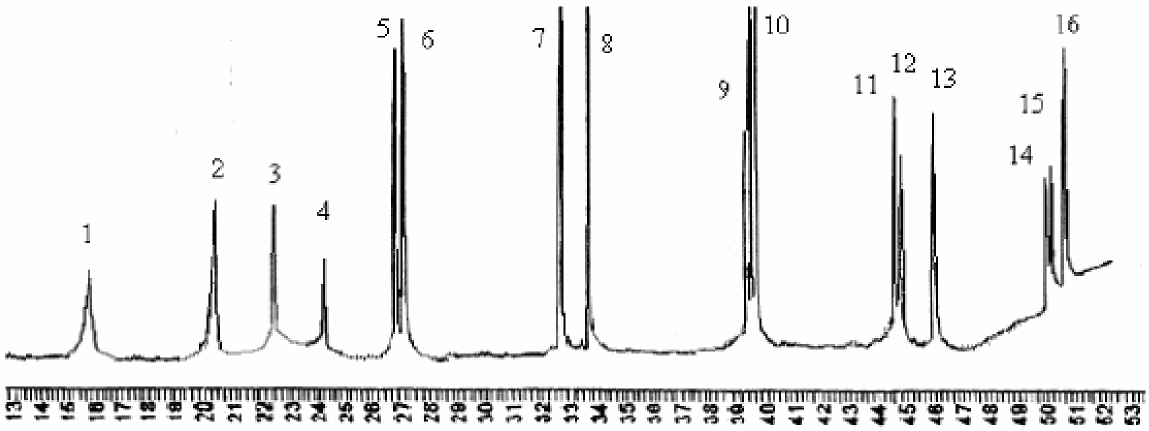


Fig. 4.1: Chromatogram of standard solution of 16 PAHs (Sigma-Aldrich)

Table 4.2: Retention Times (t_R), standard deviations and detection limit of 16 PAHs for standard solution (Sigma-Aldrich)

S. No.	PAHs	Retention Time (t_R) (Minutes)	Detection Limit (µg ml^{-1})
1.	Nap	15.40(±0.01)	2
2.	Acp	20.25	2
3.	AcPy	22.23	2
4.	Flu	24.19	3
5.	PA	26.40(±0.01)	1
6.	Ant	27.10(±0.01)	1
7.	FL	32.47	1
8.	Pyr	33.55	1
9.	BaA	39.32(±0.01)	1
10.	CHR	39.53	1
11.	BbF	44.22	1
12.	BkF	44.48	1
13.	BaP	46.06(±0.02)	1
14.	IND	49.54	2
15.	DBA	49.21	2
16.	BghiP	50.51	1

4.2. Results and Discussion

4.2.1. Incineration

The incineration of two types of biomedical waste (BMW) viz., CBB and BCC and two types of Acrylic industrial waste viz., AWS and CWF was carried out in laboratory scale incinerator at different temperatures and air flow rates to study the amount of total emissions and PAHs.

4.2.1.1. Total Emissions

Upon introduction of exactly weighed sample (~ 0.5 g) of waste to the preheated incinerator at the desired temperature and airflow rate, sample got ignited with a sooty flame. The emissions were passed through 7 g of XAD-4 resin kept at room temperature and increase in weight of glass filter cartridge along with the weight of the soot stroked to walls of tube was measured during each incineration experiment.

4.2.1.1.1 Blood Contaminated Blood Bag: The amount of total emissions from incineration of Blood Contaminated Blood Bag (CBB) at different temperatures and airflow rates is shown in Fig. 4.2. The incineration at 700, 800, 900 and 1000°C at airflow rates of 1, 2, 3 and 4 L min^{-1} (measured at room temperature and atmospheric pressure) shows the emissions of 189, 197, 203 and 208 mg g^{-1}; 203, 210, 216 and 217 mg g^{-1}; 256, 241, 228 and 218 mg g^{-1}, and 238, 229, 225 and 219 mg g^{-1} of the waste respectively. The standard deviation at 700ºC was found to be ±4, ±2, ±3 and ±4 mg g^{-1} at airflow rates of 1, 2, 3 and 4 L min^{-1} respectively.

At 700 and 800°C, the amount of emissions increases with increase in airflow rate while at 900 and 1000°C the amount of emissions was found to be decreasing with increase in airflow rate. So, total emissions were reduced at higher flow rate and with the increase in temperature above 900°C. Thereby suggesting that incineration temperature above 900°C and higher airflow rate of 4 L Min^{-1} leads to lowering of total emissions. Total emissions were lowest at 700°C and at flow rate of 1 L Min^{-1}.

4.2.1.1.2 Blood Contaminated Cotton: The amount of emissions from incineration of Blood Contaminated Cotton (BCC) at different temperatures and airflow rates is shown in Fig. 4.3. The incineration at 700, 800, 900 and 1000°C at an airflow rate of 1, 2, 3 and 4 L min $^{-1}$ (measured at room temperature and atmospheric pressure) shows the emissions of 156, 159, 165 and 188 mg g^{-1}; 167, 166, 179 and 191 mg g^{-1}; 173, 165, 162 and 152 mg g^{-1}, and 179, 170, 169 and 167 mg g^{-1} of the waste respectively.

At 700 and 800°C, the amount of emissions increases with increase in airflow rate while at 900 and 1000°C these were found to be decrease with increase in airflow rate. These results showed that total emissions were reduced with increase in flow rate and on increasing the temperature above 900°C. Total emissions were lowest at 900°C and flow rate of 4 L Min^{-1}.

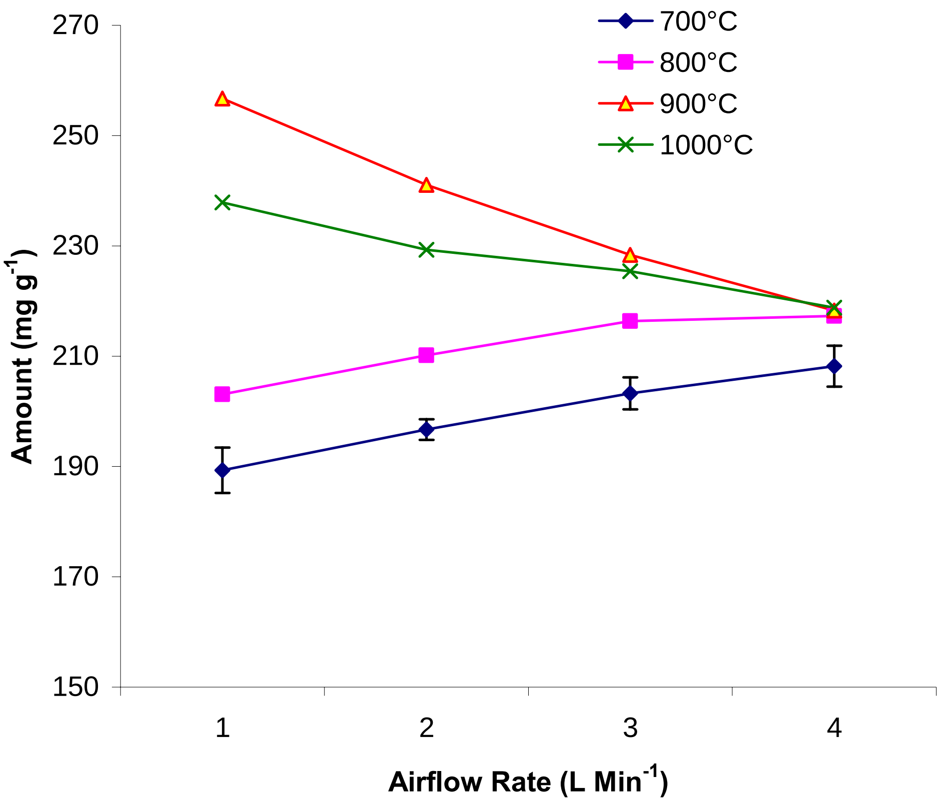


Fig. 4.2: Total emissions from incineration of blood contaminated blood bag at different temperatures and airflow rates

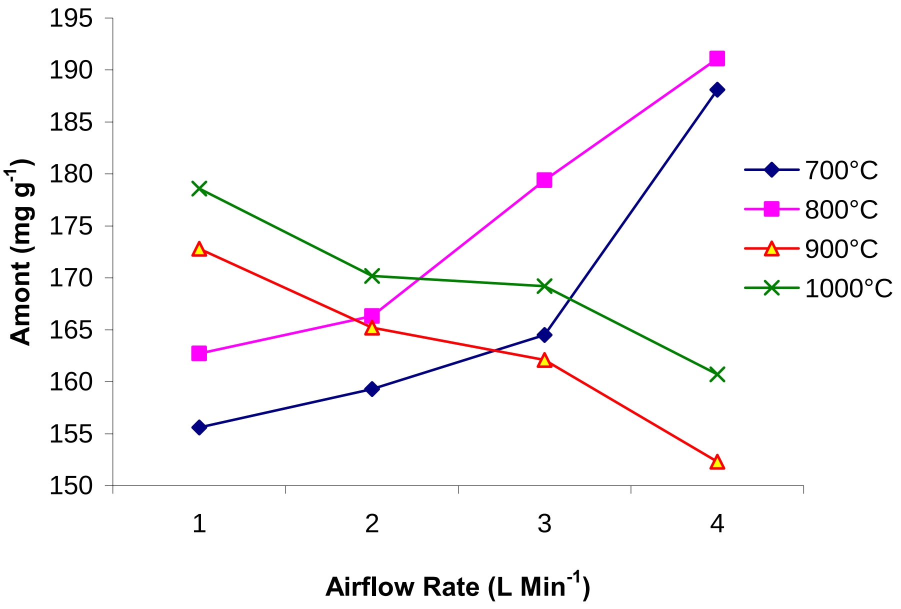


Fig. 4.3: Total emissions from incineration of blood contaminated cotton at different temperatures and airflow rates

4.2.1.1.3 Acrylic Waste Sample: The amount of total emissions from incineration of Acrylic Waste Sample (AWS) at different temperatures and airflow rates is shown in Fig. 4.4. The total emissions at 700°C were found to be 185, 286, 342 and 370 mg g^{-1}; at 800°C, were found to be 196, 243, 318 and 350 mg g^{-1}; at 900°C were found to be 280, 263, 242 and 218 mg g^{-1} and at 1000°C were found to be 287, 250, 249 and 200 mg g^{-1} of waste with airflow rates of 1, 2, 3 and 4 L min^{-1} (measured at room temperature and atmospheric pressure) respectively in each case. The standard deviation at 700ºC was found to be ±8, ±4, ±4 and ±4 mg g^{-1} at airflow rates of 1, 2, 3 and 4 L min^{-1} respectively.

At 700 and 800°C, the amount of emissions was found to be increased with airflow rate while at 900 and 1000°C, the amount of emissions were found to be decreased with increase in airflow rate. Lower amount of emissions were observed at 700-800°C with airflow rate of 1 L Min^{-1} and also at higher temperature of 900-1000°C with airflow rate of 4 L Min^{-1}.

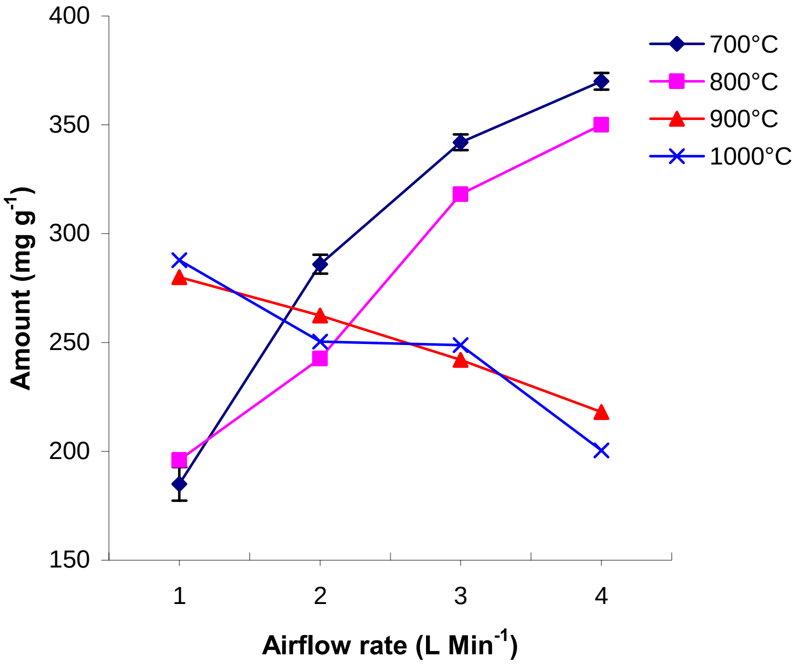


Fig. 4.4: Total emissions from incineration of acrylic waste solution at different temperatures and airflow rates.

4.2.1.1.4 Cellulose Waste Filter: The emissions from incineration of Cellulose Waste Filter (CWF) with an airflow rate 1 L Min^{-1} were found to be 210, 157, 244 and 231 mg g^{-1} of waste at 700, 800, 900 and 1000ºC respectively. The total emissions at 700°C were 210, 256, 266 and 298 mg g^{-1}; at 800ºC were 157, 182, 220 and 249 mg g^{-1}; at 900ºC were 244, 234, 211 and 200 mg g^{-1}; while at 1000ºC were found to be 231, 226, 222 and 208 mg g^{-1}of waste with airflow rates of 1, 2, 3 and 4 L min^{-1} respectively. These changes in amount of emissions at different temperatures and airflow rates has been shown in Fig. 4.5.

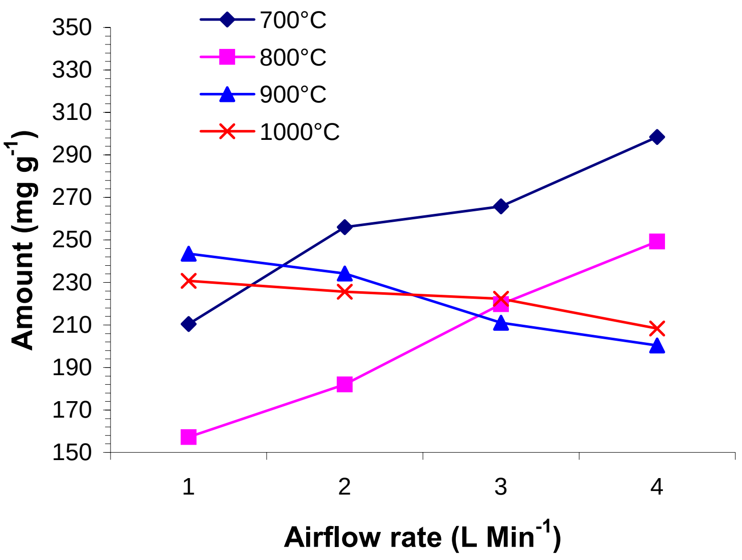


Fig. 4.5: Total emissions from incineration of cellulose waste filter at different temperatures and airflow rates.

At 700 and 800°C the amount of the emissions increases with increase in airflow rate. At 900 and 1000°C, the amount of total emissions decreases with increase in airflow rate. Less emissions were observed at 800°C at airflow rate of 1-2 L Min^{-1}. Other conditions for lower emissions was 900-1000°C with airflow rate of 4 L Min^{-1}.

The above observations regarding the effect of temperature and air flow rate towards total emissions may be rationalised on the basis of following assumptions:

Lower temperature with lower airflow rate may help in reducing the volatilization rate and promotes mixing of air and volatile matters from the solid waste thereby leading to more effective combustion and reduction in total emissions. However, lower temperature and with increase in airflow rate, there seems reduction in the mixing of the air with less volatilized waste in incineration chamber of fixed length thereby leading to higher emissions. At higher *temperature and at lower airflow rate, highly volatilized sample get less oxygen thereby leading to more amount of total emissions. However, at higher temperature and higher airflow rate, the rate of volatilization and mixing become proper thereby decreasing the total emissions.*

4.2.1.2 Polycyclic Aromatic Hydrocarbons

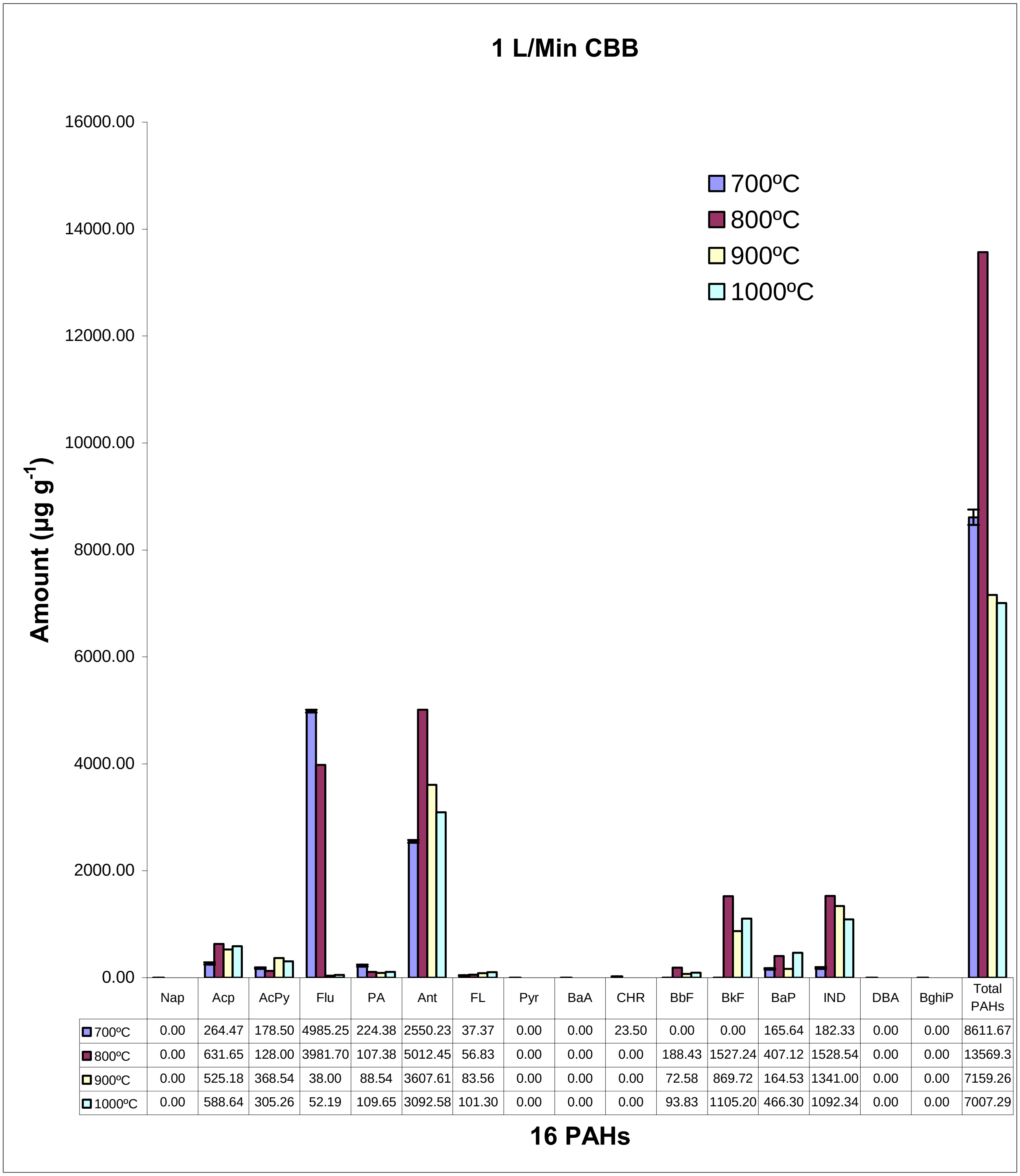
The final concentrated solutions obtained from the soxhlet extraction of XAD-4 ambralite resins and dichloromethane of traps were analyzed for 16 PAHs classified as priority pollutants according to US EPA from the incineration of blood contaminated blood bag, blood contaminated cotton, acrylic waste solution and cellulose waste filter.

4.2.1.2.1 Blood Contaminated Blood Bag: The incineration of CBB showed the presence of 9-10 PAHs and the absence of Nap, Pyr, BaA, DBA and BghiP at 700-1000ºC with airflow rate of 1-4 L Min^{-1} at an interval of 100ºC in an electrically heated vertical quartz tube incinerator (Figs. 4.6-4.9). BbF and BkF were absent at all airflow rates at 700ºC. Absence of CHR was observed at higher temperatures (800-1000ºC). At all flow rates, the major fractions of Ant were observed at all temperatures and more amount of Flu was also observed at 700-800ºC. Distribution of PAHs showed no definite trend. Similar findings were reported by Mastral et al. (1999) on PAHs emissions from coal atmospheric fluidized bed combustion.

The amount of total 16 PAHs at different temperatures and airflow rates is represented in Fig. 4.10. At a flow rate of 1-2 L Min^{-1}, total amount of PAH increases up to 800ºC, then decreases with increase in temperature. Similar results are reported on combustion of PVC (Wang et al., 2003) showing emissions of PAHs increases with increase in temperature from 600 to 900°C and in another study during the combustion of polystyrene (You et al., 1996) showing increase in PAHs formation with increase in temperature followed by decrease in PAHs from 900 to 1000°C. However, at a flow rate of 3-4 L Min^{-1}, decrease in total PAHs has been observed with rise in temperature. Similar results are shown by Panagiotou et al. (1996) indicating that amount of total PAHs emissions during combustion of PVC decreases with increasing temperature from 900 to 1200°C.

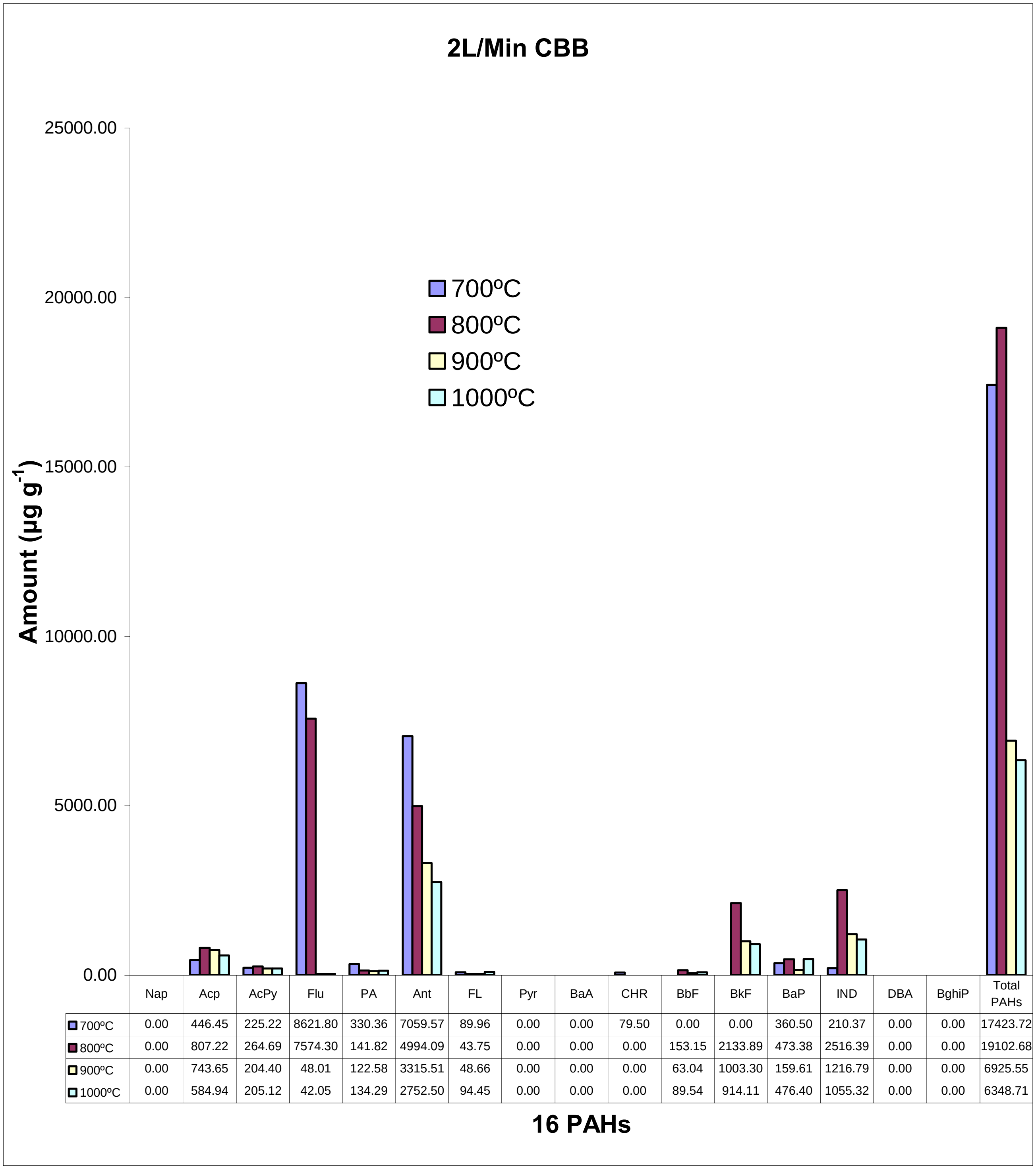
Lowest amount of total PAHs are observed at 900-1000ºC at all flow rates under study. The highest amount of PAHs were observed with an airflow rate of 4 L Min^{-1} at 700ºC (22277.34 µg g^{-1}) which was 4.4 times higher than at 1000ºC with same flow rate. In other laboratory scale studies during the combustion of PVC, the maximum amount of the total PAHs emissions was found to be 35000 µg g^{-1} at 850ºC (Aracil et al., 2005), 19000 µg g^{-1} at 950ºC (Hawley-Fedder et al., 1984) and 5113.7 µg g^{-1} at 900ºC (Kim et al., 2004). The chromatogram of PAHs from incineration of blood contaminated blood bag at 1000ºC is shown in Fig. 4.11.

The total amount of 2A and 2B PAHs from incineration of blood contaminated blood samples are shown in figs. 4.12-4.13. The sum of total probable human carcinogens (2A) PAHs (BaP+DBA+BaA) was highest at 1000ºC (476.39 µg g^{-1}) with an airflow rate of 2 L Min^{-1} and were lowest at 900ºC with small variations at all the flow rates under study (Fig. 4.12). The sum of total possible human carcinogen (2B) PAHs (BbF+BkF+IND+Nap) were highest at 800ºC and lowest at 700ºC with all air flow rates (Fig. 4.13). However, at all temperatures of study, total 2B PAHs decreases with increase in flow rate from 2 to 4 L Min^{-1}. The optimum range of reduced carcinogenic potential (2A+2B PAHs) was found at 700 or between 900-1000ºC with all airflow rates (Fig. 4.14).



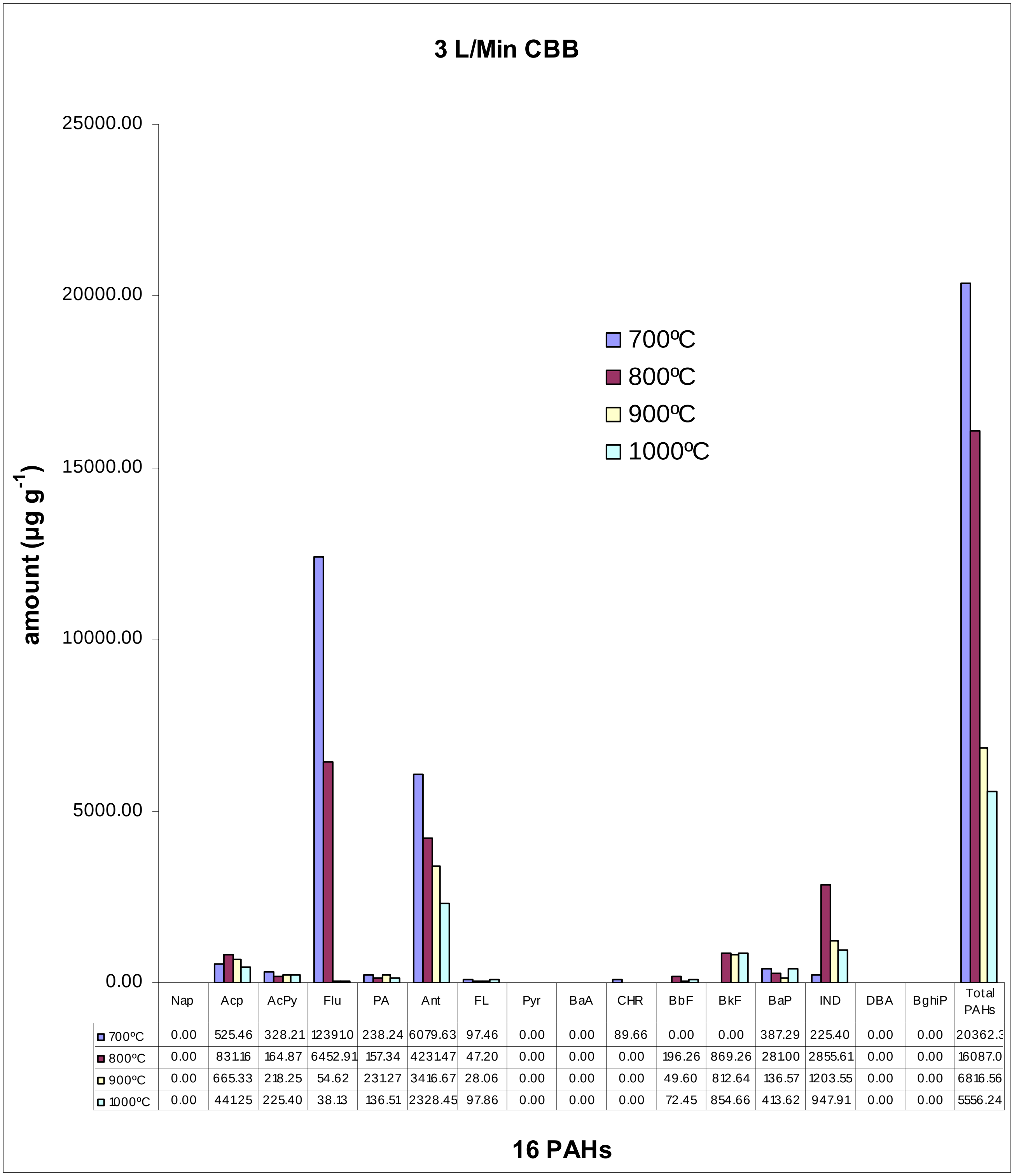
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	0.00	264.47	178.50	4985.25	224.38	2550.23	37.37	0.00	0.00	23.50	0.00	0.00	165.64	182.33	0.00	0.00	8611.67
800ºC	0.00	631.65	128.00	3981.70	107.38	5012.45	56.83	0.00	0.00	0.00	188.43	1527.24	407.12	1528.54	0.00	0.00	13569.3
900ºC	0.00	525.18	368.54	38.00	88.54	3607.61	83.56	0.00	0.00	0.00	72.58	869.72	164.53	1341.00	0.00	0.00	7159.26
1000ºC	0.00	588.64	305.26	52.19	109.65	3092.58	101.30	0.00	0.00	0.00	93.83	1105.20	466.30	1092.34	0.00	0.00	7007.29

Fig. 4.6: Amount of 16 PAHs emissions from incineration of blood contaminated blood bag with an airflow rate of 1 L Min^{-1} at different temperatures



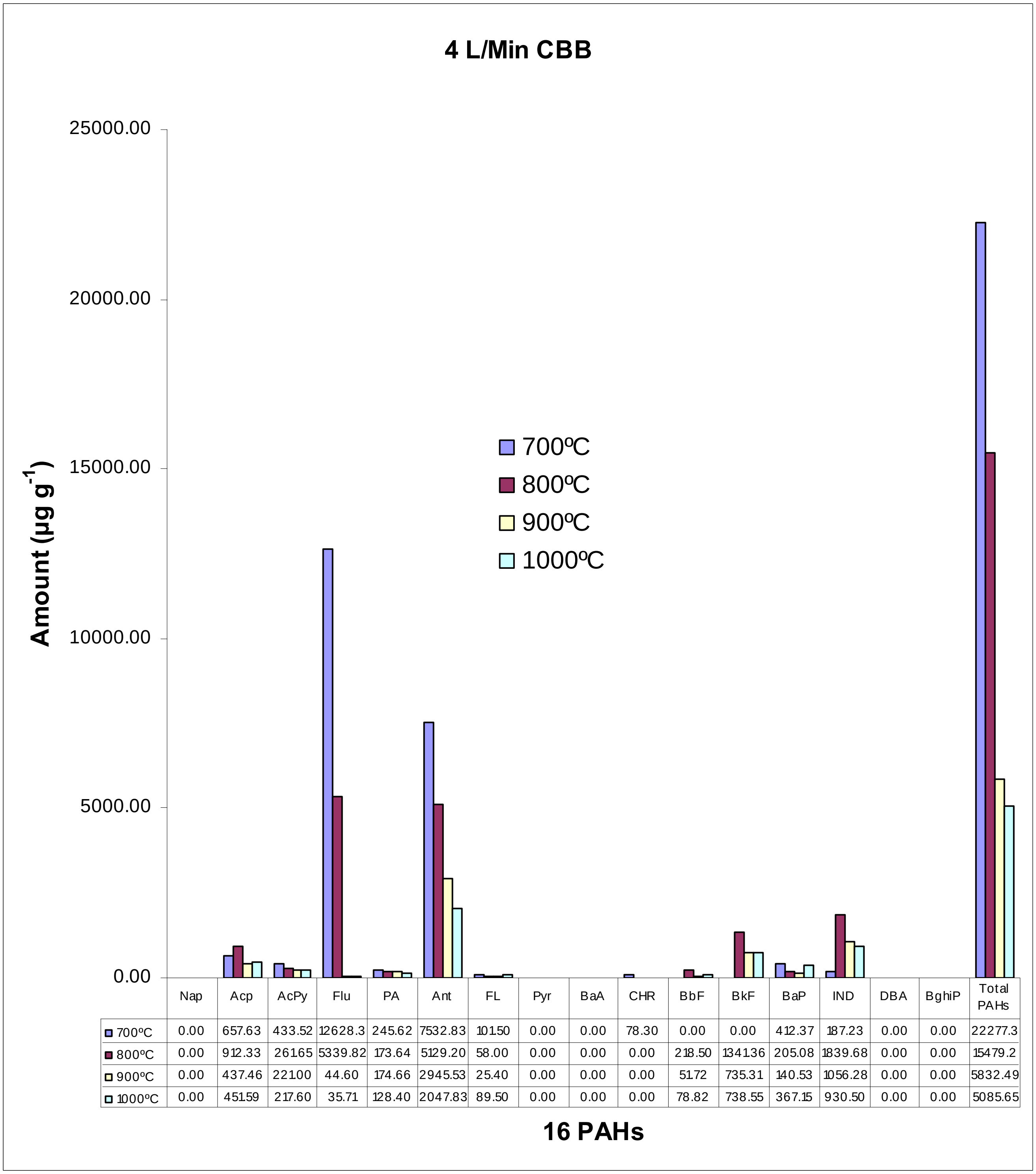
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	0.00	446.45	225.22	8621.80	330.36	7059.57	89.96	0.00	0.00	79.50	0.00	0.00	360.50	210.37	0.00	0.00	17423.72
800ºC	0.00	807.22	264.69	7574.30	141.82	4994.09	43.75	0.00	0.00	0.00	153.15	2133.89	473.38	2516.39	0.00	0.00	19102.68
900ºC	0.00	743.65	204.40	48.01	122.58	3315.51	48.66	0.00	0.00	0.00	63.04	1003.30	159.61	1216.79	0.00	0.00	6925.55
1000ºC	0.00	584.94	205.12	42.05	134.29	2752.50	94.45	0.00	0.00	0.00	89.54	914.11	476.40	1055.32	0.00	0.00	6348.71

Fig. 4.7: Amount of 16 PAHs emissions from incineration of blood contaminated blood bag with an airflow rate of 2 L Min^{-1} at different temperatures



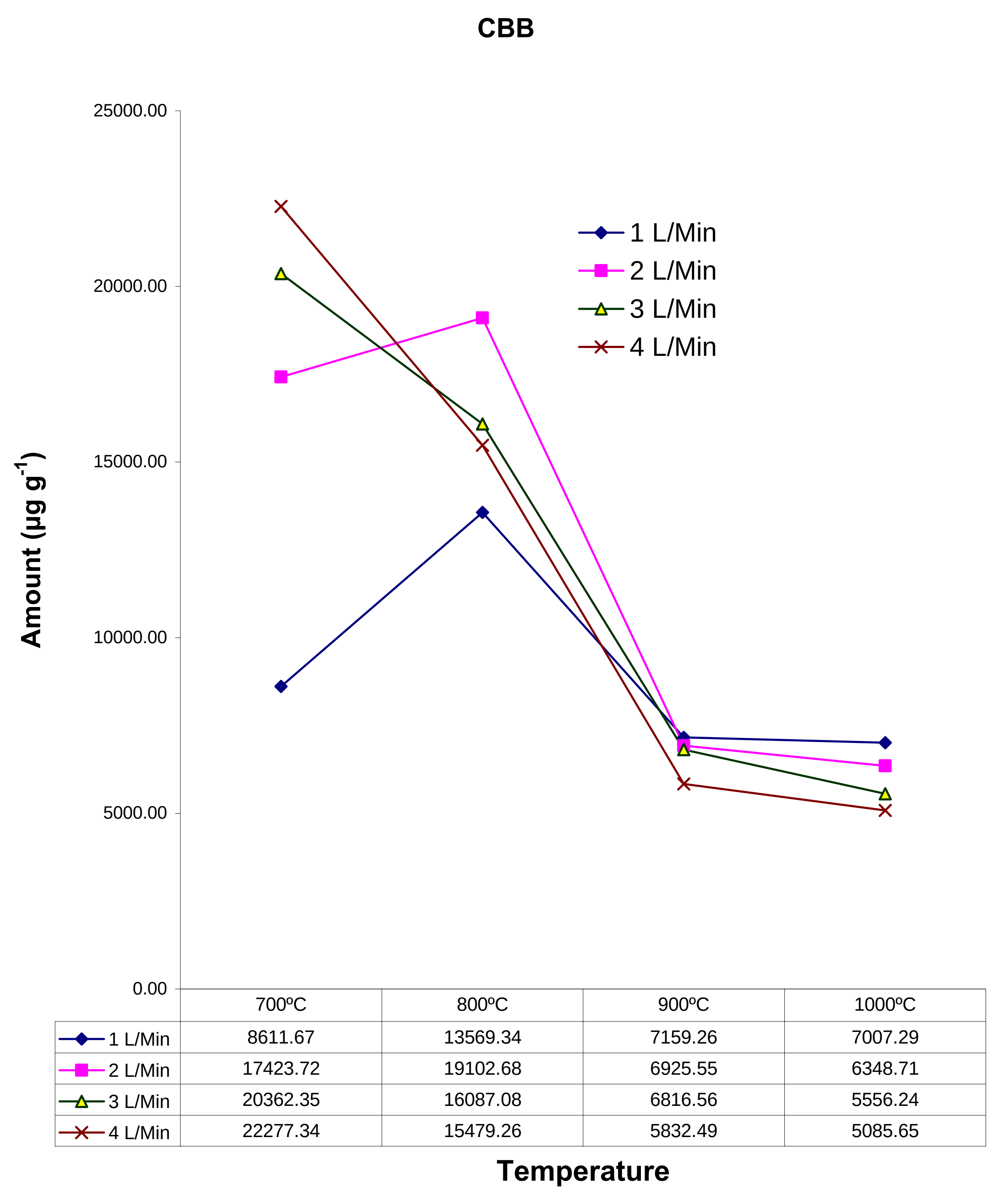
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	0.00	525.46	328.21	12391.0	238.24	6079.63	97.46	0.00	0.00	89.66	0.00	0.00	387.29	225.40	0.00	0.00	20362.3
800ºC	0.00	831.16	164.87	6452.91	157.34	4231.47	47.20	0.00	0.00	0.00	196.26	869.26	281.00	2855.61	0.00	0.00	16087.0
900ºC	0.00	665.33	218.25	54.62	231.27	3416.67	28.06	0.00	0.00	0.00	49.60	812.64	136.57	1203.55	0.00	0.00	6816.56
1000ºC	0.00	441.25	225.40	38.13	136.51	2328.45	97.86	0.00	0.00	0.00	72.45	854.66	413.62	947.91	0.00	0.00	5556.24

Fig. 4.8: Amount of 16 PAHs emissions from incineration of blood contaminated blood bag with an airflow rate of 3 L Min^{-1} at different temperatures



	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
▫ 700ºC	0.00	657.63	433.52	12628.3	245.62	7532.83	101.50	0.00	0.00	78.30	0.00	0.00	412.37	187.23	0.00	0.00	22277.3
▪ 800ºC	0.00	912.33	261.65	5339.82	173.64	5129.20	58.00	0.00	0.00	0.00	218.50	1341.36	205.08	1839.68	0.00	0.00	15479.2
▫ 900ºC	0.00	437.46	221.00	44.60	174.66	2945.53	25.40	0.00	0.00	0.00	51.72	735.31	140.53	1056.28	0.00	0.00	5832.49
▫ 1000ºC	0.00	451.59	217.60	35.71	128.40	2047.83	89.50	0.00	0.00	0.00	78.82	738.55	367.15	930.50	0.00	0.00	5085.65

Fig. 4.9: Amount of 16 PAHs emissions from incineration of blood contaminated blood bag with an airflow rate of 4 L Min^{-1} at different temperatures



	700ºC	800ºC	900ºC	1000ºC
1 L/Min	8611.67	13569.34	7159.26	7007.29
2 L/Min	17423.72	19102.68	6925.55	6348.71
3 L/Min	20362.35	16087.08	6816.56	5556.24
4 L/Min	22277.34	15479.26	5832.49	5085.65

Fig. 4.10: Amount of total 16 PAHs emissions at different temperatures and airflow rates from incineration of blood contaminated blood bag

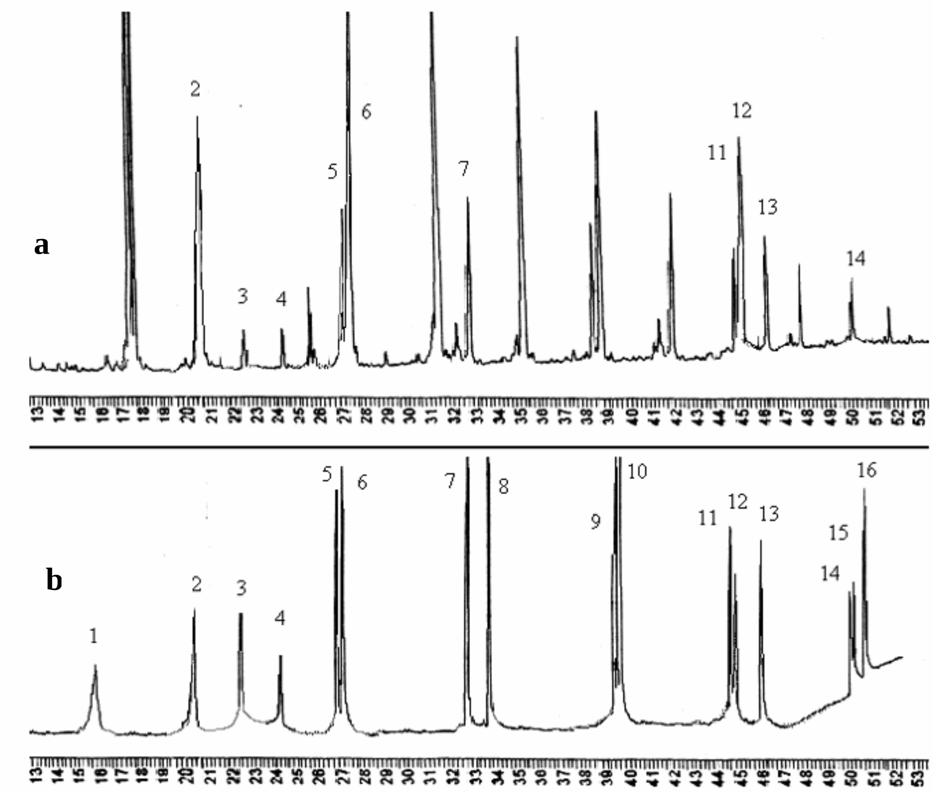


Fig. 4.11: Chromatogram of PAHs from incineration of blood contaminated blood bag at 1000ºC with airflow rate of 4L Min^{-1} (a) along with chromatogram of Standard solution of 16PAHs (b)

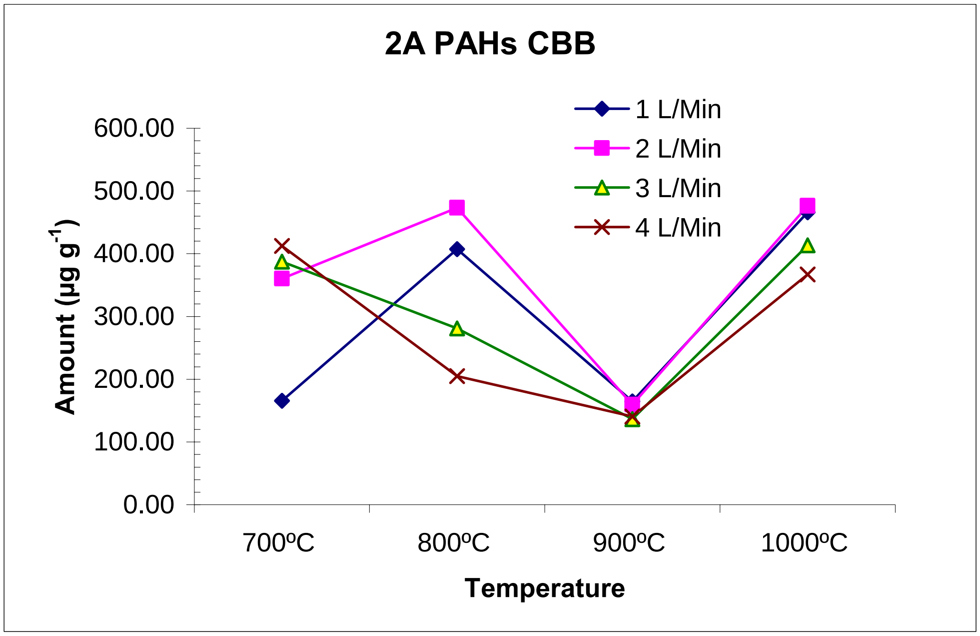


Fig. 4.12: Amount of 2A PAHs from incineration of blood contaminated blood bag at different temperatures and airflow rates

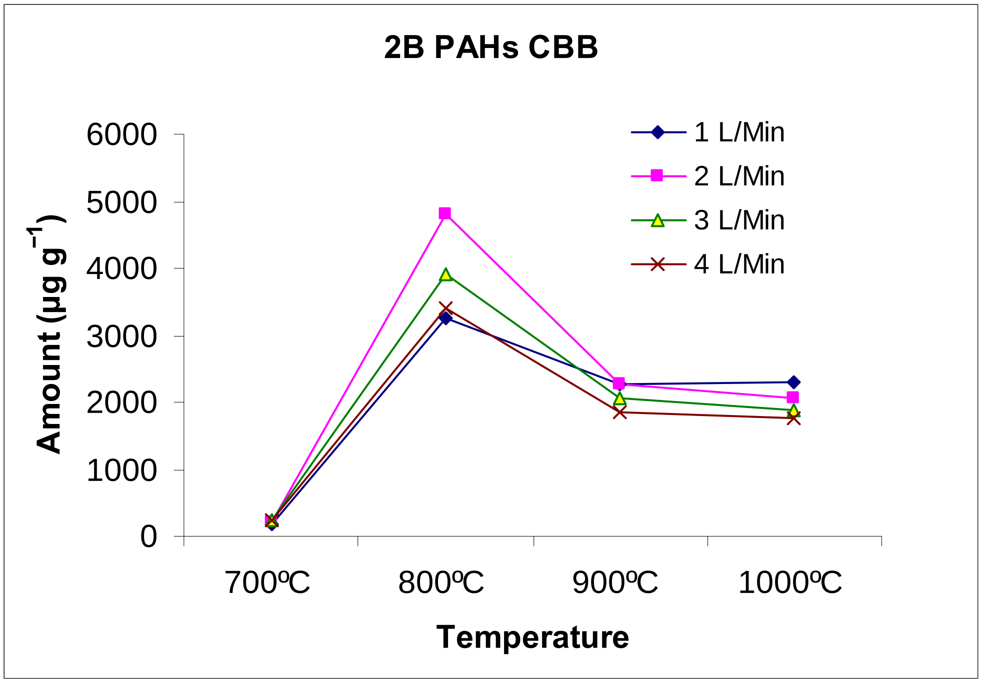


Fig. 4.13: Amount of 2B PAHs from incineration of blood contaminated blood bag at different temperatures and airflow rates

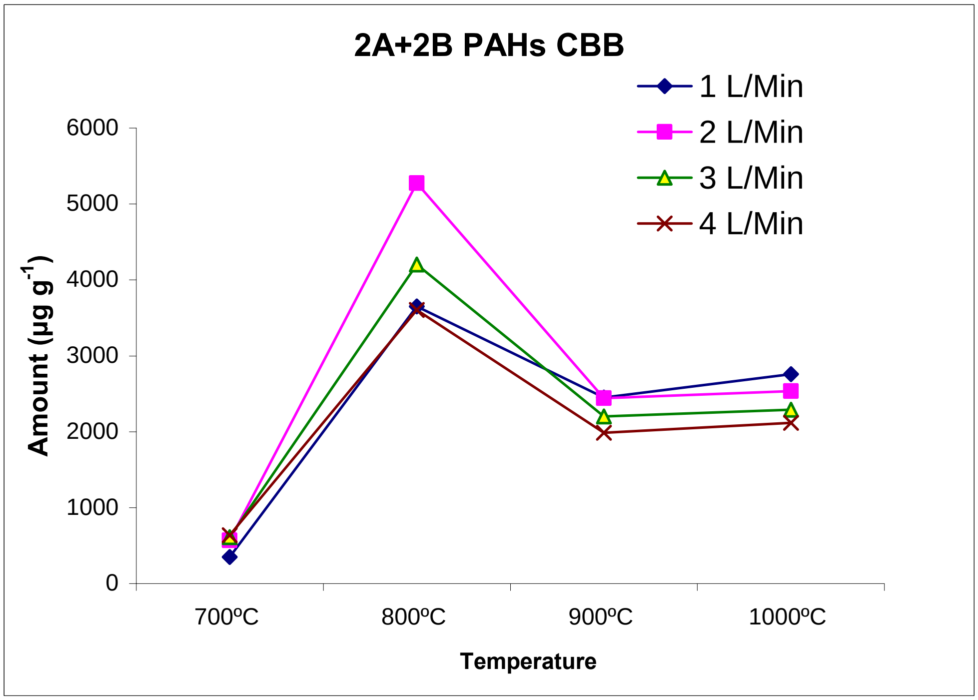
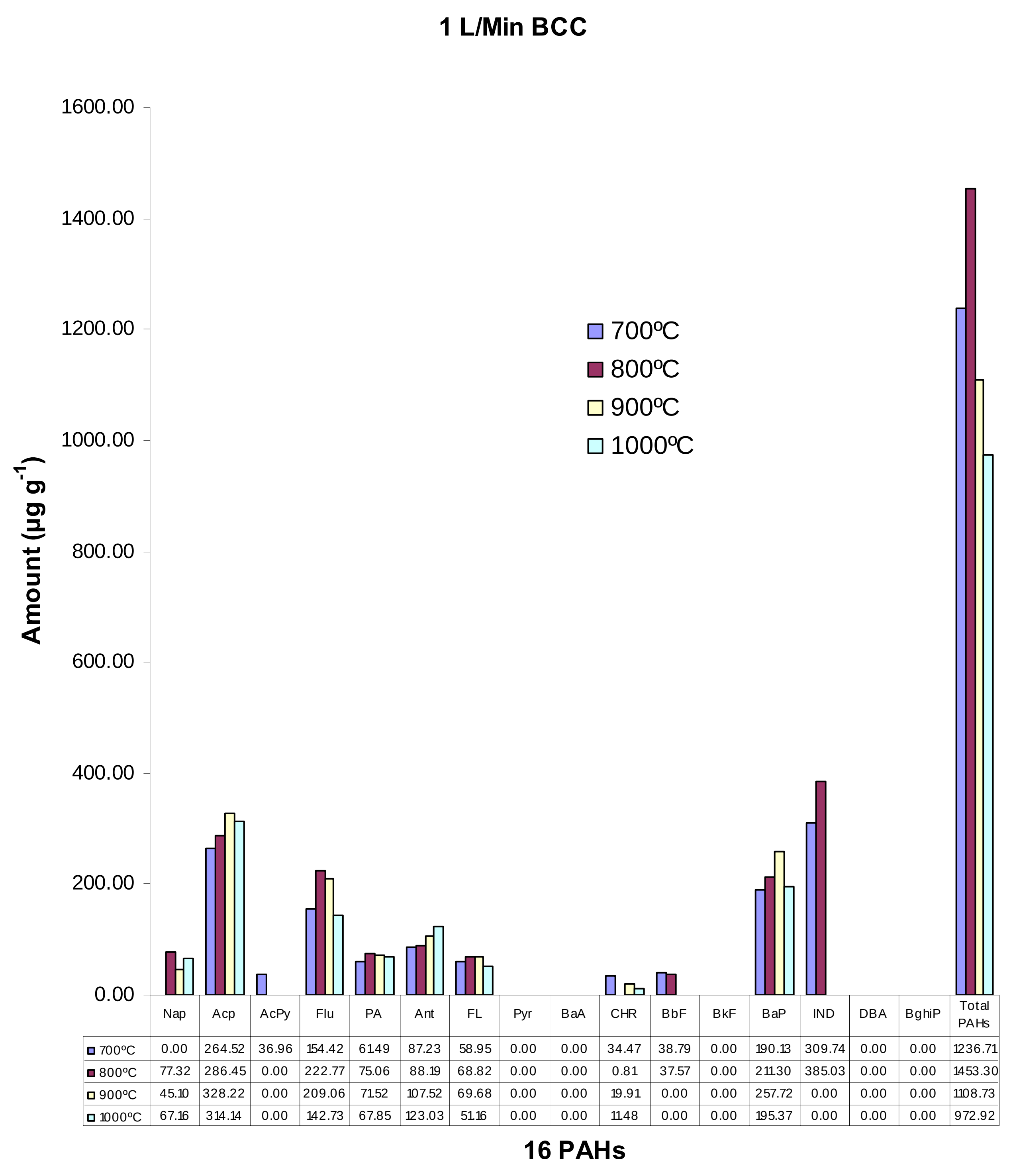


Fig. 4.14: Amount of sum of total 2A and 2B PAHs from incineration of blood contaminated blood bag at different temperatures and airflow rates

4.2.1.2.2 Blood Contaminated Cotton: The incineration of BCC showed the presence of 8-11 PAHs and the absence of Pyr, BaA, BkF, DBA and BghiP at 700-1000ºC at an interval of 100ºC with airflow rate of 1-4 L Min^{-1} in an electrically heated vertical quartz tube incinerator (Figs. 4.15-4.18). The major fractions of Acp were observed at all temperature and airflow rates. However, IND was also a major fraction at 700 and 800ºC. Distribution of PAHs showed no definite trend. Similar findings by Mastral et al. (1999) showed no definite trend on distribution of 16 PAHs as a function of temperature.

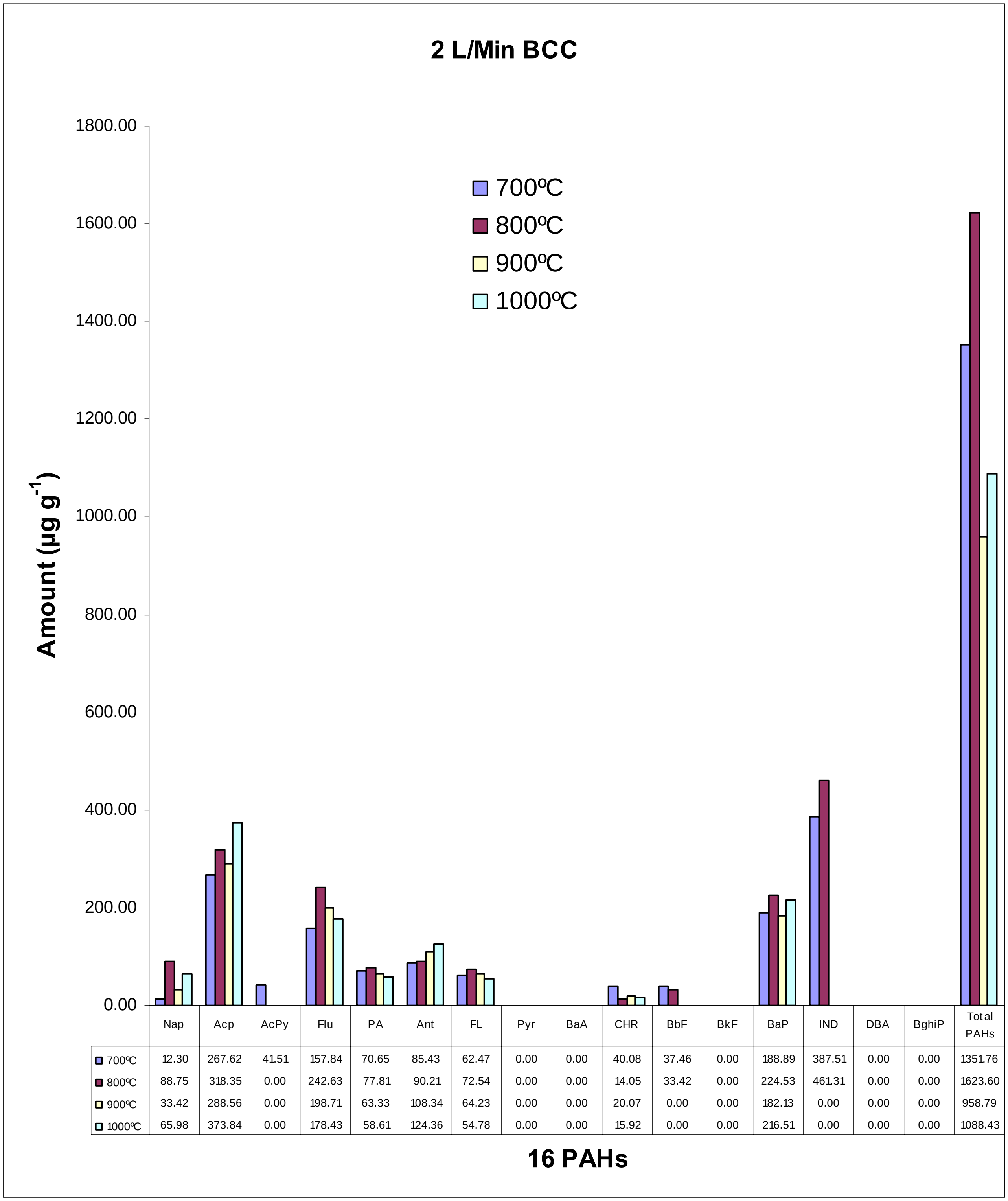
Total amount of 16 PAHs is represented in Fig. 4.19 at all temperatures and flow rates under study. At a flow rate of 1 L Min^{-1}, total amount of PAH increases up to 800ºC, then decreases with increase in temperature. You et al. (1996) found the increase in PAHs formation as combustion temperature is increased and decrease in the formation of PAHs from 900 to 1000°C during the combustion of polystyrene. In our laboratory studies at a flow rate of 2-3 L Min^{-1}, there is firstly an increase then decrease and again an increase in total PAHs with increase in temperature. Similar findings were reported by Mastral et al. (1999) on PAHs emissions from coal atmospheric fluidized bed combustion showing that total 16 PAHs firstly increases then decreases and again increases with increase in temperature in fluidized bed combustion of coal in a pilot plant study (Fig. 4.20). Our laboratory study at 4 L Min^{-1} airflow, also showed decrease in total PAHs up to 900ºC and then increases at 1000ºC. Hawley-Fedder et al. (1984) observed that amount of total PAHs reduced remarkably from 800 to 900°C during combustion of PVC and the maximum amount of PAHs was obtained at 950°C. Our laboratory study showed lowest amount of total PAHs are observed at 800-1000ºC with airflow rate of 1-4 L Min^{-1}. A chromatogram of PAHs from incineration of blood contaminated cotton is shown in Fig. 4.21.

The sum of total 2A PAHs was highest at 800ºC (281.6 $\mu g\ g^{-1}$) with an airflow rate of 3 L Min^{-1} and lowest at 900ºC (130.72 $\mu g\ g^{-1}$) at airflow rate of 4 L Min^{-1} (Fig. 4.22). The sum of total 2A PAHs firstly increases then decreases and again increases at flow rate of 2-3 L Min^{-1}. However, at airflow rate of 1L Min^{-1}, total 2A PAHs first increases then decreases. At airflow rate of 4 L Min^{-1}, there is decrease followed by increase in total 2A PAHs with increase in temperature. The sum of total 2B PAHs increases with increase in temperature at flow rate of 1-3 L Min^{-1} (Fig. 4.23). However, at 4 L Min^{-1} flow rates, total 2B PAHs decreases up to 800ºC and then increases with increase in temperature. At airflow rate of 4 L Min^{-1}, the sum of total 2B PAHs was highest at 700ºC (587.86 µg g $^{-1}$) and lowest at 800ºC (18.31 µg g^{-1}). The emissions of carcinogenic PAHs for 2B were lower at 700-800ºC at all airflows of study. However lower values of sum of 2A+2B PAHs was also found at 700-800ºC (Fig. 4.24).



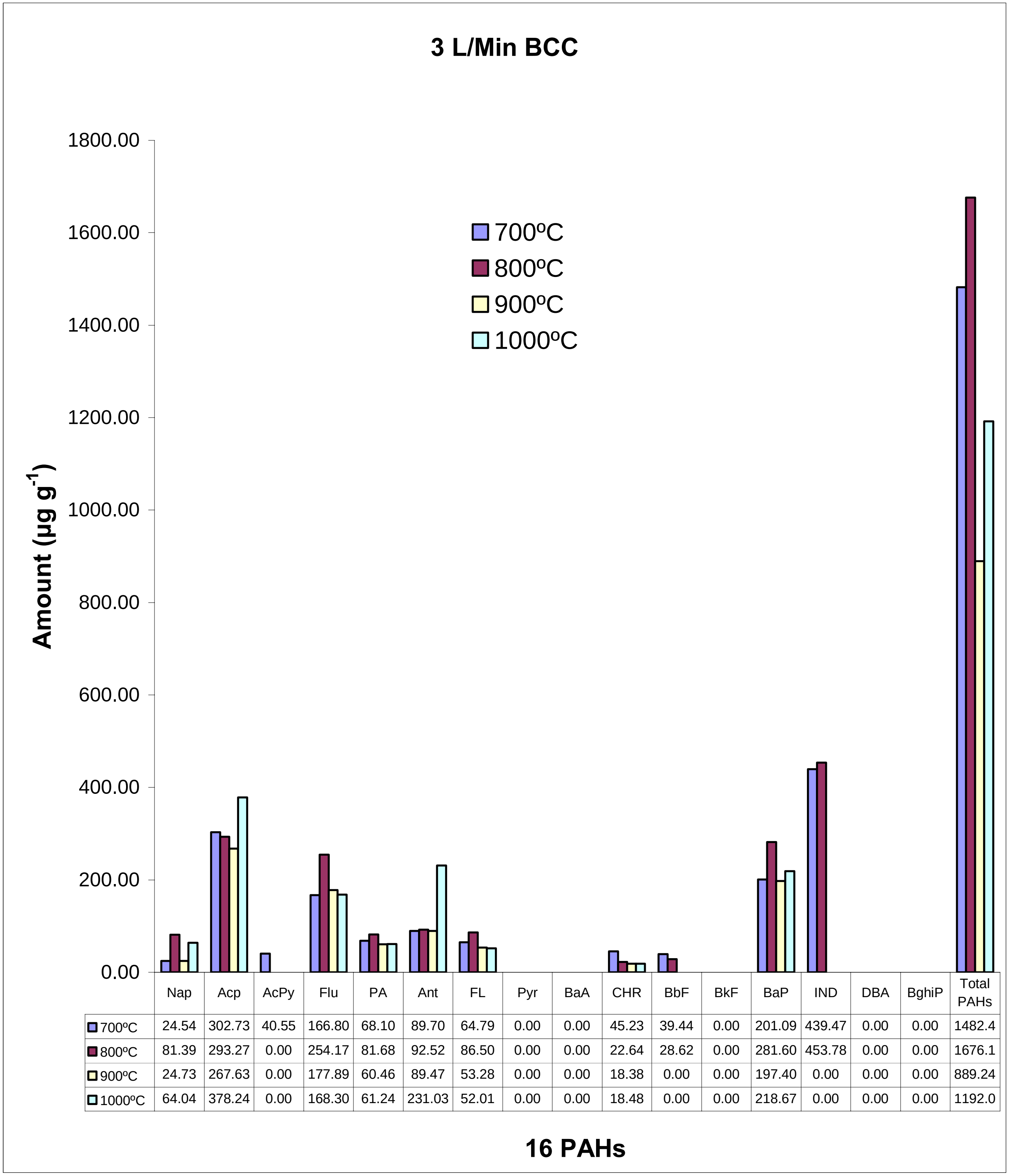
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
■ 700ºC	0.00	264.52	36.96	154.42	61.49	87.23	58.95	0.00	0.00	34.47	38.79	0.00	190.13	309.74	0.00	0.00	1236.71
■ 800ºC	77.32	286.45	0.00	222.77	75.06	88.19	68.82	0.00	0.00	0.81	37.57	0.00	211.30	385.03	0.00	0.00	1453.30
□ 900ºC	45.10	328.22	0.00	209.06	71.52	107.52	69.68	0.00	0.00	19.91	0.00	0.00	257.72	0.00	0.00	0.00	1108.73
□ 1000ºC	67.16	314.14	0.00	142.73	67.85	123.03	51.16	0.00	0.00	11.48	0.00	0.00	195.37	0.00	0.00	0.00	972.92

Fig. 4.15: Amount of 16 PAHs emissions from incineration of blood contaminated cotton with an airflow rate of 1 L Min^{-1} at different temperatures



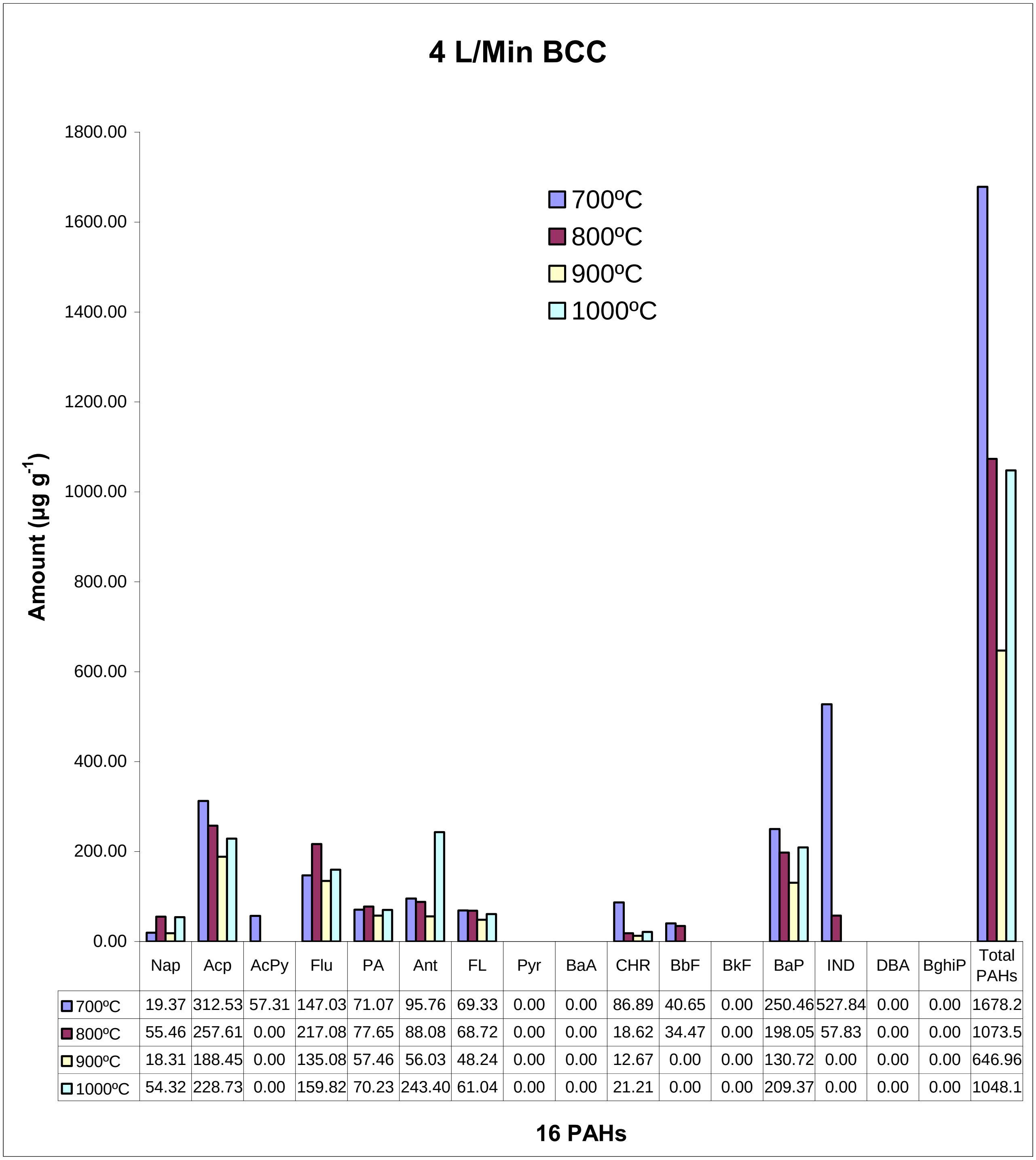
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	12.30	267.62	41.51	157.84	70.65	85.43	62.47	0.00	0.00	40.08	37.46	0.00	188.89	387.51	0.00	0.00	1351.76
800ºC	88.75	318.35	0.00	242.63	77.81	90.21	72.54	0.00	0.00	14.05	33.42	0.00	224.53	461.31	0.00	0.00	1623.60
900ºC	33.42	288.56	0.00	198.71	63.33	108.34	64.23	0.00	0.00	20.07	0.00	0.00	182.13	0.00	0.00	0.00	958.79
1000ºC	65.98	373.84	0.00	178.43	58.61	124.36	54.78	0.00	0.00	15.92	0.00	0.00	216.51	0.00	0.00	0.00	1088.43

Fig. 4.16: Amount of 16 PAHs emissions from incineration of blood contaminated cotton with an airflow rate of 2 L Min^{-1} at different temperatures



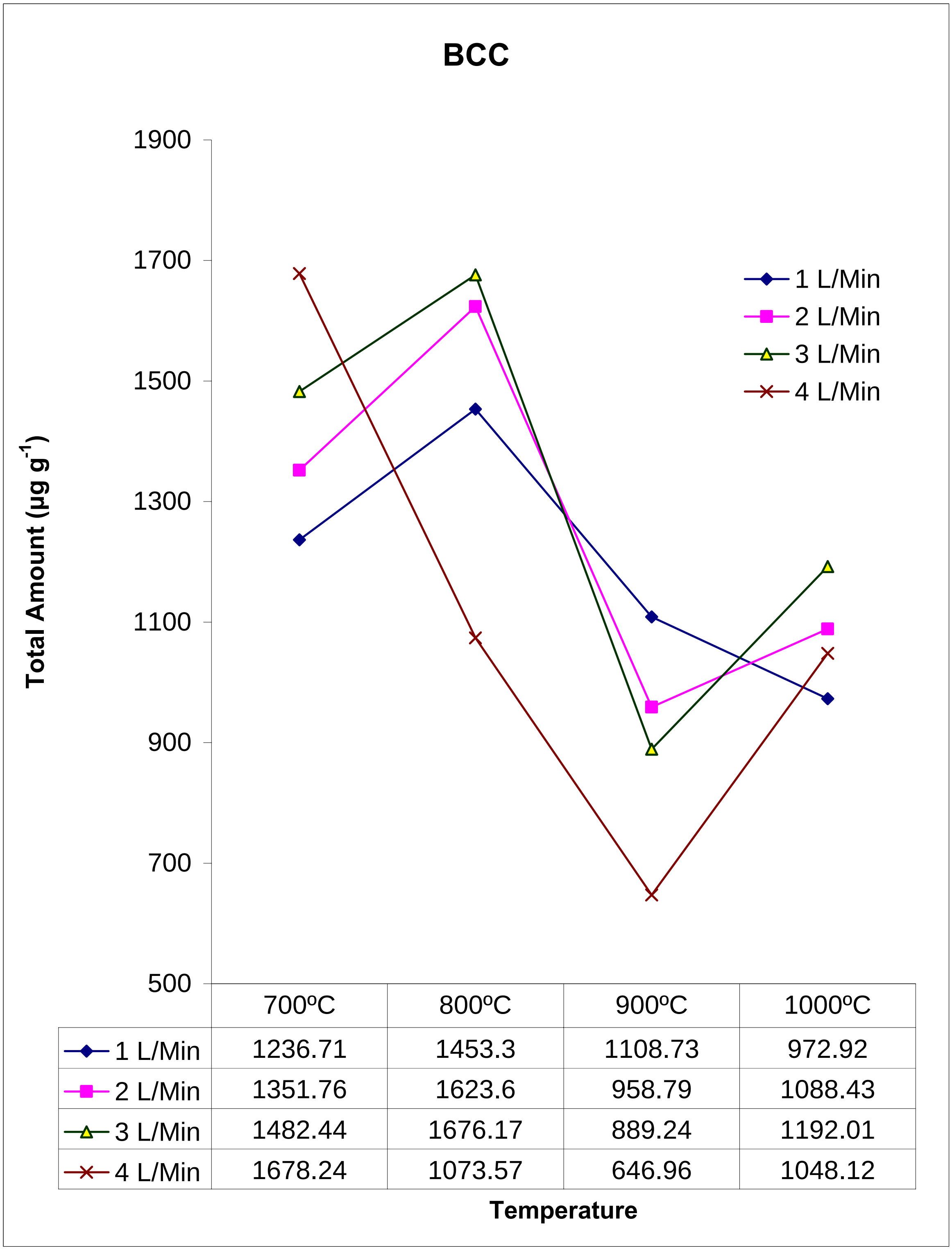
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	24.54	302.73	40.55	166.80	68.10	89.70	64.79	0.00	0.00	45.23	39.44	0.00	201.09	439.47	0.00	0.00	1482.4
800ºC	81.39	293.27	0.00	254.17	81.68	92.52	86.50	0.00	0.00	22.64	28.62	0.00	281.60	453.78	0.00	0.00	1676.1
900ºC	24.73	267.63	0.00	177.89	60.46	89.47	53.28	0.00	0.00	18.38	0.00	0.00	197.40	0.00	0.00	0.00	889.24
1000ºC	64.04	378.24	0.00	168.30	61.24	231.03	52.01	0.00	0.00	18.48	0.00	0.00	218.67	0.00	0.00	0.00	1192.0

Fig. 4.17: Amount of 16 PAHs emissions from incineration of blood contaminated cotton with an airflow rate of 3 L Min^{-1} at different temperatures



	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	19.37	312.53	57.31	147.03	71.07	95.76	69.33	0.00	0.00	86.89	40.65	0.00	250.46	527.84	0.00	0.00	1678.2
800ºC	55.46	257.61	0.00	217.08	77.65	88.08	68.72	0.00	0.00	18.62	34.47	0.00	198.05	57.83	0.00	0.00	1073.5
900ºC	18.31	188.45	0.00	135.08	57.46	56.03	48.24	0.00	0.00	12.67	0.00	0.00	130.72	0.00	0.00	0.00	646.96
1000ºC	54.32	228.73	0.00	159.82	70.23	243.40	61.04	0.00	0.00	21.21	0.00	0.00	209.37	0.00	0.00	0.00	1048.1

Fig. 4.18: Amount of 16 PAHs emissions from incineration of blood contaminated cotton with an airflow rate of 4 L Min^{-1} at different temperatures



	700ºC	800ºC	900ºC	1000ºC
◆ 1 L/Min	1236.71	1453.3	1108.73	972.92
■ 2 L/Min	1351.76	1623.6	958.79	1088.43
▲ 3 L/Min	1482.44	1676.17	889.24	1192.01
× 4 L/Min	1678.24	1073.57	646.96	1048.12

Fig. 4.19: Amount of total 16 PAHs emissions at different temperatures and airflow rates from incineration of blood contaminated cotton

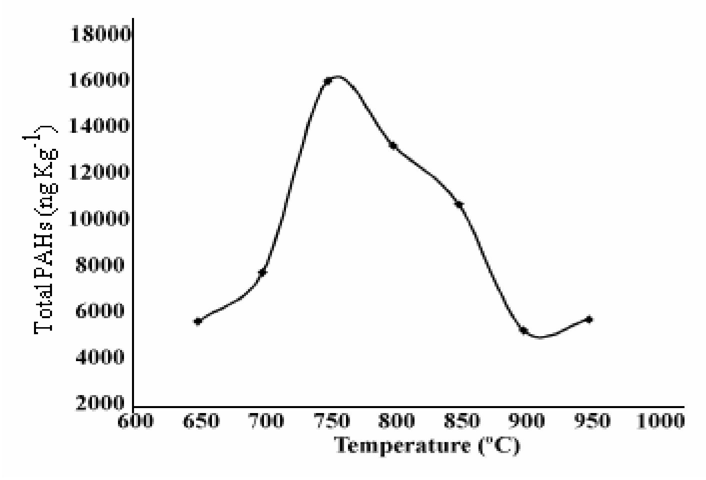


Fig. 4.20: Total PAHs emitted as a function of temperature from coal combustion (**Source:** Mastral et al., 1999; Thankfully acknowledged)

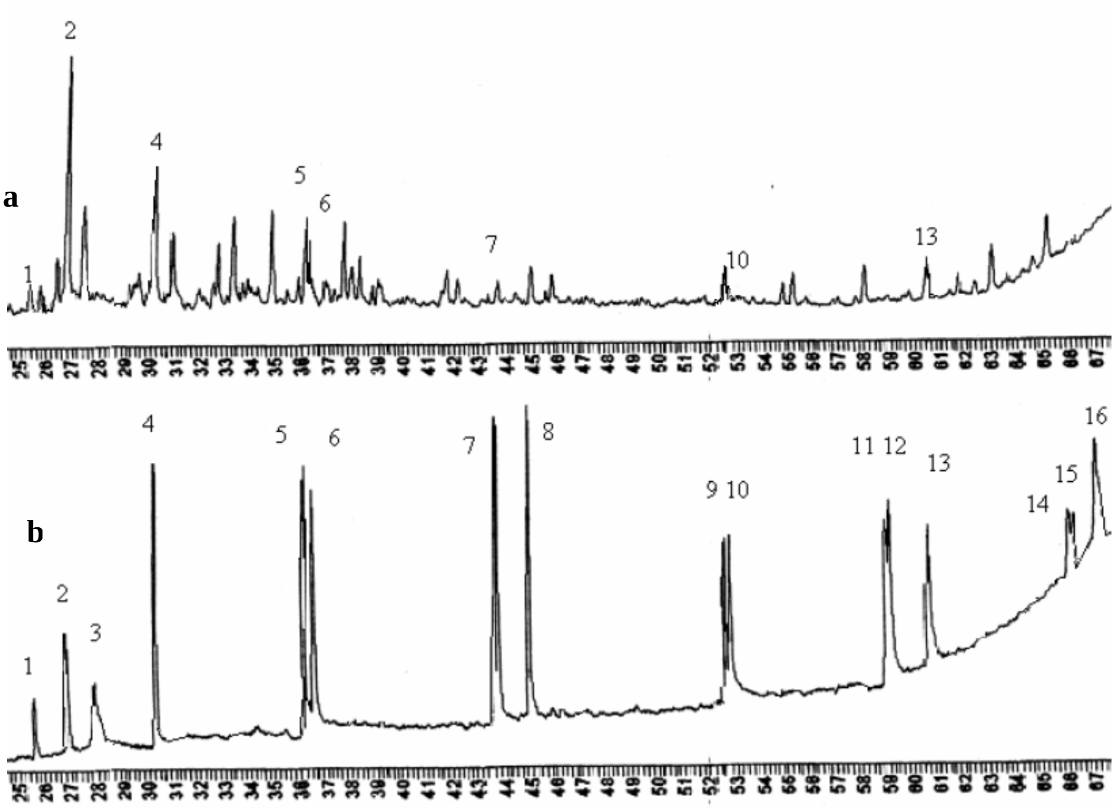


Fig. 4.21: Chromatogram of PAHs from incineration of BCC at 900ºC with airflow rate of 4L Min^{-1} (a) along with chromatogram of Standard solution of 16 PAHs (b)

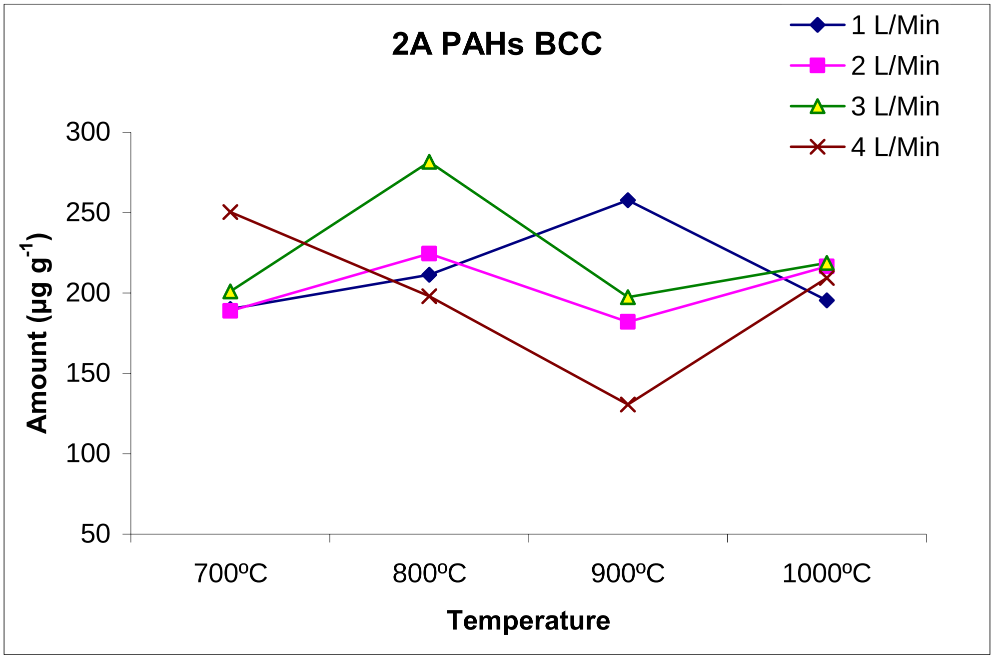


Fig. 4.22: Amount of 2A PAHs from incineration of blood contaminated cotton at different temperatures and airflow rates

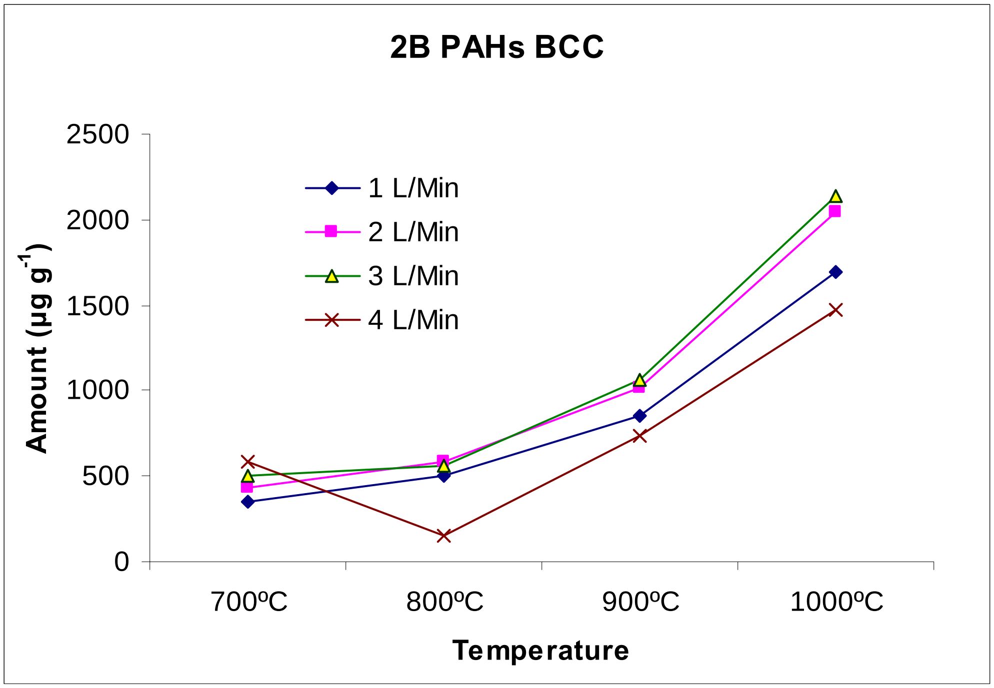


Fig. 4.23: Amount of 2A PAHs from incineration of blood contaminated cotton at different temperatures and airflow rates

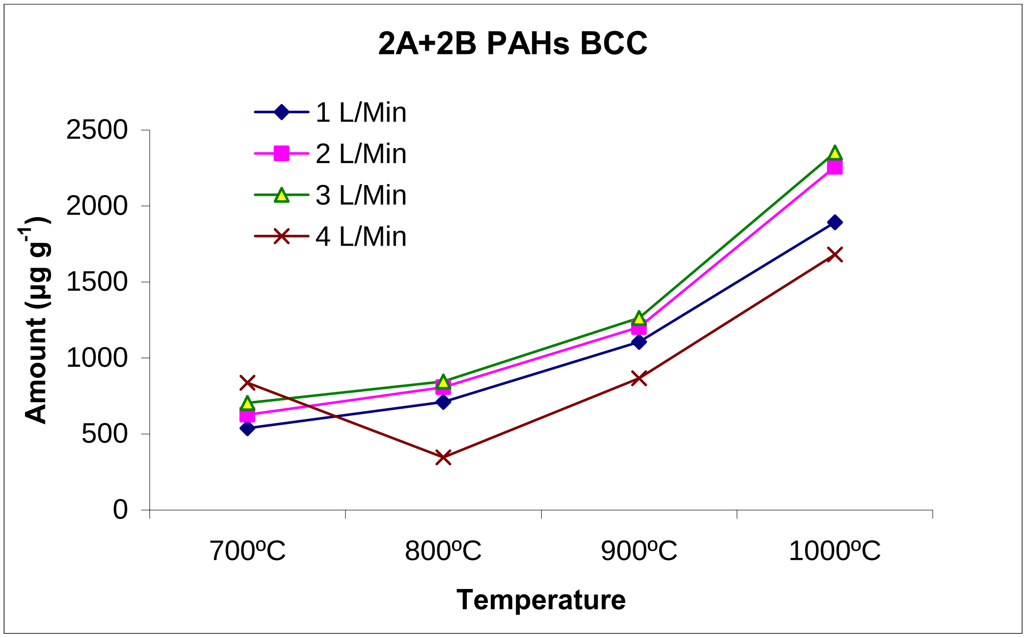
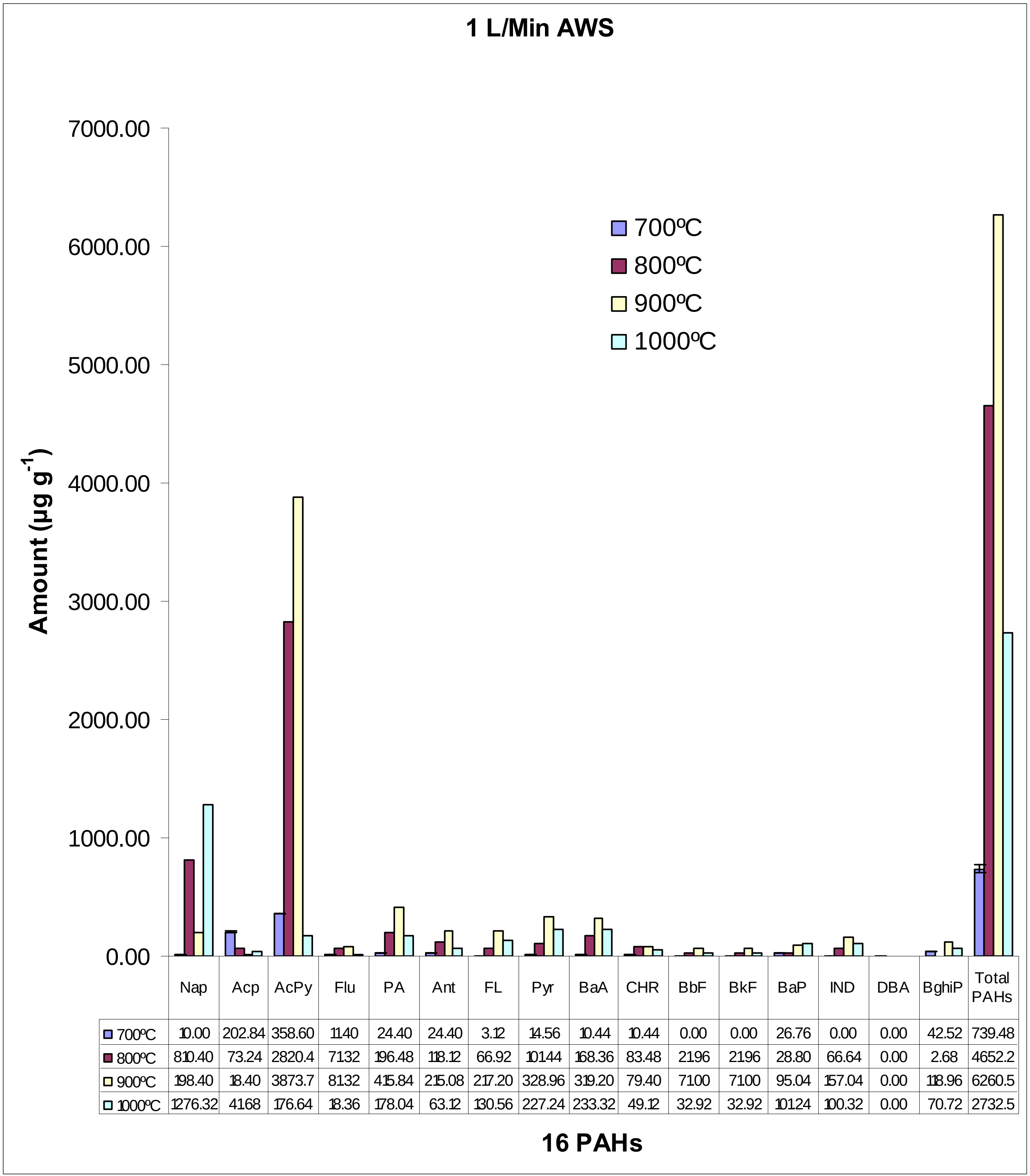


Fig. 4.24: Amount of sum of total 2A and 2B PAHs from incineration of blood contaminated cotton at different temperatures and airflow rates

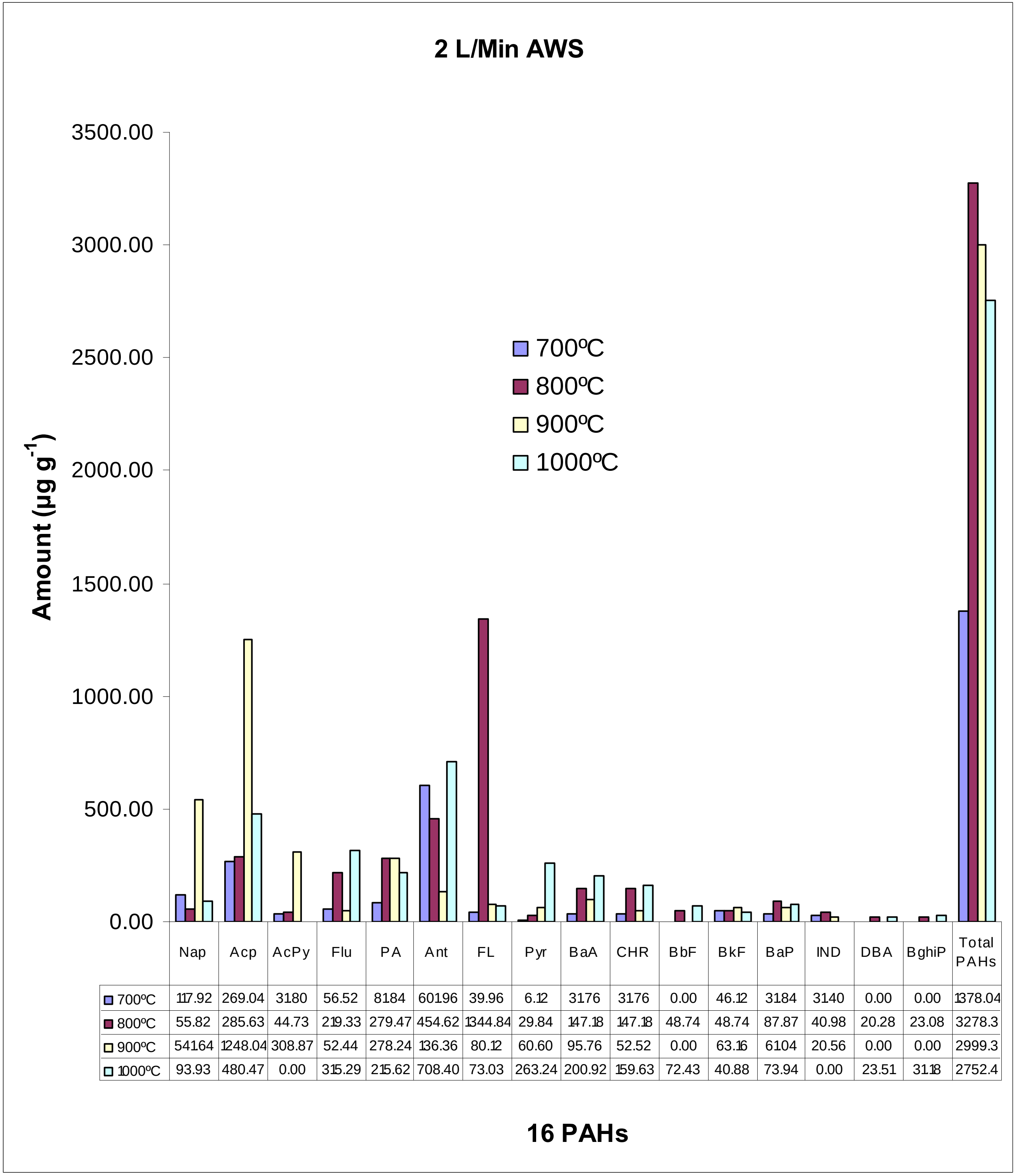
4.2.1.2.3 Acrylic Waste Solution: The incineration of AWS shows the presence of 12-16 PAHs at different temperature and airflow rates. The amounts of 16 PAHs emissions from incineration of AWS with different airflow rates at 700, 800, 900 and 1000°C are listed and graphically represented in Figs. 4.25-4.28. Distribution of PAHs showed no definite trend. Similar findings by Mastral et al. (1999) showed that there is no definite trend on distribution of 16 PAHs as a function of temperature. The amount of total 16 PAHs at different temperatures and airflow rates is represented in Fig. 4. At a flow rate of 1-2 L Min^{-1}, total amount of PAHs first increases then decreases with increase in temperature. You et al. (1996) found increase in PAHs formation as combustion temperature is increased during the combustion of polystyrene and found the decrease of PAHs from 900 to 1000°C. However, at a flow rate of 3 L Min^{-1}, there is increase in total PAHs over increase in the temperature. Kim et al. (2004) had found an increase of the total amount of 16 PAHs with increase in temperature from 300 to 600°C and 600 to 900°C during combustion of PVC. At 4 L Min^{-1}, there is first decrease then increase in total PAHs. Hawley-Fedder et al. (1984) observed that amount of total PAHs reduced remarkably from 800 to 900°C during combustion of PVC and the maximum amount of PAHs was obtained at 950°C. Lower amounts of total PAHs are observed at 700ºC with airflow rate of 1-3 L Min^{-1} or 800-900ºC with flow rate of 2-4 L Min^{-1} (Fig. 4.29). A chromatogram sowing the lowest emission of total PAHs is given in Fig. 4.30.

The effect of different temperatures and airflow rates on the emission of 2A and 2B PAHs has been represented in Figs. 4.31-4.32 respectively. The sum total of 2A PAHs was highest at 1000°C (683.59 µg g^{-1}) and lowest at 700°C (37.2 µg g^{-1}) with an airflow rate of 3 and 1 L Min^{-1} respectively. The sum total 2B of PAHs was highest at 1000°C (1442.48 µg g^{-1}) and lowest at 700°C (10 µg g^{-1}) with an airflow rate of 1 L Min^{-1}. The optimum conditions for lower values of 2A and 2B PAHs are 700-900°C and with an airflow rate of 2-4 L Min^{-1}. However, lower value of sum of total of 2A+2B PAHs were at 700 to 900ºC with airflow rate of 1-4 L Min^{-1} (Fig. 4.33).



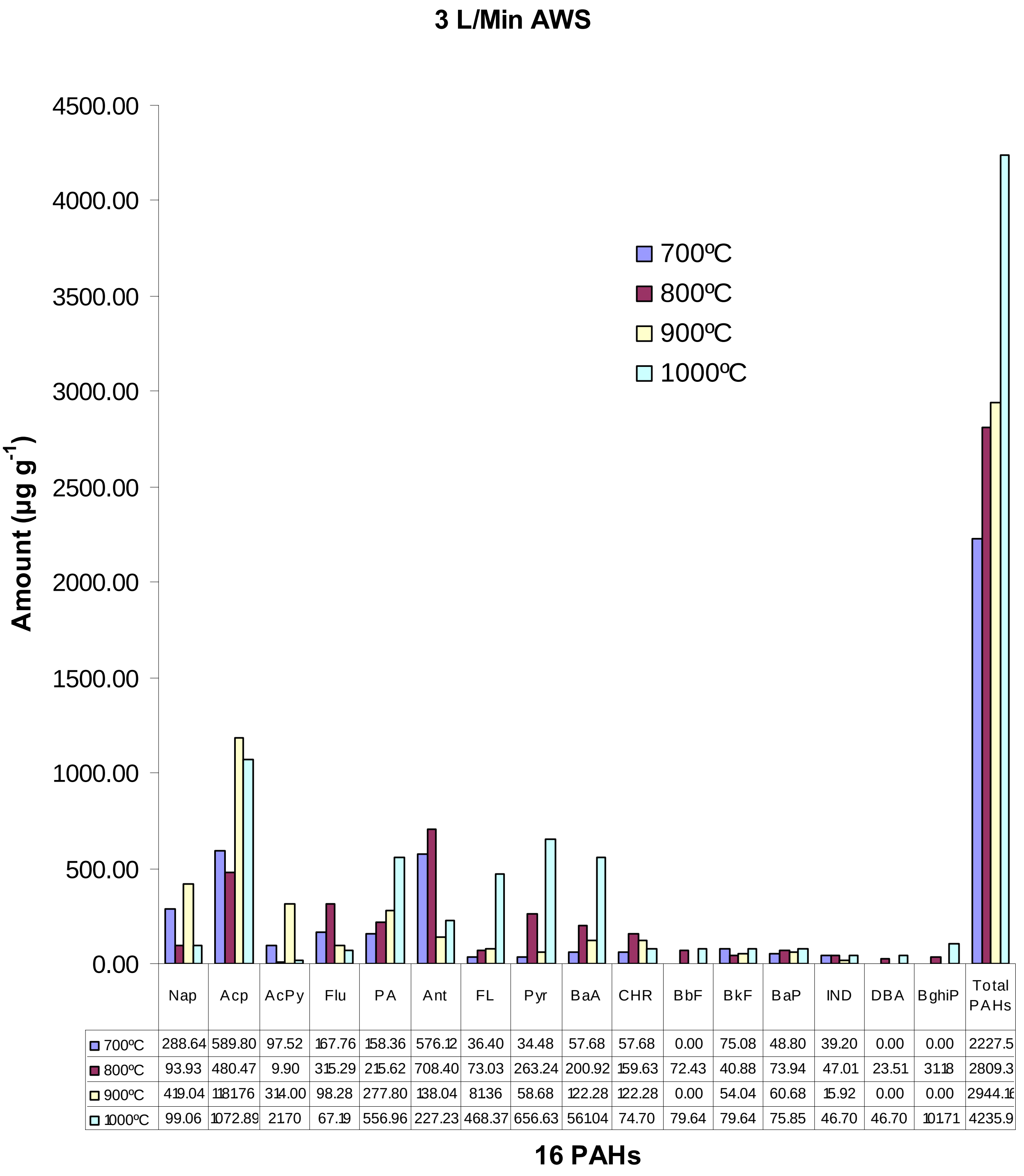
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	10.00	202.84	358.60	11.40	24.40	24.40	3.12	14.56	10.44	10.44	0.00	0.00	26.76	0.00	0.00	42.52	739.48
800ºC	810.40	73.24	2820.4	71.32	196.48	118.12	66.92	101.44	168.36	83.48	21.96	21.96	28.80	66.64	0.00	2.68	4652.2
900ºC	198.40	18.40	3873.7	81.32	415.84	215.08	217.20	328.96	319.20	79.40	71.00	71.00	95.04	157.04	0.00	118.96	6260.5
1000ºC	1276.32	41.68	176.64	18.36	178.04	63.12	130.56	227.24	233.32	49.12	32.92	32.92	101.24	100.32	0.00	70.72	2732.5

Fig. 4.25: Amount of 16 PAHs emissions from incineration of acrylic waste solution with an airflow rate of 1 L Min^{-1} at different temperatures



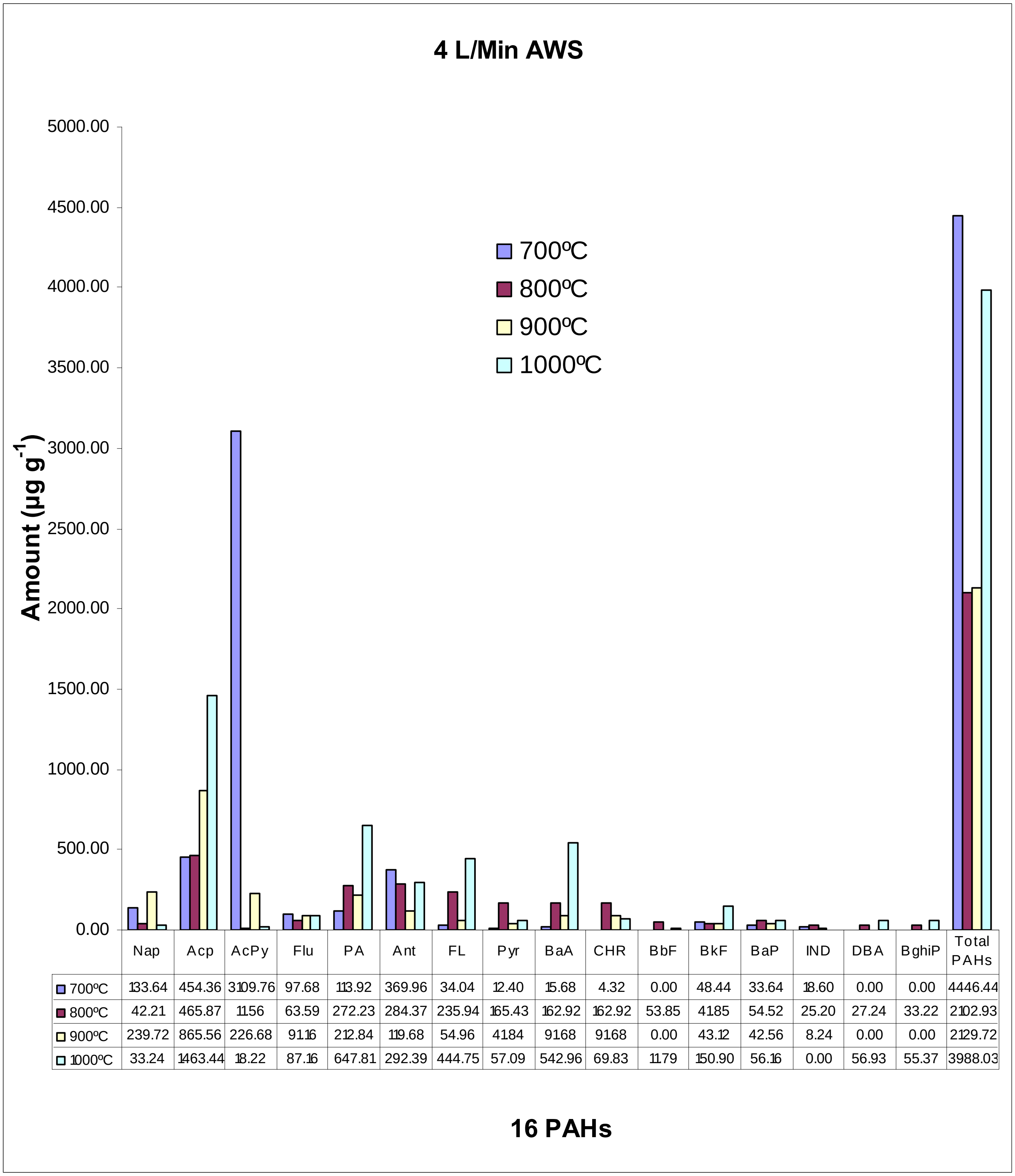
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
▢ 700ºC	117.92	269.04	3180	56.52	8184	60196	39.96	6.12	3176	3176	0.00	46.12	3184	3140	0.00	0.00	1378.04
■ 800ºC	55.82	285.63	44.73	219.33	279.47	454.62	1344.84	29.84	147.18	147.18	48.74	48.74	87.87	40.98	20.28	23.08	3278.3
▢ 900ºC	54164	1248.04	308.87	52.44	278.24	136.36	80.12	60.60	95.76	52.52	0.00	63.16	6104	20.56	0.00	0.00	2999.3
▢ 1000ºC	93.93	480.47	0.00	315.29	215.62	708.40	73.03	263.24	200.92	159.63	72.43	40.88	73.94	0.00	23.51	31.18	2752.4

Fig. 4.26: Amount of 16 PAHs emissions from incineration of acrylic waste solution with an airflow rate of 2 L Min^{-1} at different temperatures



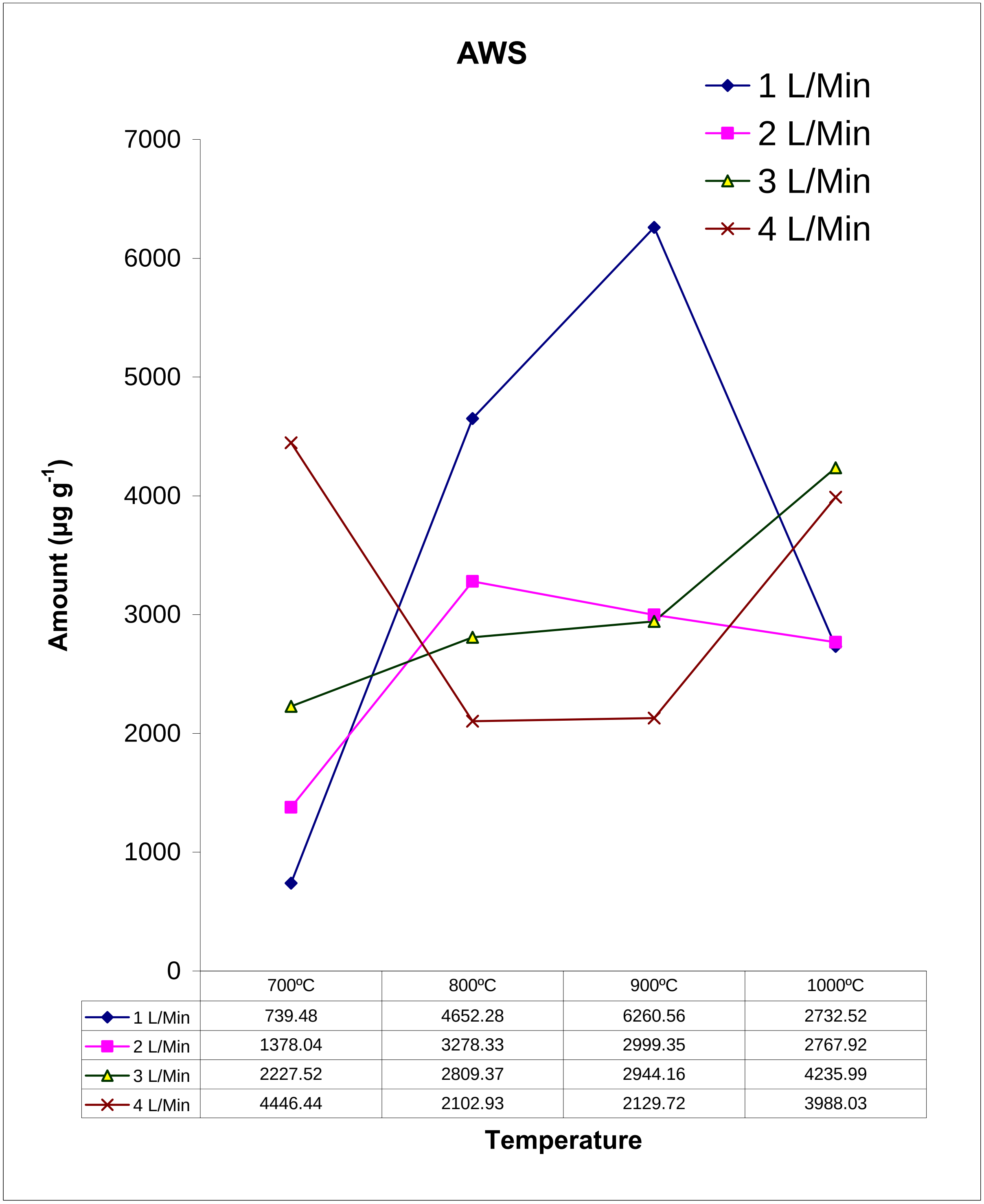
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
▨ 700ºC	288.64	589.80	97.52	167.76	158.36	576.12	36.40	34.48	57.68	57.68	0.00	75.08	48.80	39.20	0.00	0.00	2227.5
■ 800ºC	93.93	480.47	9.90	315.29	215.62	708.40	73.03	263.24	200.92	159.63	72.43	40.88	73.94	47.01	23.51	31.18	2809.3
☐ 900ºC	419.04	118176	314.00	98.28	277.80	138.04	8136	58.68	122.28	122.28	0.00	54.04	60.68	15.92	0.00	0.00	2944.1
☐ 1000ºC	99.06	1072.89	2170	67.19	556.96	227.23	468.37	656.63	56104	74.70	79.64	79.64	75.85	46.70	46.70	10171	4235.9

Fig. 4.27: Amount of 16 PAHs emissions from incineration of acrylic waste solution with an airflow rate of 3 L Min^{-1} at different temperatures



	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	133.64	454.36	3109.76	97.68	113.92	369.96	34.04	12.40	15.68	4.32	0.00	48.44	33.64	18.60	0.00	0.00	4446.44
800ºC	42.21	465.87	11.56	63.59	272.23	284.37	235.94	165.43	162.92	162.92	53.85	41.85	54.52	25.20	27.24	33.22	2102.93
900ºC	239.72	865.56	226.68	91.16	212.84	119.68	54.96	41.84	91.68	91.68	0.00	43.12	42.56	8.24	0.00	0.00	2129.72
1000ºC	33.24	1463.44	18.22	87.16	647.81	292.39	444.75	57.09	542.96	69.83	11.79	150.90	56.16	0.00	56.93	55.37	3988.03

Fig. 4.28: Amount of 16 PAHs emissions from incineration of acrylic waste solution with an airflow rate of 4 L Min^{-1} at different temperatures



	700ºC	800ºC	900ºC	1000ºC
◆ 1 L/Min	739.48	4652.28	6260.56	2732.52
■ 2 L/Min	1378.04	3278.33	2999.35	2767.92
▲ 3 L/Min	2227.52	2809.37	2944.16	4235.99
× 4 L/Min	4446.44	2102.93	2129.72	3988.03

Fig. 4.29: Amount of total 16 PAHs emissions at different temperatures and airflow rates from incineration of acrylic waste solution

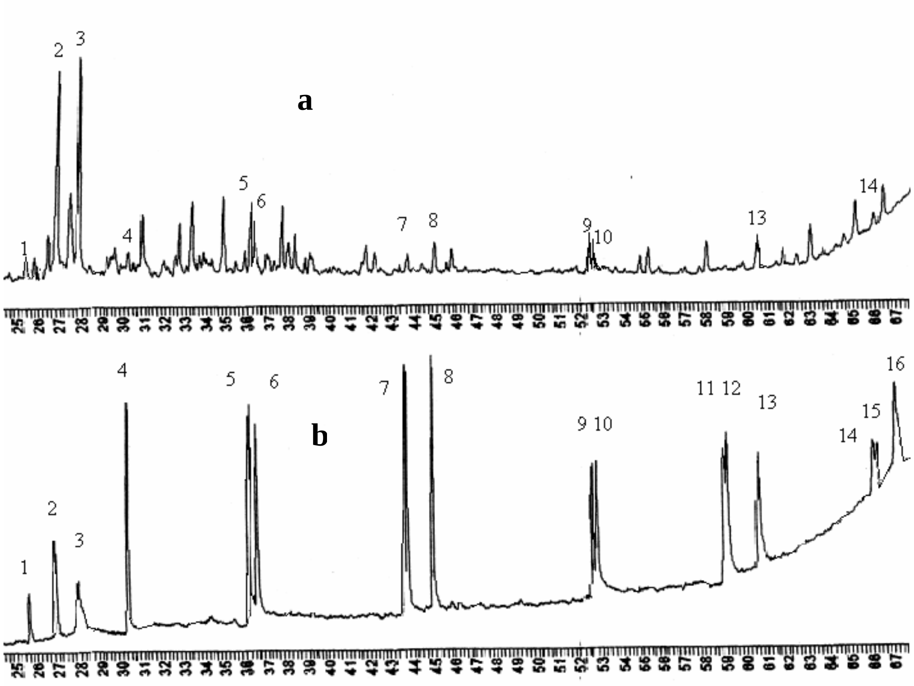


Fig. 4.30: Chromatogram of PAHs from incineration of acrylic waste solution at 700ºC with airflow rate of 1L Min^{-1} (a) along with chromatogram of Standard solution of 16 PAHs (b)

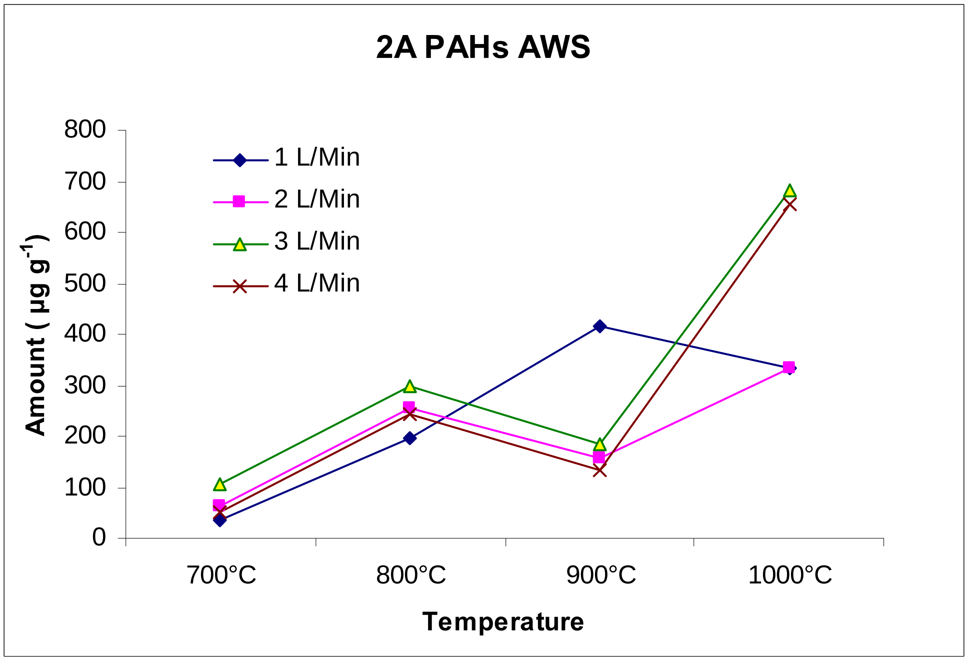


Fig. 4.31: Amount of 2A PAHs from incineration of acrylic waste solution at different temperatures and airflow rates

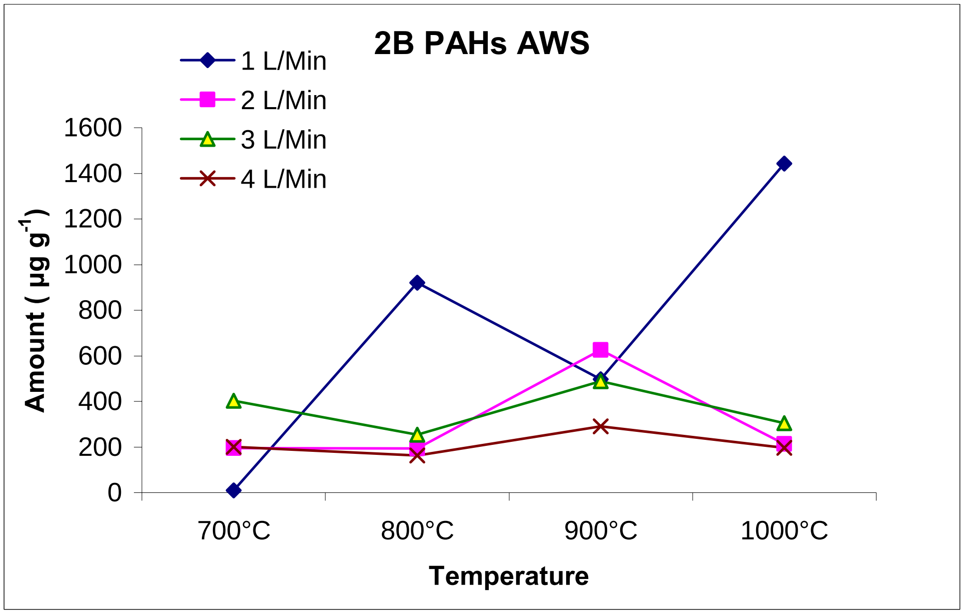


Fig. 4.32: Amount of 2B PAHs from incineration of acrylic waste solution at different temperatures and airflow rates

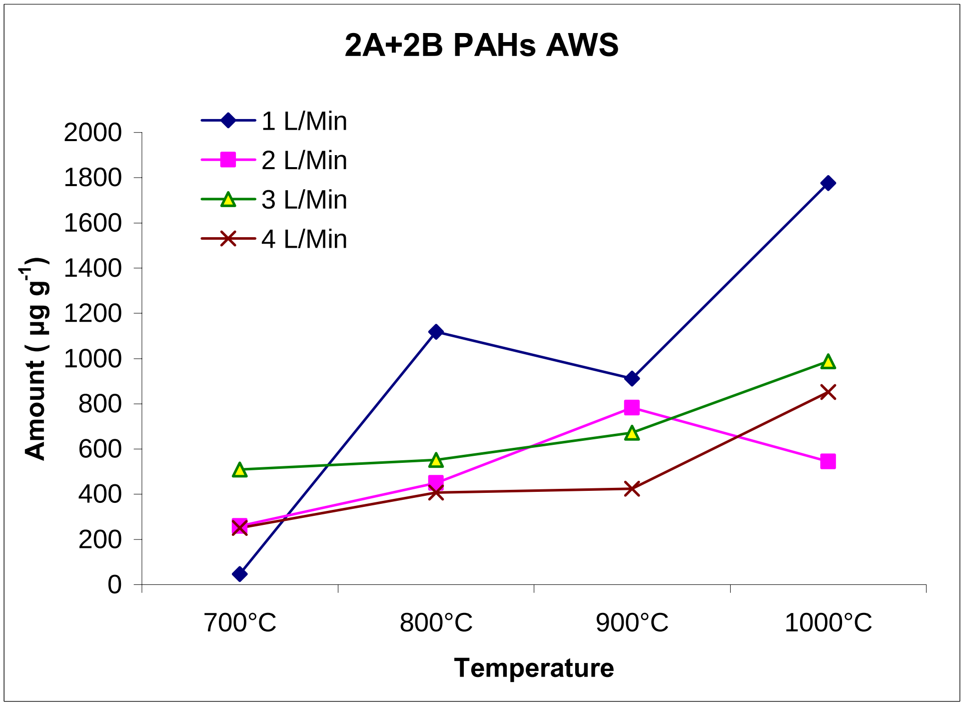
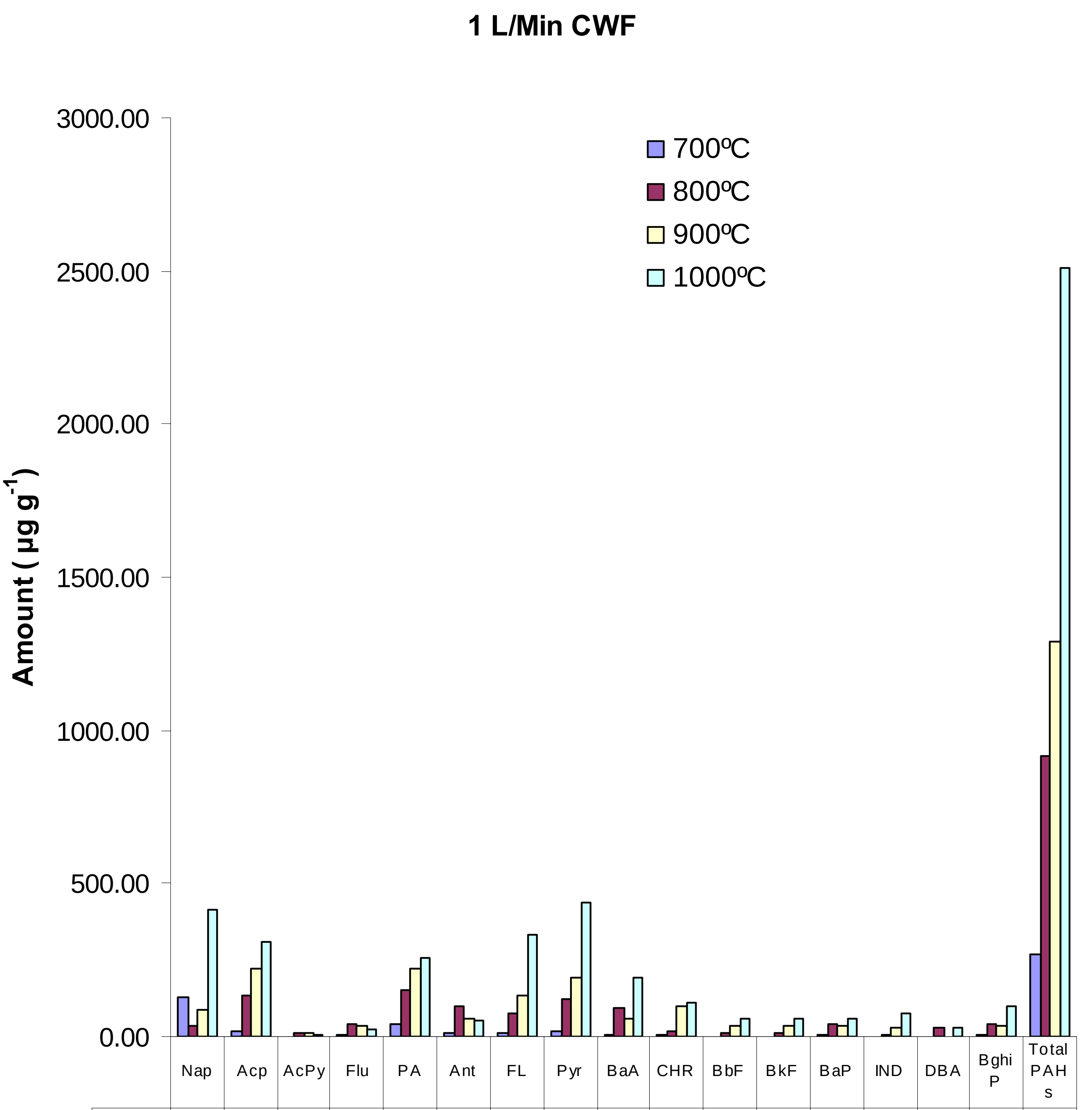


Fig. 4.33: Amount of sum of total 2A and 2B PAHs from incineration of acrylic waste solution at different temperatures and airflow rates

4.2.1.2.4 Cellulose Waste Filter: The incineration of CWF showed the presence of 13-16 PAHs at 700-1000°C after an interval of 100°C at different airflow rates (Figs. 4.34-4.37), with major fraction of Nap at 700 and 1000°C. Distribution PAHs showed no definite trend of PAHs. Similar findings by Mastral et al. (1999) showed that there is no definite trend on distribution of 16 PAHs as a function of temperature.

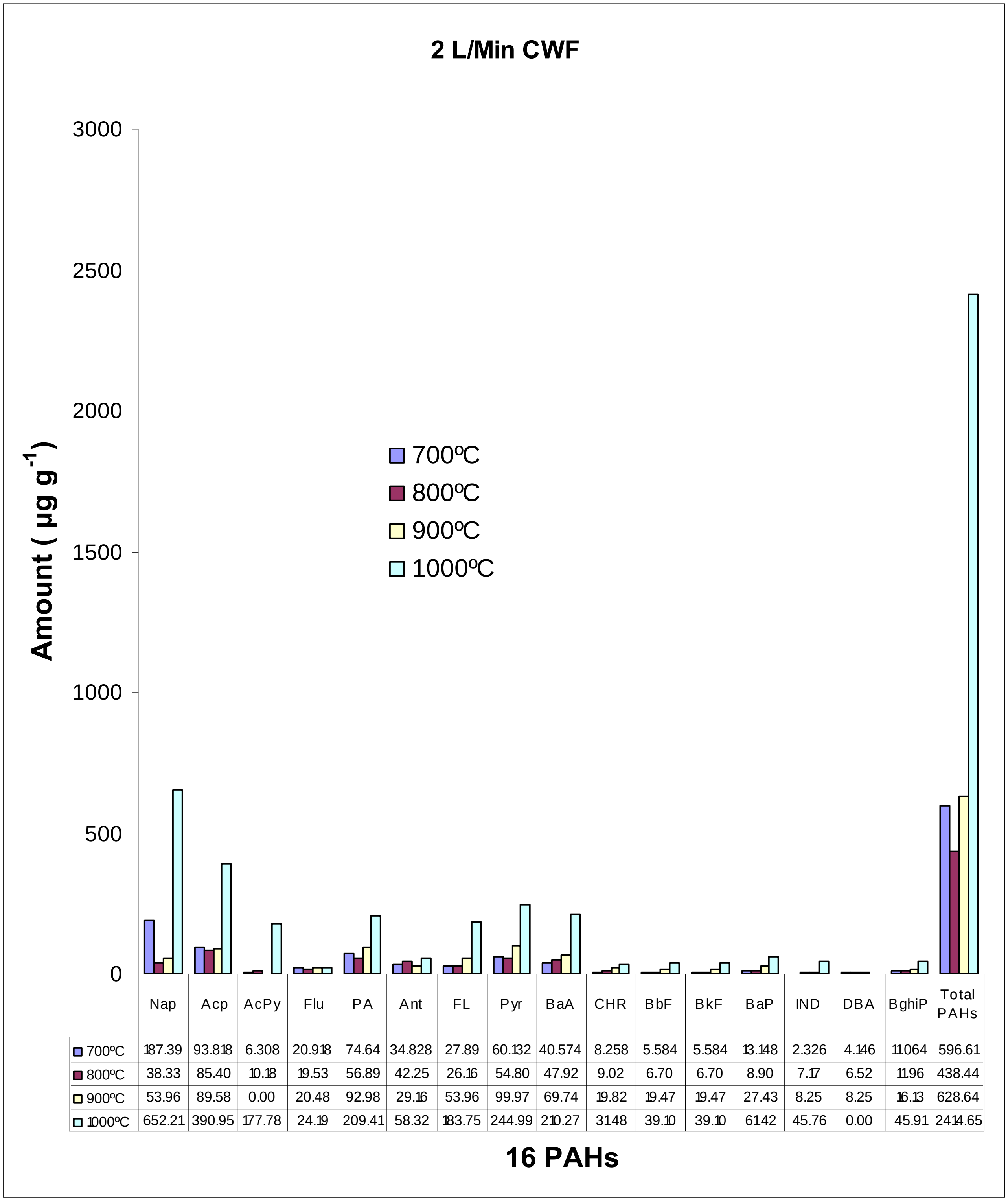
The amount of total 16 PAHs was about 9.4 times higher at 1000°C than at 700°C. The amount of total 16 PAHs at different temperatures and airflow rates is represented in Fig. 4.38. At a flow rate of 1 and 4 L Min^{-1}, total amount of PAH increases with increase in temperature. Kim et al. (2004) had found an increase of the total amount of 16 PAHs with increase in temperature from 300 to 600°C and 600 to 900°C during combustion of PVC. However, at a flow rate of 2-3 L Min^{-1}, there is first decrease and then increase in total PAH with increase in temperature. Hawley-Fedder et al. (1984) observed that amount of total PAHs reduced from 800 to 900°C during combustion of PVC and the maximum amount of PAHs was obtained at 950°C. Our study showed lowest amount of total PAHs are observed at 700-900ºC at 1-3 L Min^{-1} airflow rates. A chromatogram showing the lowest amount of total 16 PAHs is given in Fig. 4.39.

The emissions of 2A and 2B PAHs from incineration of CWF, effect of temperature and airflow rate is given in Figs. 4.40-4.41. The sum of total 2A PAHs were highest at 1000°C (424.54 μg g^{-1}) with an air flow rate of 3 L Min^{-1} and lowest at 700°C (16.43 μg g^{-1}) with an air flow rate of 1 L Min^{-1}. However, the sum of total 2B PAHs were highest at 1000°C (1324.06 μg g^{-1}) with an air flow rate of 4 L Min^{-1} and lowest at 900°C (37.14 μg g^{-1}) with an air flow rate of 3 L Min^{-1}. The sum of total 2A+2B PAHs emissions were less at temperature of 700-900°C with airflow rate of 1-2 L Min^{-1} (Fig. 4.42).



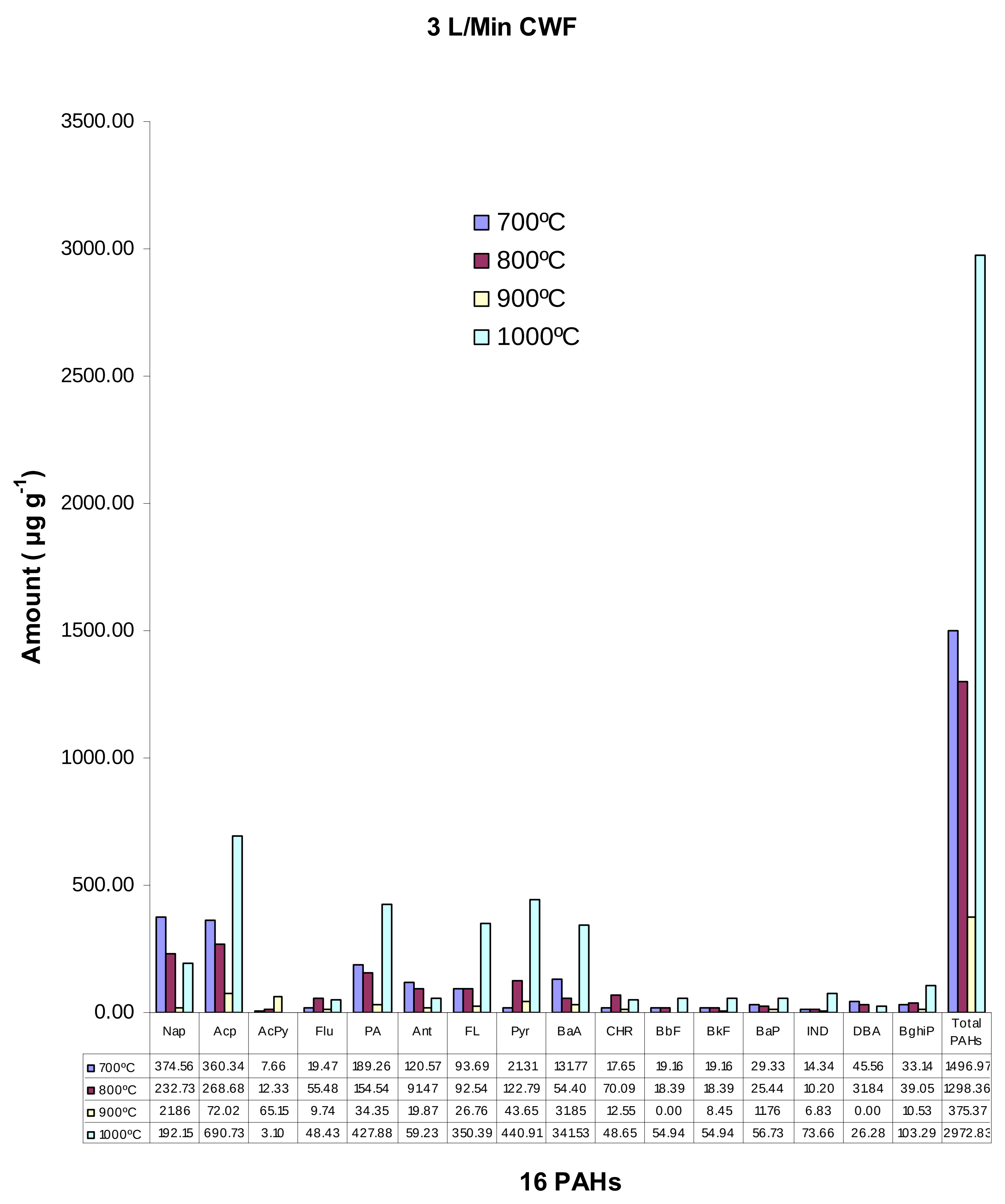
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	Bghi P	Total PAH s
▢ 700ºC	128.58	16.61	2.40	3.93	40.29	12.61	11.87	19.17	7.87	7.87	0.00	0.00	8.42	0.00	0.14	8.26	268.03
■ 800ºC	33.50	136.99	11.19	39.43	149.64	99.11	73.72	125.19	91.64	20.28	9.91	9.91	38.90	7.63	28.03	43.25	918.31
▢ 900ºC	86.76	219.23	10.29	36.54	222.17	58.03	136.86	195.20	57.92	96.49	36.08	36.08	36.86	27.46	0.00	35.14	1291.11
▢ 1000ºC	414.65	308.85	4.54	23.74	259.15	49.67	332.63	435.25	194.39	111.84	58.33	58.33	58.50	75.05	30.12	96.43	2511.48

Fig. 4.34: Amount of 16 PAHs emissions from incineration of cellulose waste filter with an airflow rate of 1 L Min^{-1} at different temperatures



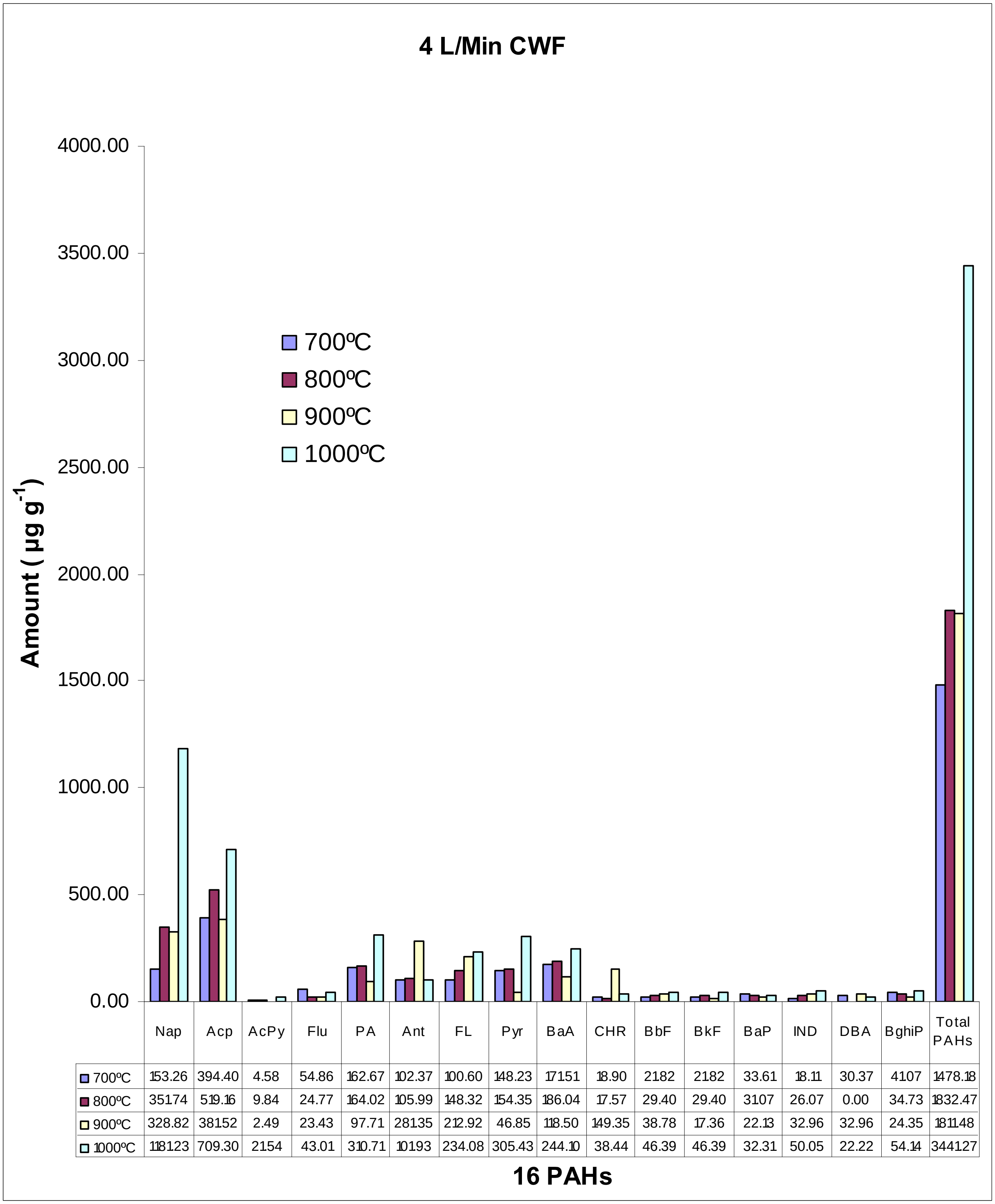
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	187.39	93.818	6.308	20.918	74.64	34.828	27.89	60.132	40.574	8.258	5.584	5.584	13.148	2.326	4.146	11.064	596.61
800ºC	38.33	85.40	10.18	19.53	56.89	42.25	26.16	54.80	47.92	9.02	6.70	6.70	8.90	7.17	6.52	11.96	438.44
900ºC	53.96	89.58	0.00	20.48	92.98	29.16	53.96	99.97	69.74	19.82	19.47	19.47	27.43	8.25	8.25	16.13	628.64
1000ºC	652.21	390.95	177.78	24.19	209.41	58.32	183.75	244.99	210.27	31.48	39.10	39.10	61.42	45.76	0.00	45.91	2414.65

Fig. 4.35: Amount of 16 PAHs emissions from incineration of cellulose waste filter with an airflow rate of 2 L Min^{-1} at different temperatures



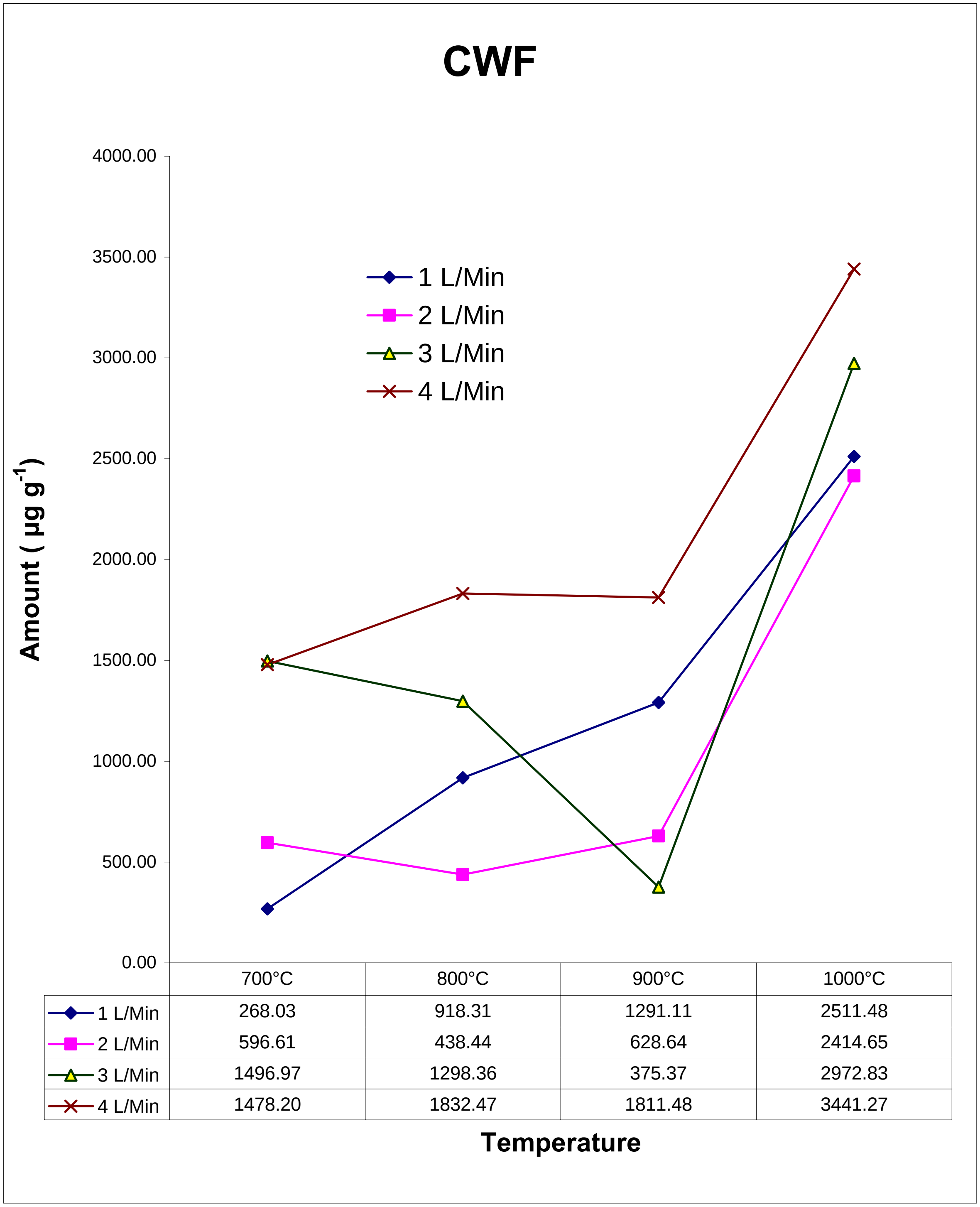
	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
■ 700ºC	374.56	360.34	7.66	19.47	189.26	120.57	93.69	21.31	131.77	17.65	19.16	19.16	29.33	14.34	45.56	33.14	1496.97
■ 800ºC	232.73	268.68	12.33	55.48	154.54	91.47	92.54	122.79	54.40	70.09	18.39	18.39	25.44	10.20	31.84	39.05	1298.36
■ 900ºC	21.86	72.02	65.15	9.74	34.35	19.87	26.76	43.65	31.85	12.55	0.00	8.45	11.76	6.83	0.00	10.53	375.37
■ 1000ºC	192.15	690.73	3.10	48.43	427.88	59.23	350.39	440.91	341.53	48.65	54.94	54.94	56.73	73.66	26.28	103.29	2972.83

Fig. 4.36: Amount of 16 PAHs emissions from incineration of cellulose waste filter with an airflow rate of 3 L Min^{-1} at different temperatures



	Nap	Acp	AcPy	Flu	PA	Ant	FL	Pyr	BaA	CHR	BbF	BkF	BaP	IND	DBA	BghiP	Total PAHs
700ºC	153.26	394.40	4.58	54.86	162.67	102.37	100.60	148.23	171.51	18.90	21.82	21.82	33.61	18.11	30.37	41.07	1478.18
800ºC	351.74	519.16	9.84	24.77	164.02	105.99	148.32	154.35	186.04	17.57	29.40	29.40	31.07	26.07	0.00	34.73	1832.47
900ºC	328.82	381.52	2.49	23.43	97.71	281.35	212.92	46.85	118.50	149.35	38.78	17.36	22.13	32.96	32.96	24.35	1811.48
1000ºC	1181.23	709.30	21.54	43.01	310.71	101.93	234.08	305.43	244.10	38.44	46.39	46.39	32.31	50.05	22.22	54.14	3441.27

Fig. 4.37: Amount of 16 PAHs emissions from incineration of cellulose waste filter a with an airflow rate of 4 L Min^{-1} at different temperatures



	700°C	800°C	900°C	1000°C
◆ 1 L/Min	268.03	918.31	1291.11	2511.48
■ 2 L/Min	596.61	438.44	628.64	2414.65
△ 3 L/Min	1496.97	1298.36	375.37	2972.83
× 4 L/Min	1478.20	1832.47	1811.48	3441.27

Fig. 4.38: Amount of total 16 PAHs at different temperatures and airflow rates from incineration of cellulose waste filter

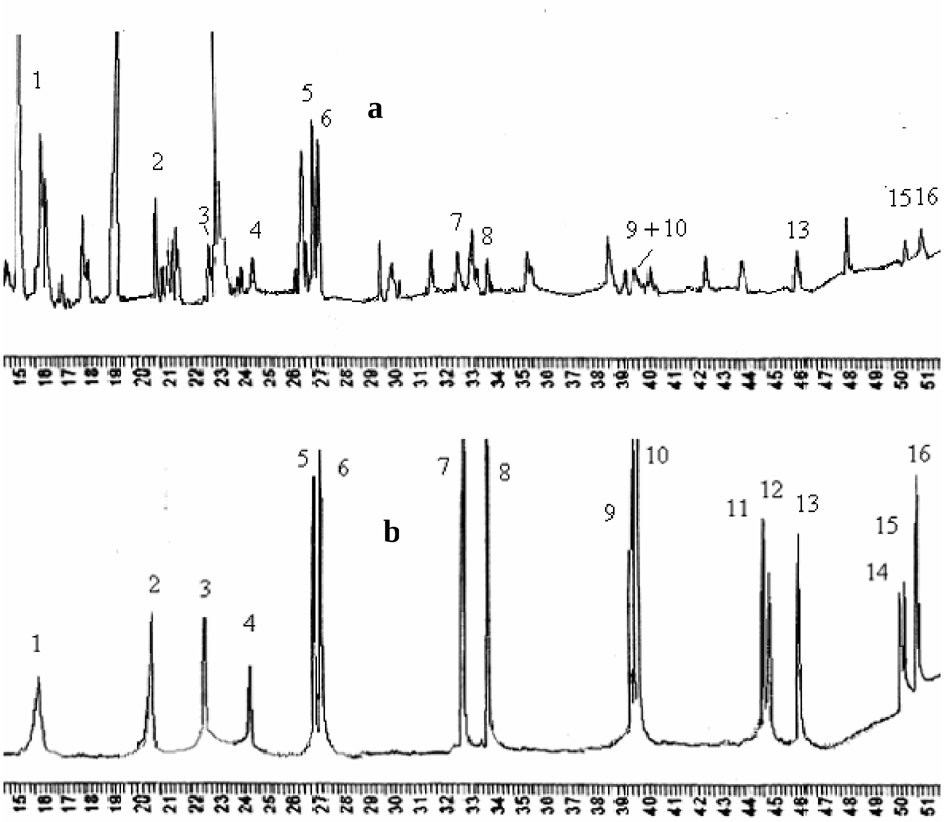


Fig. 4.39: Chromatogram of PAHs from incineration of cellulose waste filter at 700ºC with airflow rate of 1L Min^{-1} (a) along with chromatogram of Standard solution of 16 PAHs (b)

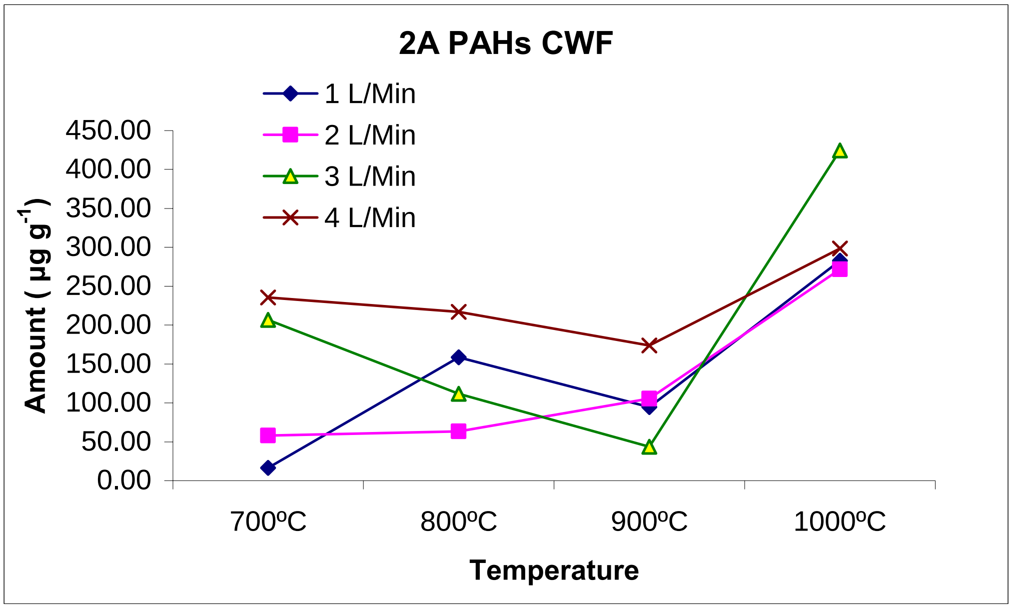


Fig. 4.40: Amount of 2A PAHs from incineration of cellulose waste filter at different temperatures and airflow rates

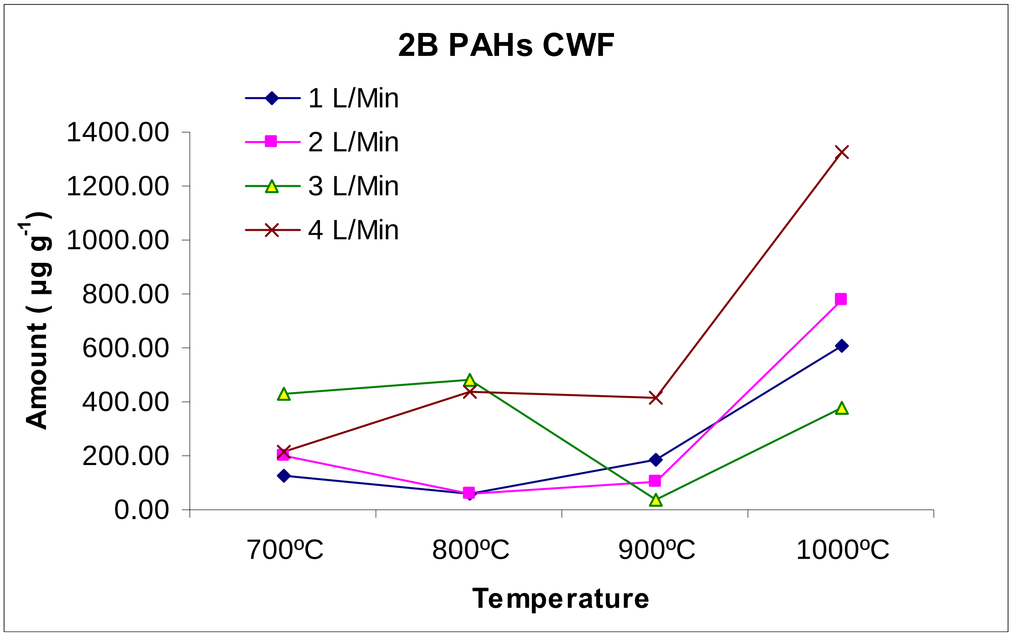


Fig. 4.41: Amount of 2B PAHs from incineration of cellulose waste filter at different temperatures and airflow rates

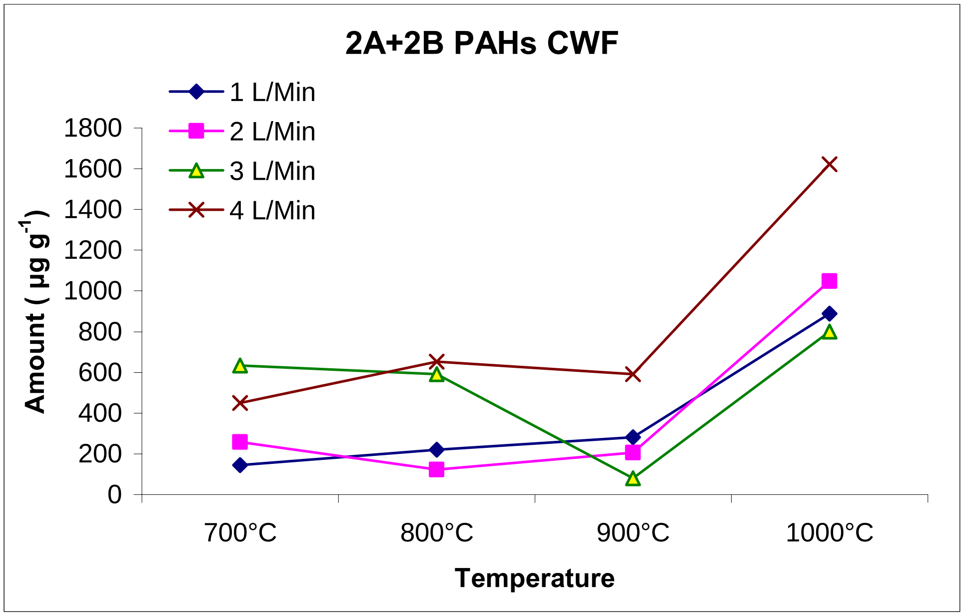


Fig. 4.42: Amount of sum of total 2A and 2B PAHs from incineration of cellulose waste filter at different temperatures and airflow rates

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Chapter - V

Hospitals/ Acrylic Industries waste management practices – A case study approach

Waste management is the collection, transport, processing, recycling or disposal of waste materials. The practices of waste management followed by local hospitals/ acrylic industries in accordance with Biomedical Waste (Management & Handling) Rules/ Hazardous Waste (Management & Handling) Rules, are being described. A case study approach has been followed for an in depth analysis of hospital/ acrylic industrial waste management practices being followed by the hospitals and industries under study. This is as per the standard management research practices adopted in conducting the research on different functional areas.

5.1 Biomedical/ Hazardous waste management- An Overview

The term 'waste management' usually relates to materials produced by human activity and is generally undertaken to reduce their effect on health, the environment or aesthetics. Hospital and industrial wastes, especially biomedical and hazardous wastes are of special environment concern. Moreover, biomedical/ hazardous waste needs management due to health, environmental, legal and aesthetic reasons. The biomedical waste management also involves ethical reasons due to social responsibilities of health professionals, as a result of their knowledge and skills apart from an obligation to alert those who are at risk. These management Health professionals, bear a responsibility to act in such a way to prevent exposure to various health hazards and exposures to PAH/ PCDD/Fs. Biomedical/ hazardous wastes are the major source of PAHs/ PCDD/Fs production during incineration, many of these are known to be carcinogenic.

5.1.1 Biomedical Waste

Hospital is a place where patient's problems are diagnosed, analyzed and treated. During these activities generation of waste is unavoidable. It is important here to distinguish how "hospital wastes", "biomedical wastes" and "infection wastes" is defined, because these terms are often mistakenly interchanged (Rutala et al., 1989;

MacNight, 1993; Burke, 1994). "*Hospital waste*" is the most general term and refers to all waste from hospitals, biological and non-biological, that is discarded and not intended for further use. It consists of infectious and non-infectious solid waste, hazardous waste and low-level radioactive waste (Cross et al., 1990; Etter et al., 1992; Rutala and Weber, 1991; Burke, 1994; Klangsin and Harding, 1998). "Biomedical waste" is a subset of hospital waste, and in turn, infectious waste is a subset of biomedical waste (Singh and Prakash, 2007). In United states, biomedical waste (BMW) is defined in Section 3 of the Medical Waste Tracking Act of 1988 "as any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals in research pertaining thereto, or in the production or testing of biologicals" (US Department of Health report, 1990). In India, BMW refers to waste generated during the diagnosis, treatment or immunization of human beings or animals or in research activities pertaining thereto or in the production or testing of biologicals, and is classified into 10 categories: human anatomical waste, animal waste, microbiology and biotechnology waste, waste sharps, discarded medicines and cytotoxic drugs, soiled waste, solid waste, liquid waste, incineration ash and chemical waste (MoEF, 1998).

It has been estimated that up to 85 - 90% of the waste generated in hospitals is non-infectious (free from microbes and has not been in contact with any body fluids - similar to domestic waste) (Mukherjee, 2004). It is the remaining 10 - 20% of waste that is of concern because of hazardous and infectious nature. Normally 20 - 40% of hospital waste can be recycled, but many hospitals recycle only 10% leaving tremendous scope for improvement. In addition, waste that is un-segregated and not properly treated would cause environmental pollution affecting the health of the community. So waste should be segregated into colored bags and treated in accordance to Biomedical Waste (Management and Handling) Rules (Fig. 5.1).

The infectious waste (red and yellow bag waste) consists of all waste that is capable of transmitting infection and is patient-related. It includes blood-stained cotton, dressings, urine catheters, human anatomical parts including amputated limbs and sharps like needles, syringes, etc. Non-infectious waste can be effectively segregated further into bio-degradable and non-bio-degradable. Bio-degradable waste can be disposed off using environment-friendly techniques like vermi-composting/

composting. The non-bio-degradable waste like mutilated bottles, glass can be segregated and further recycled/ resold, thereby leading to optimum utilisation of resources.

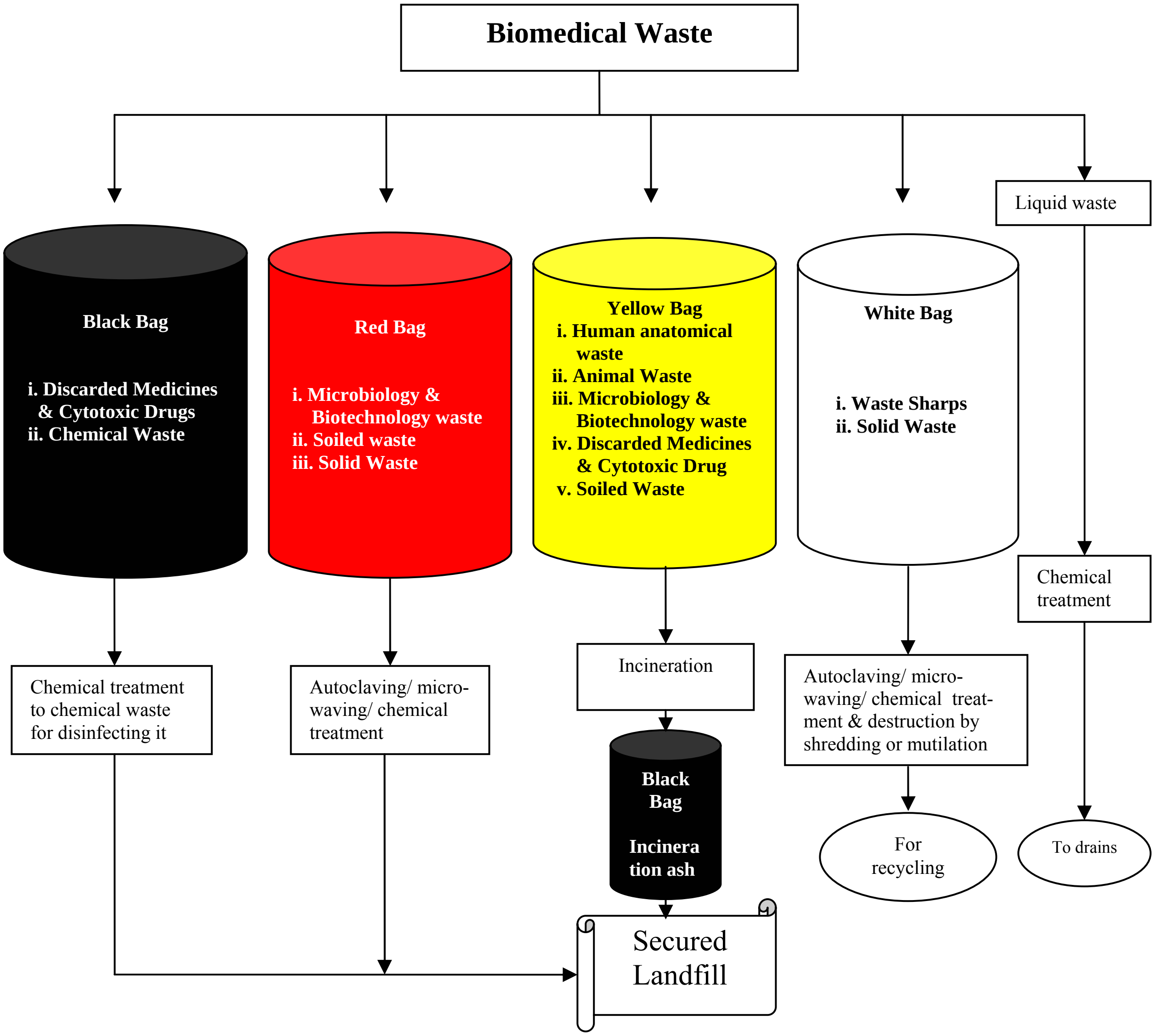

Fig. 5.1: Segregation of Biomedical Waste for treatment and disposal according to Biomedical Waste (Management and Handling) Rules, 1998

To control the spread of infection from BMW to human health, the Government of India passed Biomedical Waste (Management & Handling) Rules, 1998, under the MoEF. The law was amended thrice in March, 2000; June, 2000 and September, 2003 to ensure effective BMW management. The effective implementation of these rules can make the difference. There are a few reports available in literature regarding studies carried out at local or regional levels in various hospitals (Yadav, 2001; Singh and John, 2003; Kishore and Ingle, 2004; Veda et al, 2007; Khajuria and Kumar, 2007).

5.1.2 Hazardous Waste

Hazardous wastes (HW) generation from industries is a world wide problem. Rapid industrial developments led to the generation of huge quantities of HW. Generally, HW may be defined as those substances which may cause adverse or chronic effects on human health or on environment (Bruner, 1994). During earlier days, HW management was a challenging concept for most of the Asian countries including India. The lack of technical and financial resources and the regulatory control for the management of hazardous wastes in the past, led to unscientific disposal of hazardous wastes in India, which posed serious risks to human, animal and plant life.

In order to manage HW, mainly solids, semi-solid and other industrial wastes which are not covered by the Water and Air Acts of 1974 and 1981, Ministry of Environment and Forests (MoEF, 1989), Government of India notified the Hazardous Waste (Management & Handling) Rules in July, 1989 under the provisions of the Environment (Protection) Act, 1986. These rules were further amended in years 2000 and 2003 in order to identify HW by means of industrial processes, waste streams, and also by way of concentrations of specified constituents of the HW. Categories of wastes banned for export and import are also defined. It was estimated that about 80 % of the total HW remains toxic for years or even centuries (Ortego et al., 1995). Inappropriate disposal of these wastes on land creates the risk of contaminating ground water and vegetation causing adverse health effects.

In past decades, efforts have been made in India to better manage the waste produced from various sources. It is the BMW/ HW which is of utmost environmental concern. A number of regulations and guidelines were issued from time to time in order to establish an integrated waste management system. Indian Ministry of Environment and Forestry (MoEF) is taking strict measure against violators of BMW/

HW management rules. Published data regarding hospitals/ acrylic industry in Punjab is not available

5.2 Methodology

The primary data was collected on the basis of a questionnaire distributed to ten hospitals (nine of Punjab and one of Union Territory), a common biomedical waste treatment facility (CBMWTF) of Punjab situated in Ludhiana and from two largest acrylic fiber producing industries of India. The questions were designed to access compliance with Biomedical Waste (Management and Handling) Rules, 1998 as amended in 2003 and Hazardous Waste (Management and Handling) Rules 1989 as amended in 2003. The primary data is compared with the secondary data collected from State Pollution Control Boards.

5.2.1 Questionnaires

The questionnaires were designed so as to collect general and technical information related to:

(i) General information about hospitals/industries
(ii) Practices being followed by them in handling biomedical/ hazardous waste
(iii) Disposal options being undertaken

The technical information was designed on the basis of Biomedical/ Hazardous Waste (Management and Handling) Rules so as to access the overall waste stream, waste generation by categories and the practices being followed during segregation, collection, treatment and final disposal. Other issues like ash management, mercury pollution, training level of employees and training need assessment were also included.

The questionnaire were also extended to have the information on the availability of any BMW management guidelines developed either by hospitals themselves or some other concerned government authorities such as State Governments or State pollution Control Boards. The question related to awareness about the impact of incineration, pollution release from burning of waste, knowledge about international conventions/treaties related to BMW/ HW or persistent organic pollutants were also included. The collected data was compared with secondary data.

5.2.2 Samples of study

Ten hospitals (small/ medium/ large scale) and a CBMWTF along with two largest acrylic fiber producing industries have been investigated during this study. Nine hospitals of Patiala city of Punjab state and another hospital situated in Union Territory of North India viz., Post Graduate Institute of medial education and research, Chandigarh were analyzed for investigation of waste management practices followed by them. The acrylic industries undertaken for study were one from Punjab (Indian Acrylics Ltd., Sangrur) and another from Uttar Pradesh (Pasupati Acrylon Ltd., Muradabad) states of India.

5.2.2.1 Characteristics/profile of Hospitals

Patiala city of Punjab state is one of the famous princely states of erstwhile Punjab, forming the south-eastern part of the state, it lies between 29°49’ and 30°47’ north latitude, 75°58’ and 76°54' east longitude. It is surrounded by the districts of Fatehgarh Sahib and Rupnagar and the Union Territory of Chandigarh in the north, Sangrur district in the west, Ambala and Kurukshetra districts of neighboring state of Haryana in the east and Kaithal district of Haryana in the south.

Nine major hospitals of Patiala city and PGI, Chandigarh (largest hospital of North after AIIMS, New Delhi) were undertaken for investigation in order to study BMW management practices and problems faced by them in complying with environmental regulations along a CBMWTF of Ludhiana district of Punjab. The data was collected through questionnaires (Annexture I) which include questions related to Biomedical Waste (Management and Handling) Rules. The characteristics of these hospitals are:

i. **Postgraduate Institute of Medical Education and Research, (PGI-MER), Chandigarh:** The Institute is an autonomous body under the Act of Parliament in 1967 functioning under the Ministry of Health and Family Welfare, Government of India. PGIMER is an institute of excellence providing state of the art tertiary care and has highest bed capacity (from the selected hospitals) of 1412 beds.

ii. **Govt. Rajendra Hospital (GRH), Patiala:** This is the biggest hospital in terms of bed capacity (~907 beds) and the number of staff in Patiala district of Punjab state. It starts functioning in 1954 and offers specialized services in surgery, obstetrics, plastic surgery, ultrasonography and radiotherapy. The hospital consists of eleven different diagnosis and treatment units along with operating rooms and surgical intensive care units, laboratories and other general units (kitchen, laundry, coffee shop, etc.).

iii. **Mata Kaushalya Hospital (MKH), Patiala**: It is a unique hospital of North India which caters to the gynae and obstetrics needs of female patients only. The hospital is having bed capacity of 154 and with about fifty staff members. Mata Kaushalaya Devi Hospital was originally founded in 1890 as the Lady Dufferin Hospital.

iv. **Amar Hospital (AH), Patiala:** AH was founded by Dr. J. S. Bahia in March, 1997 with all the latest technology and modern facilities. It is multispeciality hospital with 55 bedded complete diagnostic centres, I.C.U/C.C.U/Cardiac lab. The C.C.U department of the hospital is specially equipped with world class cardiac facilities. It is a private hospital and offers the services to employer, employee and their families of State sector undertakings.

v. **Diesel Component Works Hospital (DCW), Patiala:** This hospital is located in the campus of Diesel Components Workshop of Indian Railways. In addition to diagnosis and treatment units, it also provides services to outdoor patient. The total bed capacity of this hospital is 50.

vi. **Kamal hospital (KH), Patiala:** The bed capacity of this hospital is 30 and it does not treat outdoor patient. In addition to diagnosis and treatment units, there is dialysis facility to serve the patients with kidney problems.

vii. **Garg Hospital and Maternity Home (GHMH), Patiala:** This hospital has total 20 numbers of beds. There is an operating room, surgical and intensive care unit apart from laboratory. This private hospital serves patients for various diseases apart from female patients as well as new born babies.

viii. **Giani Lal Singh Memorial Hospital (GLSMH), Patiala:** This is a small hospital with seven diagnosis and treatment units. The number of the beds is 19 and caters to the needs of Arthritic patients.

ix. **Singla Hospital (SH), Patiala:** This hospital is the smallest and has total bed capacity of 15 beds. This hospital has six patient treatment wards.

x. **Community Health Centre (CHC), Patiala:** Community Health Centre delivers free primary health care, health education, counseling, and chronic-disease prevention, education and management services. This health center has capacity of 10 beds.

xi. **SembRamky Environmental Management Pvt. Ltd. (SEMPL), Ludhiana:** SEMPL is a largest biomedical waste treating common BMW treatment facility (CBMWTF) which collects BMW from most of hospitals (1374) of Punjab and treat almost 2000 - 2300 kg of BMW per day (24461 beds covered) as record of 2006.

So these ten hospitals have different characteristics in terms of number of beds and the type of patients. It is possible that their waste composition differs. However, all wastes of nine hospitals of the Patiala city are currently collected together and transported to CBMWTF viz., SEMPL, Ludhiana. The primary data from above said health care facilities/ CBMWTF is collected and compared with the secondary data from Punjab Pollution Control Board, Patiala; and Punjab State Council of Science and Technology, Chandigarh.

5.2.2.1.1 Categorization of Hospitals

The hospitals undertaken for study are divided into three categorized depending upon their bed capacity in accordance to the Schedule VI of Biomedical Waste (Management and Handling) Rules (Table 5.1). Category A includes hospitals having bed capacity more than or equal to 500, Category B includes hospitals having bed capacity in between 50 to 200 and Category C includes hospitals having bed capacity less than or equal to 50.

Table 5.1: Categorization of Hospitals under study in accordance to Schedule VI of Biomedical Waste (Management and Handling) Rules

Category	Bed Capacity of Hospitals	No. Hospitals under Studied (Hospitals Name)
A	Hospitals having bed capacity ≥ 500	2 (PGI MER & GRH)
B	Hospitals having bed capacity ≥ 50-200	3 (MKH, AH & DCWH)
C	Hospitals having bed capacity ≤ 50	5 (KH, GH, GLSML, SH & CHC)

5.2.2.2 Characteristics/profile of Acrylic Industries

Two largest acrylic fiber producing industries of India were undertaken for study of Hazardous Waste (Management and Handling) practices. There are five acrylic fibers producing industries in India. Three of them are taken over by Reliance Industries. To analyse the hazardous waste management practices followed by Acrylic Industries, the primary data collected through questionnaire (Annexture II) based upon list of hazardous waste presents in schedule I and II of Hazardous Waste (Management and Handling) Rules, 2003.

The characteristics of Industries under study are:

i. **Indian Acrylics Limited (IAL), Sangrur (Punjab):** IAL is the largest acrylic fiber producing industry in India and is situated in Sangrur district of Punjab state with a fiber producing capacity of 40,000 TPA. The production capacity of this plant matched the international level capacity. The plant has more than 600 employees and is the only acrylic fiber producing industry of Punjab.

ii. **Pasupati Acrylon Limited (PAL), Thakurdwara (Uttar Pradesh):** PAL is the second largest acrylic fiber producing industry of India having about 525 employees. The capacity of fiber production is 30,000 TPA. This industry is situated at Thakurdwara, Muradabad district of Uttar Pradesh. This is the only acrylic fiber producing Industry of Uttar Pradesh.

These two industries differe in the rate of production of acrylic fiber and the number of employees.

5.3 Current Scenario of Biomedical/ Hazardous waste management in Punjab

Current scenario of biomedical (BMW)/ hazardous waste (HW) management is studied from the collected data. BMW management practices being adopted by Patiala city of Punjab and PGI MER, Chandigarh (U.T.) and HW management of acrylic industries of Punjab and Uttar Pradesh states of India are under taken for study.

5.3.1 Biomedical waste

In Punjab, BMW is treated and disposed off according to Biomedical Waste (Management and Handling) Rules, 1998 as amended in 2003. The responsibility to ensure the proper treatment and disposal of BMW by health care facilities (HCFs) rests with Punjab Pollution Control Board (PPCB), Patiala. During 2003 (PSCST, 2003), there were 220 hospitals, 1,482 dispensaries and 441 primary health centers in the state. Apart from these, there were 1,362 Veterinary Hospitals, and 25,362 medical institutions in the state (Table 5.2). Total numbers of HCFs were 2,760. HCFs with bed capacity ≥ 500, 200-500, 50 - 200 and ≤ 50 were 6, 12, 88, and 2403 respectively. There were 251 other institutions generating BMW. Almost 62 % of HCFs were violating the BMW (M&H) rules. Only 0.01% HCFs had possessed BMW treatment facilities while 38% HCFs had employed Common Bio medical waste treatment facility (CBMWTF).

With the ever growing population and the number of hospitals and other medical facilities, the problems of pollution from BMW are supposed to be increasing simultaneously but according to the data collected from PPCB, It has been observed that the total number of hospitals situated in Punjab decrease from 2,760 to 2,398 within five years (PPCB, 2003 - 2008) (Tables 5.2 - 5.3). This may due to problems faced by them in complying with Biomedical Waste (Management and Handling) Rules/ violation of Biomedical Waste (Management and Handling) Rules, resulting in the closer of some of the HCFs.

There are total 181 hospital/HCFs in Patiala district as on March, 2007 (PPCB, 2007). There being only one hospital having bed capacity of more than 500 beds viz., Govt. Rajendra Hospital (907 beds). There are 12 hospitals having bed capacity of 558 beds in category of HCFs having beds more than 50 but less than 200 beds. The hospital with less than 50 bed capacity are 155 having total bed capacity of 1810 beds. The 98 % hospitals of Patiala district supply their waste to CBMWTFs. Only 2 % hospitals have BMW treatment and disposal facilities. The rate of BMW generation in Patiala is 129 g bed^{-1} day^{-1} while rate of total BMW generation is 424.2 Kg day^{-1} (Table: 5.4).

In Punjab (PPCB, 2007), HCFs with bed capacity ≥ 500, 200-500, 50-200 and ≤ 50 are 5, 11, 98, and 1947 respectively. There are 321 other institutions generating BMW. 16% of HCFs numbering 372 violate the Biomedical Waste (Management and Handling) Rules. 70 % of hospitals in Punjab utilize CBMWTF for BMW treatment. There being 9 hospitals having BMW treatment and disposal facilities. Only 0.004% hospitals numbering 9 have BMW treatment and disposal facilities. Only 98% of the total BMW is treated daily (Table 5.5). The secondary data is collected from Central Pollution Control Bard (CPCB), New Delhi, Punjab Pollution Control Board (PPCB), Patiala and Punjab State Council of Science and Technology (PSCST), Chandigarh.

The analysis of secondary data showed that hospitals having less bed capacity produce more BMW bed^{-1} day^{-1} as compared to larger bed capacity hospitals (Fig. 5.2). 14% BMW bed^{-1} day^{-1} is produced by the hospitals having bed capacity more than 500 while hospitals having bed capacity less than 50 produce 37% BMW bed^{-1} day^{-1}. The quantities of BMW generated in various Districts/ Regions of Punjab (PSCST, 2003; PPCB, 2008) are shown in the bar diagram (Figs. 5.3 - 5.4). After the amendments of 2003 in Biomedical Waste (Management and Handling) Rules, there is a continuous reduction in the percentage of violators of these rules in subsequent years (Fig. 5.5). In 2003, 62.32 % HCFs violated these rules where as by march 2008, the percentage was greatly reduced to 3.67 % as a result of monitoring by PPCB as per rules.

Table: 5.2: Overview of health care facilities in Punjab for the year 2003 - 2005 according to BMW Management Rules

(**Source:** PSCST, 2003 and PPCB, 2004 - 2005)

HCFs under Schedule VI	Hospital with beds 500 and above			Hospital with beds 200 and above but less than 500			Hospital with beds 50 and above but less than 200			Hospital with beds less than 50			HCFs/ Institutions not included previously			Total		
	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005
No. hospitals	6	5	5	12	11	11	88	94	94	2403	1938	1884	251	228	225	2760	2276	2219
Total No. of beds	..	4059	4059	….	3184	3184	…	7024	7025	…	18983	19430	…	0	0	….	33250	33698
No. of hospital which are utilizing CBWTF / Private Agencies	0	2	2	3	9	9	22	81	86	977	1471	1517	44	61	66	1,046	1624	1680
No. of hospital which have BMW treatment & disposal facilities	….	3	3	…..	2	2	…	10	6	…	17	12	…	0	0	….	32	23
Total quantity of BMW generated & Treated (Kg/Day)	….	333.5	333.5	…..	351.8	372.3	…..	2147.3	1070.9	….	2407	2692	….	155	176	….	5394.6	4644.7
No. of Hospitals Violated BMW (M&H) rules	4	3	2	6	2	3	76	9	7	1417	419	310	217	161	177	1720	594	499

Table: 5.3: Overview of health care facilities in Punjab for the year 2006 - 2008 according to BMW Management Rules

(**Source:** PPCB, 2006 - 2008)

HCFs under Schedule VI	Hospital with beds 500 and above			Hospital with beds 200 and above but less than 500			Hospital with beds 50 and above but less than 200			Hospital with beds less than 50			HCFs/ Institutions not included previously			Total		
	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
No. hospitals	5	5	5	11	11	11	95	98	99	1906	1947	2005	321	321	278	2338	2382	2398
Total No. of beds	3869	3869	3869	3284	3284	3399	7245	7511	7600	19112	19322	19948	1000	0	0	34510	33986	34816
No. of hospital which are utilizing CBWTF / Private Agencies	4	4	5	9	11	11	91	97	98	1441	1711	1850	20	46	82	1565	1869	2046
No. of hospital which have BMW treatment & disposal facilities	1	1	0	1	0	0	6	7	1	149	0	4	7	0	0	164	9	5
Total quantity of BMW generated & Treated (Kg/Day)	338.15	338.15	338.15	427.3	415.8	386.15	1217.7	1261.9	1385.8	2335	4309.7	3266.5	159.5	158.21	131.12	4477.6	6483.8	5507.9
No. of Hospitals Violated BMW (M&H) rules	2	1	1	2	0	0	14	14	2	296	246	62	111	111	23	425	372	88

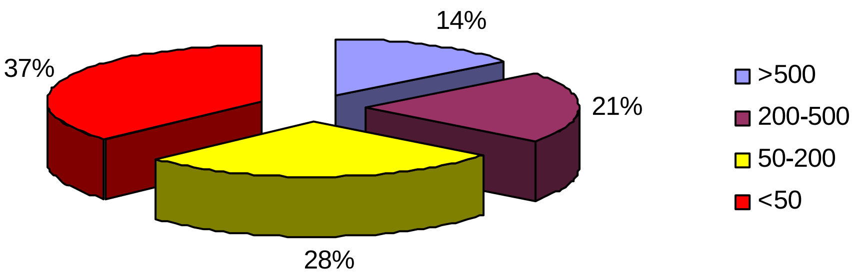

Fig. 5.2: Percentage of biomedical waste produced in Punjab based upon bed capacity (**Source:** PPCB, 2007)

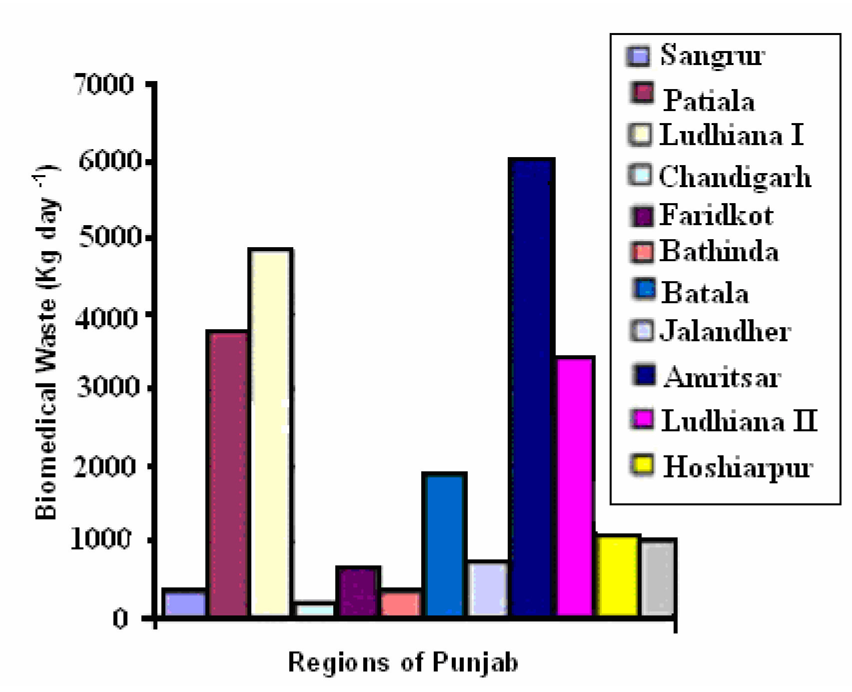

Fig. 5.3: Biomedical waste produced in various regions of Punjab and Chandigarh in 2003 (**Source:** PSCST, 2003)

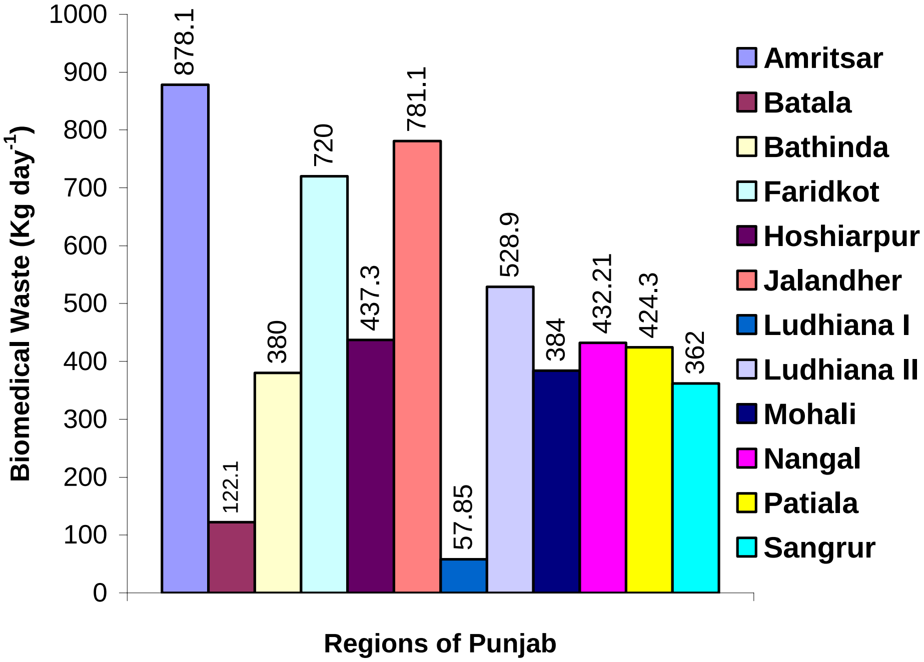

Fig. 5.4: Biomedical waste produced in various regions of Punjab in 2008 (**Source:** PPCB, 2008)

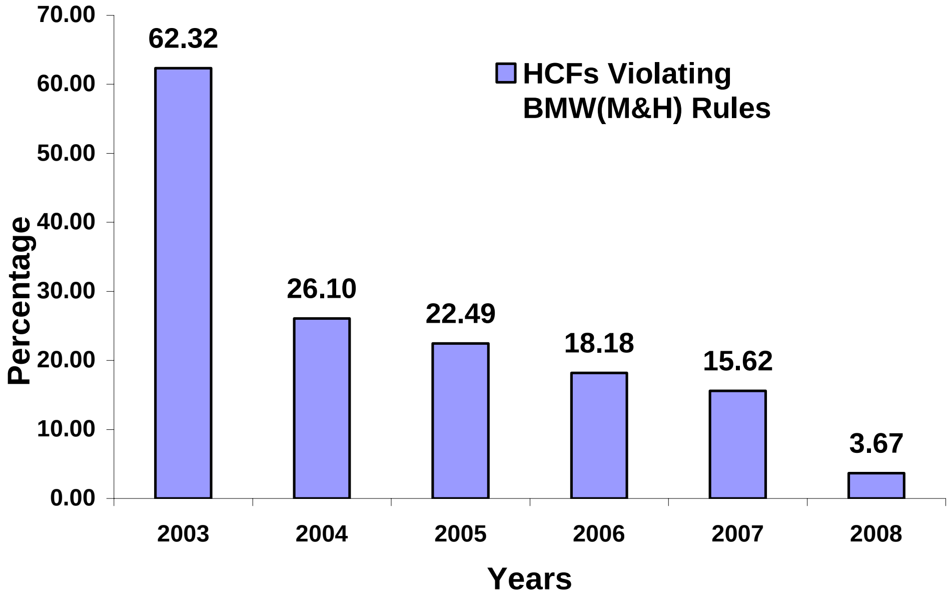

Fig. 5.5: Percentages of Health Care Facilities violating the Biomedical Waste (Management and Handling) Rules in Punjab (**Source:** PPCB, 2003 - 2008)

Table 5.4: Overview of biomedical waste management in health care facilities in Patiala district of Punjab (**Source:** PPCB, 2007)

Health Care Facilities (HCF) under Schedule VI	**Total No. of HCFs**	**Total No. of Beds**	**No. of CBMWTF /private agencies**	**No. of HCF which are utilizing CBMWTF/ private agencies**	**No. of HCF having BMW treatment & disposal facilities**	**Total quantity of BMW generated (Kg d^{-1})**	**Total quantity of BMW treated (Kg d^{-1})**	**No. of HCF violated BMW rules**
With 500 beds and above	1	907	….	1	….	80	80	….
With 200 beds and above but less than 500 beds	….	….	….	….	….	….	….	….
With 50 beds and above but less than 200 beds	12	558	….	12	….	102.9	102.9	….
With less than 50 beds	155	1810	….	151	4	201.4	201.4	1
All other institutions generating BMW above	13	….	….	13	Nil	40	40	….
CBMWTF	….	….	4	….	….	….	….	…
Total	**181**	**3275**	**4**	**177**	**4**	**424.2**	**424.3**	**1**

Table 5.5: Overview of biomedical waste management in health care facilities situated in Punjab (**Source:** PPCB, 2007)

Health Care Facilities (HCF) under Schedule VI	**Total No. of HCFs**	**Total No. of Beds**	**No. of CBMWTF/ private agencies**	**No. of HCF which are utilizing CBMWTF/ private agencies**	**No. of HCF having BMW treatment & disposal facilities**	**Incinerator (Double chamber)**	**Autoclave (a), Microwave (b), Hydroclave (c) & Shredder (d) [a, b, c & d]**	**Total quantity of BMW generated (Kg d^{-1})**	**Total quantity of BMW treated (Kg d^{-1})**	**No. of HCF violated BMW rules**	**Total No. of say cause notices issued to defaulters**
With 500 beds and above	5	3869	0	4	1	0	0, 0, 0 & 0	338.15	338.15	1	1
With 200 beds and above but less than 500 beds	11	3284	0	11	0	0	0, 0, 0 & 0	415.8	415.8	0	0
With 50 beds and above but less than 200 beds	98	7511	0	97	1	1	1, 0, 0 & 0	1261.9	1261.9	14	7
With less than 50 beds	1947	19322	0	1711	7	0	1, 1, 0 & 0	4309.7	4298.7	246	245
All other institutions generating BMW not included above	321	0	0	46	0	0	0, 0, 0 & 0	158.21	53.21	111	125
CBMWTF	0	0	4	0	0	4	4, 0, 0 & 4	0	0	0	0
Total	**2382**	**33986**	**4**	**1869**	**9**	**5**	**6, 1, 0 & 4**	**6483.76**	**6367.76**	**372**	**378**

PGI MER - Chandigarh is the second largest hospital of North region having bed capacity of ~1400 and produces BMW 1400-1600 Kg day^{-1}. It generates the largest amount of BMW (1.06 kg bed^{-1}day^{-1}). The PGI MER has its own incinerator for treatment of incinerable waste of PGI Chandigarh which also caters to 319 other medical establishments in Chandigarh. Non-incinerable waste is treated in a CBMWTF of U.T., viz., M/s Alliance Envirocare Company Pvt. Ltd., Chandigarh.

Common BMW Treatment Facilities. In Punjab, many hospitals (78%) hand over the BMW to CBMWTF (PPCB, 2007). Presently there are four CBMWTF in Punjab and one in Chandigarh. All these facilities have installed double chambered incinerator with air pollution control devices (APCDs), autoclave, shredders and effluent treatment plant. Out of four facilities three have adopted conveyer waste feeding system while one situated at Mohali district of Punjab is using mechanical batch lifting process for waste feeding. These four CBMWTF of Punjab (Table 5.6) are:

A. SembRamky Environmental Management Pvt. Ltd., Ludhiana.
B. Rainbow Environments (A Unit of Raidical Builders India Pvt. Ltd. Mohali.
C. Bio-Medical Waste Treatment Plant Pvt. Ltd. Village- Pangoli, Pathankot.
D. Amritsar Health Care Systems, Village- Ibban kalan, Chabhal Road, Amritsar.

SembRamky Environmental management Pvt. Ltd. Ludhiana collects BMW from 55% hospital situated in Punjab. Nearly 2000 - 2300 kg BMW is collected and treated by the facility daily (CPCB, 2007). In 2006, Central Pollution Control Board Zonal Office, Lucknow has monitored the CBMWTFs of Punjab and Chandigarh, and suggested that segregation of BMW needed to be done in different hospitals and maintenance of records of BMW areas needed improvement (CPCB, 2006a).

Table: 5.6: Common biomedical waste treatment facilities in Punjab and Chandigarh (**Source**: CPCB, 2007)

S. No.	Name & address of facility	Equipment installed & their capacity	No of medical establishment connected	No. of Beds covered	Total quantity of waste treated (Kg d^{-1})
	Punjab :				
1.	SembRamky Environmental Management Pvt. Ltd., Ludhiana	Incinerator 200 Kg h^{-1} Autoclave 500 L per batch Shredder (2) 400&50 Kg h^{-1}	1374	24461	2000-2300
2.	Rainbow Environments (A Unit of Raidical Builders India Pvt.Ltd.Mohali	Incinerator 65 Kg h^{-1} Autoclave 50 kg per batch Shredder (2) 25&50 Kg h^{-1}	475	4320	600-800
3.	Bio-Medical Waste Treatment Plant Pvt. Ltd. Village-Pangoli, Pathankot.	Incinerator 200 Kg h^{-1} Autoclave 75 kg per batch Shredder 100 Kg h^{-1}	171	1780	150
4.	Amritsar Health Care Systems, Village- Ibban kalan, Chabhal Road, Amritsar	Incinerator 100 Kg h^{-1} Autoclave 150kg per batch Shredder (3) 100, 50&50 Kg h^{-1}	300	3700	450-500
	Total		2320	34261	3750
	Chandigarh:				
1.	PGI-Chandigarh	Incinerator (2) 200 Kg h^{-1}	319 (+PGI)	1402	650
2.	Alliance Envirocare Company Pvt. Ltd. Plot no. 181/10, Industrial Area, Phase-1, Chandigarh.	PGI Incinerator is used. Autoclave: 40 kg per batch. Shredder: 15 Kg h^{-1}	319	649	150 kg d^{-1}

All CBMWTFs have APCDs except Alliance Envirocare (as only non incinerable part is treated)

5.3.2 Hazardous Waste

During 1999, hazardous waste (HW) generated in the country per annum was estimated to be around 4.4 million tones (EISC, 2007). Out of this, 38.3% is recyclable, 4.3% is incinerable and the remaining 57.4% was disposable in secured landfills. Twelve States of the India viz., Maharashtra, Gujarat, Tamil Nadu, Orissa, Madhya Pradesh, Assam, Uttar Pradesh, West Bengal, Kerala, Andhra Pradesh, Karnataka and Rajasthan; accounted for 97% of total hazardous waste generation. The top four HW generating states were Maharashtra, Gujarat, Andhra Pradesh and Tamil Nadu. In 2006 (CPCB, 2006b), the HW generation rate increases to 8.3 million tones per annum (Table 5.7). In India, Punjab and Uttar Pradesh states contributed 0.9% and 1.4% of the total HW generated in country whereas Rajasthan was found to be highest generator of 43% HW.

HW needs to be treated and disposed off according to Hazardous Waste (Management and Handling) rules, 1989 as amended in 2003. The responsibility rests with Central Pollution Control Board and State Pollution Control Boards to identify the HW generating units and ensure the proper treatment and disposal of HW generated by them. With the ever growing population and the number of industries, the problems of pollution from HW are also supposed to be increasing simultaneously. In Punjab, there were 700 hazardous waste generating units by the year 2000 which were generating HW of 22,745 TPA. On the basis of all India average, only 0.5 % HW is generated in Punjab up to 2000. It was estimated that HW generated by the industries in Punjab was about 36,000 TPA, out of which Ludhiana had alone contributed 40 % (iGovernment, 2007). During 2004, numbers of HW generating industries in Punjab were 1448 which increases to 3023 in four years (PPCB, 2004 - 2008) indicating that HW producing industries became double in four years. The production of HW becomes almost seven times during this period. In 2007, 2628 industries produced HW of 1,24,675 TPA. Out of this, 12,574 TPA waste was storable, 96,992 TPA was recyclable while 15,109 TPA waste was incinerable. After 2006, about 15000 TPA of incinerable hazardous waste is generated in each subsequent year till 2008. The details of HW produced are given in Table 5.8. District wise rate of HW generation in Punjab for the year 2006 is given in Table 5.9. There are fourteen incinerators in Punjab for treatment of HW. The storable HW is packed in high density polythene cans and stored in reinforce cement concrete lined HW storage pits.

Table 5.7: Amount of hazardous waste generated in various States/ Union Territory of India during 2006 (**Source:** CPCB, 2006c)

S. No	State/ UT	Quantity in TPA
1	Andhra Pradesh	495985
2	Arunachal Pradesh	0
3	Assam	16038
4	Bihar	3967
5	Chhattisgarh	73001
6	Delhi	18600
7	Goa	10274
8	Gujarat	1276027
9	Haryana	19240
10	Himachal Pradesh	33517
11	Jammu & Kashmir	41353
12	Jharkhand	181227
13	Karnataka	71625
14	Kerala	88794
15	Madhya Pradesh	121537
16	Maharashtra	1407480
17	Manipur	0
18	Mizoram	0
19	Meghalaya	29493
20	Nagaland	11
21	Orissa	83915
22	Punjab	78931
23	Rajasthan	3557323
24	Sikkim	0
25	Tamilnadu	190924
26	Tripura	264
27	Uttaranchal	7759
28	Uttar Pradesh	117572
29	West Bengal	236000
30	Andaman & Nicobar	0
31	Chandigarh	836
32	Daman, Diu, D & NH	30862
33	Lakshadweep	0
34	Pondicherry	34768
	Total	**82,27,323**

Table 5.8: Amount of hazardous waste generated in Punjab

(**Source:** PPCB, 2004 - 2008)

Year	No. of Industries	Hazardous waste generated (in TPA)			
		Storable	Recyclable	Incinerable	Total
2004	1448	…..	….	….	17017.89*
2005	1448	…..	….	….	18772*
2006	2290	22932	41293	14706	78931
2007	2628	12574	96992	15109	124675
2008	3023	13601.08	89480.54	14831.48	117913.1

* Quantity of hazardous waste as per Hazardous Waste (Management and Handling) rules, 1989 and as amended in 2000

Table 5.9: Hazardous Waste generation in various districts of Punjab
(**Source:** PPCB, 2006)

S.No.	District	Quantity of hazardous waste generated in TPA			
		Storable	Recyclable	Incinerable	Total
1	Amritsar	213	833	0	1046
2	Bathinda	101	131	0	232
3	Mansa	2	50	0	52
4	Mukatsar	59	13	0	72
5	Gurdaspur	18	554	0	572
6	Ropar	14	159	0	173
7	Mohali	8337	13393	14495	36225
8	Faridkot	22	159	0	181
9	Moga	2	83	0	85
10	Ferozepur	43	106	0	149
11	Hoshiarpur	923	3666	65	4654
12	Nawanshahar	5206	2295	90	7591
13	Jalandhar	1486	116	0	1602
14	Kupurthala	557	2	0	559
15	Ludhiana	4335	6407	35	10777
16	Sangrur	552	13106	9	13667
17	Patiala	521	204	12	737
18	Fatehgarh	541	16	0	557
	Total	**22932**	**41293**	**14706**	**78931**

5.4 Findings based upon Primary Data

The primary data information is based upon the questionaire designed for eliciting information about biomedical/ hazardous waste management practices. The secondary data is obtained on the basis of published annual reports/ Pollution Control Boards. The collected data through quentionares is compared with secondry data collected from pollution control boards to know the emerging sanerio of waste management and problems faced by them in complying with environmental regulations. The higher authorities of Army Hospital, Patiala were also requested to provide the primary data but request application to provide data was not entertained. However, *the army hospitals* do not come under State Pollution Control Boards but under CPCB.

5.4.1 Biomedical waste

As BMW is of special environmental concern so its generation, segregation, transportation, treatment, disposal methods are evaluated along with overall expenditure over BMW management (Table 5.10).

5.4.1.1 Waste Generation, Segregation and Transportation

The generation rate of hospital waste is the fundamental information for evaluating and designing the disposal system of hospital waste. The survey conducted on nine hospitals situated in Patiala city and another PGI MER – Chandigarh, to determine the BMW management and handling practices followed by them. The primary data is collected from ten hospitals along with one CBMTF (SembRamky Environmental management Pvt. Ltd., Ludhiana) through questionnaire.

The occupancy rate of PGI, GRH and MKH is always 90 - 120 %. The numbers of patient in summer season are more than winter season. The data was collected from the PGI-MER, GRH, MKH, AH, DCW, KH, GHMH, GLSMH, SH and CHC hospitals, having the bed capacity of ~ 1412, ~907, 154, 55, 50, 30, 25, 19, 15 and 10 respectively. These hospitals generate the BMW approximately 1500, 800, 20, 6, 6, 0.75, 0.5, 0.5, 0.5 and 0.5 kg day^{-1}. PGI MER, GRH and GH have more than eleven patient treatment wards. Only KH does not entertain the outdoor patient.

Table: 5.10: Overview of Hospital waste management practices (Based upon primary data)

S.N.	Name of Hospital	PGI MER, Chandigarh	GRH, Patiala	MKH, Patiala	AH, Patiala	DCWH, Patiala	KH, Patiala	GH, Patiala	GLSMH, Patiala	SH, Patiala	CHCMT, Patiala	SEMPL Ludhiana
1	**No. of Patient Treatment wards** **XX […..]**	11[0]	11[0]	7[Pathology, pharmacology, Therapeutics & ENT]	8 [Therapeutics, CC & ENT]	9[ENT & RI]	10 [Pharmacology]	11[0]	7[Pathology, Theraptcs, RI & MB]	6[Patho, Gynea, Maternity, CC & MB]	9[ENT & MB]	….
2	**No. of Beds**	~ 1412	907	154	55	50	30	25	19	15	10	…
3	**Outdoor Patient per day**	~ 4000	1700-1800	400-500	150-300	~500	N.A.	~20	~14	10-20	170-180	….
4	**Waste generation rate per day**	2100-2400 Kg	100 Kg	30 Kg	10-15 Kg	10-50 Kg	2-5 Kg	~5 Kg	2-5 Kg	1-2 Kg	2-5 Kg	…..
5	**Biomedical waste generation/collection rate per day**	1400-1600 Kg	> 80 Kg	~ 20 Kg	5-7 Kg	5-10 Kg	500g-1 Kg	~500g	0-500 g	5 Kg	0-500 g	> 150 Kg
6	**Segregation of BMW with colour bags**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	**No. of employees for Segregation/treatment**	8	Done by Staff	2	10-12	0-5	1	0-5	1	0-5	0-5	> 100
8	**BMW collected by central vehicles**	No	Yes, supplied to SEBRAMKY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	**No. of vehicles for collection & transport of BMW**	-	1 for Patiala city	1	1	1	1	1	1	1	1	25
10	**Disposal of BMW at premises of Hospital/ facility**	Yes	No	No	No	No	No	No	No	No	No	Yes
11	**Techniques for BMW treatment**	Chemical (hypo), Incineration & Landfilling (sharps)	Autoclaving & chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Incineration	Chemical	Autoclaving, chemical, incineration & landfilling

XX[….] = No. of wards present in hospital [Non existing wards from the list in questionnaire (Annexure I)]

Table: 5.10: Overview of Hospital waste management practices (Based upon primary data)

S.N.	**Name of Hospital**	**PGI MER, Chandigarh**	**GRH, Patiala**	**MKH, Patiala**	**AH, Patiala**	**DCWH, Patiala**	**KH, Patiala**	**GH, Patiala**	**GLSMH, Patiala**	**SH, Patiala**	**CHCMT, Patiala**	**SEMPL Ludhiana**
12	**i. Human anatomical Waste**	Incineration	√	√	√	√	√	√	√	√	X	Incineration
	ii. Animal waste	Incineration	X	X	X	√	X	X	X	X	X	Incineration
	iii. Microbiology & Biotechnology Waste	Incineration	X	√	√	√	√	X	X	X	X	Incineration
	iv. Waste sharps	Deep burial, chemical & Mutilation	√	√	√	√	√	√	√	√	√	Deep burial, autoclaving & chemical
	v. Discarded medicines	X	X	X	√	X	X	√	X	√	X	Incineration
	vi. Soiled waste	Incineration, DB, chem., muti & shred	√	√	√	√	√	√	√	√	√	Incineration
	vii. Solid waste	Incineration, chemical & shredding	√	√	√	√	√	√	√	√	√	Chemical & autoclaving
	viii. Liquid waste	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Not available
	ix. Incineration Ash	Deep burial	X	X	X	X	X	X	X	X	X	Deep burial
	x. Chemical waste	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	X	Chemical	X	Chemical	Not available
13	**Poster Displayed for public awareness**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
14	**Whether Govt. provides funds for waste treatment**	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	No.
15	**Annual expenditure on waste treatment (Rs.)**	6 corers	2 Lacs	72,000	3,600	1,900	5,000	7,200	10,000	4,000	12,000	240 lacs

X = Not generated; √ = Supplied to CBMWTF

Note: Data compiled on the basis of questionnaires administrated to hospitals in Patiala city, PGI - MER, Chandigarh and a CBMWTF

The results of data collected are compared with the data available from CPCB, PPCB and PSCST. It has been observed that the rate of BMW generation per bed per day is more in larger hospitals as compared to smaller ones. The rate of BMW generation for these hospitals was 1062.32, 1066.67, 129.87, 109.09, 120.00, 25.00, 20.00, 26.32, 33.33 and 50.00 g day^{-1} bed^{-1} respectively. Category wise rate of BMW generation is given in Table 5.11.

Table: 5.11: Category wise rate of biomedical waste generation in 2007

Category of Hospital		**BMW from Primary Data (g bed^{-1} day^{-1})**	**BMW Data from PPCB for Punjab (g bed^{-1} day^{-1})**	**BMW Data from PPCB for Patiala (g bed^{-1} day^{-1})**
	GRH, Patiala	88	---	88
A	PGI (UT)	1060	---	---
	Punjab	---	87	---
B		130	168	184
C		80	223	111

Govt. Rajendra hospital, Patiala is the largest generator of BMW and generates 23 % of total BMW produced in district. On an average about 45% of the total waste produced in hospitals is BMW. Segregation process of BMW with color bags is followed by all hospitals. The number of employees engaged with segregation process vary from 1-12. Only in GRH, the segregation process is done on spot under the supervision of Doctors and Nurses, and eight persons are kept for transportation of BMW up to central collecting vehicle. All hospitals of Patiala district supply their waste to CBMWTF (SEMPL, Ludhiana) except PGI Chandigarh (which have own incinerator). There is one vehicle available to collect the BMW from Patiala city. SEMPL, Ludhiana is having 25 vehicles for collecting the waste from different regions of Punjab.

5.4.1.2 Treatment, Disposal and Expenditure

For treatment and disposal of BMW (except liquid and chemical waste) all hospitals of Patiala city under study supply their waste to CBMWTF. PGI-MER has its own treatment facility. The treatment facilities given by CBMWTF and PGI MER to BMW are given in Table 5.12. Chemical waste and liquid waste are treated by hospitals themselves. Fewer posters were displayed for public awareness by all hospitals while BMW dealing containers were labeled with bio-hazardous and cytotoxic symbols.

Table 5.12: Facilities available with CBMWTF and PGI MER

BMWTFs	Incinerator	APCDs	Autoclave	Shredder	No. of establishment connected	No. of Beds covered	Total quantity of waste treated
SEMPL, Ludhiana	200 kg h^{-1}	WS & VS	500 L $batch^{-1}$	400 & 50 kg h^{-1}	1374	24461	2000-2300 kg day^{-1}
PGI-MER, Chandigarh	200 kg h^{-1}	VS	No	200 kg h^{-1}	319	1402	650 kg day^{-1}

VS - Ventury Scrubber *WS - Wet Scrubber*
APCDs - Air Pollution Control Devices

Final disposal provided by CBMWTF/ PGI MER to the yellow bag waste is incineration followed by deep burial of ash inside the municipal landfill. GRH and PGI MER too have incinerators but the incinerator of Rajendra hospital, Patiala was not in working condition due to lack of funds and trained staff since 2002. Both the incinerators (of CBMWTF and PGI MER) are starved air incinerators. The incineration capacity of incinerator of PGI is > 100-150 kg h^{-1} and trained operators were kept to operate incinerators. The analysis for emission gases CO_x, NO_x and SO_x is being done routinely. PAHs/ PCDD/Fs and Hg in emission gases of incinerators are not analyzed by PGI and CBMWTFs as segregated waste (Hg contamination free) is being treated. Heavy metals in ash are monitored monthly by both waste treatment facilities. APCDs are used in the incinerators of PGI (VS) as well as of CBMWTF (VS and WS). These facilities also provide treatments to the waste water produced after cleaning the APCDs. No facility is recovering the energy from waste incineration. Combustion efficiency of all incinerators reported by them is 99%. Stack heights are of 30 meters as per requirements. The incinerators of CBMWTF/ PGI MER and emission standards for the incinerators are listed in Table 5.13.

Table 5.13: Comparison of Incineration systems of PGI and CBMWTF

Incineration Parameters	**PGI MER**	**CBMWTF**
Type of Incinerator	Starved	Starved
Capacity of Incinerator (Kg h^{-1})	200	200
Analysis of CO_x, NO_x & SO_x	Once in week	Once in week
Analysis of PAHs/Dioxin	No	No
Analysis of Heavy metals in ash	Yes (Monthly)	Yes (Monthly)
Analysis of Hg Emission	No	Yes
Use of APCDs	VS	VS & WS
Treatment provided to residue/water from APCDs	Deep burial	Deep burial
Energy recovery from Incinerator	No	No
Combustion efficiency (%)	99.99	99.99
Stack height (meter)	30	30
Treatments and disposal options given to BMW	Chemical (hypo), incineration, recycling & land filling	Autoclaving, chemical, incineration, recycling & land filling

For Government hospitals funds are provided by State Governments to treat and dispose off the biomedical waste. The per annum expenditure over biomedical waste management for PGI-MER, GRH, MKH, AH, DCW, KH, GHMH, GLSMH, SH, CHC and CBMWTF is approximately Rs. 6,00,00,000/-, 2,00,000/-, 72,000/-, 3,600/-, 1,900/-, 5,0000-, 7,200/-, 10,000/-, 4000/-, 12,000/- and 2,40,00,000/- respectively. All the BMW from Patiala city is collected by SembRamky Environmental management Pvt. Ltd. Ludhiana except Army Hospital, Patiala (as they have their own incinerator). Average expenditure is Rs. 56.61 bed^{-1} day^{-1} for all hospitals under study. The daily expenditure over BMW in PGI MER was found to be Rs. 106.72 bed^{-1} day^{-1}. The per annum expenditure for hospitals of Patiala city was found to be Rs. 118.

Since, PGI MER is functioning under the Ministry of Health and Family Welfare, Government of India, so there is no scarcity of funds while in case of GRH even after having incinerator in the premises, they used to supply their waste to CBMWTF due to supply of less funds by Punjab State Government on BMW management. Since the rate of BMW generation in smaller hospitals is quite less, so they prefer to supply their waste to CBMWTFs instead of having their own incinerators. Comparison of BMW from primary and secondary data is given in Table 5.14.

Table 5.14: Comparison of hospital waste management practices followed by health care facilities in 2007

Parameters	**Punjab***	**Patiala***	**Hospitals Studied@**
No. of Hospitals	2061	168	10
No. of HCFs	2382	181	10
BMW generated (in Kg day^{-1})	6483.76	424.3	1620.25
BMW treated (%age)	98	100	100
HCFs violates rules (%age)	16	0.5	0
HCFs utilizes CBMWTFs (%age)	78	98	90
HCFs having treatment facilities (%age)	0.4	2.2	10
HCFs neither utilizes CBMWTFs nor have treatment facilities (%age)	22	0	0
BMW (g bed^{-1} day^{-1})	186	117	610

* Data from PPCB @9 from Patiala city & 1 from Chandigarh

5.4.2 Hazardous Waste

As hazardous waste is also of special environmental concern so its generation and disposal methods are evaluated. In Punjab, the numbers of hazardous waste producing industries are 3023 which daily generate HW in the range of approximately 323 ton. Out of this 37 ton waste is disposable; 245 ton is recyclable while 41 ton waste is incinerable (PPCB, 2008). There were five acrylic fibers producing Industries in India but most of them were overtaken by Reliance Industries. Indian Acrylics Ltd. (IAL) is the only acrylic fiber producing industry in Punjab while Pasupati Acrylon Ltd. (PAL) is also only acrylic fiber producing industry of Uttar Pradesh.

According to the data collected from PAL, it was strongly shown that no HW is generated in their industry but at the same time it was admitted that waste categories 1.9, 5.1, 26.2, 33.3, 35.1 were produced (Table 5.15) and are being sent to M/s Bharat

Oil Ltd. for incineration in their incinerator located at Sahibabad having modern sophisticated incinerator facility duly registered and authorized by Uttar Pradesh Pollution Control Board for incineration of industrial waste. Industrial waste like ETP sludge, used oil and butyl rubber hand gloves etc. are being sent for incineration. Regarding general waste, paper produced 2 kg day^{-1}. Liquid waste generated in the form of effluent ~ 1000 m^3 day^{-1}. Segregation practices are followed by industry before supplying the waste for incineration. Boiler ash is being disposed properly. In IAL HW of category 1.9, 5.1, 26.2, 33.3, 34.2, 35.1 and 36.2 are produced. The comparision of primary data and secondary data is shown in Table 5.15. It has been observed that the contribution of IAL, Sangrur (Punjab) and PAL, Muradabad (Uttar Pradesh) towards the generation of total HW in respective states is only 0.2 and 0.1 % respectively.

During the collection of data IAL claimed that no ash contents/ fly gas cleaning residue (Categary 36.2) generated form HW incineration. However workers have told on condition of anonymity that HW is burnt for heating of boilers. The PPCB data signify the ash contents from incineration. So there is discrpency in data collected from IAL, and PPCB. Various industries are needed to find out factual position regarding the mentainance and upkeepment of incinerator in industries.

5.5 Problems faced by waste generators/ during collection of data

All the generators of waste considered it their ethical responsibility to provide healthy environment to the present and future generations, rather they are happy that particular route is provided to treat the particular category of waste in environmental friendly manner. Upkeep of incinerator is very costly. State Govt does not provide well trained operating staff in medium/larger hospitals for segregation of biomedical waste, thereby putting extra burden on doctors and nurses to supervise the segregation. The industries do take care of segregation of hazardous waste. However, the burden of waste generators has been reduced by provisions contained in the rules to supply the waste to common treatment facilities thereby hospitals/acrylic industries sends their waste to common treatment facility. During collection of data there was difficulty in convincing the officials to provide the information regarding biomedical/ hazardous waste management. Industries do not allow visiting to the incinerator site.

Table 5.15: Comparison of primary and secondary data obtained from PPCB for IAL and PAL

Category No.	**Category**	**Amount of HW in IAL (PPCB, 2007)**	**Amount of HW in IAL (Primary Data)**	**Amount of HW in PAL (UPPCB, 2007)**	**Amount of HW in PAL (Primary Data)**
1.9	ETP sludge containing hazardous constituents	4.9 TPA	Max. 0.584 TPA	0.73 TPA	0.73 TPA
5.1	Used/spent oil	3.8 TPA	Max. 8.03 TPA	0.73 TPA	0.025 TPA
26.2	Chemical sludge from waste water treatment	146 TPA	Max. 146 TPA	131.4 TPA	~ 131.4 TPA
33.3	Discarded containers / barrels / liners used for hazardous wastes/ chemicals	1500-2000 Month^{-1}	1500-2000 Month^{-1}	1200-1700 Month^{-1}	1200-1700 Month^{-1}
34.2	Toxic metal-containing residue from used-ion exchange material in water purification	1 TPA[*]	1 TPA[*]	….	….
35.1	Filters and filter material which have organic liquids in them, e.g. mineral oil, synthetic oil and organic chlorine compounds	….	8.03 TPA	4.75 TPA	4.75 TPA
36.2	Ash from incineration of hazardous waste, flue gas cleaning residues	0.54 TPA	Not generated[$]	Not Produced	Not Produced
	Total Hazardous Waste (in TPA)	**156[#]**	**163[#]**	**137.61[#]**	**136.9[#]**

[*] Assuming 1 L = 1 Kg

[#] Excluding categary No. 33.3

[$] Industry claimed that this HW is not generated but PPCB report indicates its generation

5.6 Suggestions

Any method used for waste management needs: To appoint a well knowledged staff for segregation, collection, transport, treatment and proper disposal of biomedical/ hazardous waste.

- In the event of non supply of biomedical waste to common biomedical waste treatment facility, their should be a provision to have sanitized and secured temporary storage areas in premises of hospitals where waste can be stored to 12 - 24 hrs.

- To store waste at site, waste should be stored category wise in specific bins (colored containers according to the Biomedical Waste (Management and Handling) Rules, 2003).
- For the packaging phase, purchase should be of good quality storage bags/ containers that can provide impermeability and resistance to perforation, and also be easy to handle and clean.
- All bags should be labeled with the name of the department where they are produced, as well as the collection date. The biological hazard symbol must be printed on bags used to collect infectious or other hazardous wastes.
- Protective clothes should be provided to waste collectors for safety measures.
- Recycling of non-hazardous waste by separating the waste into organic and inorganic factors, selling the inorganic waste and making composite from organic waste can also be practised.
- The non-biodegradable waste like mutilated bottles, glass should be segregated and further recycled/ resold which may lead to optimum utilisation of resources.
- Infectious, pathological and incinerable hazardous waste should be feed into incinerator after achieving the temperature of more than 800ºC for primary chamber.
- Regular monitoring of emission gases and ash contents from incinerator should also be practised.
- Incinerator operator should be well trained.

- Indian Ministry of Environment and Forests should specify PAHs emissions standard limit after getting the flue gases of incinerators to be analysed by independent agency for PAHs emissions as to that of for dioxins from biomedical/ hazardous waste incineration.
- In those cases where treatment is given to the patient in his or her own house when the hospitalization is not possible, the ‘domestic BMW’ is generated. Such a biomedical waste should be carefully handled and needed to be managed according to biomedical waste management rules.
- Incineration processes should be encouraged to recover energy from them, wherever possible.

These above said suggestion can be efficient to reduce the burden of waste over incinerators which in turn will reduce the emissions of persistent pollutant to environment.

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Chapter -VI

Summary

Natural and anthropogenic sources results into organic and inorganic emissions into the environment. Organic emissions like PAHs, PCDD/Fs, PCB occur during combustion processes and are of special environmental concern. US EPA has classified 16 PAHs as priority pollutants, some of these have been declared as human probable and possible carcinogenic by IARC. Although published reports on incineration showed the effect of combustion variable (temperature, airflow rate, excess of oxygen etc.) on PAHs emissions from various samples (PVC, PS, PE, coal etc.) in laboratory scale studies. There is lack of studies on real world samples. Thus it was worth while apparent that to study the PAHs emissions from waste incineration and study the management aspect of biomedical/ hazardous waste.

Our laboratory scale incineration of two samples of each, biomedical waste (blood contaminated blood bag, blood contaminated cotton) and hazardous waste (acrylic waste solution, cellulose waste filters) indicated that there is no definite trend on PAHs distribution as a function of temperature and airflow rate. Two-ring (Nap), and three-ring (Acp, AcPy, Flu, PA, Ant) compounds contributes more to the total amount of 16 PAHs. The total emissions and PAHs emissions are greatly influenced by varying the combustion parameters like temperature and airflow rate. The amount of total emissions increases with increase in airflow rate (1-4 L Min^{-1}) at 700 and 800°C while it decreases with increase in airflow rate at 900 and 1000°C for the samples studied.

Incineration of blood contaminated blood bag showed the presence of 9-10 PAHs at different temperatures and airflow rates. The minimum amount of total PAHs was found at 1000°C with airflow rate of 4 L Min^{-1} (5085.65 µg g^{-1}) which was 1/4th the amount at 700°C with same airflow rate of 4 L Min^{-1}. The amount of 2A and 2B PAHs were found to be lesser at 900°C and 700°C respectively at all airflow rates while lower values of sum of total 2A and 2B PAHs were at 700ºC or between 900-1000ºC with air flow rate of 1-4 L min^{-1}.

Incineration of blood contaminated cotton showed the presence of 8-11 PAHs at different temperatures and airflow rates. The minimum amount of total PAHs was found at 900°C with airflow rate of 4 L Min^{-1} (646.96 µg g^{-1}) which was 1/3rd the amount at 700°C with the same airflow rate. The amount of 2A PAHs were found to be lowest at 900°C with airflow rate of 4 L Min^{-1} while lesser amount of 2B PAHs were observed at 900 and 1000°C at all airflow rates. However, the lower values of sum total of 2A and 2B PAHs were at 700-800ºC with airflow rate of 1-4 L min^{-1}.

Incineration of Acrylic waste solution showed the presence of 12-16 PAHs at different temperatures and airflow rates. The minimum amount of total PAHs was found at 700°C with airflow rate of 1 L Min^{-1} (739.48 µg g^{-1}) which was 1/8th the amount at 900°C with an airflow rate of 1 L Min^{-1}. The lesser amount of 2A PAHs were found at 700°C with all airflow rates while less amount of 2B PAHs was found at 700°C (with airflow rate of 1-2 L Min^{-1}), 800°C and 1000°C (with airflow rate of 2-4 L Min^{-1}). The sum of total of 2A and 2B PAHs were found to be lowest at 700-900ºC with airflow rate of 2-4 Lmin^{-1}.

Incineration of Cellulose waste filters showed the presence of 13-16 PAHs at different temperatures and airflow rates. The minimum amount of total PAHs was found at 700°C with airflow rate of 1 L Min^{-1} (268 μg g^{-1}) which was 1/13th the amount at 1000°C with an airflow rate of 4 L Min^{-1}. The lesser amount of 2A PAHs was found at 700-1000°C with all airflow rates while for less amount of 2B PAHs was found at 700°C and 800°C (with airflow rate of 1-2 L Min^{-1}), 900°C (with airflow rate of 1-3 L Min^{-1}) and 1000°C (airflow rate of 3 L Min^{-1}). However, the sum of total 2A and 2B PAHs were found to be less at 700-900ºC with airflow rate of 1-2 L min^{-1}.

Since most of incineration processes lead to PAHs emissions, it is necessary to minimise the waste generation by studying the management aspect of biomedical/ hazardous waste. Increase in number of health care facilities/ industries resulted in the generation of large quantities of biomedical/ hazardous waste which need to be managed effectively in an environment friendly manner. Incineration is considered to be best available technology to render these wastes less toxic. During incineration, emissions do contain PAHs/ PCDD/Fs. Keeping in view the health of the society, Governments of various countries made legislations by specifying the standards of various pollutants so as to manage their level in air, water and soil.

In India, Ministry of Environment and Forests made Biomedical/ Hazardous Waste (Management & Handling) Rules to manage biomedical/ hazardous waste and to lower the pollutant emissions from incineration of theses waste into environment. In past decades, efforts have been made to better manage the waste produced from hospitals and industries. About 4.4% of hazardous waste generated in the country has incineration potential. Laboratory scales studies have shown that PAHs are emitted from incineration of biomedical waste as well as from industrial waste. However in India, Waste (Management & Handling) Rules are silent about PAHs emissions from combustion processes.

Based on the observations made during the study of ten hospitals, common biomedical waste treatment facility and two acrylic fiber producing industries, the biomedical/ hazardous waste management practices adopted by hospitals and industries are effective and efficient. Health care staff is involved in the identification and segregation of waste and is adhering to the guidelines imposed by Ministry of Environment and Forests. In Punjab, about 15% of the total waste produced in hospitals is biomedical waste and its average rate of generation was found to be 88, 161, 414 g bed^{-1} day^{-1} for the hospitals of Punjab having bed capacity ≥ 500, 50-200 and ≤ 50 beds. SembRamky Environmental management Pvt. Ltd., Ludhiana is a common biomedical waste treatment facility which collects biomedical waste from almost 55% hospitals of Punjab and treat about 2000-2300 Kg of biomedical waste per day. Biomedical waste from all health care facilities of Patiala is also collected by common biomedical waste treatment facility.

In India, the hazardous waste generation rate was 8.3 MTA during 2006 from 29,716 hazardous waste generating industries. Punjab and Uttar Pradesh states of India contribute 0.9 and 1.4% of the total hazardous waste generated respectively in the country. Indian Acrylics Ltd., Sangrur is the only acrylic fiber producing industry in Punjab having highest production rate in India. Pasupati Acrylon Ltd., Muradabad is also only and second highest acrylic fiber producing industry of India in Uttar

Pradesh State. Both industries were found to comply with Hazardous Waste (Management & Handling) Rules. It has been found that contribution of Indian Acrylics Ltd., Sangrur and Pasupati Acrylon Ltd., Muradabad towards the generation of total hazardous waste in respective states is only 0.2 and 0.1% respectively.

Further Scopes:

i. It has been observed that PAHs have been emitted from waste incineration of real world samples of hospital/ hazardous waste at laboratory scale; however there is a need for further studies at pilot scale.

ii. Emission of PCCD/Fs from waste can also be studied at laboratory scale as well as pilot scale from waste incineration.

iii. Incineration is a costly technique but a two stage combustion vertical quartz tube incinerator can be fabricated for more elaborate study of organic emissions from waste incineration.

iv. Independent studies on the gases/ ash contents of hospitals/ hazardous waste incinerators are needed to verify the reports submitted by them to Govt. agencies.

v. There is scope of study for the health status of the public living in the vicinity of incinerators.

Record of Publications/conferences from this work

Publications

1. Satnam Singh and *Vinit Prakash*, “Toxic Environmental Releases from Medical Waste Incineration: A Review” **Environmental Monitoring and Assessment,** 132 (2007) 61-87.
2. *Satnam Singh and Vinit Prakash*, “The effect of temperature on PAHs Emissions from Incineration of Acrylic waste” **Environmental Monitoring and Assessment,** 127 (2007) 73-77.
3. *Vinit Prakash and Satnam Singh*, “Effect of combustion parameters on PAH’s Emissions from Incineration of Cellulose waste filters” **Environmental Monitoring and Assessment,** (DOI: 10.1007/s10661-009-0861-5), 2009.

Conferences

1. *Vinit Prakash and Satnam Singh*, “The Effect of combustion variables on PAHs Emissions from Incineration of blood contaminated cotton” National symposium on Green chemistry application in Science and Engineering, organized by School of Chemistry & Biochemistry, Thapar University, Patiala (Punjab) held from February, 05-06, 2009, p. 65.
2. *Satnam Singh and Vinit Prakash*, “PAHs emissions from incineration of Wheat Straw” National symposium on Green chemistry application in Science and Engineering , organized by Department of Chemistry, Sant Longowal Institute of Engineering & Technology, Longowal (Punjab) held from March, 29-30, 2007, p. 41.
3. *Vinit Prakash and Satnam Singh*, “PAHs emissions from incineration of acrylic Waste” National symposium in chemistry, organized by Department of Chemistry, Indian Institute of Technology, Bombay Powai, Mumbai held from Feburary, 3-5, 2006, p. 97.
4. *Satnam Singh and Vinit Prakash*, “PAHs from incineration of samples of blood bags from hospital waste” National seminar on chemistry at interfaces-trends & perspectives, organized by Department of Chemistry, Sant Longowal Institute of Engineering & Technology, Longowal (Punjab) held from Dec.19-20, 2003, p. 40.

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Annexure I

Questionnaire For Bio-Medical Waste Management

1. Name of Hospital/Health care facility:
2. Name of Contact person :
3. Address :
4. Phone numbers, fax (Optional) :
5. Numbers of patient treatment wards…………

Pathology ☐ Pharmacology ☐

Gynecology ☐ Therapeutics ☐

Child care ☐ Operation Theatre ☐

Maternity ☐ Radiology & Imaging ☐

ENT ☐ Micro-biology ☐

Surgery ☐

If others please specify………

6. Outdoor patients per day (average)……..

☐ 10-20 ☐ 20-40

☐ 40-50 ☐ More than 50

7. Numbers of beds………

☐ 1-20 ☐ 20-50

☐ 50-100 ☐ More than 100

8. Waste generation rate per bed per day (Average)…………..

☐ 1-2 kg ☐ 2-5 kg

☐ 5-10 kg ☐ More than 10 kg

9. Bio-Medical Waste generation rate per bed per day…………..

☐ 0-500 g ☐ 500 g-1 kg

☐ 1-2 kg ☐ More than 2 kg

10. Total Hospital waste generation rate per day………

☐ 10-50 kg ☐ 50-100 kg

☐ 100-150 kg ☐ More than 150 kg

11. Whether the practices of segregation of Bio Medical waste from total waste is being followed?

☐ Yes ☐ No

12. Are Colored bags/containers such as Yellow, Red, Blue/White or Black employed to differentiate type of waste used?

☐ Yes ☐ No

13. Numbers of employs engaged for segregation of waste

☐ 0-5 ☐ 5-10

☐ 10-20 ☐ More than 20

14. Whether the Biomedical waste is collected to central place by common vehicles for local facilities

☐ Yes ☐ No

14.1 In case No, numbers of vehicles to collect and transport biomedical waste

☐ 0 ☐ 1-2

☐ 2-5 ☐ More than 5

15. Whether biomedical waste disposal is done at the premises of hospital

☐ Yes ☐ No

16. Which technique is used for Medical Waste Treatment

☐ Autoclaving ☐ Micro waving

☐ Chemical treatment ☐ Incineration

☐ Land filling ☐ All above

If any others, please specify……………

17. Final Disposal if treatments other than incineration are applied

☐ Municipal landfill ☐ Burying inside premises

☐ Discharge into sewer ☐ Others (please specify)

…………….

18. Is Incinerator available in hospital/health care facility?

☐ Yes ☐ No

i) If yes, Type of Incinerator……..

☐ Starved air ☐ Excess air

☐ Rotary kiln ☐ Others (please specify)

………..

ii) Capacity of Incinerator:

☐ ≤ 50 kg h^{-1} ☐ 50-100 kg h^{-1}

☐ ≥ 100-150 kg h^{-1} ☐ Don’t know

iii) Whether trained manpowers are operating the incinerator?

☐ Yes ☐ No

iv) Have gaseous emission analysis been done for CO_x, NO_x and SO_x?

☐ Yes ☐ No

v) Are polycyclic aromatic hydrocarbons studied in emission gases?

☐ Yes ☐ No

vi) Whether heavy metals are detected in bottom ashes?

☐ Yes ☐ No

vii) Whether Hg emission studied?

☐ Yes ☐ No

viii) Whether the ash is properly disposed off?

☐ Yes ☐ No

ix) Whether Air pollution control devices are employed?

☐ Yes ☐ No

19. Type of Waste generated and Treatment applied

i) Whether <u>Human Anatomical Waste</u> (human tissues, organs or body parts) is generated

☐ Yes ☐ No

If yes, treatment of Human Anatomical Waste by……..

☐ Incineration ☐ Deep burial

☐ Local autoclaving ☐ Micro-waving

☐ Chemical treatment ☐ Auto claving

☐ Mutilation ☐ Shredding

☐ All above ☐ None of above

ii) Whether Animal Waste (Animal tissues, organs, body parts carcasses, bleeding parts, fluid, blood and experimental animals used in research, and waste generated by veterinary hospitals colleges, discharge from hospitals and animal houses) is generated

☐ Yes ☐ No

If yes, treatment of Animal Waste by…….

☐ Incineration ☐ Deep burial

☐ Local autoclaving ☐ Micro-waving

☐ Chemical treatment ☐ Auto claving

☐ Mutilation ☐ Shredding

☐ All above ☐ None of above

iii) Whether Microbiology & Biotechnology Waste (Wastes from laboratory cultures, stocks or specimens of micro-organisms live or attenuated vaccines, human and animal cell culture used in research and infectious agents from research and industrial laboratories, wastes from production of biologicals, toxins, dishes and devices used for transfer of cultures) is generated

☐ Yes ☐ No

If yes, treatment of Microbiology & Biotechnology Waste by…….

☐ Incineration
☐ Local autoclaving
☐ Chemical treatment
☐ Mutilation
☐ All above
☐ Deep burial
☐ Micro-waving
☐ Auto claving
☐ Shredding
☐ None of above

iv) Whether Waste sharps (Needles, syringes, scalpels, blades, glass, etc. that may cause puncture and cuts. This includes both used and unused sharps) is generated

☐ Yes ☐ No

If yes, treatment of Waste sharps by…….

☐ Incineration
☐ Local autoclaving
☐ Chemical treatment
☐ Mutilation
All above
☐ Deep burial
☐ Micro-waving
☐ Auto claving
☐ Shredding
☐ None of above

v) Whether Discarded Medicines and Cytotoxic drugs (Wastes comprising of outdated, contaminated and discarded medicines) is generated

☐ Yes ☐ No

If yes, treatment of Discarded Medicines and Cytotoxic drugs by…….

☐ Incineration ☐ Deep burial

☐ Local autoclaving ☐ Micro-waving

☐ Chemical treatment ☐ Auto claving

☐ Mutilation ☐ Shredding

☐ All above ☐ None of above

vi) Whether Soiled Waste (Items contaminated with blood, and body fluids including cotton, dressings, soiled plaster casts, lines, beddings, other material contaminated with blood Wastes comprising of outdated, contaminated and discarded medicines) is generated

☐ Yes ☐ No

If yes, treatment of Soiled Waste drugs by……

☐ Incineration ☐ Deep burial

☐ Local autoclaving ☐ Micro-waving

☐ Chemical treatment ☐ Auto claving

☐ Mutilation ☐ Shredding

☐ All above ☐ None of above

vii) Whether Solid Waste (Wastes generated from disposable items other than the waste sharps such as tubings, catheters, intravenous sets etc.) is generated

☐ Yes ☐ No

If yes, treatment of Soiled Waste drugs by……

☐ Incineration ☐ Deep burial

☐ Local autoclaving ☐ Micro-waving

☐ Chemical treatment ☐ Auto claving

☐ Mutilation ☐ Shredding

☐ All above ☐ None of above

viii) Whether Liquid Waste (Waste generated from laboratory and washing, cleaning, house-keeping and disinfecting activities) is generated

☐ Yes ☐ No

If yes, treatment of Liquid Waste by……

☐ Incineration ☐ Deep burial

☐ Local autoclaving ☐ Micro-waving

☐ Chemical treatment ☐ Auto claving

☐ Mutilation ☐ Shredding

☐ All above ☐ None of above

ix) Whether Incineration Ash (Ash from incineration of any bio-medical waste) is generated

☐ Yes ☐ No

If yes, treatment of Incineration Ash by……

☐ Incineration ☐ Deep burial

☐ Local autoclaving ☐ Micro-waving

☐ Chemical treatment ☐ Auto claving

☐ Mutilation ☐ Shredding

☐ All above ☐ None of above

10) Whether <u>Chemical Waste</u> (Chemicals used in production of biologicals, chemicals used in disinfection, as insecticides, etc.) is generated

☐ Yes ☐ No

If yes, treatment of Chemical Waste by……

☐ Incineration ☐ Deep burial

☐ Local autoclaving ☐ Micro-waving

☐ Chemical treatment ☐ Auto claving

☐ Mutilation ☐ Shredding

☐ All above ☐ None of above

19. Are posters displayed for Public Awareness?

☐ Yes ☐ No

20. Whether Govt. provides funds for collection, transport and disposal of waste

☐ Yes ☐ No

If yes please specify…………………

21. Annual expenditure on Biomedical waste management…………….

Annexure II

Questionnaire For Acrylic Industrial Waste Management

i. Name of Industry :
ii. Name of Contact person :
iii. Address :
iv. Phone numbers, fax (Optional) :

1. Characteristics of waste produced from Industry

Component	Name	By Weight
i. Paper	……….	……….
ii. Plastic and rubber	……….	………..
iii. Organic	……….	………..
iv. Glass and ceramic	……….	………..
v. Textile	……….	………..
vi. Liquid waste	………..	……….
Others like…….		
Total		

2. Please (√) for Hazardous Wastes generated in Industry:

S.No.	Processes	Hazardous Wastes
1	**2**	**3**
1.	Petrochemical processes and pyrolytic operations	1.1 Furnace/reactor residue and debris* 1.2 Tarry residues 1.3 Oily sludge emulsion 1.4 Organic residues 1.5 Residues from alkali wash of fuel 1.6 Still bottoms from distillation process 1.7 Spent catalyst and molecular sieves

		1.8 Slop oil from wastewater 1.9 ETP sludge containing hazardous constituents
2.	Drilling operation for oil and gas production	2.1 Drill cuttings containing oil 2.2 Sludge containing oil 2.3 Drilling mud and other drilling wastes*
3.	Cleaning, emptying and maintenance of petroleum oil storage tanks including ships	3.1 Oil-containing cargo residue, washing water and sludge 3.2 Chemical-containing cargo residue and sludge 3.3 Sludge and filters contaminated with oil 3.4 Ballast water containing oil from ships.
4.	Petroleum refining/re-refining of used oil/recycling of waste oil	4.1 Oily sludge/emulsion 4.2 Spent catalyst 4.3 Slop oil 4.4 Organic residues from process 4.5 Chemical sludge from waste water treatment 4.6 Spent clay containing oil
5.	Industrial operations using mineral/synthetic oil as lubricant in hydraulic systems or other applications	5.1 Used/spent oil 5.2 Wastes/residues containing oil
6.	Secondary production and/or use of zinc	6.1 Sludge and filter press cake arising out of zinc sulphate production 6.2 Zinc fines/dust/ash/skimmings (dispersible form) 6.3 Other residues from processing of zinc ash/skimmings 6.4 Flue gas dust and other particulates*
7.	Primary production of zinc/lead/copper and other non-ferrous metals except aluminium	7.1 Flue gas dust from roasting* 7.2 Process residues and Arsenic-bearing sludge 7.3 Metal bearing sludge and residue including jarosite 7.4 Sludge from ETP and scrubbers
8.	Secondary production of copper	8.1 Spent electrolytic solutions 8.2 Sludges and filter cakes 8.3 Flue gas dust and other particulates*
9.	Secondary production of lead	9.1 Lead slag/Lead bearing residues 9.2 Lead ash/particulate from flue gas
10.	Production and/or use of cadmium and arsenic and their compounds	10.1 Residues containing cadmium and arsenic
11.	Production of primary and secondary aluminium	11.1 Sludges from gas treatment 11.2 Cathode residues including pot lining wastes 11.3 Tar containing wastes

12.	Metal surface treatment, such as etching, staining, polishing, galvanising, cleaning, degreasing, plating, etc.	11.4 Flue gas dust and other particulates* 11.5 Wastes from treatment of salt slags and black drosses* 12.1 Acid residues 12.2 Alkali residues 12.3 Spent bath/sludge containing sulphide, cyanide and toxic metals 12.4 Sludge from bath containing organic solvents 12.5 Phosphate sludge 12.6 Sludge from staining bath 12.7 Copper etching residues 12.8 Plating metal sludge 12.9 Chemical sludge from waste water treatment
13.	Production of iron and steel including other ferrous alloys (electric furnaces; steel rolling and finishing mills; Coke oven and by product plant)	13.1 Process dust * 13.2 Sludge from acid recovery unit 13.3 Benzol acid sludge 13.4 Decanter tank tar sludge 13.5 Tar storage tank residue
14.	Hardening of steel	14.1 Cyanide-, nitrate-, or nitrite-containing sludge 14.2 Spent hardening salt
15.	Production of asbestos or asbestos-containing materials	15.1 Asbestos-containing residues 15.2 Discarded asbestos 15.3 Dust/particulates from exhaust gas treatment.
16.	Production of caustic soda and chlorine	16.1 Mercury bearing sludge 16.2 Residue/sludges and filter cakes* 16.3 Brine sludge containing mercury
17.	Production of acids	17.1 Residues, dusts or filter cakes* 17.2 Spent catalyst*
18.	Production of nitrogenous and complex fertilizers	18.1 Spent catalyst* 18.2 Spent carbon* 18.3 Sludge/residue containing arsenic 18.4 Chromium sludge from water cooling tower 18.5 Chemical sludge from waste waster treatment
19.	Production of phenol	19.1 Residue/sludge containing phenol
20.	Production and/or industrial use of solvents	20.1 Contaminated aromatic, aliphatic or napthenic solvents not fit for originally intended use 20.2 Spent solvents 20.3 Distillation residues

* Unless proved otherwise by the occupier based on sampling and analysis carried out by a laboratory recognized under the Act not to contain any of the constituents mentioned in Schedule 2 to the extent of concentration limits specified therein.

S.No.	**Processes**	**Hazardous Wastes**
1	**2**	**3**
21.	Production and/or industrial use of paints, pigments, lacquers, varnishes, plastics and inks	21.1 Wastes and residues 21.2 Fillers residues
22.	Production of plastic raw materials	22.1 Residues of additives used in plastics manufacture like dyestuffs, stabilizers, flame retardants, etc. 22.2 Residues of platicisers 22.3 Residues from vinylchloride monomer production 22.4 Residues from acrylonitrile production 22.5 Non-polymerised residues
23.	Production and/or industrial use of glues, cements, adhesive and resins	23.1 Wastes/residues (not made with vegetable or animal materials)*
24.	Production of canvas and textiles	24.1 Textile chemical residues* 24.2 Chemical sludge from waste water treatment
25.	Industrial production and formulation of wood preservatives	25.1 Chemical residues 25.2 Residues from wood alkali bath
26.	Production or industrial use of synthetic dyes, dye-intermediates and pigments	26.1 Process waste sludge/residues containing acid or other toxic metals or organic complexes 26.2 Chemical sludge from waste water treatment 26.3 Dust from air filtration system
27.	Production or industrial use of materials made with organo-silicone compounds	27.1 Silicone-containing residues 27.2 Silicone oil residues
28.	Production/formulation of drugs/ pharmaceuticals	28.1 Residues and wastes* 28.2 Spent catalyst / spent carbon 28.3 Off specification products 28.4 Date-expired, discarded and off-specification drugs/ medicines 28.5 Spent mother liquor 28.6Spent organic solvents
29.	Production, use and formulation of pesticides including stock-piles	29.1 Wastes/residues containing pesticides 29.2 Chemical sludge from waste water treatment 29.3 Date-expired and off-specification pesticides
30.	Leather tanneries	30.1 Chromium bearing residue and sludge 30.2 Chemical sludge from waste water treatment
31.	Electronic Industry	31.1 Residues and wastes*
32.	Pulp & Paper Industry	
33.	Disposal of barrels / containers used for handling of hazardous	

	wastes / chemicals	31.2 Spent etching chemicals and solvents 32.1 Spent chemicals 32.2 Corrosive wastes arising from use of strong acid and bases 32.3 Sludge containing adsorbable organic halides 33.1 Chemical-containing residue from decontamination and disposal 33.2 Sludge from treatment of waste water arising out of cleaning / disposal of barrels / containers 33.3 Discarded containers / barrels / liners used for hazardous wastes/chemicals
34.	Purification processes for air and water	34.1 Flue gas cleaning residue* 34.2 Toxic metal-containing residue from used-ion exchange material in water purification 34.3 Chemical sludge from waste water treatment 34.4 Chemical sludge, oil and grease skimming residues from common industrial effluent treatment plants (CETPs) and industry-specific effluent treatment plants (ETPs) 34.5 Chromium sludge from cooling water treatment
35.	Purification process for organic compounds/solvents	35.1 Filters and filter material which have organic liquids in them, e.g. mineral oil, synthetic oil and organic chlorine compounds 35.2 Spent catalyst* 35.3 Spent carbon*
36.	Waste treatment processes, e.g. incineration, distillation, separation and concentration techniques	36.1 Sludge from wet scrubbers 36.2 Ash from incineration of hazardous waste, flue gas cleaning residues 36.3 Spent acid from batteries 36.4 Distillation residues from contaminated organic solvents

3. Total Hazardous waste generation rate per day…………..

☐ 0-500 g ☐ 500 g-1 kg

☐ 1-2 kg ☐ More than 2 kg

4. Which technique is employed for the treatment of hazardous waste?

☐ Chemical treatment ☐ Incineration

☐ Land filling ☐ All above

If any others, please specify……………

5. Is there any separate analytical laboratory facility for testing the quality of waste?

☐ Yes ☐ No

6. Is Incinerator available in Industry?

☐ Yes ☐ No

i) If yes, Type of Incinerator……..

☐ Starved air ☐ Excess air

☐ Rotary kiln ☐ Others (please specify)

………..

ii) Capacity of Incinerator:

☐ ≤ 50 kg h^{-1} ☐ 50-100 kg h^{-1}

☐ ≥ 100-150 kg h^{-1} ☐ Don't know

iii) Whether trained manpowers are operating the incinerator?

☐ Yes ☐ No

iv) Have gaseous emission analysis been done for PM, HCl, CO_x, NO_x and SO_x?

☐ Yes ☐ No

If yes, then at what Interval………….

v) Are PAHs/dioxins studied in emission gases?

☐ Yes ☐ No

If yes, then at what interval…………..

vi) Whether heavy metals are detected in bottom ashes?

☐ Yes ☐ No

vii) Whether the ash is properly disposed off?

☐ Yes ☐ No

ix) Whether Air pollution control devices are employed?

☐ Yes ☐ No

x) Stack height of the Incinerator ………………

xi) Is waste segregated before incineration ? ☐ Yes ☐ No

xi) What is the incineration temperature ? …………………………….

xii) Are storage & feeding requirements studied like Physical form of waste, pH, hazardous waste properties such as inflammability, reactivity, compatibility with other wastes etc. for segregating the waste and to store accordingly, in order to suit feeding mechanism?

☐ Yes ☐ No

xiii) Are operating conditions of the furnaces like viscosity, moisture content, total organic carbon, calorific value, volatility of the waste, special incompatible wastes, inorganic salts, metals etc.

☐ ☐

Yes No

7. Is appropriate treatment to the wastewaters from the cleaning of exhaust gases be provided?

☐ Yes ☐ No

8. Is the retention time of incinerator known ?......................

9. Frequency of monitoring

i. TOC in stack emission ………..

ii. TOC in residue/ash ....

iii. Combustion/stack temperature ....

iv. Pressure inside combustion chamber………..

v. Excess O_2 ………………..

10. Annual expenditure on Hazardous waste management…………….