Ph.D. Thesis

ON

STUDIES IN TECHNO ECONOMIC ASPECTS OF POWER GENERATION FROM AGRIWASTE IN INDIA

Submitted by

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This is to certify that the thesis entitled **"STUDIES IN TECHNO ECONOMIC ASPECTS OF POWER GENERATION FROM AGRIWASTE IN INDIA"** which is being submitted by Mr. Badhai Lonia in fulfilment of the requirements for the award of the degree of Doctor of Philosophy in the Mechanical Engineering Department, Thapar Institute of Engineering & Technology, (Deemed University), PATIALA, is a record of candidate's own work carried out by him under our supervision and guidance from July, 2001 to June, 2005. The matter presented in this thesis has not been submitted in part or full for the award of any degree in any other University or Institute.

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LIST OF ABBREVIATIONS

AC	Ash Content
AWBPP	Agriwaste Based Power Plant
AWIGT/GT	Agriwaste Integrated Gas Turbine/Gas Turbine
AWIGT/STIG	Agriwaste Integrated Gas Turbine/Steam Injected Gas Turbine
Ca	Calcium
CaO	Calcium Oxide
CDC	Coal Dust Combustion
CFB	Circulating Fludized Bed
CFBS	Circulating Fludized Bed Cabust
CHP	Combined Heat & Power
CO_2	Carbon Dioxide
COE	Cost of Electricity
CV	Calorific Value
DMD	Dry Matter Digestibility
EPIC	Erosion Productivity Impact Calculator
FBN	Fuel bound Nitrogen
GIP	Galvanized Iron Pipe
GIS	Geographic Information System
GJ	Giga Joules
GT	Gas Turbine
GW	Giga Watt,
IREDA	Indian Rural Energy Development Agency
J	Joule
JPPL	Jalkheri Power Plant Limited
Kgoe	Kilograms of oil equivalent
kPa	Kilopascal
kW	Kilowatt
LMTD	Log Mean Temperature Difference
MC	Moisture Content

Mha	Million Hectare
MNES	Ministry of Non-Conventional Energy Sources
mt	Metric Tonne
MWh	Mega Watt Hour
NO_x	Nitrogen Emissions
OMD	Organic Matter Digestibility
PEDA	Punjab Energy Development Agency
R&D	Research and Development
RPR	Residue to Product Ratio
SiO_2	Silicon Oxide
SMAC	Spacecraft Maximum Allowable Concentrations
SO_x	Sulphur Oxide Emissions
TCIRDC	Thapar Corporate Industrial Research Development Centre
VC	Volatile Content
Pb	Punjab
Hr	Haryana
HP	Himachal Pradesh
RJ	Rajasthan
UP	Uttar Pradesh
UA	Uttaranchal
MP	Madhya Pradesh
AP	Andhara Pradesh
WB	West Bengal
MH	Maharashtra
GJ	Gujarat
TN	Tamil Nadu
KA	Karnataka
Lac/s	10^5 , or 1/10th of a million or 100 thousands

INDEX

LIST OF FIGURES

LIST OF TABLES

LIST OF ANNEXURES

ABSTRACT

Industrialization and urbanization has led to rapid increase in energy demand. The energy crisis of 70's brought awareness all over the world to exploit the non conventional and renewable fuel sources. The total energy consumption in India has gradually increased from 64.91 million tones of oil equivalent (mtoe) during 1973 to 400 mtoe by 2001, indicating constant growth. As the fossil fuels (non renewables) are depleting, these are to be replaced by renewable resources such as agriwastes, wind, solar, hydel and tidal.

Problems of growing abundance of agriwaste in different parts of the country, environmental pollution resulting from burning of agriwaste, and issues related to inappropriate land use, all add urgency to the challenges faced in building sustainable and environmentally sound energy systems. While every effort is being made to bridge the gap between demand and supply, there exist various technological and environmental limitations to achieve the same in practice.

This study evaluates the potential of agriwaste power generation technologies, form of use of agriwaste, pre-conversion methods, utilization and its contribution to the reduction of environmental pollution, with focus on Northern region (India) (states like Punjab, Haryana, Rajasthan, Himachal Pradesh, Uttar Pradesh).

An agricultural residues survey was carried out to cover rice, wheat, maize, sugarcane, and cotton crops, both for the Rabi and Kharif seasons. Samples were collected from different areas in accordance with the agro-ecological zones. Estimates for agriwastes for different ecological zones were made based on the ratios between the crop size and agricultural residues. This list of major crops was further supplemented by waste forestry materials like leaves twigs and grass. Some of the industrial wastes, mainly agro based which could possibly be used as binders cum fuels like deoiled cake, spent wash (liquid and dry) mallee, bio fertilizer, saw dust and even bakelite were considered. While calorific value and other combustion parameters were mostly known for the major crops all these were calculated for the supplementary materials and even crops wherever necessary. Bomb calorimeter for

calorific value and muffle furnace were used for volatile content, ash content and moisture content.

At this stage, to have an insight into the real life situations and the issues involved in the use of agriwaste on commercial scale for power generation the case study on TWO agriwaste based power plants in Northern Region i.e. Jalkheri power plant Ltd.(JPPL) At Jalkheri village in Fategarh Sahib District of Punjab and Unichem Power Plant in Tohana village of Hisar district of Haryana were conducted. Jalkheri plant (10 MW) is using rice straw (32x28x17 bale)” in fluidized bed combustion system Nuchem Powers Ltd (4 MW) uses mustard stalks and cotton stalks and rice straw in stoker fired system. The major issues of major concerns for these plants are non availability of agriwastes, agglomeration, ash slagging and social and management problems related to collection, handling, transportation, and storage of agriwaste. The magnitude of transportation related problem can be gauged from the fact that JPPL plant needs daily 500 loads of trucks (8 tonne per truck) and trollies loads (0.8 tonne per trolly) while NPL plant needs daily 150-200 loads of trucks and trollies.

With an aim to study combustion properties and alleviate problems related to agglomeration and ash slagging, agriwaste briquettes of various sizes were prepared from agri-residues i.e. rice straw, husk, bagasse, sawdust, leaves, mustard straw, cotton stalks, sunflower, groundnut shell, wood chips, deoiled cake(DOC), maize in different combinations and mixes(ratios) by weight Nine such multifuel combinations were prepared.The combustion parameters (CV; AC;VC;and MC).Their specific ranges were: Calorific values 16800-21840 kJ/kg (4000* – 5200 kCal/kg), ash (5 – 18%) and moisture content in the range 8 – 35%.Similar study was done for the six combinations of Bi-fuels samples.

Linear programming model was used to optimize fuel mix for briquetting that would minimize fuel cost and provide a briquette having greater than preset value.A computer programme in C++ was developed for this purpose. The values were calculated for different combinations. These were validated using TORA Software (Annexure-E).

Linear programming studies were done to find fuel mixes that would have a minimum unit cost and still have calorific value more than 16800 kJ/kg.(4000 kcal/kg). The results

BFI-----BF6 (bifuel combinations)
MF1-----MF9 (multifuel combinations)

The range of HHV for 9 samples of multifuel came out to be 16800-21840kJ/kg (4000-5200kCal/kg): and cost range was between Rs.1550-2150 (US$ 35-48) per tonne. Similarly bifuel HHV ranged between: 16800-21840kJ/kg (4000-4500kCal/kg) and cost range Rs.1350 -1900 (US$ 40-42) per tonne.

* *As a bench mark*

A fluidized combustor was developed for use in the incineration of agriwaste (briquetted) to find multi-fuel mixes that would burn without ash slagging and agglomeration problem. . The system has been tested with agriwaste briquettes (bi or multi) fuel combinations. By using the multifuel combination, better combustion results could be attained even at lower Bed temperature (300° C) against the recommended minimum temperature (330°C)**. The ash contents in the multifuel combinations were also better as it gave lesser ash content (5-18 %) than single fuel results (8-22.5%).

The range of temperature for minimizing the alkali formation for single fuel is recommended to be 330°C -750°C**. In our test cases, the range turned out to be 330°C - 950°C with negligible traces of alkali formation.

The FBC exhaust gases were tested. The results obtained for various emissions were NO 40-114 ppm (150-200)*; NO_2 2 ppm (200-300)*; SOx 30-47 ppm (200-500)*; O_2 6-15% (41%) and CO_2 was 6%.

All these results prove that Bi fuel and multi fuel agriwaste combinations are better not only on the combustion efficiency parameters, but also on the environmental related parameters as well. Thus, the agriwastes which are low value wastes can be turned into high value added fuels which are both energy efficient and environmental friendly.

*(*Permissible limits approved by Punjab Pollution Control Board (PPCB), Govt. of Punjab, India)*

*(** Fluidized bed incineration tests of toxic liquid waste 'Proceedings of the 15th International Conference on Fluidized bed combustion, May 16-19, 1999, Savannah, Georgia; Grubor Borislav et al – Laboratory of thermal Engineering & Energy Research, Yugoslavia, Paper No. FBC 99-0121)*

CHAPTER: 1

INTRODUCTION

Energy, particularly its electrical form, has become virtually the life line of human activities. Undoubtedly, it is one of the most vital inputs to industry. In fact, there is no field of human activity where the role of energy can be underestimated. But, with a growing demand, both due to rise in populations as well as fast industrialization, the gap between the available electric power and its requirement is ever growing. With the fossil fuels gradually depleting and hydro sources having reached the verge of full exploitation, we are compelled to think in terms of searching for and developing alternative sources of energy. Over the recent years, the problem of environment pollution, sustainability and safety have been added to the scene, calling for development of power generation systems which are techno economically viable, ecofriendly, sustainable and safe. Several alternative sources of energy are being thought of, including the nuclear, solar, geothermal, wind, tidal and the biomass based. Keeping in view the three fold objective stated above viz. economic-viability, sustainability and safety, biomass as a source of energy holds a good and bright promise. In India, the use of biomass especially agriwaste is of particular interest and it may also lead to the environmental safety.

India being agriculture based economy, 70% of its GDP comes from either agriculture or agro based industry [61,62]. Any enhancement of income from this sector is based upon adequate supply of basic inputs in this Sector. Regular and adequate power supply is one such input. But the status of power supply in our country is deteriorating day-by-day with a major share of power produced being sent to the industry and urban areas. Hence, there is a perennial shortage of power in the agriculture sector. Consequently, there is an urgent need to produce more power, in order to fulfil the needs of agriculture sector effectively. Energy consumption in India has gradually increased from 65 million tones of oil equivalent (mtoe) in 1973 to 400 mtoe by 2001, showing a growth rate of over eight per cent during the entire period. The per capita energy consumption has also increased from 108 kilograms of oil equivalent (kgoe) in 1970-71 to about 400 kgoe in 2000-2001, which is still very low as compared to the global level [61,62].

India, with a total land area of 328.8 million hectares (mha) [62] has an estimated human population of 1000 million and a live stock strength of about 500 million, with a major percentage living in about 5,90000 villages [62]. The annual production of food grains is 150 million metric tones (mmt) [19,21,47,54,62,62]. Though there is no authentic data available with regard to the quantity of agricultural and agro-industrial residues, its rough estimate can be put at about 350 million tones(mt) per year [54,62]. It is also estimated that the total cattle refuse generated is nearly 250 mt per year [62]. Further, nearly 20% of the total land is under forest cover, which produces approximately 50 mt [62] of fuel wood and with associated forest waste of about 5 mt [54,62]. The total availability of agriwaste, energy plantations and agro-industrial waste in the country is placed around 405mt per year [6,54, 62].

The ever increasing need and demand for energy; especially electrical power energy: the fast pace of depletion of fossil fuels had focussed the attention of the world towards the non-conventional energy resources. Biomass in general and agriwaste in particular is being considered as the one of the alternatives with possibly the highest potential.

During the last three decades number of researchers, academicians, experts ,professionals and administrators have researched and deliberated on the issues concerned with this aspect and other related issues like cost economics, efficiencies and environmental impact etc, see for example[3,6,19,20,21,23,31,48,54,55,57,60,62,68].

Taking into account the utilization of even a fraction (say 40%) [6,54,62] of agriresidue and agro industrial waste as well as energy plantations on one million hectare (mha) of wastelands for power generation through bio energy technologies, a potential of some 18000 MW[62] of power is estimated.

1.1 AGRIWASTE SCENARIO

Agriresidue has traditionally been a handy and valuable source of heat energy all over the world in rural as well as the sub urban areas. In spite of rapid increase in the supply of, access to and use of fossil fuels, agriresidue is likely to play an important role in developing countries in general and India in particular, in the foreseeable future. Thus, developing and promoting techno-economically viable technologies to utilize agriresidue for power generation, remains a pursuit of high priority.

One way of accomplishing this is to set up agriwaste based captive power plants in agro-based industries and small capacity power generation plants in rural areas as decentralized power supply sources. One such power plant can satisfy the power need of a cluster of 30 to 40 nearby villages. The agriwaste, like rice-straw, saw-dust, sugarcane-trash, coir-pith, peanut -shells, wheat-stalks and straw, cotton-seed, stalks and husk, soybean stalks, maize stalks and cobs, sorghum, bagasse, waste wood, walnut shells, sunflower seeds, shells, hulls and kernels and coconut husk can be fruitfully utilized in power generation[15,19,23,47,54,62]. This stuff is otherwise a waste and liability and consumes a lot of effort on its disposal; in addition to being a source of fire and health hazard. Apart from the above, it causes serious air pollution in the form of smoke, un-burnt suspended particles and unwanted addition of heat to atmosphere. Surely, agriwaste stuff at present is available in abundance and prospects of its utilization in producing energy are enormous. These agriwaste components can be procured at reasonably low rates from farmers who will thus be benefited economically, apart from being relieved of the responsibility of its disposal. Annexure .A exhibits the details of classification, location, forms, production and combustion related data of various types of agriwastes [62].

The various processes preferred for adequate production, efficient conversion and effective utilization of agriresidue/waste are; agriresidue production, collection, briquetting, combustion, gasification and cogeneration. The main factors which influence the agriwaste utilization in generation of electricity include technology development, environmental, economic, fiscal and managerial skills.

On the basis of calorific value, agriresidue is comparable with coal. Fuel value of the agriwaste component of a plant depends upon the fibrous content present in the stem of the plant [30] and this fibrous content that burns like fossil fuels to produce heat. Further, it is suggested that the burning process and its outcome depend upon digestibility and nitrogen content present in the fuel.

The agriwaste, apart from being a disposal responsibility, obviously poses a serious environmental threat which in turn jeopardizes ecology and human health alike, because presently, some of the agriresidues are being discarded at the fields and burnt in-situ, which results in environmental pollution and also affects the quality and fertility of soil. If these wastes are used for producing electric power it may help control the environment related problems. But this requires an elaborate collection process and economic conversion operation as well.

Agricultural waste can be collected either manually or by mechanized methods. In manual method, harvesting threshers are used which give output in the form of straw (wheat and rice), while in mechanized system, employing tractor operated threshers or harvester combines, the crop is divided into stalks, straw and grains. Harvesting and handling operation results in losses in product yield (residue). However, the extent and significance of these losses depends on the method of collection, the degree of mechanization used in harvesting operations and other local factors. Major factors which influence the design of agriwaste collection and storage facilities include:

- The physical properties of the crop waste viz size, shape, nature, density etc.
- Pattern of weather and seasonal conditions.
- Backup storage capacity and desired reliability-level of supplies.
- Storage area available and its proximity to the location of use e.g. combustion unit, boiler etc.
- Operational constraints related to conversion process and power plant operations.

The present study assesses the potential of agriwastes for power generation and explore suitable alternatives for the same.

The amount of agriwaste available depends upon the level of waste component of a crop which in turn depends upon the nature and structure of the plant, agricultural operations carried out and the volume of production in a particular area. The level of waste is measured and specified based on acreage of land deployed in agriculture (Annexure A; column V and VIII).

In the present scenario, the agriwaste stuff is processed to conform to the power generation requirements where it is to be used as a fuel. Feedstock characteristics and quality greatly influence the design, choice and performance of conversion technologies, design, of plant components, fuel handling and ash disposal. Fuel feed systems are used to transfer agriwaste from active storage to the hopper for metering and feeding it into the boiler. Number of options are available for fuel preparation and handling systems. Agriwaste can be used independently or together with agro-forestry plantations and/or fossil fuel to generate power.

Critical evaluation of two agriwaste based power plants i.e. Jalkheri Power Plants Ltd. (10 MW) at Jalkheri Village in Fatehgarh Sahib District of Punjabn using rice straw (32x28x17 bale)" in fluidized bed combustion system, Nuchem Powers Ltd (4 MW) in Tohana of Mahindergarh District of Haryana using mustard stalks and cotton stalks in stoker fired system.

Jalkheri and Nuchem plants were facing the problems of agglomeration, shortage of fuel, pollution, reduced efficiency, frequent cleaning and social problem of movement of more than 500 trucks and trollies on the village roads.

Agricultural residues study was carried out to ascertain the sources of energy, their characteristics like shape, size etc. both for the Rabi and Kharif seasons. Samples were collected from different areas in accordance with the agro-ecological zones[77]. These samples were dried under specified conditions and their resultant residual fuel values were calculated. Ratios between crop size and agricultural residues were developed and estimates for different agro-ecological zones were made. On the basis of adhesion and combustion and volatile content, the materials like deoiled cake, spentwash (liquid, dried), mallee, twigs, biofertizer, leaves (ashoka, shisham, teakwood) and bakelite were considered as fuel cum binders. The problems like bulkiness, lower heat content, transportation, handling and storage are mitigated by briquetting the agriresidue. Work on composite fuel briquetting is in the infancy and needs focussed attention. Issues associated with briquetting also need to be effectively addressed.

Pre-conversions for utilization of agriwaste in power generation system are pellatisation, briquetting direct firing, pyrolysis and incineration [13,19,21,23,54]. The processes involve drying, removal of non-combustion grinding, mixing and production of briquettes.

Agriwaste briquettes of size (1, 2, 3, 4 and 8) inch^3 and 3x2x1 cuboids were prepared, considering residues from Annexure-A, using cowdung, deoiled cake and molasses as binders for various samples. In some cases water was used as a binder. Nine combinations of fuels were selected according to ratios by weight. Calorific values 14700 – 18900 kJ/kg (3500 – 4500 kCal/kg) ash (5-18%), moisture (10 – 30%) content was calculated. Linear programming model (Annexure-H) was used to develop equations for maximising the calorific value and minimising the cost of fuel [ref. table 4.2(a), (b), (c), (d), (e), (f)]. A fluidized bed combustor has been developed for use in the incineration of agriwaste (briquetted). The system has been tested with bi/ multi composite fuel briquettes. The temperatures attained in FBC were 300^{o}C –850^{o}C (950^{o}C). The temperature of combustion in FBC is controllable, making it possible to limit alkali formation and slagging. Fluidized bed combustor is fuel flexible[79]. Emissions like SO_x, NO_x are limited. Briquetted fuel is an effective substitute for coal. It does not corrode the walls of FBC due to less sulphur content.

Present research on agriwaste combustion is focused on improvements of existing system with respect to ease of operation, higher efficiency, higher calorific value of composite (bi or multi) fuel, low cost of fuel (including transportation, labour and maintenance cost and marketing cost) and emission controls. New technology which can mitigate the problems of existing conventional combustion systems to a great extent is fluidized bed combustion system.

It is in this context that the present study has been conceived and formulated. Although, efforts are already afoot in the country to generate electric power from agriwaste and couple of agencies like Indian Renewable Energy Development Agency (IREDA), Ministry of Non-conventional Energy Sources (MNES), and State level agencies like Punjab Energy Development Agency (PEDA) are trying their best to develop suitable systems, yet lot many problems are being faced in terms of heterogeneity of the resource, seasonal and geographical dispersion of source crops, non-availability of basic relevant data, inadequate R&D, lack of effective infrastructure and appropriate equipment design. Furthermore, most of the solutions developed are area or resource specific [54,56,57,61,62]. A comprehensive and holistic system has yet not come up on the scene. Therefore, there is an urgent need to develop a generalized yet effective approach leading to a pragmatic, sustainable and economic solution.

1.2 DELPHI SURVEY

The Delphi Survey was planned and conducted in two stages (phases). A questionnaire was prepared (*Delphi Questionnaire Annexure- B, B1, B2*) and mailed too 100 experts in the region which included Academicians; Researchers; Officials of the energy, environmental and agriculture departments and agencies, State electricity boards to seek their opinion on the energy scenario in the region. This was carried out during July – August 2002 .Response was received from 40 people. The analysis of the plan revealed that most of the respondents were thinking nuclear power and power from agriwastes as possible alternatives for future for the region. The opinion also focussed on the issues of lack of facilities of Research and Development on the agriwaste energy resources, the bulkiness of the agriwastes and possible higher cost of generation.

In the second round, the opinion of a smaller group of 40 persons was taken. It focussed on the prospects and problems involved both in the nuclear and the agri waste based projects.

In the second phase the specific cost estimates, the solutions to volumes of the agriwastes, the feasible size and the mode of agri waste based plant, the catchment area for the fuel supply and the locational and environmental issues were involved. Discussions were held in groups and independent opinions were sought. The cost estimates revealed that installation cost of agriwaste plants was lower i.e. about Rs 4-5 crores/ MW against Rs 8 -10 crores/MW for Nuclear Project. The agriwaste Projects are suitable for small capacities (5-20 MW) range due to bulkiness of the fuel, hence had to be located near the availability of the agriwastes. On the other hand Nuclear could be of much higher capacity i.e. more than 1000 MW. Due to threat perception (being Border States) the opinion was not in favour of Nuclear Plants. Moreover the environmental degradation due to agriwaste burning in the field (especially Rice Straw, Wheat Stubs) and abundance of agriwastes was also given as a factor favouring agriwaste Power Plants. Employment Generation was also considered as a favourable factor for agriwaste plants.

This chapter enlists the status of scenario and issues involving agriwastes particularly in respect of energy particularly the electric energy. The Northern Regions are summarized. Theoretical aspects of the energy which can be produced from the various available bio resources have been evaluated. Further the benefits of using agriwaste in terms of conservation of environment and fossil fuel for the production of energy has been highlighted. Finally the need for the present study has been established. The next chapter will review the literature on all these issues.

CHAPTER : 2

LITERATURE REVIEW

Active efforts are afoot to devise appropriate and economic power generation systems from agriwaste all over the world. Although most of the work in the frontal areas of the problem has been done in USA, UK and China, but some pioneering work has been done in a couple of enterprising, developing countries too, resulting in identification of various constraints and problems related to utilization of agriwaste, agro-industrial waste and forest residue for generating electric power. Literature surveyed unfolds the following scenario at the world level. Whereas technology related developmental efforts have been made chiefly in USA, UK and China, the countries like Mexico, Hawaii, Vietnam, Nepal, India and Pakistan have focused mainly on applied and operational aspects. Diverse aspects of the problem have been examined and the results of studies reported at national and international level.

Khoa et al. (1999) of Vietnam observe the potential of agriwaste as a major source of energy. However, as in the case of most other developing states, reliable estimates of agriwaste energy use in different economic sectors of Vietnam are not available. In this study they have presented the sectorial and end-use utilization of different agriwaste fuels by end use technology [35].

Gutierrez-Vera (1999) of Maxico has projected renewable energy trends in Mexico in the third millennium. Realizing that by the end of the first half of next century there will be a shortage of oil and gas as source of energy and that renewable sources of energy will play a very important role in providing clean and productive sources of energy, the current scenario of various renewable sources of energy being utilized in Mexico have been discussed in this paper with due concern [24].

Jiao et al. (1999) have examined agriwaste as a source of energy in China. In China, the agriwaste energy consumption during the year 1993 was estimated at about 185 million tons oil equivalent (MTOE). The shares of agriculture residues, fuelwood and animal wastes in the total agriwaste use for energy were 57.5%, 39.2%, and 3.2% respectively. Annually about 213 MTOE of agricultural residues and about 200 billion kg of dry animal wastes could be potentially available as energy source. Presently, most of the agriwaste energy is consumed by cook stoves. The household sector alone accounts for about 94% of the total agriwaste energy consumption in the country. It has been projected that the fuelwood remain an important source of energy in China in the foreseeable future [32].

Yokoyama et al. (2000) of Thailand made estimation of agriwaste energy potential including agriwaste residue and forestry agriwaste in Thailand taking into account the amount of agriwaste residue which has already been used and possibility of agriwaste energy plantation in accordance with the national plan of the Thai Government. According to this estimation, 65 PJ can be derived from agricultural and forestry waste and 770 PJ can be generated if half of the area allocated for cultivation of plantation forests could be used for agriwaste energy plantations. Today, agriwaste energy is 810 PJ, which is 30% of the total primary energy [69].

Kumaradasa et al. (1999) has estimated the agriwaste energy potential in Sri Lanka. In 1993, agriwaste consumption for energy was about 11.37 billion kg, which is equivalent to about 3.6 million tons of oil equivalent (MTOE) and accounted for nearly 66% of the total primary energy consumption of the country. The share of fuel wood in the traditional energy supplies is about 88%. The household sector is the major end user and consumes 88.4% of the total agriwaste energy [38].

Elaurica et al. (1999) observed that the total energy consumption in the Philippines in 1995 is about 32.45 million tons oil equivalent (MTOE) in which share of agriwaste is about 11.5 MTOE or 35.45% shares of woodfuel, agricultural residues and charcoal in the total agriwaste use for energy were 57%, 39% and 0.04%, respectively. Only about 20% of the potentially available agriwaste as a source of energy were used in 1995. Most of the agriwaste consumption (about 69%) was in the residential sector with cookstoves as the major end user [11].

Haider (1996) of Pakistan in a study stated that Pakistan is endowed with large natural gas resources discovered in the early 50s. Traditional fuels like firewood, crop residues are used by a majority of the rural population in Pakistan for heating purposes. Reliable statistics on the consumption of traditional fuels are not available, since these are not widely traded in the market. Agriculture wood survey was carried out to cover cotton, sugarcane, maize, rice and wheat crops, both for the Rabi and the Kharif seasons. The structure of the household sector in South-East Asian Association for Regional Cooperation states is similar to that of Pakistan [25].

Jenkins (1996-97) discussed boiler deposits from biomass firing and melting behaviour of salt mixtures in the system [2, 31].

As outlined by Amur and Bhattacharya (1999) **a**griwaste is a major source of energy in Pakistan too. However, reliable estimates of agriwaste energy use in different sectors of the country are not available. This paper presents the status of agriwaste energy use in Pakistan. About 65.07% billion kg consumption has been estimated, which is equal to 22.57 MTOE and accounts for 44% of the total primary energy needs of the country. The share of firewood in the traditional energy is about 56%. The household sector is the major end user and consumes 86% of the total agriwaste energy. The traditional cook stoves are the major end users of agriwaste energy, and consume about 80% of the total quantity [1].

From India Grover (1996) has studied agriwaste feed, especially agro-residue which is available in different forms, such as husks, straw, and stalks of various crops. He observes that due to this heterogeneous nature, the utility of these materials for energy becomes limited, and conversion processes tend to become agriwaste specific [19].

Sharma and Sharma (1999) observed that with the increase in industrialization coupled with population growth; the demand for power has rapidly increased, thereby influencing the economic and social growth of the country. In addition to power from conventional sources, the new and renewable energy sources (NRES) have been found to have enormous potential. About 800 MW of power from renewable has already been created while about 2000 MW is likely to be added in near future. Among the NRES, bagasse based co-generation of surplus power in Indian sugar mills has been given a new boost, as more than 3500 MW of surplus power potential exist in sugar mills only. These industries are being encouraged by the Govt.

of India to generate surplus power and feed to the grid by offering a number of incentive schemes. An attempt has been made in this paper to present energy scenario, co-generation potential, technological options available, incentives for encouraging power generation in sugar industry, techno-economic analysis of co-generated power and future scope of research and development in this vital field [57].

Studies of Singh et al. (2000) deals with the prospect and perspective of bio-energy in India. The present bio-energy status in India has been compared with that elsewhere. A brief description of the research work carried out so far in this area at Regional Research Laboratory (RRL) Bhubaneswar was presented. It has been concluded that agriwaste has immense potential in the Indian context. All efforts should be made to make optimum use of it. Requirement of an action oriented national policy for proper utilization of agriwaste resources available in the country was highlighted [61].

Progress and possibilities of bioenergy in United States have been examined by Cook and Beyea (2000). They have highlighted concerns about global climate change and air quality and hence increased interest in agriwaste and other energy sources that are potentially CO_2 neutral and less polluting. According to these authors large-scale bioenergy development could indeed bring significant ecological benefits - or equally significant damage-depending on the specific paths taken. In particular, the land requirements for agriwaste production are potentially immense. They reveal that various entities in the United States have performed research; prepared cost-supply assessments, environmental impact assessments, life cycle analysis and externality impact assessments; and engaged in demonstration and development regarding agriwaste crops and other potential agriwaste energy feedstocks. These efforts have focused on various agriwastes, forest management issues, and agriwaste crops, including both perennial herbaceous crops and fast growing woody crops. Simultaneously, several regional and national groups of bioenergy stakeholders have issued consensus recommendations and guidelines for sustainable bioenergy development. It is a consistent conclusion from these efforts that displacing annual agricultural crops with native perennial agriwaste crops could in addition to reducing fossil fuel use and ameliorating associated ecological problems - also help restore natural ecosystem functions in worked landscapes and thereby preserve natural biodiversity. Conversely, if forests are managed and harvested more intensively - and/or if agriwaste crops displace more natural land cover such as forests and wet lands - it is likely that ecosystem functions would be improved resulting in biodiversity conservation [10].

In another interesting study, Grahan et al. (2000)have dealt with Geographic Information System(GIS)-based modelling system for evaluating the cost of delivered energy crop feedstock and have described a regional-scale, GIS-modelling system for estimating potential agriwaste supplied from energy crops. While GIS models can capture geographic variation that may influence agriwaste costs and supplies, the presented modelling system estimates the costs and environmental implications of supplying specified amounts of energy crop feedstock across a state. The system considers where energy crops could be grown, the spatial variability in their yield, and transportation costs associated with acquiring feedstock for an energy facility [18].

Singh (1982) have discussed the determination of Nitric oxide in gas emissions [60].

A study entitled "Bioenergy - a renewable carbon sink" by Sims (2001) of New Zealand presents an outline of the potential energy contribution from agriwaste with particular emphasis on examples of commercial projects in Australia. Bioenergy is a mature technology which, in its several facets using modern agriwaste conversion systems, provides a significantly greater contribution towards the global primary energy supply than do all the existing and planned wind and solar projects together. Where specialist long rotation energy crops are grown on land that was previously in pasture or manual crops, agriwaste also provides a carbon sink. However, the 'image' of agriwaste is generally poorer than wind and solar in the public mind due to a lack of understanding of the technology and policy makers and media also paying greater attention to usually more photogenic wind and solar technologies [58].

Gelatukha and Martsenyuk (1999) have presented a picture of energy potential of agriwaste in Ukraine [16].

Ghaly and Mansaray of Canada (1999) in a Comparative study on the thermal degradation of rice husk in various atmospheres presented the thermo gravimetric behaviour of four types of rice husk at three heating rates in air, oxygen, and nitrogen atmospheres. The thermal degradation rate in active and passive zones, the initial degradation temperature, and the residual weight at 700^{o}C were determined. These thermal degradation indices are dependent on the heating rate, atmosphere employed, inorganic substances in rice husk, and chemical composition of rice husk. The initial degradation temperature decreased, while both the thermal degradation rate and the residual weight at 700^{o}C increased when the heating rate was increased. The higher the celluloric content of the rice husk, the higher the thermal degradation rate and the initial degradation temperature. Also, higher ash content in the rice husk resulted in a higher residual weight at 700^{o}C. The thermal degradation rate in the active zone was higher in the presence of oxygen than in the presence of air and nitrogen. More residual weight was recorded in the nitrogen atmosphere compared to the oxidative atmospheres of the air and oxygen atmospheres. The residual weights of the rice husk samples at 700^{o}C in air and oxygen atmospheres were lower than their initial ash contents, with percentages of ash lost ranging from about 2.95 to 13.10% in the case of air and 4.20 to 17.05% in the case of oxygen [17].

Ganesh and Banerjee (2001) studied a wide range of process and routes available for power generation from agriwaste and have emphasized that pyrolysis is another emerging technology, wherein agriwaste is converted to liquids, gases and char. Power generation using this technology is essentially the use of pyrolytic oils for the gas turbine integrated into a combined cycle [13].

Gupta and Panesar (1996-97) presented biomass gasification, thermal mode of heating and performance of 10 kW paddy husk gasifier [20,21,22,47,48,49].

Singh of India (1996) has presented an overview of agriwaste programme in India. He has discussed various technologies, production and improvement practices, agriwaste briquetting, agriwaste gasification, combustion, co-generation, improved cookstoves, biogas, and energy recovery from municipal and industrial wastes, fiscal incentives in this paper [62].

Gupta of India (1996) states that agriwaste potential is renewable source which is available in several forms. Technology of pyrolysis has been used for obtaining charcoal from wood and woody agriwaste, but very little information is available on pyrolysis as a means for using paddy straw. The high volatile matter content in paddy straw suggests that it is an excellent material for pyrolysis. The char and tar mixture can be pressed into briquettes or fuel balls without any extra binding agent [23].

Iniyan et al. (2000) present a reliability based socio-economic optimal renewable energy model for India. They feel renewable energy sources have to play a vital role in the developing states like India in order to meet the growing energy demand. In the last five years, some renewable energy sources had emerged as technically and economically viable alternatives in the energy sector. As a result, more ambitious plans for their dissemination were being launched. In this situation, development of energy model exclusively for renewable, will help in the allocation of appropriate renewable energy systems for different end-uses in the future. An attempt has been made by them to develop a reliability based socio economic optimal renewable energy model for India in the year 2020-2021. The effect of social acceptance variation in OREM model was analysed. The lighting end-use would be met by solar PV and biogas system to an extent of 0.5198 multiplied by 10**/**5 KJ and 0.75 multiplied by 10**/**5 kj, respectively. Similarly, the renewable energy utilization is found for other end uses [29].

Purvis et al. (2000) have studied NO/X emissions from the underfeed combustion of coal and agriwaste. Underfeed stokers have an inherent ability to minimize smoke emissions, thus providing environmental benefits in the combustion of solid fuels, such as agriwaste materials, which have a high volatile matter content. An evaluation of this attribute requires comparisons of the performance of combustion equipment using these fuels against reference data for coals. They have pointed out that in UK, this reflects a lack of commercial interest in small-scale coal firing due to the wide availability of inextensive gas and oil fuels [53].

A Comprehensive agriwaste combustion model" has been presented by Jones et al. (2000) of University of Leads. A combustion model for wheat straw is discussed and compared to that of a bituminous coal, Pittsburgh No.8. The combustion behaviour of the two fuels is investigated using a laminar flow CFD model of a drop-tube furnace. The results indicate that, because of the low calorific nature of the straw volatiles, the combustion takes place at a lower temperature, but with rapid ignition and rapid devolatilization. The straw char is highly microporous with relatively high ash and oxygen contents; consequently, the burnout is quicker than the analogous coal char burnout [33].

Karaosmanoglu of Turkey (2000) conducted a study on Biobriquetting of rapeseed cake. In this study, without adding a binder the briquetting possibility of rapeseed cake obtained through cold press. The shatter indices, water resistivities and calorific values of the briquetts were established. The bio-briquet prepared from the extracted cake tested under a pressure of 150 MPa and with a moisture level of 10.1% was determined as an alternative biofuel and subjected to thermogravimetric analysis in an oxidizing atmosphere of air [34].

Zhang, et al. (1999) in China have discussed application of HPB-I agriwaste briquetting machine. The structure, working principle and application of HPB-I agriwaste briquetting machine have been discussed. A novel two-way briquetting structure with two reciprocating pistons was designed. The results of performance test and analysis indicate that the machine has long life time, low consumption smooth and reliable performance, low cost and short returned period of investment. Its economic and environmental benefits are obvious. It would have a promising future for generalization [73].

R&D requirements in agriwaste combustion and gasification have been examined by Rao (1996). He observes that agriwaste production and conversion has attracted attention from the scientists and technologists only recently. The important factors are increasing prices of fossil fuels, renewability and scope of further development and improvement in hot gas clean-up systems to make agriwaste gasification more attractive for combined cycle power generation. Finally harvesting, collection, transport and material processing affect agriwaste utilization technically and economically. Therefore, R&D in these areas needs to be continued together with the conversion technologies [54].

Tripathi et al. (2000) have surveyed agriwaste briquetting in India. Results of a questionnaire-based preliminary survey of agriwaste briquetting plants in India are briefly presented along with a summary of suggestions made by briquetting plant owners themselves [68].

Mann and Spath (1999) conducted a life cycle comparison of electricity from agriwaste and coal. It is widely accepted that agriwaste power offers opportunities for reduced environmental impacts compared to fossil fuel-based systems. Intuitively obvious are the facts that per kilowatt-hour of energy produced, agriwaste systems will emit less CO//2 and consume less non-renewable energy. To quantify the magnitude of these and other environmental benefits and drawbacks, life cycle assessments (LCA) on the production of electricity from agriwaste and coal systems were performed. Each assessment was conducted in a cradle-to-grave manner to cover all processes necessary for the operation of the power plant, including raw material extraction, feed preparation, transportation, and waste disposal and recycling. Results demonstrate significant differences between the agriwaste and coal systems per kWh of electricity produced. The life cycle energy balance of the coal system is significantly lower than the agriwaste system because of the consumption of a non-renewable resource. For each unit of energy consumed by the agriwaste system, almost 16 units of electricity are produced; the average coal system produces only 0.3 units of electricity per unit of energy consumed. Not counting the coal consumed the net energy produced was found to be still lower than that of the agriwaste system because of energy used in processes related to flue gas clean up [38].

Zevenhoven et al. (2000) have predicted the behaviour of ashes from five different solid fuels in Fluidized Bed Combustion (FBC) by the combination of extended fuel analysis with advanced global thermodynamic equilibrium calculations. The extended fuel analysis is a fractionation method. In order to cover a broad spectrum of fuels, coal, peat, forest residue and Salix were studied. The results from the fractionation showed clear differences in mineral distribution in the fuels [72].

Pilavachi of Belgium (2000) in his article ‘Power generation with gas turbine systems and combined heat and power’ gives an overview of power generation with gas turbine (GT) and

Combined Heat and Power (CHP) systems. It also presents the European Union strategy for developing gas turbines and CHP systems. He emphasizes that ways to improve the performance of the several types of gas turbine cycle will be major objective in the coming years. The targets are combined cycle efficiencies above 60%, industrial gas turbine system efficiencies of atleast 50% and small gas turbines efficiencies above 35% and designs for the use of fuels with less than 25% heating value of that of natural gas. The main CHP targets are the reduction of the overall costs and the development of above 40 kW agriwaste fired system [51].

Splielhoff et al. (2000) in Germany carried out extensive investigations on co-combustion using a 0.5 MW pulverized-coal-fueled experimental furnace with fuel preparation, accompanied by tests on an electrically heated tube reactor. The outcome was that the agriwaste (e.g. straw or wood) compared with coal, allows a clearly coarser milling due to its higher content of volatile matter. While the particles must be less than 1 mm for wood to completely combust, for straw they may be coarser. Co-combustion also had an effect on emission behaviour. Owing to their high volatile matter content, sewage sludge, straw and wood are suited for application in air and fuel staging with a view to nitrogen abatement. Besides the emission and combustion behaviour the factors to be taken into account in co-combustion are the operational behaviour (slagging, fouling and corrosion) and the quality of the byproducts [66].

Nishiyama and Shibagaki of Japan (1999) studied the circulating fluidized Bed (CFB) boiler with regard to the possibility of stable burning for the low quality fuel. Recently, the large scale CFB boiler for the biofuel-applied coal-combustion-technology has been carried out. Towards this end, agriwaste utilization technologies that use Foster wheeler CFB have been introduced for utilization of agriwaste [44].

The application of the theory to bagasse combustion in fluidized bed is discussed by Rasul and Ruddph of Australia (2000). Application of fluidized bed combustion (FBC) technology to energy generation from sugarcane bagasse has been prevented, amongst other reasons, by the difficulties associated with fluidizing this material. This difficulty arises because bagasses is often light weight and of unusual morphology, and manifests itself by either matting-up within the bed or by segregating out, usually floating to the surface. So, the potential benefits of mixing inert solid and fuel, desirable for efficient combustion, is lost. For FBC to be viable, proper mixing of inert fluidizing solids and fuels are necessary [55].

Gaoppi et al. (2000) have described the mathematical modelling of catalytic combustion of low heating value (LHV) fuels from gasification of agriwastes which has attracted attention in recent years in order to reduce net CO//2 emissions in the atmosphere. A European project, ULECAT, has been undertaken to investigate this matter along with combustion of diesel fuel since 1996. This investigation describes part of the work performed in the mathematical modelling task of this project in connection with the analysis of atmospheric pilot scale experiments. Simulation results obtained with a single channel 2D model of the monolith catalyst are presented and compared with experimental results obtained in an atmosphere pilot scale facility. From this analysis a quantitative description of the role of the different governing phenomena in determining the combustor performance is derived and discussed to provide insight into the catalyst behaviour under severe conditions. The most critical parameters in the simulations are also identified and discussed [14].

Nielsen et al. (2000) emphasize the implications of chlorine-associated corrosion on the operation of agriwaste-fired boilers. The design of new agriwaste-fired power plants with increased steam temperature has raised concerns of high-temperature corrosion. The high potassium and chlorine contents in many agriwastes are potentially harmful elements with regard to corrosion [43].

Tranuik et al. (1999) studied the bed fouling problems in an agriwaste fired commercial CFB boiler. The use of agriwaste fuels in circulated fluidized bed (CFB) combustion is becoming more important because of increasing energy demand and the polluting nature of existing fossil fuel energy sources. The commercial circulating fluidized bed boiler at Vaxjo Energy Limited has large fuel flexibility, and can be fired with low moisture, high grade fuels, as well as high moisture, low grade fuels like agriwaste. The major ash-related problem encountered at VEAB is bed agglomeration which, in the worst case, may result in total defluidization and unscheduled shut down. Non-agglomerated and agglomerated ash samples resulting from the firing of 50% sawdust and 50% forestry residues were analysed. On the basis of the AFM experimental results and evidence of the non-height difference in the topography of the agglomerated samples, formation of binary or ternary eutectic melts were proposed [67].

Ohman and Nordin of Turkey (2000) have discussed the role of Kaolin in prevention of bed agglomeration during fluidized bed combustion of agriwaste fuels. The increased agglomeration temperature was explained by the decreased fraction of melt in the bed particle coatings, i.e. coatings were somewhat depleted in the potassium content by the corresponding potassium-enriched in the Kaolin-derived aggregates [45].

Zoelzer (2000) enumerates the advantages and disadvantages of fluidized bed applications for different applications. The evaluation is confined to the most common type of atmospheric circulating fluidized bed combustion (CFBC) system used in power plants and also includes the principles of coal dust combustion (CDC) as a basis for comparison. The operating experiences of 17 CFBC operators and some operators of CDC plants were taken into account as part of a survey [75].

According to Bhatnagar (1996) paddy husk is an important source of energy. Use of paddy husk as fuel in rice mill grate type furnaces and boilers has become common in some states. However, gasifier used in rice mill boilers operation is still to be introduced. Large-size paddy husk based gasifiers and pyrolyser systems of capacity 100 KW and above are not yet available in the country. However, the grate type and husk fired furnaces need certain improvements [6].

Gatlin (1999) have studied the reclamation of nitrogen from boiler flue gases as a cogeneration option in USA. The use of nitrogen from boiler flue gases as fuel is being considered to address the need for alternative energy sources as well as increasing concern over environmental safety. This natural gas is substantially free of ash and mixes intimately with air to provide complete combustion at low excess air and does so without producing smoke [15].

Zhou et al. (2000) have presented the results of their studies on release of fuel-bound nitrogen during agriwaste gasification. Gasification of four agriwaste feedstocks (Leucaena, Sawdust, bagasse and banagrass) with significantly different fuel-bound nitrogen (FBN) content was investigated to determine the effects of operational parameters and nitrogen content of agriwaste on the portioning of FBN among nitrogenous gas species. Data were obtained over a range of temperatures and equivalence ratios representative of commercial agriwaste gasification processes. An assay of all major nitrogenous components in the gasification products was performed for the first time, providing a clear accounting of the evaluation of FBN. It was found that the structural formula and content of fuel nitrogen in agriwaste feedstock significantly affect the formation and evolution of nitrogen species during agriwaste gasification [74].

Sayigh, Ali of Bahrain in his paper at Energex-98 outlines the growing need of energy in the developing states and the acute population growth, which will exceed 10 billion by the year 2050. It describes the achievement and progress made in geothermal, hydropower, agriwaste conversion, solar thermal technology, wind energy conversion and the ever increasing usage of photovoltaics. The paper also addresses the barriers and problems which face renewable energy users and producers. It is evident now that global warming is setting in and is going to change the climate as well as the terrain of many states unless drastic measures are taken. The recent Kyoto meeting emphasized the importance of limiting CO and CO_2 emissions and to abide by some form of agreement to reduce emissions. States such as India, China and Indonesia, which represent nearly half the world's population, are actively involved in using renewable energy as a major means of sustaining their energy growth. It concludes that renewable energy penetration into the energy market is much faster than was expected a few years ago and by the year 2020, 10-15% of our prime energy will be met by renewable energy [56].

From China, Catania (1999) comments that the issues related to rural energy development and the escalating economic activities have given rise to a complex, interrelationship among societal, economics, energy, environment and rural policies. With 7% of the world's farm land to produce food for 23% of the world's population combined with the increasing energy demands for modernized farming has resulted in a dynamic rural energy policy for

China. The characteristics of a rural society, outlines the relationship of rural energy supply and demand management, the interrelationship between energy and environmental utilization. The results indicated the integrated rural energy-policy, that is, the social benefits to farmers and the decrease of energy consumption per unit of output. Emerging nations must undertake a comprehensive analysis and synthesis of their respective rural energy developments and the corresponding interrelationships between technology, economics and the environment [9].

Mehta (1979) discusses waste heating using Osmo hydro power [39].

Skrifvars (1998, 2000) Zevenhoven and Hupa discussed ash bahvaiour in FBC system, Effect of fuel quality on bed agglomeration and ash chemistry in fluidized bed gasification [63,64,65].

In comparison to other crops, sugarcane gives a very high dry matter per unit land area. Bagasse and sugarcane tops and leaves are the main residues of which the former is normally used as an energy source for steam generation while the latter is normally used as cattle feed or is burnt in the fields [57].

2.1 SUMMARY

The literature survey carried out above revealed the following significant facts:

1. Efforts for generating electric power from non-conventional resources in general and biomass in particular are being made in several countries in the world including India.

2. Agriwaste, Agri-industrial residue supplemented by energy plantation is a potential future renewable source of energy which can reduce the pressure on fossil fuels and contribute to regional economic imbalances considerably.

3. The research carried out the world over in this area is focused mainly on use of one particular, local and abundantly available agriwaste (say bagasse or rice husk) as feedstock. Efforts to study and use a composite fuel made up of more than one agriwaste material are still scant.

4. There are several problems which are being faced with processes like briquetting, fludized bed combustion of agriwaste, evolution of gases during combustion process and influence of clay on combustion efficiency. These problems still need to be addressed carefully and effectively.

5. There is a general consensus among researchers that agriwaste holds a bright promise as a renewable source of energy in future and through careful policy planning and dedicated research. The techno-economic viability of this power generating option can be substantially enhanced. What might need to be done is to suitably supplement the agriwaste stuff by energy plantation so that year round availability of feedstock is made a reality. Also fresh look is needed at the design of power plant components to enhance the effectiveness of conversion process and improve the overall performance of the power plant.

2.2 OBJECTIVES OF STUDY

Considering the above observations the objectives of study emerged out as below:

1. To study the types, characteristics and pattern of availability of agriwaste resource in India; with focus on the northern region of the country.

2. To review the existing literature on utilization of agriwaste for generating electric power in various parts of the World, to highlight the efforts made, their direction, the success level, constraints and limitations of various efforts made to make a comprehensive projection of the lessons learnt.

3. To study the energy related characteristics of the agriwaste materials with regard to their suitability and effectiveness when used as feed stock for power generation and design a suitable fuel mix with optimal calorific value and reasonably low processing cost.

4. To critically appraise the existing agriwaste based power plants in Northern India and highlight the problems faced in their working.

5. To develop and standardize features of an improved agriwaste based power generation system for higher efficiency and cost effective performance, using Fluidized Bed Combustion technology* and taking care of associated environmental pollution considerations.

*** Justified at page 6 para 1 (Fuel flexible technology)**

2.3 METHODOLOGY OF THE STUDY

Following methodology was adopted to achieve the stated objectives:

1. Review of various aspects of the problem of power generation from agriwaste/biomass and conducted a Delphi Survey to seek the considered opinion of experts to develop a clearer scenario of prospects and problems of power generation from agriwaste in India.

2. Collected relevant information data through field, site visits and questionnaires. Focus of study was North Indian States namely Punjab, Haryana, Himachal, Rajasthan & Uttar Pradesh and tested the materials for evaluation of physico-mechanical and combustion related properties (case Study-I).

3. Developed a Linear Programming (LP) model for seeking an optimal combination of various available agriwaste/residue components to produce fuel-mix of specific calorific value, within practical constraints of size, cost etc.

4. Visited the existing agriwaste based power plants in North Zone, especially in Punjab, Haryana and Uttar Pradesh identified the technical and operation related problems of the system components, using Cause and Effect Approach (Case Study - II).

5. Finally, developed and standardized a suitable improved design of agriwaste based thermal power plants operatable on Fluidized Bed Combustion Technology using composite agriwaste fuel, incorporating the concepts of efficiency, economy, sustainability, energy conservation and currently operative regulations related to environmental pollution in India.

Figure 2.1 exhibits various aspects and stages of work that was carried out in a phased manner.

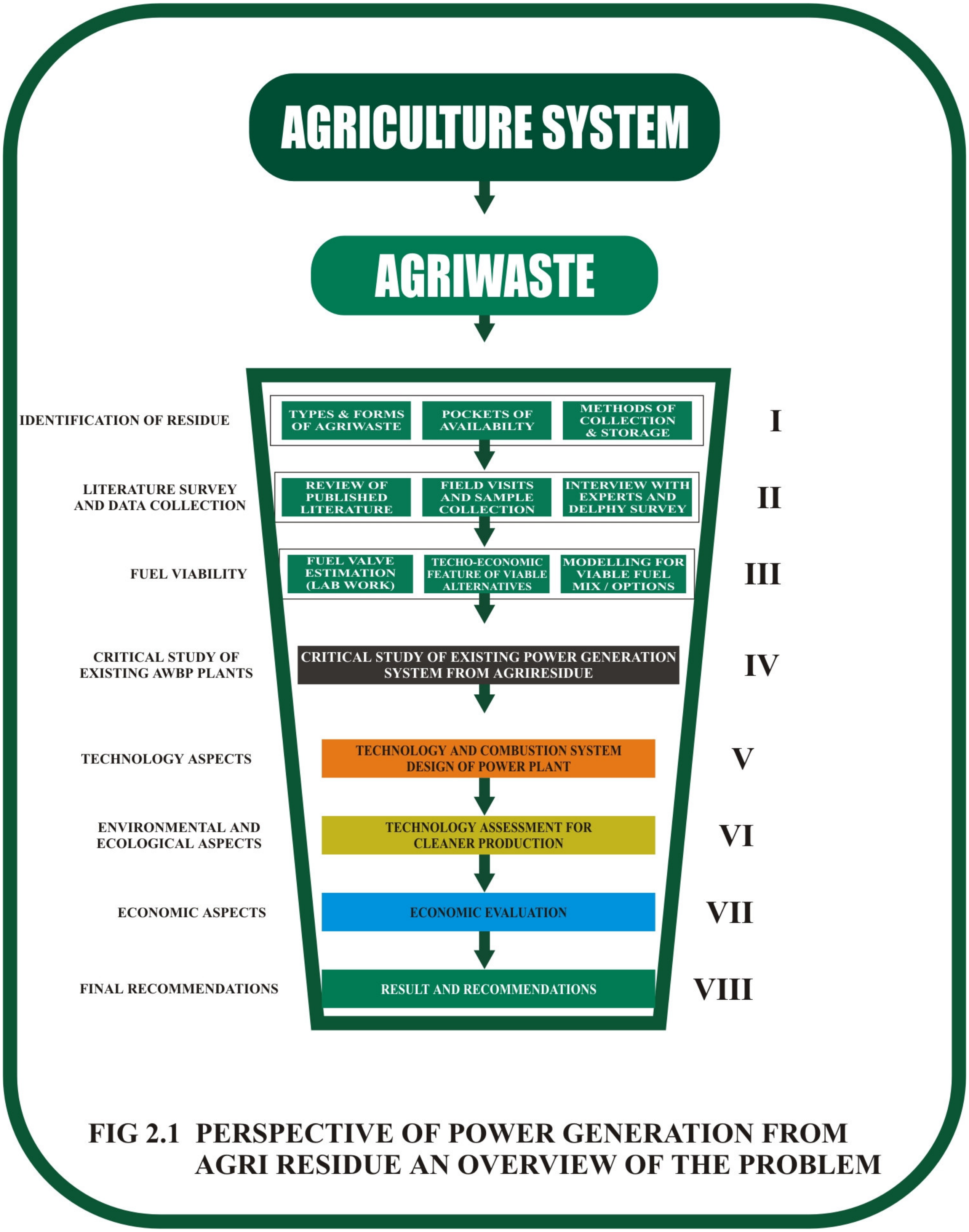


FIG 2.1 PERSPECTIVE OF POWER GENERATION FROM AGRI RESIDUE AN OVERVIEW OF THE PROBLEM

2.4 PLAN OF STUDY

Keeping in view the set objectives and intended methodology of the study the time frame selected is shown in the Gantt chart (Figure 2.2)

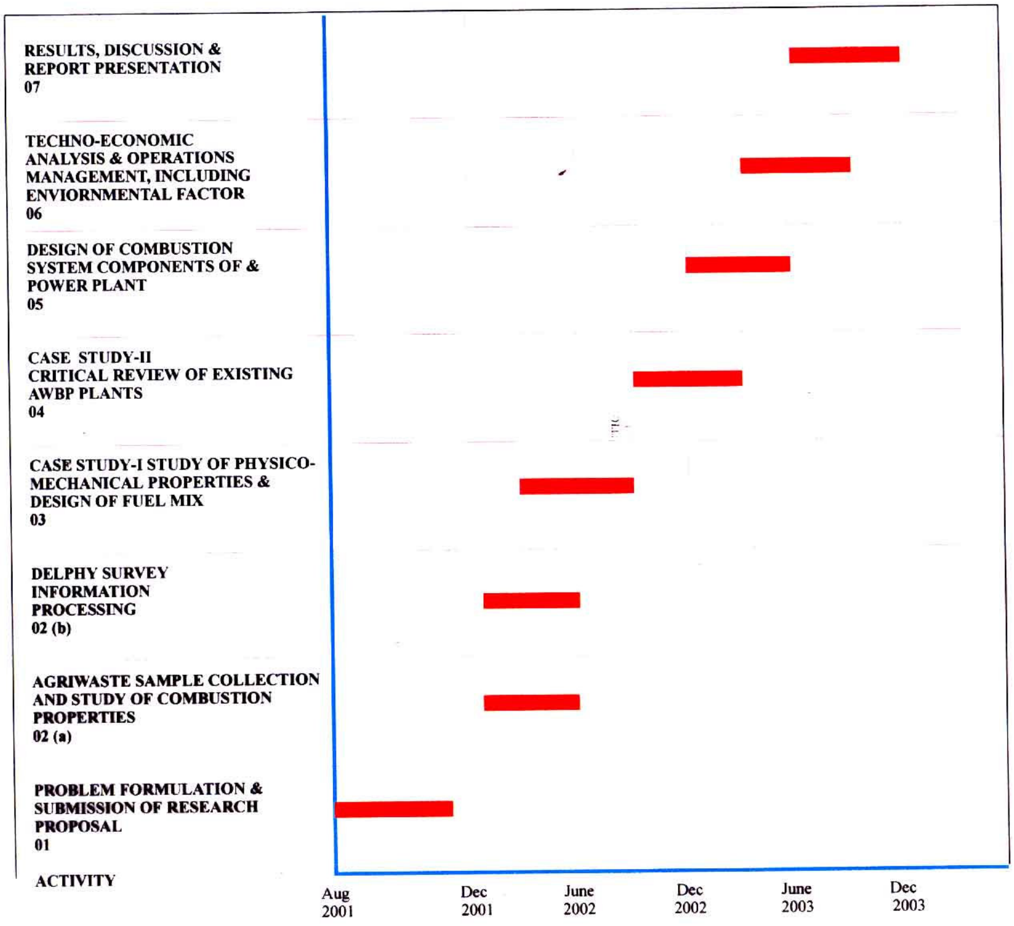


FIG 2.2 TENTATIVE SCHEDULE OF STUDY

CHAPTER – 3

CASE STUDIES

The research plan envisaged the collection of necessary and relevant details on agriwaste in the region and their thermal properties. For this purpose the relevant secondary data was collected from the records and statistics for all the states under study.[6, 47, 76, 77, 78, 81]

This was further supplemented by the primary data collected through formal and informal channel. For this purpose, field visits were undertaken in Punjab, Haryana and Rajasthan.

Patiala, Bathinda, Fatehgarh Sahib, Sangrur, Ludhiana and Faridkot districts were covered in Punjab. Mohindergarh, Bhiwani and Dabwali in Haryana and Ganganagar in Rajasthan were covered. These visits provided the real feel of the situation regarding the quantum and extent of agriwaste the process and time span of their disposal and the possible alternatives available. This information was supplemented by interacting the various segments of people involved in the process viz the farmers, the agricultural and district officials, the officials and technocrats of agri-processing industries like Flour Mills, Rice Shellers, Mills and Sugar Mills, Cotton Processing Units, Oil Mills, Distilleries, Academics and experts from the agricultural universities and public at large. [Annexure B, B1, B2]

This chapter covers two case studies. The first case, deals with the major agri-residues available in the region under study. This further includes some supplementary materials which could be used as binder cum fuels. The calorific value of most of this supplementary material was computed through laboratory experiments (Reference Annexure-G1, G2). This in turn established the possibility of their use in the targeted composite fuel.

The second case deals with the detailed techno-economic and operational study of two agriwaste power generation plants; one each in Punjab and Haryana. This is with a view to have a critical analysis of all the issues* involved in setting up and running of these plants.

**Refer to page 24*

3.1 ENERGY POTENTIAL OF AGRI-WASTE: A CASE STUDY-1

The need for utilizing agriwaste as a source of energy for power generation was established through the Delphi survey. The next logical step was to establish the potential of these agri-wastes in terms of volumes/weights and their energy. For this the major crops of the region were mapped (Ref. Annexure-A) the wastes generated by each one (quantum and nature/type of waste on the basis of yield to waste relationship) were established relevant combustion parameter were found wherever not available.

Agricultural residues survey (Annexure-A) was carried out to cover rice, wheat, maize sugarcane, sunflower, cereals and cotton crops, both for the rabi and the kharif seasons (*summer and winter crops*). Samples were drawn from different areas in accordance with agro-ecological zones[77], and for different productivity conditions**. These samples were dried in sun (Annexure C1, C2) for 30 days and their calorific values were calculated (Refer. Annexure-G1, G2). The ratios between crop size and the agri-residue were taken and estimates for different agro-ecological zones in Northern Region were made [76, 77, 78, 81]. The agri-residues/ wastes like leaves (Ashoka, Teak wood, Shisham) grass, flowers of Ashoka tree, deoiled cake (DOC), mallee, spent wash liquid*, spent wash dried, biowaste (mixture of spent wash & bagasse) and bakelite sheet residue were tested for calorific values, moisture, ash, and volatile content. The test results are listed in Table 3.1

Table 3.1 The combustion parameters of the supplementary binders/fuels (MC, AC, VC and CV)

S.No.	Material	MC %	Ash %	Volatile %	CV kJ/kg (kCal/kg)
1.	**Leaves dried**				
	Ashoka	5-10	2-3	78.5	21840 (5200)
	Shisham	5-10	2-5	80	21000 (5000)
	Teak wood	5-10	2-8	79	20790 (4950)
2	Grass	5-15	2-5	80	21210 (5050)
3	DOC	5-10	2-10	82	22470 (5350)
4	Mallee	5-12	5-15	78.2	20916 (4980)
5	Spentwash Liquid	-	-	60.0	12600 (3000)
	Spentwash dry	5-8	2-5	83	22890 (5450)
6	Biowaste	5-15	5-15	65	13400 (3200)
7	Bakelite Wash	2-5	2-3	89.2	29400 (7000)
8	Twigs	9.45	3.5	81.5	16800 (4000)

**Waste from the distillery*

*** Productivity conditions have been taken constant in this study*

As can be seen from the table volatile content of the seven materials except the biowaste is near or more than 75% which shows that the agriwaste has high volatile content which makes them fit to be used as fuel. In the subsequent experiments and studies these materials will be used in various combinations to get the appropriate fuels for power generation.

3.2 Case Studies - II

As mentioned earlier this part covers two agriwaste based power generation projects, one each in Punjab & Haryana.

a) Punjab Case: Jalkheri Power Plant Limited (JPPL)

1. Name of the Plant	:	Jalkheri Power Private Ltd., Village Jalkheri, The.Sirhind, Distt. Fatehgarh Sahib, Punjab.
2. Location of the Plant	:	15 km from Patiala District
3. Plant Specification	:	1x10 MW rice straw thermal power station using FBC system

INTRODUCTION

The Jalkheri Power Plant was a joint effort between Bharat Heavy Electricals Ltd., Haridawar ,Uttar Anchal; Punjab State Electricity Board; and Ministry of None Conventional Energy Sources, (MNES) formally department of Non-conventional sources (DNES) Government of India in 1985.

The basic idea was to gainfully utilize the rice straw in Punjab which was getting burnt in fields immediately after the harvesting usually in a span of 40-45 days. As estimated, this straw is capable of producing 1000 MW of power in a year.* 10 MW unit size was chosen as a reasonable unit size which would need Straw from a 10 Km radius area with 25% as effective utilisation area. Jalkheri in Patiala district was chosen as the site as Patiala had enough paddy cultivation around Jalkheri village.

** Source : Annual report of Punjab State Electricity Board and references 6, 76, 77, 78, 81*

NECESSITY OF THE PLANT

The state of Punjab has been the victim of acute power shortages, load shedding and power cuts, year after year, for the last one decade. Even though the Punjab was allocated shares from the generation of Atomic power station at Kota and Thermal Power Station at Badapur, yet no power worth the name has been supplied to Punjab from Baira-Siul Hydro electric project and Singrauli Super Thermal Plant, in spite of allocation made to Punjab out of these central sector projects. The situation in the State, therefore, became from bad to worse on account of non-availability of committed power from these central enterprises. This has served as a definite dis-incentive for coming up of the new industries in the State.

From June to September the agricultural requirement of power is the maximum on account of paddy cultivation. On 31.03.85, there were about 4.10 lacs (present status 9.75 lacs) tube wells in Punjab which are run by electric energy[76]. Since connection to other aspirants for obtaining tube well connections could not be given, these agriculturists in Punjab are running their tube wells on diesel which is quite uneconomical. Estimated power supply position at time, (Energy Basis) requirement (16807kWh) availability (14233kWh) deficit (2574kWh); Capacity basis (in MW) peak demand 3198 MW generating capacity 2207 MW leaving a deficit of 991 MW*[77].

The above deficit was anticipated with the power availability from Hydro Source as per dependable year studies. In case of dry weather and draught conditions deficit would increase. To meet the deficit brought out above, additional generating capacity required needs to be progressively planned and provided for. The Hydro Projects and thermal Stations which would benefit Punjab up to 1998-99 were accounted for. Full share from Central sector projects were also included. The power deficit was expected to continue and as such installation of Agro-reject based Thermal plants was a necessity in the State.

** Lac :- $(10)^5$ or $1/10^{th}$ of a million or 100 Thousands.*

*(** Present need is 9200 MW, deficit is 3499 MW and future need is 18400 MW)*

POWER GENERATION RESOURCES

Thermal and Hydro are the two major conventional sources of power generation in Punjab. Hydro Power Generation is dependent upon the availability of water and generation of energy fluctuates over the year. Further more, as the resource is limited energy generation is not possible beyond certain limit.

Thermal Power Generation is dependent upon the availability of coal. As Punjab is geographically situated far away from the coal mines the installed capacity of Thermal Power Generation is again restricted. The Thermal Power Generation in Punjab is restricted on account of transportation of coal to Punjab from Coal Mines and expenditure on freight of coal. In view of above it was considered that use of non-conventional energy resources may be tapped, one of which are Crop Residues.

ADVANTAGES OF NON CONVENTIONAL ENERGY RESOURCES

The crop residues are renewable, abundantly available (170 lacs tonne of wheat and paddy straw) at reasonably low costs. These materials have low ash content and high volatile content as shown in the table given below:

Sr.No.	**Crop Residue**	**% Ash Content**	**Volatile Matter**	**Calorific value**
1.	Coal	36.00%	30 %	17640kJ/kg (4200 kCal/kg)
2.	Wheat Straw	8.4%	73.6%	17207 kJ/kg (4097 kCal/kg)
3.	Rice Husk	16.48 %	71.2 %	15590 kJ/kg (3712 kCal/kg)
4.	Rice Straw	19.2 %	69.7 %	15078 kJ/kg (3590 kCal/kg)

Source : Project report and hand book of Punjab State Electricity Board [76,77,78]

NATURE AND TYPE OF FUEL ITS THERMAL PROPERTIES AND PROCESSING:

Crop residue i.e. rice straw being used having ash content 19.2%, volatile matter 69.7% and dry calorific value 15078 kJ/kg (3590 kCal/kg).

Rice straw so collected (Annexure-A, Col. VI) was bailed and stored at two sites other than the plant site. The process of rice straw collection and further requirement of about two months is kept at the power house and the balance quantity is kept at two other centres to avoid fire hazard. The procurement cost per tonne is Rs.150/- taken for the purpose of project analysis including the difference of Rs.80/- per tone is towards cutting, bailing and transportation.

STORAGE AND TRANSPORTATION OF AGRIWASTE TO THE SITE

Transportation of Rice Straw

Cards were issued to the farmers for supplying rice straw on their tractor trolleys which were collected at five centres*. The rice straw so collected was bailed and stored at two sites other than the plant site**.

Disposal

Unlike coal ash, the crop residue ash is not at all harmful to the soil. In case nitrogen and sulphur is added to the crop residue ash it could act as a useful fertilizer thus solving ash disposal problem. This ash lifted by the neighbouring villagers for use as fertilizer in their fields.

** The operation of these centres as per the availability of raw material (They are in the catchment area – upto 10 km in radius).*

*** They are the storage areas within the vicinity about of 1 km of the plant.*

Jalkheri Power Plant faced the troubles right from its commissioning and infancy. It had initial run of about a month and hick ups started immediately afterwards. Some of the problems, were:

- Bales were not properly moisturized (20% moisture content) at appropriate interval of time.
- The hydraulically operated system to cut the bales was not in working condition and it did not operate at the regular intervals.
- Bales of larger size (32”x28”x17”) were fed to the boiler which was strictly against operation manual.
- Pressure inside the furnace was low (0 to -10 mm water column).*
- Inlet Adjusting Dampers/guide vanes could not open at regular intervals, i.e. 30 seconds.
- Movement of 500 tractor trolleys/trucks in a stipulated interval (30 minutes) of time caused nuisance to the villagers, which caused social and ecological problems.
- The cards were issued but the payments of the farmers were delayed which caused resentment.
- Agglomeration, slagging, clinker formation
- Collection, Transportation, Storage had its own challenge due to the shear bulk & volume
- Fire hazard due to storage of rice straw in stacks
- Frequent shut downs
- Operatable for 10 to 15days in a month

This process of fits and starts carried on for few months only when it was to shut down finally (1992-93).**

From 1995, Punjab State Electricity Board started making efforts to sell the plant on outright basis but could not. Finally in the year 2000 the Board decided to lease out the plant. In the year 2001 it was leased out to M/s Bermaco Systems Energy Limited (BSEL) for Rs. 40.529 crores. The PSEB agreed to buy back the power at mutually agreeable rates according to MNES norms. It was expected to go on stream within four months (in 2001 itself).

** Source: Unit operating manual of Bharat Heavy Electricals Limited.*

***Source: Report of Punjab State Electricity Board, Internal audit report of company, interaction with the company officials.*

- Once BSEL tried to restart the plant the problems started to crop up due to shut down of the plant for about 9 years. Most of the equipments were rusted and damaged.
- They started rebuilding and it took more than 3 years for the whole set up. The plant could eventually come on stream only in December 2004.
- The new set up had almost 20% (1/5th) of the manpower as compared to the earlier set up under about 70 people only against more than 350 under PSEB.
- The plant is being run on Rice straw, wood chips and saw dust. They have attained a capacity utilization of about 85%.
- The present cost of generation comes out to be Rs. 4/- per unit. This cost is on the basis of project cost being assumed as Rs. 66 crores (as at present cost).

PSEB is reluctant to pay the requisite price; hence the major portion is being sold to the National Grid in the price range of Rs. 4/- to Rs. 7/- per unit as the case may be. The plant has achieved the break even point (BEP) and is likely to generate profits in the ensuing years. This could be more so if the plant run to full capacity.

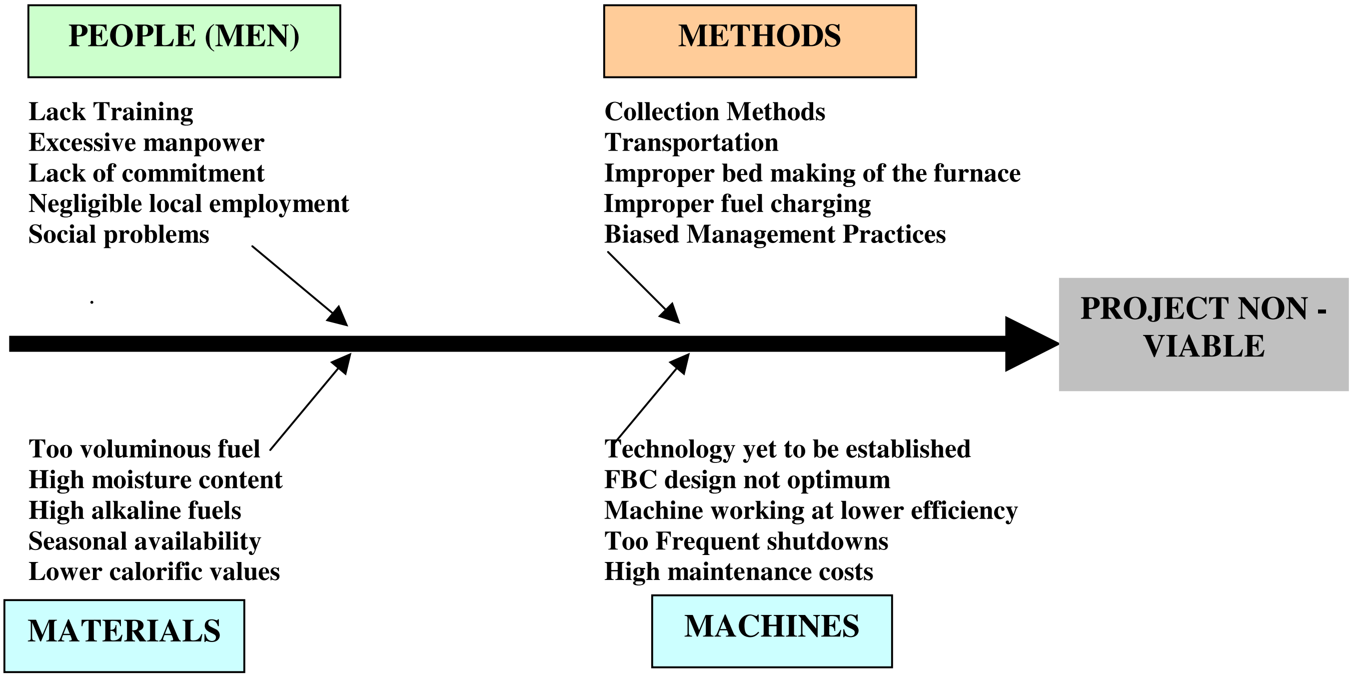


Fig. 3.1: Causes and Effect Diagram (Ishi Kawa diagram)

Shortage of raw material (rice straw) was given one of the reasons of failure which seemed to be contrary to the statistics of the requisite agri-wastes in the catchment area. An in-depth study using cause and effect diagram (Ishikawa diagram) as shown in fig.3.1 into various technical, financial, managerial and social aspects revealed that there was really not the shortage of raw material but some other reasons for the operational problems viz;

- The agriwastes being too voluminous were not properly handled, processed & stored.
- The alkaline nature of the fuels (agriwastes) and the high ash content resulted in agglomeration, slagging and clinker formation and chocking of valves and dampers.
- There were problems of working capital which resulted in delayed and non payment to the agriwaste suppliers (mainly the farmers) which caused the short fall in the materials.
- Further it was revealed that there was pick and choose policy being adopted for implementing the card system for the fuel supply. This was another factor inhibiting the regular supply of materials by majority of farmers.
- The feeding of the over-sized bales in the furnace which was against instructions of the operational manual, created the combustion efficiency and other related problems.
- Overstaffing in case of JPPL was another reason for faulty operation. There was lack of accountability at various levels. There were 60 technical executives and 70 skilled and semi-skilled workers for the plant and another 200 unskilled persons for handling and stores. When the project exchanged hand, the entrepreneur in private sector had only 10 technical executives, 10 skilled operators and another 40 unskilled workers. Almost 20% of the earlier strength, and the plant were working more efficiently.
- There were social problems also with these projects. The major was disenchanted local population. In case of both the projects, there was hardly any employment provided to local unskilled or semi skilled persons including those whose land had been acquired for the projects. To an extent this was the reason of short supply of fuel (agriwaste) also.

Source: Audit report of the company and interaction with the officials

The magnitude and nature of the transport operations involved created some other problems. There were 500 trucks and trollies transporting the material to the plant each day. On the one hand this caused traffic bottlenecks on the village link roads causing problems to nearby villages. This heavy traffic load also shortened the lifespan of the roads. There was some sort of social tension also due to the large number of outsiders frequenting the villages.

INFERENCES:

- Plant was promoted and implemented by the P.S.E.B. The apex body for generation, transmission and distribution of power in the state (Punjab)
- The plant and equipment was indigenously supplied by the Bharat Heavy Electricals Ltd.(BHEL) another public sector organisation.
- Ministry of non conventional energy resources (MNES) provided the due funding and subsidies.
- The project was also aided by to the tune of Rs.12.5 crores by DANIDA; a government of Denmark agency.
- The cost of power generation was low at the time of project planning
- The detailed project report (DPR) was prepared by the Thermal Design Wing of PSEB in 1985 and the projected cost was Rs. 21.76 crores. It was expected to be commissioned by 1988-89.
- The project implementation did face problems and there were significant cost (Rs. 26.00 crores) and time over runs (3 years) in the project. The commission cost was Rs. 47.45 crores and the project was commissioned in 1992.

Conclusions & Recommendations:

1. It was path breaking effort to narrow the gap of energy requirements using the agriwaste.
2. The plant operation was Okay.
3. The fuel was of voluminous nature which had the logistics and operational challenges.
4. The operational staff required specific training and change in mindset.
5. Clearly laid down procurement policy for agriwaste should have helped the smooth running of the plant.
6. Timely implementation of the project can avoid project time and cost turns which in turn results reduced operational cost and lower break even point.

Source: Audit report of the company and interaction with the officials

b) Haryana Case: Nuchem Powers (P) Limited (NPL), Tohana

Nuchem Powers Ltd. (NPL) Tohana is a unit of M/s NUCHEM Chemicals (P) Ltd. The project parameters are as per table3.2. It was envisaged as a semi-captive power generating unit, part of power (2.5 MW) to be used by the Parent Co. (NCL) and part (1.5 MW) to be sold to Haryana State Electricity Board (HSEB) at mutually agreeable rates.

The project was planned in 1990 and was commissioned in 1992. The project report was prepared by M/s Dalal & Associates (Consultants). Some of the equipments were common with the parent organization (NCL). Hence it was very difficult to totally earmark the costs. Still the envisaged cost of the project was around Rs. 10 crores. The plant equipment was indigenously supplied. Boiler by the Indian Boiler: Turbine by Triveni and Alternator by BHEL.

It was to run on Mustard straw, Rice straw and cotton stocks. The project has been running well since its commissioning. The main problems being low capacity running (at 60-65% of the rated capacity) or 2.5 MW; the power required for their captive use; as the HSEB has not been fulfilling the power buying commitments. The requirements of fuel are about 7-8 tons per hour i.e. 170-200 tons/day.

Table.3.2 NUCHEM POWERS (P) LTD.TOHANA HARYANA

1.	Name of the Plant	:	Nuchem Powers Ltd Tohana Haryana
2.	Location of the Plant	:	34 kms from Mahindergarh District towards North
3.	Plant Specifications	:	4MW Stoker Fired
4.	Nature & type of fuel and its thermal properties	:	Mustard Straw, Cotton Stalks, Rice Straw (Refer Annexure A), AC low, VC high, Moisture content medium, CV ranging from 16800-20160 kJ/kg (4000-4800 kCal/kg). Raw material easily available
5.	Processing if any	:	Baling
6.	How agriwaste is brought to the site	:	By Trucks and Trollies
7.	Storage, upkeep, cost of processing/tonne consumption	:	Open, Stacking, Rs.80/tonne
8.	How long the stock lasts Pattern of receipt of agriwaste from fields	:	Thirty days
9.	Firing system, equipment, methodology and problems faced if any	:	Stoker fired ,
10.	Cost of power generated/unit,		Rs. 3.91/unit

Inferences:*

- Project well planned, appraised and implemented
- No significant cost and time over runs
- The major share of power out put being for captive use hence that level (60-65%) plant load factor (PLF) despite the Haryana State Electricity Board not honouring the agreement.
- There is clear contrast of the effectiveness and efficiency of a private sector unit with a public sector unit (JPPL).
- The viability of power generation project based on agriwaste is established, as per the project report and operation of the plant This could be further enhanced with improved PLF and more efficient fuel/fuel combinations.**

Shortage of the raw material was given as the major cause of non performance of the project as per the report of company.

As reported in Table 3.2, the power project based on agriwaste is a viable proposition (Refer. Annexure-F). It is faulty operation of the project which made it sick and ultimately looked out to be non viable. Careful planning implementation and operation will leave enough scope for such projects to thrive in agri-residue abundant states like Punjab, Haryana, UP and Rajasthan.

The Combined Inferences:

- Both the projects 4-10 MW were planned and appraised by the professional agencies.
- Indigenous technology was available as both the plants had the major equipments (Boilers turbines and alternators) supplied by the indigenous manufacturers.
- There was not much of delay in implementation of the projects.
- There was not significant cost over runs in any of the projects.
- The problems with both the projects were at the operational stage. Apparently it looked as if the shortage of fuel (agri-waste) materials was the major cause of faulty operations.

** Source: Report of the company and interaction with the officials*

*** Source: Project report and operations of the plants*

There seemed clear economic viability of the projects. Both the projects retained the maximum operational efficiency between 65-80%. Despite this the cost/unit was coming out of around Rs. 3.90 at present. In case the plants run near full capacity, the cost will be still lower; say around Rs. 3.50/ units.

In case the social cost benefit analysis is done based on the increased income to farmer and improved environmental level, the cost will be still lower. Hence these are truly feasible and viable projects with lot of social and environmental advantages*. The case studies of the two plants revealed that on the whole the power generation units based on agri-waste are viable projects in case some of the operational parameters can be controlled. For further enhancing the viability the plants need to be run to near full capacity and use compact and more effective fuels. This postulate provided direction to the next stage of the project. That is briquetisation and optimisation of the composite fuels. The next chapter takes up these aspects in detail.

**The recent increase of 10 to 20%in power tariff for various category consumers in Punjab will further enhance viability of such projects (Hindustan Times, June 15; 2005, P-1)*

CHAPTER : 4

AGRIWASTE: ITS PROCESSING AND BRIQUETTING

This chapter deals with the information of agriculture residues regarding its availability, collection of data, costs of agriresidue , composite fuel modelling, briquetting and their efficiency as bio fuel. Further, it highlights briquettes as renewable energy source for the future generations. Based on the various data goal programming equations have been developed, which can be utilised for forecasting calorific value and cost factors.

An agricultural residues survey [Annexure-A] was carried out to cover the cotton, sugarcane maize, rice, and wheat crops, both for the rabi and kharif seasons(Refer page 29, line-8). Samples were drawn from different areas in accordance with agro-climatic zones[77], and for different productivity conditions[77]. These samples were oven dried under specified conditions (80 – 100 °C), and their resultant residual fuel values were calculated. Ratios between crop size and the agricultural residues were developed, and estimates for different agro-ecological zones[77], and at the provincial levels, were made (Refer. Annexure-A). The estimated quantities [19, 22, 23, 53, 62, 77] of crop residues and classification based on shapes & sizes are given in Table (4.1 a & b). Also refer annexure-A.

Table 4.1 (a) Potential availability of agriwaste in India

Table (a1) Foodgrains productions ***(Million tonnes)***

Crop/Year	**1999-00**	**2000-01**	**2001-02**	**2002-03**	**2003-04***
Rice	89.7	85.0	83.3	72.7	86.4
Wheat	76.4	69.7	72.8	65.1	72.7
Coarse cereals	30.3	31.1	33.4	25.3	36.8
Pulses	13.4	11.1	13.4	11.1	14.9
Food grains (cereals, rice, wheat, coarse cereals, gram)					
Kharif	105.5	102.1	112.1.	87.8	110.5
Rabi	104.3	94.7	100.8	86.4	100.3
Total	209.8	196.8	212.9	174.2	210.8

** Third advance estimates, Source: Economic Survey 2003-04, annual conducted by the Deptt. of Economic Affairs by Ministry of Finance, Govt. of India*

Table (a2) Commercial Crop Production *(Million tonnes)*

Crop/Year	1999-00	2000-01	2001-02	2002-03	2003-04*
Groundnut	5.3	6.4	7.0	4.4	8.5
Rapeseed/Mustard	5.8	4.2	5.1	3.9	5.9
Soyabean	7.1	5.3	6.0	4.6	7.6
Other oilseeds	2.5	2.5	2.6	2.2	3.0
Total nine oilseeds	20.7	18.4	20.7	15.1	25.0
Cotton	1.955	1.61	1.7	1.47	2.29
Jute & Mesta	1.90	1.90	2.10	2.05	2.016
Sugarcane	299.3	296.0	297.2	281.6	244.8

Table (a3) Index numbers of Agricultural Production *(Million tonnes)*

***(Base: Triennium ending 1981-82=100)**

Crop/Year	1981-82*	1999-00	2000-01	2001-02	2002-03P**
Foodgrains	62.92	169.7	158.4	172.0	140.0
(a) Cereals	54.98	175.1	165.5	177.8	144.8
Rice	29.74	180.3	170.9	187.5	146.1
Wheat	14.45	217.0	198.0	206.7	184.9
Coarse cereals	1.79	104.8	107.2	112.3	87.4
(b) Pulses	7.94	132.1	109.3	131.3	109.8
Gram	3.07	124.4	93.7	133.1	100.4
Non foodgrains	37.08	189.0	178.2	189.0	167.8
(a) Oilseeds Total	12.64	193.3	176.5	194.8	152.2
Groundnut	5.60	87.7	106.8	117.2	72.2
Rapeseed & Mustard	2.41	283.7	205.2	249.1	188.3
(b) Fibres	5.09	149.5	126.6	133.8	119.0
Cotton	4.37	153.3	126.6	132.9	116.2
Jute	0.55	145.9	144.2	163.3	160.1
Mesta	0.14	66.1	72.5	64.0	60.7
(c) Plantation crop	2.29	205.3	209.0	208.9	208.9
Tea	1.46	149.0	151.3	151.1	151.1
Coffee	0.44	210.1	216.8	216.3	216.3
Rubber	0.39	410.8	416.1	416.8	416.8
(d) Others					
Sugarcane	8.11	191.6	189.4	190.2	185.4
Tobacco	1.12	109.1	71.8	113.6	102.4
Potato	2.09	265.4	241.5	256.9	248.7
All commodities	100.0	176.9	165.7	178.3	150.5

*** P: Provisional, Source, Economic Survey 2003-04 conducted annual by the Dept. of Economic Affairs, Ministry of Finance, Govt. of India.*

Table: 4.1 (b): Classification of agriwaste based on physical shape and size and in terms of ash content (%)

Ash content	Powdery	Total % age of ash	Coarse/granular material	% age of ash	Stalk-like material	% age of ash
Low ash (upto 4%)	Eucalyptus sawdust	0.4	Kikar (Acacia)	0.6	Grewia optiva (bhimal)	0.32
	Sawdust (saw mill)	1.3	Walnut shell	0.7	Elephant grass (Miscathus)	0.4
	-	-	Labakshi	0.75	Khair wood	0.8
	-	-	Amla seeds	1.2	Corn cob	1.2
	-	-	Cedar cones	1.5	Jute stick	1.2
	-	-	Waste from Dabur	1.5	Vitex negundo	1.5
	-	-	Pine needle	1.5	Carissa carandas	1.6
	-	-	Harid	1.6	Soyabean stalk	1.5
	-	-	Coffee spent	1.8	Sunflower stalk (without spongy part)	1.9
	-	-	Bagassee	1.8	Adhatoda vasica	2.0
	-	-	Coconut shell	1.9	Mulberry stick	2.1
	-	-	Khandasari bagassee	2.6	Artemisia parviflora	2.3
	-	-	Fibre of green coconut	2.8	Tea bush stem	2.5
	-	-	Subabul leaves	3.6	Rhus cotinus (tunga)	3.0
	-	-	Groundnut shell	3.6	Besaram	3.1
	-	-	Tea waste	3.8	Jowar straw	3.1
	-	-	-		Arhar stalk	3.4
	-	-	-		Lantana cammara	3.5
	-	-	-		Mallotus phillippensis	3.7
	-	-	-		Thakal kanda	3.8
Medium ash (> 4% and upto 8%)	-	-	Cherry coffee	4.0	Congress grass (Parthenium hyusterophorus)	4.2
					Sunflower branch	4.3
	-	-	Tamarind husk	4.2	Gokhru (Xanthium strumarium)	4.5
	-	-	Sweet Sorghum bagassee	4.2	A grade grass	5.2
	-	-	Coffee chaff	4.6	Chirotha	5.2
	-	-	Cotton shells	4.6	Castor stick	5.4
	-	-	Tannin waste	4.8	Bidens	5.6
	-	-	Waste from Dabur (Bark)	5.1	Dry potato waste	5.8
	-	-	Arecanut shell	5.1	Ragi stick	7.1
	-	-	Coconut coir	5.2	Sweet sorghum stalk	7.4
	-	-	Coffee husk	5.8	-	-
	-	-	Coconut waste (top cover)	6.3	-	-
	-	-	Tea leaves	6.7	-	-
	-	-	Soyabean husk	7.2	-	-
	-	-	Sugarcane leaves	7.7	-	-
	-	-	Bagasse pith	8.0	-	-
High ash (>8%)	Industrial bamboo dust	9.9	Copver of castor	-	B grade grass	8.8
	Tobacco sawdust	19.1	Oil seeds	9.0	Jowar stalk	9.5
	Fly dust	19.2	Sal seed husk	9.4	Ageratum conyzoides	9.5
	Jute dust	19.9	Sunflower	10.1	C. ciliaris grass	9.7
	De-oiled bran	28.2	Waster hyacinth	10.8	Banmara weedq	10.9
	Dal lake weed	48.7	Mentha piperascens	13.5	Ficus	10.9
	Tobacco dust	49.4	Effluent sludge	14.4	Hybrid napier grass	11.5
			Mustard shell	15.4	Ground paddy straw	15.5
			Senna leaves	17.25	-	-
			Spearmint	18.1	-	-
			Sal seed leaves	19.7	-	-
			Decaffeinated tea waste	19.8	-	-
			Rice husk	22.4	-	-

Source: Proceedings of International Conference, New Delhi, April 3-6, 1995, pp 181-182[6, 53, 61, 76, 77]

4.1 AVAILABILITY OF AGRICULTURAL WASTES

Agriculture is the principal source of income and employment for most of the rural population in the country. Increased agricultural productivity is associated with increased biomass supplies which can be converted into high grade energy sources with modern technology. Such conversion is obviously preferable from an economical and environmental perspective compared to other energy delivery systems such as imported fossil fuels. In India, agricultural residues are the most abundant type of wastes available in the country. The principal agricultural residues produced in this sector are wheat straw, rice husk and straw, residues from cotton and arhar plantations, sugarcane, bagasse, stem, trash, ground nut shells, grass, coco shell, saw dust and animal residues.

Agriwaste materials are highly volatile as compared to coal. Over 80% of the heating value of agriwaste fuel is obtained from its volatile matter. Moisture content of agriwaste depends not only on natural conditions but also the storing conditions – whether stored in ponds or on dry decks. In general, agriresidue from young plantations contains more water than wood from an old plantation of the same species. Water contained in the agriwaste adds to its transportation cost. An increase in the moisture content from 10 to 30% in straw decreases its calorific value by 28% [19,23,54]. The calorific value or heat of combustion for a given volume of agriwaste material is primarily determined by its chemical composition, moisture content, and specific gravity.

4.2 AGRIWASTE BRIQUETTING

On the issues involved with agriwaste based energy and more particularly on the briquettisation potentials, processes, technologies, problems and remedies. researches have come up in the near past [see for example 13,19, 20,21,23, 54,]

Process

Briquetting is the process of compaction of agriwaste to produce homogeneous, uniformly sized solid pieces of high bulk density which can be conveniently used as a fuel. The compaction /densification of the agriwaste can be achieved by any one of the following methods:

(i) Pyrolised briquetting using binder
(ii) Direct briquetting (densification) of agriwaste using binder
(iii) Binder less briquetting

Except wood, all other agriwaste species have low bulk densities (74 kg/m^3 to 200kg/m^3, refer to Annexure-A). Accordingly, these are inconvenient and uneconomical to handle, store, and transport. Furthermore, the direct use of these materials for energy is associated with inefficient conversion and widespread combustion-related pollution. For efficient and less polluting environment utilization, it is imperative to process these materials so as to make them convenient fuels. The main feed preparation techniques are sizing, like making chips; densification; briquetting, pelletization and carbonization are shown in figure 4.1. To carry out the above operations, it is invariably desirable to dry the materials, either naturally in the sun or through mechanical processing.

Drying

While green wood contains 50–55% moisture, several agro-residues have the same or higher moisture content. These are needed to be dried to extract maximum energy. Annexure A gives the calorific values of agriwaste. Firstly, agriwaste is dried in the sun up to 20 – 25% moisture and later by thermal processes upto 5%. While various systems are employed for drying, the most common practice for chips and powdery materials is to simultaneously convey and dry the materials in entrained bed or flash pneumatic driers.

Size reduction

Many agriwaste residues are cut into smaller sizes for easy handling and efficient combustion. Straw and stalk-type materials are chopped by chaff-cutters into granular materials, either for baling or for easy transportation. Similarly, sticks are shredded for their efficient use in mixing. Size reduction is needed for briquetting and many other operations. It is desirable to use the materials in the original form as each conversion operation needs energy, and their handling results in the loss of material. The prices of agri residues are given in Annexure- A column xvii and briquettised agriwaste fuel prices in table (4.2 a, b, c, d, e, f).

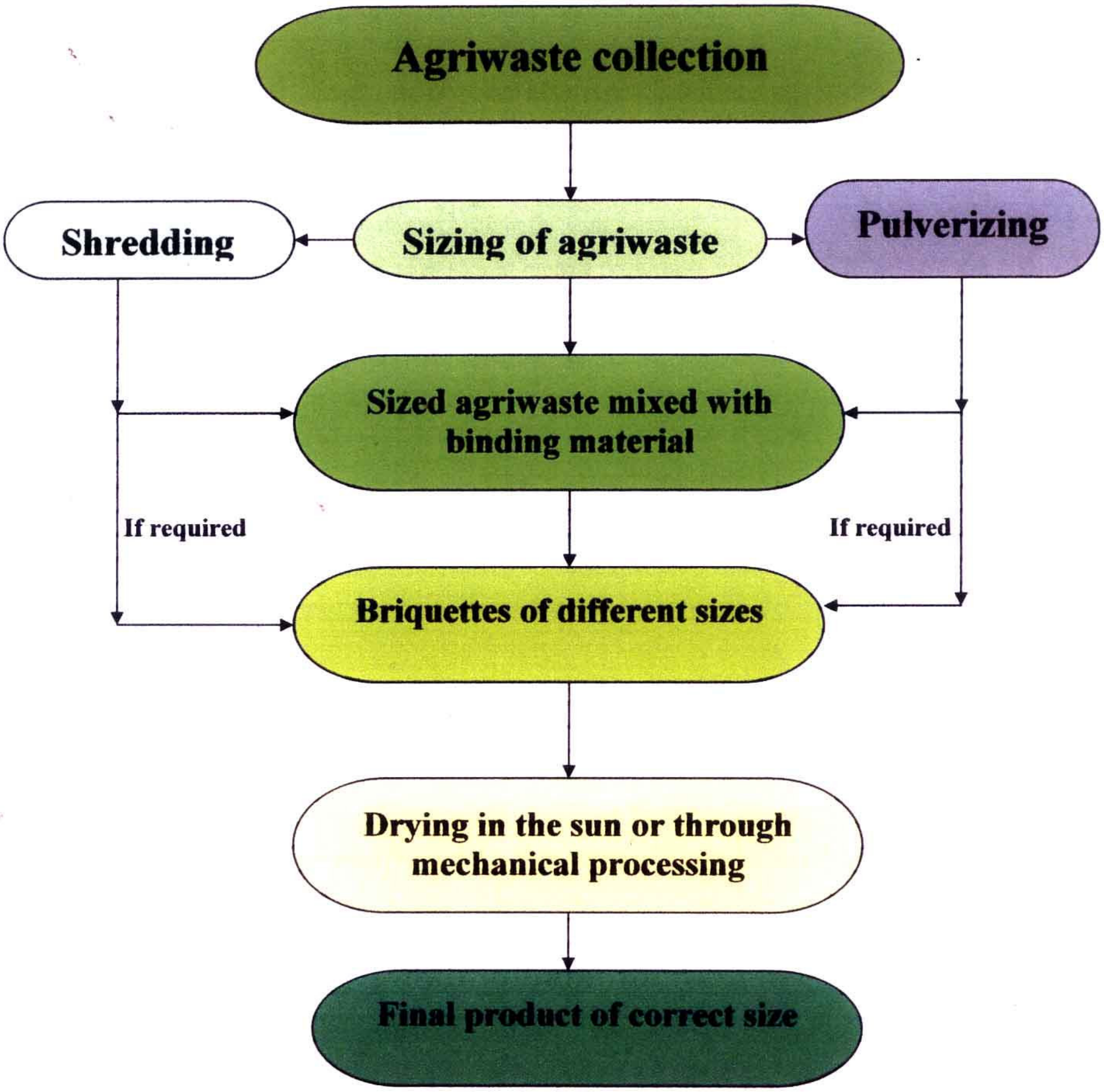


Fig. 4.1 Feed Preparation Flow Chart

Pre-Requisites for briquetting of agriwaste

- Raw Material Mix - There should be a minimum of two raw materials and one of them should be soft with high lignin or oil content.
- Raw Material Storage - Stock of material should be around 3 months of production capacity to maintain desired mix in the lean season.
- Briquetting Press - Presses should be in a position to work for 20 hours in a day and six days a week without heating.
- Pre-Processing Equipment - (i) Efficient drying is essential, (ii) Proper grinding to achieve desired bulk density is necessary; (iii) Heating of biomass may also increase the production and reduce the costs of power and wear of parts.
- Reliable and Adequate Power Supply - Continuous working of plant is desirable to increase the output and reduce the cost.

4.3 SUITABLE TECHNOLOGY FOR BRIQUETTING

There are many technologies like screw press, piston press, hydraulic press and roller press available for briquetting the agriwaste and the normal process is as follows: the agriwaste should be properly dried through some suitable drier to have a moisture content from 10 to 15%; the material is then crushed to bring it into uniform particle size. Many agriwastes are available in uniform size and need not be crushed. After the technology is chosen other parameters can be fixed. However, the briquettes of different sizes (1”x1”x1”, 2”x2”x2”, 3”x3”x3”, 4”x4”x4”, 8”x8”x8” inch cube and 3”x2”x1” cuboid) were prepared using Universal Testing Machine. These types of briquettes were dried over a period of 30 days. Moisture content and weights were regularly monitored under natural conditions. It was observed that the moisture content and weights of samples decreased and are shown in figures 1, 2, 3, 4 and 5 as in annexure C-2.

Figure-2 shows that on third day there was increase in moisture content due to heavy rain which affected the slope of the graph. In figure-5 again there was diversion in the graph due to sudden change of weather. The above mentioned figure show that as the day passes by, the moisture content in the samples decreases which results in the constant decrease in the weight of the samples.

4.4 FUEL MODELING (LINEAR PROGRAMMING)

Linear programming is applied to optimisation models in which the objective and constraint functions are strictly linear. This technique is used in a wide range of applications. It has efficient computational algorithms for problems with thousands of constraints and variables. Due to its large computational efficiency LP is the backbone of solutions algorithms.

In practice if linear programming models involve large number of variables and constraints the only feasible way to solve such models is by using computers. “TORA” is one such computer package which was available for the present work to solve moderate size problems. Data input in Tora is straight forward and simpler.

The following equations were developed by using Tora for maximisation of calorific value (HHV) and minimisation of cost.

Maximisation of Calorific Value

$W_1 CV_1 + W_2 CV_2 +$ ……………..$\geq$* W x HHV (weight x calorific value)

$X_1 CV_1 + X_2 CV_2 +$ ……………… $\geq$ HHV (Calorific value)

$W_1 + W_2 +$…………………………= W (weight)

$X_1 + X_2 +$ ………………………… = 1

$W_1 C_1 + W_2 C_2 +$ ……………….. $\leq$ W X C (weight x cost)

Or $X_1 C_1 + X_2 C_2 +$ ……………. $\leq$ C (cost)

C = Cost

* We have different combinations of fuels which should give calorific value (HHV) greater or equal to the value i.e. 4000 kCal/kg. In no case, calorific value given by fuel combinations should be less than (HHV) least it can be equal to HHV.

Minimisation of cost

$Z = X_1 C_2 + X_2 C_2 +$ …………… $+ X_n C_n$ (minimise cost)

(1) $X_1 CV_1 + X_2 CV_2 +$ ………… $CV_n X_n \geq CV$ (Ref. table 4.2a)

(2) $X_1 + X_2 + X_3$ ………………… $X_n = 1$

(3) $X_1 C_1 + X_2 C_2 +$ ……………… $X_n C_n \leq C$

$X_i \geq 0$

`Xi = fraction of the fuel

CVi = Calorific value of the fuel

Ci = Cost of the fuel

Wi = Weight

C = Cost, that is to be minimised

CV = calorific value that is to be maximised

C& CV are calculated for the maximum possible combinations which are shown in table 4.2a and 4.2b . Value of C & CV can be seen from the said tables.

A computer programme in C++ was developed (Annexure-D). The values of CV were calculated for different combinations. These were further validated by TORA Software (Annexure-E). The Tables 4.2 (a, b & c) show the raw material, transportation, power and labour maintenance & repair and marketing costs for various bi & multi fuel combinations.

TORA Optimization system, Source: Hamdy A. Taha, May 11, 2005.

Table 4.2(a) : BRIQUETTISATION OF AGRIWASTE

Fuel	Cost of raw material (Rs).	Multifuel product Mixes						Material Cost for multifuel combinations (Rs.)					
		I						II					
		MF1	MF2	MF3	MF4	MF5	MF6	MF1	MF2	MF3	MF4	MF5	MF6
F1 Rice Straw	400 – 600	50	50	-	-	-	30	300	300	-	-	-	180
F2 Rice Husk	350 – 450	-	-	50	45	40	10	-	-	300	270	240	60
F3 Saw Dust	400 – 600	25	5	30	35	25	15	150	30	180	210	150	90
F4 Leaves	50 – 100	15	30	10	15	30	30	15	20	10	15	20	25
F5 Flowers	100 – 200	-	15	-	5	5	15	-	30	-	10	10	30
F6 Wheat Straw	450 – 600	-	-	10	-	-	-	-	-	60	-	-	-
F7 Branches	25 – 50	-	-	-	-	-	-	-	-	-	-	-	-
F8 Bagasse	400	-	-	-	-	-	-	-	-	-	-	-	-
F9 Cottom Stocks	400 – 450	-	-	-	-	-	-	-	-	-	-	-	-
F10 Mustard Stocks	200 – 350	-	-	-	-	-	-	-	-	-	-	-	-
F11 Cotton pods	200 – 250	-	-	-	-	-	-	-	-	-	-	-	-
F12 Ground Nut (Shell Husk)	400 –500	-	-	-	-	-	-	-	-	-	-	-	-
F13 Trees	100 –150	10	-	-	-	-	-	15	-	-	-	7.5	-
F14 Grass	10 – 50	-	-	-	-	-	-	-	-	-	-	-	-
Raw material cost (Rs.) per tonne →								**480**	**380**	**550**	**505**	**427**	**385**
Calorific value kJkg →		**18000**	**16580**	**19725**	**19785**	**17780**	**16850**	**Raw Material + Transportation Cost**					
								830	805	875	880	802	910
								A	B	C	D	E	F
Power & Labour 01 →								800	500	600	400	600	400
Maintenance & Repair 02 →								400	150	300	200	300	200
Marketing 03 →								100	100	100	100	100	100
Total Cost (Rs.) of the Fuel per tonne								**2130**	**1555**	**1875**	**1580**	**1802**	**1610**

Like $MF1 = 0.5\,F1 + 0.25F2 + 0.15F4 + 0.1F14 \geq HHV$

Similarly $MF5 = 0.4F2 + 0.25F3 + 0.30F4 + 0.05\,F5 \geq HHV$

Table 4.2(b) : Cost of Transportation for multifuel combinations (Rs.)

Transportation cost					
MF1	MF2	MF3	MF4	MF5	MF6
150	150	-	-	-	150
-	-	100	100	100	100
75	75	75	75	75	75
50	50	50	50	50	50
-	150	-	150	150	150
-	-	100	-	-	150
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
75	-	-	-	-	-
350	**425**	**325**	**375**	**375**	**525**

Table 4.2(c) : Cost of Briquettised bifuel combinations

(Bi-fuel)						
	BF1	BF2	BF3	BF4	BF5	BF6
F1 Rice Straw (400-600)	80	70	-	-	-	-
F2 Saw dust (400-600)	20	-	-	-	-	-
F3 Malee (400-600)	-	30	80	40	15	40
F4 leaves (50-100)	-	-	20	60	-	60
F5 Grass (10-50)	-	-	20	-	85	-
Cost of raw material + transportation cost	600	600	500	300	132	300
Labor Cost	800	500	600	400	600	400
Maintenance Cost	400	150	300	200	300	200
Marketing Cost	100	100	100	100	100	100
Total cost	**1900**	**1350**	**1500**	**1000**	**1132**	**1000**

Table 4.2(d) : Element-wise contribution towards Transportation of end product (Rs.)

	0 – 10	10 – 30	100 – 200	< 200
Rice Straw	100	150	-	-
Saw Dust	50	75	150	200
Grass	50	100	150	-
Leaves	25	50	100	-
Flowers	100	150	-	-
Cotton Stalk	150	200	-	-
Mustard Stalk	75	150	-	-
Trees	50	75	-	-
Rice Husk	50	100	150	-
Wheat Straw	50	100	200	-

Table 4.2 (e) : BIFUEL BRIQUETTES

Combinations	BF7	Rice Straw = 80% Groundnut = 20%	CV = 16712 kJ/kg
	BF8	Rice straw = 80% Maize = 20%	CV = 14360 kJ/kg
	BF9	Rice Straw = 50% DOC = 50%	CV = 19158 kJ/kg
	BF10	Rice Straw = 20% Leaves = 80%	CV = 19776 kJ/kg
	BF1	Rice Straw = 70% Malee = 30%	CV = 16800 kJ/kg
	BF12	Grass = 80% Rice Husk = 20%	CV = 19800 kJ/kg.

Table 4.2 (f) : MULTIFUEL BRIQUETTES

Combinations	MF7	Rice Straw = 20% Saw dust = 50% Leaves = 15% Branches = 15%	18000 App. kJ/kg
	MF8	Rice Straw = 60% Groundnut shell=10% Leaves = 20% Flowers = 10%	16880 kJ/kg
	MF9	Saw dust = 45% Sunflower = 20% Mustard Stock = 20% Wheat Straw = 15%	19725 kJ/kg
	MF10	Malee = 40% Leaves = 30% Mustard stock = 20% Rice husk =10%	19785 kJ/kg
	MF11	Rice Husk = 45% Saw dust = 25% Leaves = 20% Branches = 15%	17880 kJ/kg
	MF12	Wood chips = 20% DOC = 20% Mustard straw = 10% Leaves = 5%	21873.6kJ/kg
	MF13	Grass = 20% Leaves = 50% DOC = 15% Branches = 15%	21630kJ/kg
	MF14	Leaves = 30% Grass = 30% Cotton pods = 40%	20937kJ/kg
	MF15	Leaves = 50% DOC = 30% Grass = 20%	21714k/kg

Tables 4.2 (a) to 4.2 (f) show the combinations of raw material of fuel so as to get the maximum calorific values and minimum cost whereas combinations from the said tables are denoted by MF1, MF15, (MF1 means multifuel at serial No. 1 from table 4.2a, MF5 fuel combination at serial No. 5.

Space Requirements

Briquette size prepared 2 x 2 x 2 = 2^3 inch^3 = 3 x 2 x 1 inch^3 Briquette of size 34 x 28 x 17 inch^3 which is being used of single material. Wt. of 2 inch^3 briquette = 52 g = 0.052 kg Area of room or shed = 20 x 20 x 20 feet^3 = 1728000 So that 20 x 20 x 20 room will have 1728000= 2303994.2 briquettes Wt. of 1728000 briquettes = 1728000 x 0.052 = Wt. of 2303994.2 briquettes = 1658875.59 kg = 165.8875 tonnes Similarly 12 x 6 x 6 size briquette will weight 1.750 g No. of Briquettes = 31808.288 Wt. of briquettes = 55664.504 kg = 55.6645 tonnes. Briquette size 3 x 2 x 1 Wt. 72 kg = 0.072 kg	*Room Size 20 x 20 x 20 cubic feet* No. of briquettes = 14.400 Wt. of briquettes = 14400 x 0.052 = 748.8 kg = . 7488 tonnes = 6.666 x 10 x 144 No. of briquettes = 9600 Wt. of briquettes = 9600 x 0.072 = 6912 kg = 6.912 ton = 1.66 x 3.33 x 144 No. of briquettes = 796.8 Wt. of briquettes = 1394.4 kg = 1.3944 tonnes

Source: RWEDP report No. 23: Proceedings of international Workshop on Biomass Briquetting, New Delhi (3-6 April 1995) pp. 24-30
BF1 – BF6 (Bi-fuel combinations)
MF1 – MF9 (Multi-fuel combinations

Raw materials from the above mentioned tables were selected for preparation of fuel briquettes. The materials like leaves, bagasse, grass, wood chips, and mustard straw cotton stalks were milled/ shredded.

These materials were mixed with binders or with out binders. Fuel briquettes of 1, 2, 3, 4, inch cube and 3 x 2 x 1 cuboid size were prepared with the help of universal testing machine applying 1.5 to 4 kN of load. Raw materials are shown in figure 4.2 and fuel briquettes in figure 4.3. These Combinations were tested for their for calorific value, moisture content, volatile content and ash content (Tables 4.3 and 4.4 present some of these of values)

Fig. No. 4.2

Fig. 4.2 (1) shows raw material mailee. Fig.4.2 (2) Mailee local. Fig. No.4.2 (3) mustard straw. Fig. 4.2 (4) Wood chips. Fig. 4.2 (5) deoiled cake (DOC). Fig. 4.2(6) Bagassee

Fig. 4. 3

Fig. 4.3 (a) Shows briquettes of rice husk, leaves, saw dust, and grass. Fig. 4.3 (b) Shows briquettes of rice straw and leaves. Fig. 4.3 (c) Shows briquettes of rice straw , saw dust and mustard straw.

4.5 TESTING OF BRIQUETTES

Proximate Analysis

The moisture, volatile matter, ash content, fixed carbon of the fuel mix, and char were determined through proximate analysis [8]. Moisture content was determined by heating 1 g of sample at 110°C in an oven for 1 hour. The weight loss of the sample during this period yielded the moisture content. Volatile matter was determined by heating 1 g of sample in a covered platinum crucible for 7 min. The weight loss during the period was used to determine volatile matter. Ash content was determined by heating 1 g of sample in an uncovered platinum crucible at 750°C until the sample was completely burnt. A constant weight of the sample after repeated heating indicated the complete combustion. Fixed carbon was determined as the difference between total mass and the sum of the moisture, ash and volatile matter. These were determined with the help of muffle furnace (specifications, Dimensions (WxHxD)= 11¼” x 18” x 15½”, Chamber size (WxHxD) = 5”x4”x6”, Watts=1000, Power 50/60 hz, VAC=120, Temperature range = 260° to 1200°C), The calorific values were estimated with the help of bomb calorimeter (IS:1359-1959, IP 12/63T, 1°C corresponds to 1.8°F, time in minutes, temperature range 25°C to 40°C (Refer Annexure-G1,G2).

COMBINATIONS (Prepared)

Table 4.3 : ***Bi Fuel***

Bi Fuels (BF) combination	MC %	AC %	VC %	CV
B/F1 Rice Straw=70% Leaves = 30%	10.2	10	78.2	16711 kJ/kg
B/F2 Wheat straw = 70% Rice Straw 30%	11.7	11.5	74.9	16863 kJ/kg
B/F3 Rice Straw = 65% Ashoka leaves 35%	14.8	8.9	74.8	19567 kJ/kg
B/F4 Mustard Straw = 55% Poplar Tree shredding = 45%	9.8	10.3	79.6	20160 kJ/kg
B/F5 Ashoka tree = 50% Leaves = 50%	10.5	9.8	79.1	20580 kJ/kg
B/F6 Leaves = 60% Wood chips = 40%	11.1	10.10	78.1	20916 kJ/kg

*** B/F1 – B/F6 Biofuel combinations**

Table 4.4 ***Multi-fuel***

Multi-fuels (MF) combination	**%age of combinations**	**MC %**	**AC%**	**VC%**	**CV**
$M^{/}F1$*	Leaves = 20% Rice Husk = 55% Wheat Straw = 25%	15.8	8.0	74.2	17997 kJ/kg
$M^{/}F2$	Saw dust = 25% Flower = 20% Mustard straw = 20% Wheat straw = 15%	16.0	10.0	73.1	19725 kJ/kg
$M^{/}F3$	Leaves = 35% Grass = 25% Trees shredding 40%	10.0	6.0	80.1	20819 kJ/kg
$M^{/}F4$	Saw dust = 10% Leaves = 20% Flowers = 10% Rice Straw = 60%	17.6	7.0	73.1	16774 kJ/kg
$M^{/}F5$	Leaves = 20% Grass = 20% Rice Straw = 30% DOC = 30%	15.8	5.8	75.9	19782 kJ/kg
$M^{/}F6$	Rice straw = 60% Wood chips = 20% Cotton stalks = 10% Bagasse = 10%	10.2	8.0	78.8	19846 kJ/kg
$M^{/}F7$	Leaves = 10% Grass = 10% Bagasse = 30% Mustard straw = 50%	10.8	9.0	79.8	20365 kJ/kg
$M^{/}F8$	Rice straw = 20% Leaves = 20% Grass = 20% DOC = 20%	10.8	7.5	80.3	20790 kJ/kg
$M^{/}F9$	Ashoka leaves = 20% Grass = 15% DOC = 15%	8.1	8.0	83.1	21882 kJ/kg

*** $M^{/}F1$ – $M^{/}F9$: Multi-fuel combinations**

4.6 TECHNOLOGIES FOR COMBUSTION

Combustion is the dominant and established technology to harness the energy from agriwaste. Several firing methods have been developed and practiced such as grate firing, stoker firing, pulverized fuel firing and fluidized-bed combustion. The selection of the most appropriate firing method depends upon the size of the unit, fuel conditions (moisture, feed size), and the energy product. The grate-fired systems have been widely used because of their ability to handle fuels with high moisture content (up to 60%); to handle fuels with large particle size; and to perform staged combustion. The Fluidised Bed Combustion System was used to test (to test combustion related properties of briquettised fuel) briquettes, (refer to chapter – 5) the details of this equipment are given in the forth coming chapter.

Salient Features of Using Fuel Briquettes

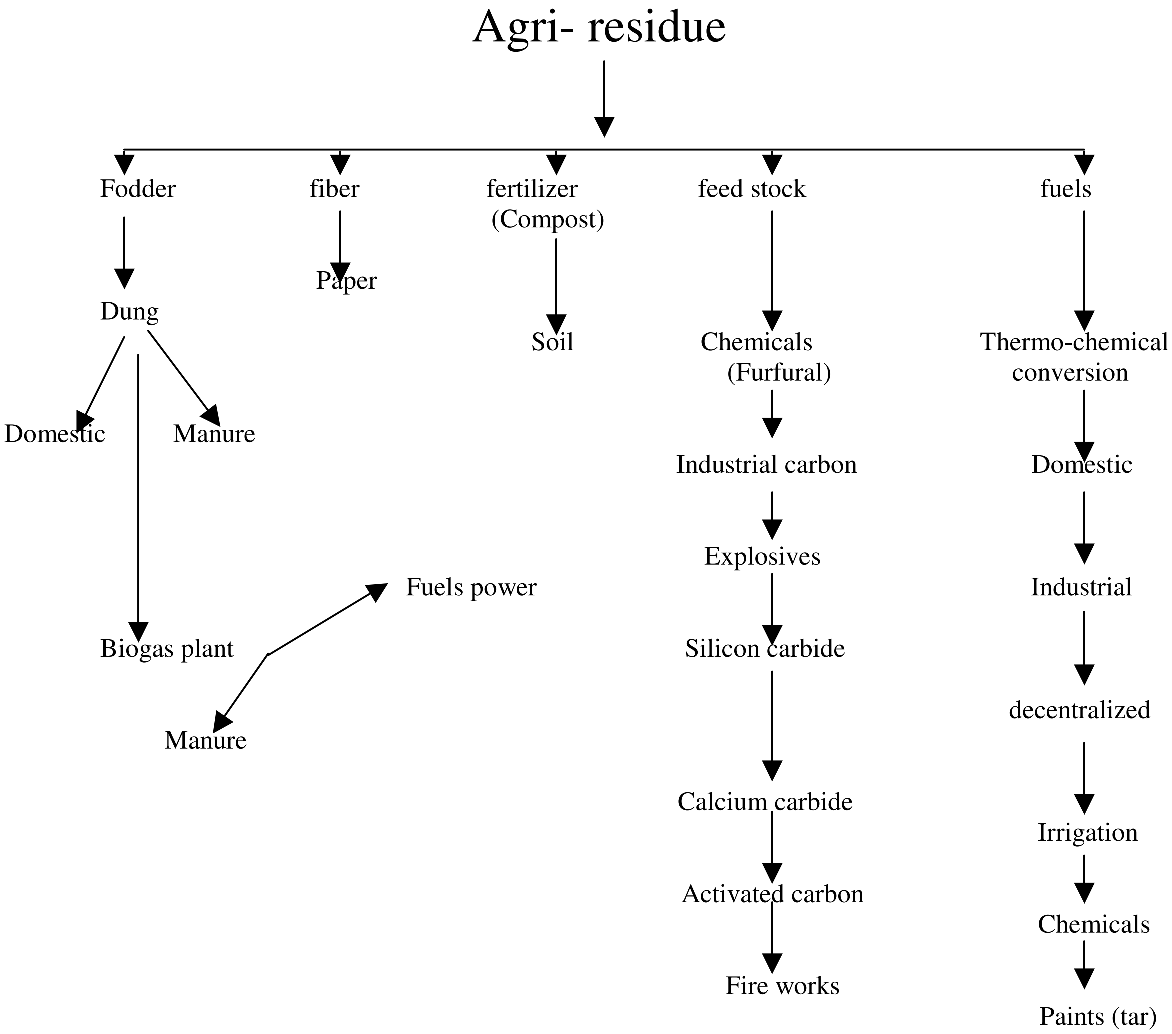
- Easy to burn - lower ignition temperature compared to coal. Smokeless burning and sustained combustion and the temperature requirement is achieved due to very efficient combustion. Leaves only white ash without any fixed carbon. Full heat value is utilized.
- Easy to handle and 1000 kgs of briquettes per cubic meter can be stored and transported against 50 kgs of agri-waste.
- Less pollution to the environment and with negligible toxic gas, sulphur emission and odour.
- Ash content is 4 to 10%.
- The natural polymer such as lignin and cellulose acts as binders and provides mechanical support and also provides resistance to decay and repels water.
- The briquettes can be used in gasifires and the partially pyrolysed briquettes can be again used as a substitute for high value added charcoal for domestic and industrial use leaving the fuelwood unutilized and thus avoiding deforestation.
- These briquettes are used in (FBC) fluidized bed combustion system.

* *Punjab State Electricity Board Report*

Social Benefits

- Environment friendly and results in less pollution as compared to all conventional fuels[6, 19, 22, 47, 54, 76, 77, 78, 81].
- Avoids using conventional non-renewable resources like coal, which means more useful in future as less dependency on fossil fuels.
- Money spent on re-forestation programmes can be minimised or more land can be re-forested.
- Due to efficient utilization of agro-waste, farmers will receive some income from their agro-waste, will make their farming more remunerative and attractive and thereby their standard of living is likely to improve.

The figure 4.4 shows the uses of agri-residues



Source: RWEDP Report No. 23: Proceedings of international workshop on biomass Briquetting, New Delhi India, April 3-6, 1996, pp. 152-158

Results:

- As mentioned earlier samples of different agriwaste were collected and calorific value of each one of them was computed (annexure-A). The material cost and transportation cost for each element was established from market conditions and the supporting literature.

- Then the fuel modeling equations were developed with the objective of maximization of CV and minimization of cost.

- Majority of combinations, both bifuel and multifuel gave a calorific value higher than the F grade coal, which was considered as a bench mark (base value). Among the bifuel combinations reported as per table 4.2(e) and 4.3 combination of leaves and branches give the higher calorific value of nearly 21000 kJ/kg. A combination of various leaves only gave CV of 20580 kJ/kg. Rice straw with groundnut shell gave CV of approximate 19600 kJ/kg(Table 4.3) Rice straw with leaves gave about 19800 kJ/kg and similar were the results of rice husk with grass (Table 4.2 e)

- Multifuels gave still better results 4.2(f) MF-6 gave a combination of CV approaching 22000 kJ/kg.

- Some other combinations gave CV valueshigher than 21000 kJ/kg (units).

- Most of the multifuel combinations tried with rice straw and rice husk as one of the major elements of the combinations gave CV of much higher than the base value 4.2(a), 4.2(f), 4.4 (MF 1, MF 9, MF 12,MF 13,MF 14, MF 15)

- The cost range for bifuel was between Rs. 1030-Rs.1900/tone of fuel (Ref. 4.2(c)

- Cost ranges of multifuel combinations were between Rs. 550-2150/tonne (Ref. 4.2a 4.2c)

CONCLUSION

- The results reveal that majority of the bifuel and multifuel combinations give higher calorific value (CV) than F grade coal.
- The price range of these fuels are much lower (less than half the price of the coal) per tonne of the fuel.
- The space requirement for storage of briquetted fuel are much less as compared to various agriwastes.
- Rice straw and rice husk give high CV combinations with some agriwaste.
- Rice straw is one of the abundantly available agriwaste and cause of environmental pollution as it is burnt in the fields after harvesting.
- It reveals that some of the agriwaste combinations can be used as fuels and have both the efficiency and cost advantage.
- These fuels are environmental friendly.

This compares well with the present landed cost of F/C grade coal (CV 4000 kCal/kg of Rs.4500 per tonne)

CHAPTER : 5

EXPERIMENTAL SET-UP OF FBC SYSTEM

5.1 INTRODUCTION

Fluidization is a technique which is used in processes where a non homogenous reaction takes place, because of wide contact surface between solid and gas.

Known since 1942, this technology[79] was applied mostly in chemical and petroleum industry. Only recently it has made an appearance in the power plant realm. Compared to conventional power plant equipped with pollution control systems, a fluidized bed combustor (FBC) has the advantage of easy operation and capability of using low quality and high moisture fuels, such as refuse derived fuels (RDF), mine residues and waste. Further more, the lower operating temperatures of FBC minimize hazardous emissions. Fluidized bed combustion (FBC) system was developed in the mechanical engineering research laboratory using dolomite as bed material and bi/multi fuel combinations as fuel in the combuster.

5.2 FABRICATION OF FBC SYSTEM

Table 5.1: Giving the material list

Components/parts	Material/specification
Furnace, cyclone, economizer	Mild steel – 18 gauge
Nozzles	Mild steel/copper – tapered drilled
Tubing	Copper
Base plate	Mild steel
Piping	G.I
Insulation	Fireclay
Bed Preparation	Silica sand, dolomite
Rota meter	
Manometer	
Thermocouples	
Blower	3hp, air velocity = 30.5m/s, 2.2kW

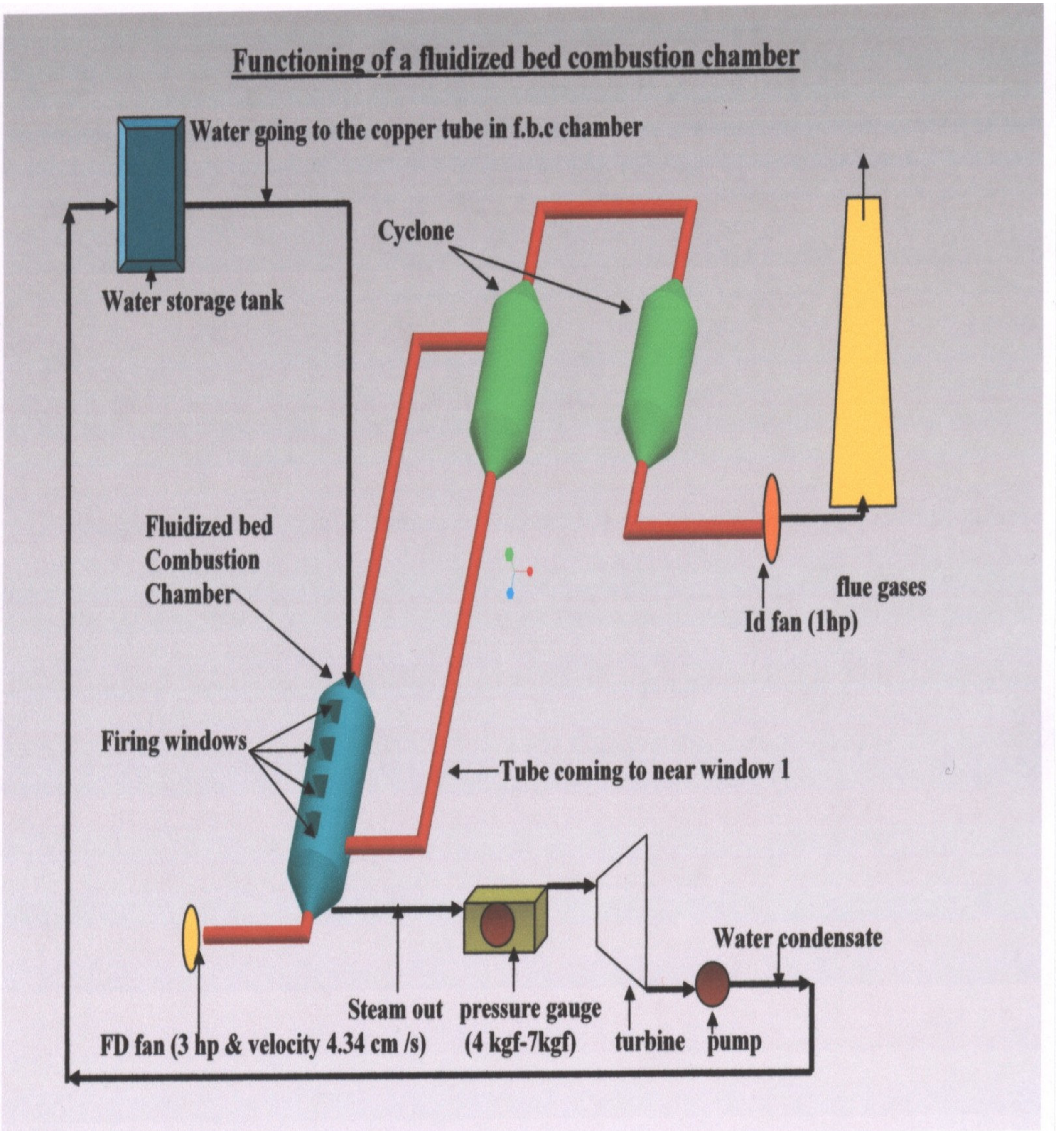


FIG. 5.1(a) : FLOW DIAGRAM OF FBC SYSTEM

PROPERTIES OF GASES
ASSUMED PARAMETERS

Table 5.2 : Representing the properties of gases and assumed parameters

Parameter	**Units**	**Magnitude**
Mass flow of air	kg/s	0.05
Air inlet temperature	°C	50
Air outlet temperature	°C	200
Water inlet temperature	°C	20
Water outlet temperature	°C	80
Tube material	-	copper
Internal Diameter	Mm	12
Tube outside diameter	Mm	15
Chosen particle	-	Silica sand
Particle size	μm	300
Minimum fluidizing velocity at 200°C	m/s	0.25
Physical Properties		
Particle density	kg/m^3	2640
Air mean specific heat	kJ/kgK	1.04
Air thermal conductivity at 200°C	W/mK	3.87×10^{-2}
Air density at 1atm, 200°C	kg/m^3	0.746
Air viscosity at 200°C	kg/ms	2.58×10^{-5}
Water viscosity at 50°C	kg/ms	544×10^{-6}
Water Prandtl number at 50°C	-	3.54
Water specific heat Cpw	kJ/kgK	4.18
Water thermal conductivity	kW/mK	634×10^{-6}
Copper thermal conductivity	W/mK	380

(*Source : Fluidised Beds, J.R.Howard, U.Kpp89-110)

5.2.1 CALCULATION OF PIPE LENGTH OF COPPER FOR THE SYSTEM

The duties required from the heat exchanger and water flow rate are,

Water flow rate = $\frac{Duty}{cp_w}(Tw_o - Tw_i)$ = 1/20kg/ s (For properties ref. Table 5.2)

$$= m_w \times cp_w (T_{wo} - T_{wi}) \quad (cp_w = 4.18)$$

$$\frac{1}{20} = \frac{Duty}{4.18}(80-20)$$

$$= \frac{Duty}{4.18}(60)$$

$$\frac{Duty}{4.18}\times 60 = \frac{1}{20}$$

$$Duty \times 60 = \frac{1}{20}\times 4.18$$

$$Duty \times 60 = 0.209$$

$Duty = 12.54$ kW (assumed)

Re = Reynolds number

$$= \frac{\rho u d}{\mu}$$

$$= \frac{1000 \times .446 \times 0.012}{544 \times 10^{-6}}$$

$$= \frac{.446 \times 0.012 \times 10^{3}}{544}$$

= 9870.34 × 1.658

= 98382

Pr = Prandtl number (Ref. table 5.2)

Nu = Nusselt number

= 0.023 $(\text{Re})^{0.8}$ $(\text{Pr})^{0.4}$ (Dittus-Bolter equation)

= 0.023 $(98382)^{0.8}$ $(3.54)^{0.4}$

= 376.00

At the inner surface, hear transfer coefficient, h

$$h = \frac{Nuk}{d}$$

$$= \frac{374 \times 634 \times 10^{-6}}{0.012}$$

= 19.75 kW/m^2K

At the outer surface, first checking that it is not outside its range of applicability

Ar = Archimedes Number

$$= \frac{(427 \times 10^{-6})^{3} \times 0.446 \times 2640 \times 9.81}{(2.58 \times 10^{-5})^{2}}$$

$$= \frac{7.7854 \times 0.446 \times 2640 \times 98.1}{(-7)}$$

$$= \frac{8.9927}{6.6564 \times 10^{-10}}$$

= 1008

At the outer surface, first checking that it is not outside its range of applicability

$$\text{Re}_{mf} = \frac{P_f U_{mf} d_p}{\mu_f} \leq 12.5$$

$$= \frac{0.745 \times 0.085 \times 300 \times 10^{-6}}{2.58 \times 10^{-5}}$$

= 7.363

h_{max} $= 35.8 P_p^{0.2} \times K_f^{0.6} \times d_p^{-0.36}$

$= 35.8(2640)^{0.2} \times (3.87 \times 10^{-2})^{0.6} \times (300 \times 10^{-6})^{-0.36}$

$= 35.8(4.8341) \times 0.1421 \times 0.1283$

= 331.31 W/m^{2}K

70% of 331.31 W/m^{2}K gives the heat transfer at the outer surface of the tube.

h_o= 231.917 W/m^{2}K

Overall thermal Resistance is given by

$$\frac{1}{UA} = \frac{1}{h_o A_o} + \frac{1}{h_i A_i} + \frac{t}{kA_m}$$

where, A_o = $\pi doL, Ai = \pi d_i L$ and $Am = 0.5\pi$ (do + di)

$$\frac{1}{UA} = \frac{1}{\pi L}\left[\frac{1}{331 \times 0.015} + \frac{1}{19.86 \times 0.012} + \frac{0.003}{380 \times 0.02043}\right]$$

$$= \frac{1}{\pi L}\left[\frac{1}{0.04952} + \frac{1}{0.2383} + \frac{0.003}{0.077634}\right]$$

$$= \frac{1}{\pi L}\left[\frac{1}{0.04952} + \frac{1}{0.2383} + \frac{1}{0.03864}\right]$$

$$= \frac{1}{\pi L}\left[174.94 + 4.19 + 25.878\right]$$

$$= \frac{205.97}{\pi L} \text{ k/kW}$$

$$\text{LMTD} = \frac{(Ta_o - Tw_o) - (Ta_o - Tw_i)}{\lambda n \dfrac{(Ta_o - Tw_o)}{(Ta_o - Tw_i)}}$$

$$= \frac{(253 - 80) - (253 - 20)}{\lambda n \dfrac{(253 - 80)}{(253 - 20)}}$$

$$= \frac{173 - 233}{\lambda n \dfrac{173}{233}}$$

$$= \frac{-60}{\lambda n \dfrac{173}{233}}$$

$$= \frac{-60}{-0.2977}$$

= 201.54 or 202K

Also

Overall thermal resistance = $\dfrac{LMTD}{Duty}$

$$\frac{1}{UA} = \frac{LMTD}{Duty}$$

$$\frac{205.97}{\pi \mathrm{L}} = \frac{202}{12.54}$$

$$\mathrm{L} = \frac{205.97 \times 12.54}{\pi \times 202}$$

$$= \frac{2582.8638}{3.142 \times 202}$$

$$= \frac{2582.8638}{634.648}$$

= 4.069m

The arrangement of pipes is shown in the Figure.1

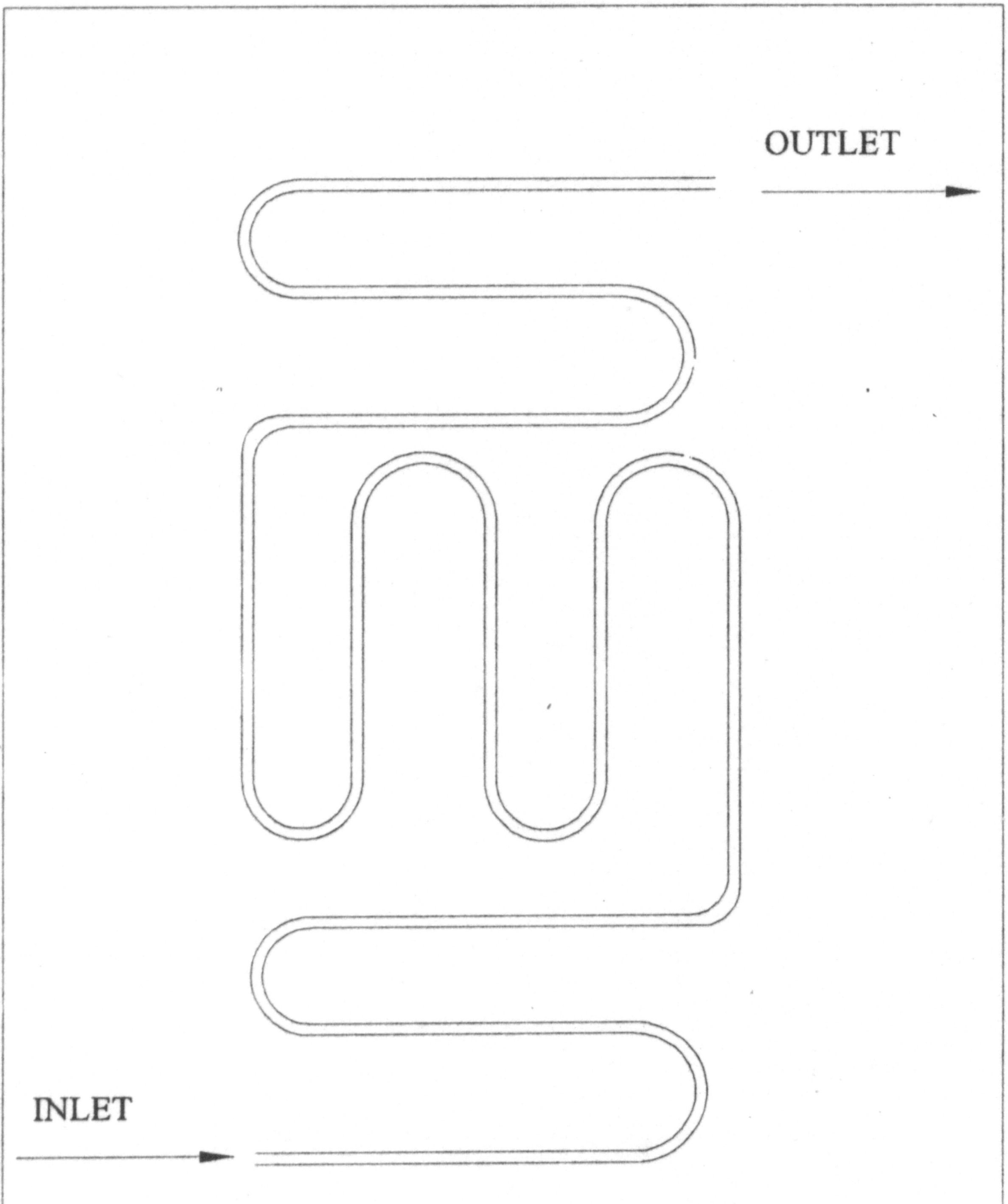


Fig . 5.1 Tube arrangement in FBC system

5.2.2 FURNACE

Furnace of mild steel (18 gage) sheet rolled to form a cylinder. The internal diameter of the cylinder is 16” and height is 36”. With the plenum at the base. The furnace contains four input windows for feeding fuel at a height of 4”, 12”, and 20”and 28’from the bottom of the furnace. Windows can be closed or opened as desired. The furnace with firing windows is shown in figure 5.2.

Fig. 5.2: Furnace with firing windows

5.2.3 DISTRIBUTOR PLATE [8, 80, 83, 86]

Distributor plate is used to distribute air equally into the furnace and to form hydrodynamics. It is fabricated from mild steel (18 gage) sheet. Diameter of the distributor plate is 16" (45.8 cm). With 14 nozzles 1 nozzle at the centre, 5 nozzles at the radial distance of 3" and remaining 8 nozzles at a radial distance of 8 inches. This distributor plate is fitted at the distance of 2" from the bottom of the furnace and welded to the furnace to make a leak proof joint. Pressure drop a cross the distributor plate

$\Delta P_{dist} = k_g \rho_b L_b \qquad \Delta p_{dist} \geq 2500\,pa$

$= 9.81 \times 2640 \times 0.05$

$\geq 2.5kPa$

k=0.3

$U_h = C_d \sqrt{\dfrac{2\Delta p_{dist}}{\rho_g .h}}$ Air velocity through the distributor plate

$= 0.6\sqrt{\dfrac{2\times 0.3}{0.64}}$

$= 0.6\times 0.77$

$= .46m/s$

Figure (5.3) (a) & (b)

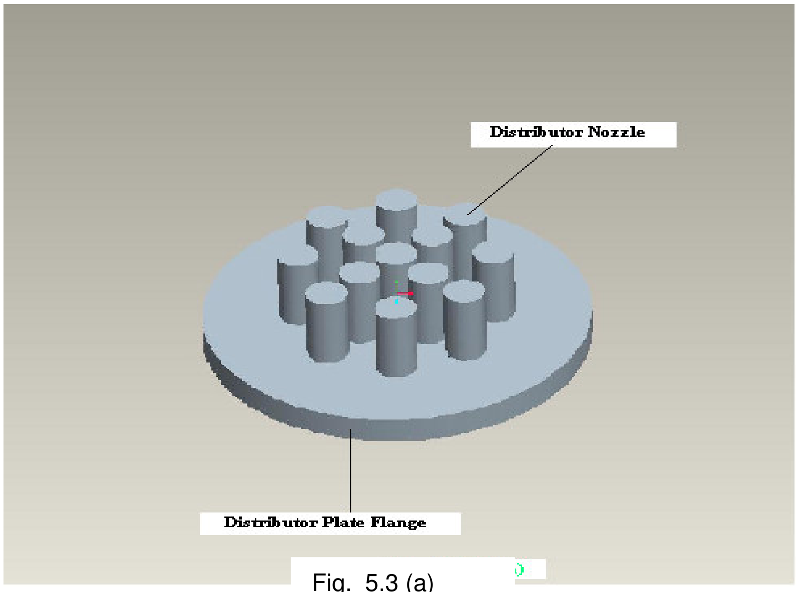


Fig. 5.3 (a)

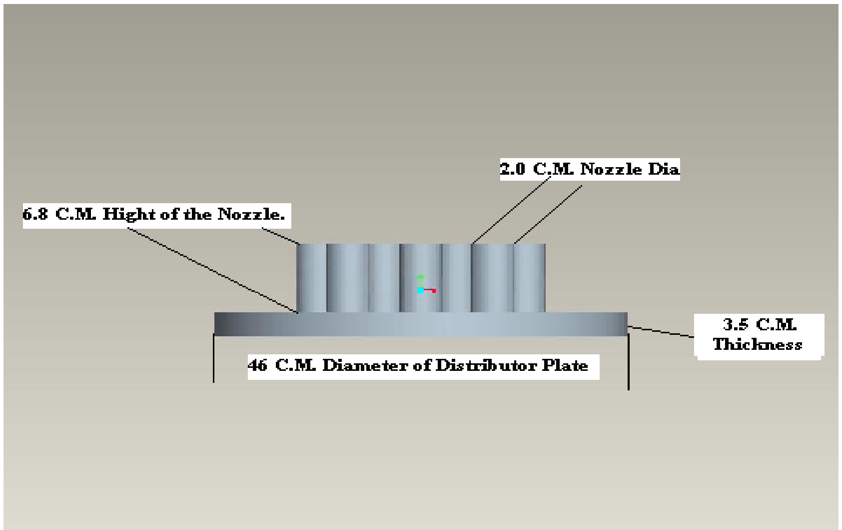


Fig. 5.3 (b)

5.2.4 NOZZLES [8, 80, 83, 86]

The nozzles are used to inject air at high pressure into the furnace and distribute equally the air into the furnace; these are also used to form hydrodynamics in the furnace. The nozzles are made from mild steel rod. Calculations are given as under :

mass flow rate of air = $.54 m^3/s$

Temperature of air = 150^oC

Inlet diameter (Assumed) = 15 mm

Mass remains constant

$m_1=m_2$

$$\frac{A_1V_1}{V_sP_1}=\frac{A_2V_2}{V_sP_2}$$

Inlet $P_1V_1 = MRT_1$ $\quad Vsp_1=\frac{287\times 423}{10^5}=1.12m^3/Kg$

$$\frac{A_2}{A_1}=\frac{V_1}{V_2}\times\frac{Vsp_2}{Vsp_1}=\frac{1.34}{6.94}\times\frac{Vsp_2}{1.21}$$

$$Vsp_2 = \frac{1}{P200°C} = \frac{1}{.746} = 1.34 m^3 / Kg$$

$$\frac{d_2^2}{d_1^2} = \frac{1.34 \times 1.34}{6.94 \times 1.21} = \frac{1.796}{8.3974} = 0.2138$$

$$\frac{d_2}{d_1} = .4624$$

$$d_2 = d_1 \times .4624 => 15 \times .4624 = 6.94 mm$$

Mass/nozzle = $.54 \times \frac{\pi}{4} (0.0508)^2 \times .4769$

= 0.3654 Kg/s

Number of nozzles = $\frac{.54}{.36} = 14$ nozzles (assumed

Each nozzle contains one exit port only Figure (5.3 a & b).

5.2.5 PLENUM [8, 80, 83, 86]

Plenum is used to collect the air from blower and to pass the air equally into the furnace through the nozzles in the distributor plate.

The plenum is made up of a frustum of a cone of mild steel (18 gage) sheet. The height of the frustum is 8", with 16" bigger diameter and 3" smaller diameter. Air is fed from the blower into the plenum with the three inch diameter GI pipe fitted at three inch diameter of the frustum Figure (5.4).

This plenum is welded at the extreme bottom of the furnace to form a leak proof space between the distributor plate and the cone.

Δp distributor as calculated in section 5.2.3 comes out to be

$\Delta p \, dist = 0.30 kPa$

$U_h = 0.46 m/s$

$$Q = U_{sup.} \frac{\pi D^2}{4} = 0.6 \times \frac{\pi \times (0.4)^2}{4}$$

$= 0.54 m^3/s$

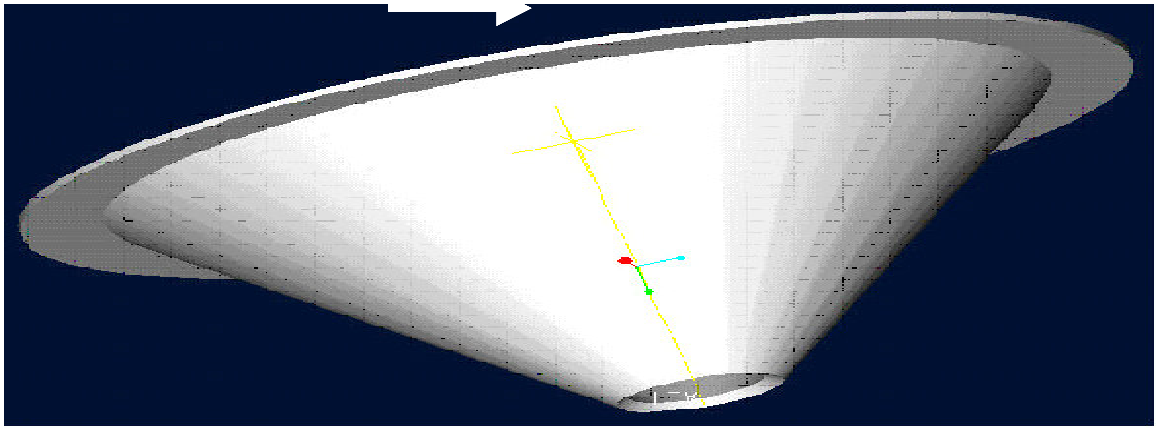


Fig. 5.4 Plenum

5.2.6 TUBING

The tubing made of copper is used for producing steam. The internal diameter is 12mm and outer diameter is 15mm. the length of the pipe taken is 4.07 metres. The inlet of water is from the lowermost horizontal tubing to the vertical middle tubing and then to the uppermost horizontal tubing which exits steam out of the furnace arrangement of the tubes is shown in figure 5.1.

5.2.7 CYCLONE

The design of cyclone is shown in the figure (5.5) Cyclone is made up of mild steel sheet with an internal diameter of 7” and height 25”. The shape of cyclone is cylindrical at the top and conical at the bottom. The flue gases are allowed to enter tangentially into the cyclone.

Fig. 5.5 Cyclones

5.3 TESTING OF FBC

A schematic diagram of the combustor is shown in Figure 5.6. The combustor consisted of 210x50 cm steel combustion chamber. An air distribution plate housed in 50 cm x 50 cm steel chamber is attached to the bottom of the combustion chamber. The combustion output from the combustor is made to pass through the cyclone. Heavy particles from the cyclone are collected and introduced into the combustor through the feeder. This combustor has been fabricated in the mechanical engineering research laboratory.

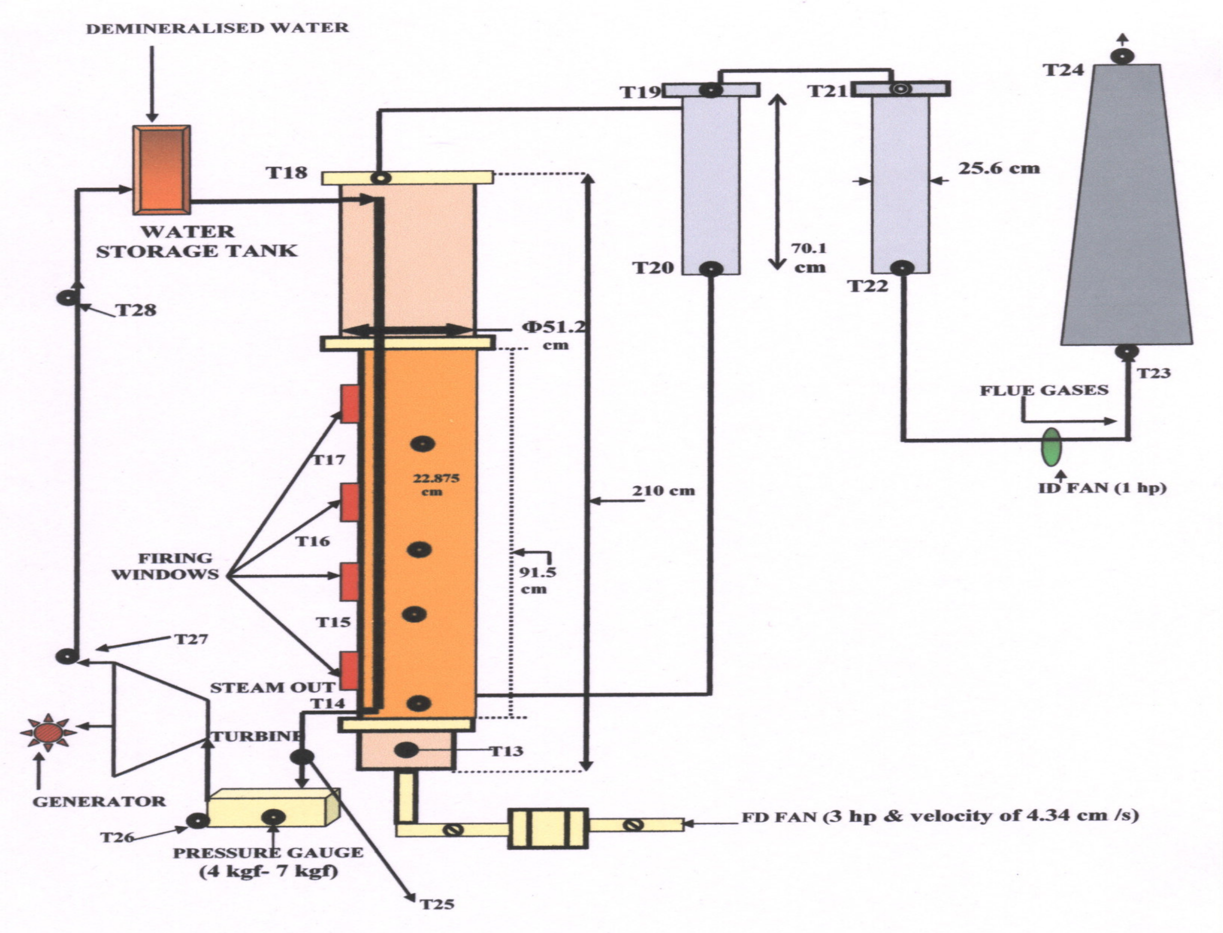


Fig. 5.6 SCHEMATIC LINE DIAGRAM OF FLUIDISED BED SYSTEM.

The combustor has three sections. The first is the plenum where preheated air expands below the distributor plate. The plenum is approximately 15 cm (6 inch) in height. Plenum is used to collect the air from blower and to pass the air equally into the furnace through the nozzles in the distributor plate. The plenum is made up of a frustum of a cone of mild steel (18 gauge) sheet. The height of the frustum is 8", with 16" bigger diameter and 3" smaller diameter. Air is fed from the blower into the plenum with the three inch diameter GI pipe fitted at three inch diameter of the frustum. The plenum (Figure5.4) is welded at the bottom of the furnace.

The second zone is the lower bed, which contains 8.5 kgs of dolomite bed material and 5kgs of sand. The fixed and expanded bed heights are 11.81" (30 cm) and 12.598" (32 cm) respectively. The final zone is the freeboard with a height of 36.02" (91.5 cm) divided into four feeding sections at a distance of 8" (20 cm) each. The freeboard provides a disengaging region for entrained bed material. The fluidized bed is operated in the bubbling bed mode using 0.80-1.00mm, CaO-stabilized dolomite. In order to obtain stable fluidization, air is supplied to the FBC at a rate of 1.3 times the air required for minimum fluidization

The cleanup system is comprised of two separate components. The cyclones 1&2 are shown in Figure 5.5, both are having the same length 27.598" (70.1cm) and diameter 10.03" (25.5cm), surface area of 11.052 x 10^4 inch^2 (56.15x10^4 cm^2). The cyclone 1 recycles the heavier particles whereas the second cyclone cum dust collector stores the ash. Ammonia can also be injected if necessary for the catalytic reduction of $NO_{x.}$

5.3.1 BED PREPARATION

Initially 5 kgs of sand was spread in the distributor plate and was left for a day, and then 8.5kgs of dolomite was added on sand. The nozzles were covered with sand and dolomite up to the height of 2.75 inches. It is necessary that the distributor plate air nozzle holes are free from blockage. In the second stage a layer of charcoal (5kgs, size 15mm-25mm) mixed with kerosene was spread over the start-up compartment.

5.3.2 CHARGING

Charcoal charging is done for the start-up through the door. Fire is introduced using a swab. It is ensured that the fire spreads uniformly over the entire surface of the top layer. Start admitting air at slow rate corresponding to increase in bed temperature. The air increase should be slow and should not be of a rate that would quench the fire. As bed temperature increases along with increase in air flow, at one stage fluidisation sets in. Air flow may be increased till the bed temperature reaches 350^{o}C.Fuel is to be introduced in the start up compartment starting from minimum rate during the charcoal burning period, if the temperature drops instead of picking up, air flow is increased. After the introduction of fuel, the feed rate is to be maintained until the bed temperature stabilizes around 350^{o}C.

The flow rates were regulated with butterfly valves and monitored through pressure drop across a calibrated orifice plate. The temperatures inside the combustion chamber were monitored with thermocouples placed 20 cm apart along the length of the combustion chamber.

The combustion products flow into the cyclone, which separates particulate matter including char from the combustion gases. The particulate matter was recirculated to be used as a combustor fuel.

5.3.3 COMBUSTOR EVALUATION WITH BRIQUETTES

omposite fuels (Bi, multi) were prepared using locally collected agriwaste Briquettes with sizes of 1'', 2'', 3'', 4''and 3x2x1'', were investigated. The ash contents of bi fuel and multi-fuel are given in Tables 4.3 and 4.4 in Chapter 4.

In order to perform an accurate material balance on agriwaste composite fuel, the following steps were taken: the FBC was thoroughly cleaned; 8500±1 g of dolomite bed material was added; and the filter was cleaned. The combustor was then operated for approximately 180 minutes at a feed rate of 60.8 ±0.3 g/min for a total 11000 ± 10 g of agriwaste fed during the test. The FBC was cooled overnight and the following materials were collected: dolomite bed material (including ash and unburned fuel); the Table 5.1 shows the weights of the various materials fed and removed from the system.

MULTIFUEL COMBINATION OF AGRIWASTE SET – I
FUEL USED 11000 GMS

Table 5.3(a) Gross contents of the bed after burning

	Windows				
	1	2	3	4	*
*MF1	10200	9980	9900	9810	9790
MF 2	10200	9901	9880	9800	9720
MF 3	10250	9810	9770	9710	9670
MF 4	10250	9910	9870	9810	9720
MF 5	10200	9808	9850	9808	9710
MF 6	10221	9901	9810	9702	9610
MF7	10200	9890	9870	9820	9800
MF 8	10210	9800	9790	9775	9600
MF 9	10190	9810	9785	9670	9610

5.3 (b) Net contents

	Windows				
	1	2	3	4	*
MF1	1700	1480	1400	1310	1290
MF 2	1700	1401	1380	1300	1220
MF 3	1750	1310	1270	1210	1170
MF 4	1700	1410	1370	1310	1220
MF 5	1750	1408	1350	1308	1210
MF 6	1721	1401	1310	1202	1110
MF7	1700	1390	1370	1320	1300
MF 8	1710	1300	1290	1275	1100
MF 9	1690	1310	1285	1170	1110

By subtracting the dolomite content taken 8500 gms

5.3(c) Unburnt Contents (materials)

Windows	**1**	**2**	**3**	**4**	*
MF1	820	600	520	430	410
MF 2	600	301	280	200	120
MF 3	1090	650	610	550	510
MF 4	930	640	600	540	450
MF 5	1112	770	712	670	572
MF 6	841	521	430	322	230
MF 7	710	400	380	330	310
MF 8	885	475	465	450	275
MF 9	810	430	405	290	230

** Repeat of window 4*

*** By subtracting the %ash content computed by experiments**
(Refer Table 4.3, 4,4 for ash contents

Windows (Refer. Fig. 5.6) : Testing of FBC
MF1 – MF9 = Multifuel combinations

AGRIWASTE AND INDUSTRIAL BASED MULTIFUEL COMBINATION SET – II

FUEL USED 11000 GMS

Table 5.4(a) Gross contents of the bed after burning

	Windows				
	1	2	3	4	*
*MF1	10000	9980	9850	9825	9800
MF 2	10130	10000	9900	9870	9800
MF 3	10100	10030	9800	9810	9790
MF 4	10000	9980	9900	9800	9725
MF 5	10200	9500	9310	9300	9280
MF 6	10100	9740	9702	9670	9500
MF 7	10108	9801	9790	9710	9600
MF 8	10100	9902	9830	9710	9610
MF 9	9980	9810	9740	9601	9570

5.4 (b) Net contents

	Windows				
	1	2	3	4	*
MF1	1500	1480	1350	1325	1300
MF 2	1630	1500	1400	1370	1300
MF 3	1600	1530	1400	1310	1290
MF 4	1500	1480	1400	1300	1250
MF 5	1700	1000	800	800	780
MF 6	1600	1240	1202	1170	1000
MF 7	1608	1301	1290	1210	1100
MF 8	1600	1402	1330	1210	1110
MF 9	1480	1310	1240	1101	1010

By subtracting the dolomite content taken 8500 gms

5.4(c) Unburnt Contents (materials)

	Windows				
	1	2	3	4	*
MF1	620	600	470	420	445
MF 2	530	400	300	270	200
MF 3	940	870	740	650	630
MF 4	730	710	630	530	480
MF 5	1062	362	162	162	142
MF 6	720	360	322	290	120
MF 7	618	311	300	220	110
MF 8	775	577	505	385	285
MF 9	600	430	360	221	190

** Repeat of window 4*

By subtracting the %ash content computed by experiments
(Refer Table 4.3, 4.4 for ash contents

Windows (Refer. Fig. 5.6) : Testing of FBC
MF1 – MF9 = Multifuel combinations

AGRIWASTE AND INDUSTRIAL BASED BI-FUEL COMBINATION SET – III

FUEL USED 11000 GMS

Table 5.5(a) Gross contents of the bed after burning

	Windows				
	1	2	3	4	*
BF1	10990	10880	10800	10795	10770
BF 2	10900	10890	10810	10790	10760
BF 3	10800	10710	10680	10660	10500
BF 4	10770	10700	10680	10607	10490
BF 5	10670	10610	10590	10550	10398
BF 6	10600	10580	10507	10498	10300

5.5 (b) Net contents

	Windows				
	1	2	3	4	*
BF1	2490	2380	2300	2295	2270
BF 2	2400	2390	2310	2290	2260
BF 3	2300	2210	2180	2160	2000
BF 4	2270	2200	2180	2107	1990
BF 5	2170	2110	2090	2050	1898
BF 6	2100	2080	2007	1998	1800

By subtracting the dolomite content taken 8500 gms

5.5(c) Unburnt Contents (materials)

	Windows				
	1	2	3	4	*
BF1	1390	1280	1200	1195	1170
BF 2	1135	1125	1045	1025	995
BF 3	1321	1231	1201	1180	1021
BF 4	1157	1067	1047	974	857
BF 5	1092	1032	1012	972	820
BF 6	989	969	896	887	689

** Repeat of window 4*

By subtracting the %ash content computed by experiments (Refer Table 4.3, 4.4 for ash contents

Windows (Refer. Fig. 5.6) : Testing of FBC
BF1 – BF6 = Bi-fuel combinations

Inspection of the bed material showed a mixture of ash, dolomite and small agglomerates of sintered ash/bed material. Samples of these agglomerates along with samples of the dolomite bed material and filter ash (including particulate collected from the inside walls of the FBC) were sent to TCIRDC for analysis. The results from this analysis are summarized in Table 5.4, along with the analysis of composite fuel ash for comparison.

It was anticipated that the sulphur and chlorine would be captured in the ash. Specifically, it was expected that the alkali component of the agriwaste ash, namely K and Ca will react with sulphur in the agriwaste to form K_2SO_4 and $CaSO_4$. As seen in Table 5.4 the bulk is filter ash and the ash agglomerates.

Table 5.6 Elemental analysis of samples taken from the FBC

Elemental Analysis of Ash %	**Agriwaste**	**Filter Ash**	**Bed material**	**Ash Agglomerates**
SiO2	56.09	54.46	1.84	37.95
Al_2O_3	2.06	2.38	1.72	3.67
TiO_2	0.02	0.13	0.13	0.13
Fe_2O_3	0.69	1.82	0.77	4.90
CaO	3.95	4.55	3.33	3.65
MgO	1.33	1.05	0.05	0.52
K_2O	20.6	17.00	0.48	8.82
CO_2	0.39	-	-	-

Referring to Table 5.4, the increase in Fe_2O_3 concentration found in the filter ash is most likely from flakes of oxidized from FBC wall material It was not feasible to separate the ash particles from the dolomite bed material; therefore, the analytical results refer to a mixture of both materials. The gaseous emissions from the combustion system indicated that negligible sulphur compounds were detected in the flue gases. Therefore, it appears likely that the sulphur present in the agriwaste fuel is captured by the alkali material, but further investigations are needed.

No chlorine emissions were detected in the gas phase. Therefore, it is assumed that the chlorine was captured by the alkali component of the agriwaste ash, forming KCl and CaCl. Variations in feed characteristics, as well as some experimental error, contribute to this discrepancy in the chlorine balance. Firing order for the FBC combustion system was also tested*. The operating/feeding windows are shown in figure 5.7 (a, b, c).

** To see the fuel combustion efficiency*

Fig. 5.7-(a)Window 2 being utilized to test the firing order

Fig.5.7 : (b) Window 3, being utilized to test the firing order

Fig. 5.7-(c) : Window 4 being utilized to test the firing order

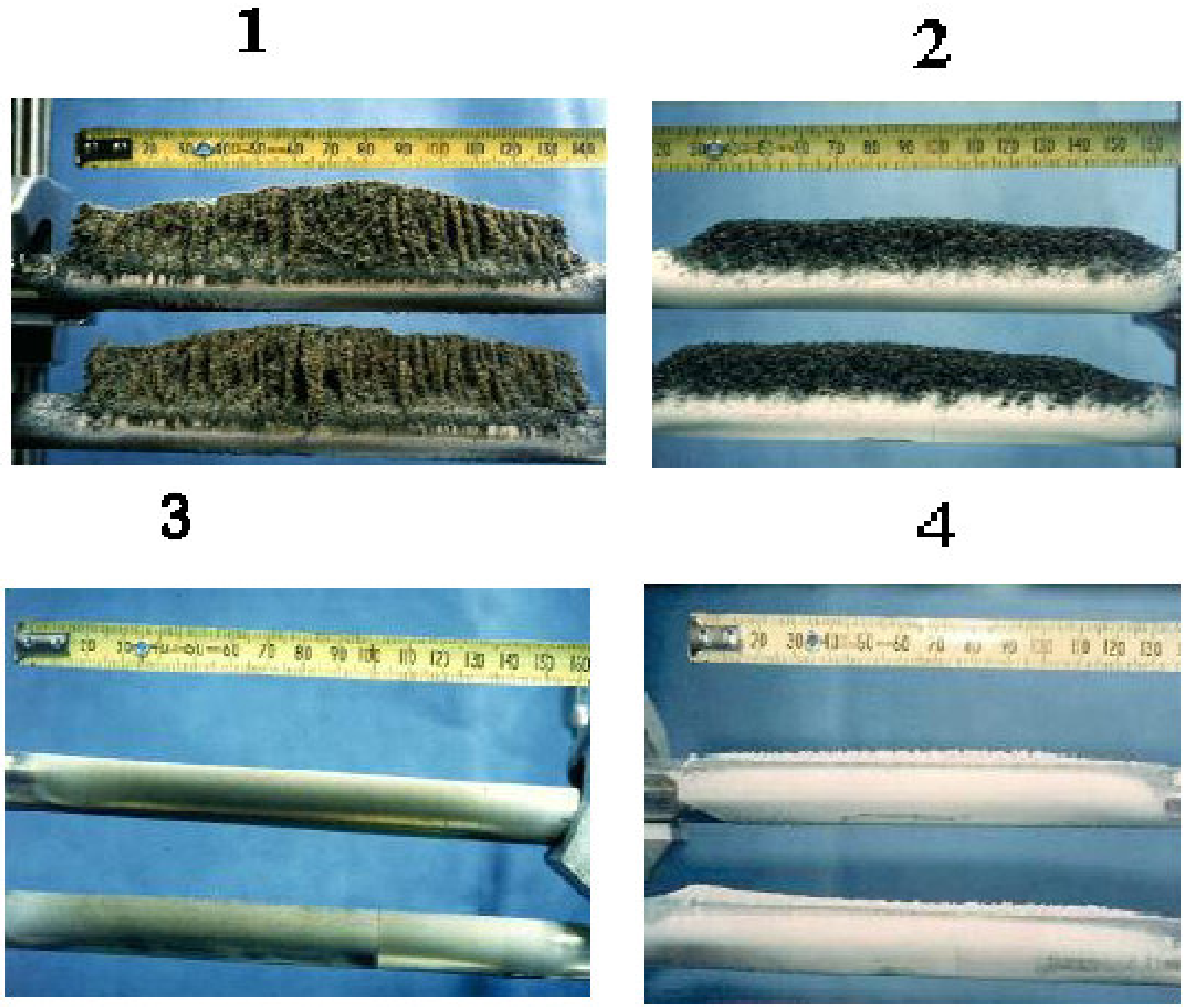


Fig. 5.8: Ash collected while firing at respective windows

5.3.4 FIRING ORDER TESTING

The dry feed material introduced from the hopper into the top section of the reactor falls towards the bed at the bottom, and during the fall the material is further dried and partially combusted. Exhaust gases from combustion are cooled during this period of the incoming feed. The fluidized bed ensures well mixed oxidation of the feed material and provides thermal stability. The top feed setup permits a more stable operation because of complete combustion in the bed. The air supplied by the blower below the distribution plate results in a constantly stirred, bubbling bed, fluid combustor. Figure 5.8 shows the ash collected when window 1 & 2 were used and Figure 5.8 (3 & 4) show the ash collected when window 3 & 4 were used or top firing order. The figure5.9 shows the different materials removed after cooling the FBC system.

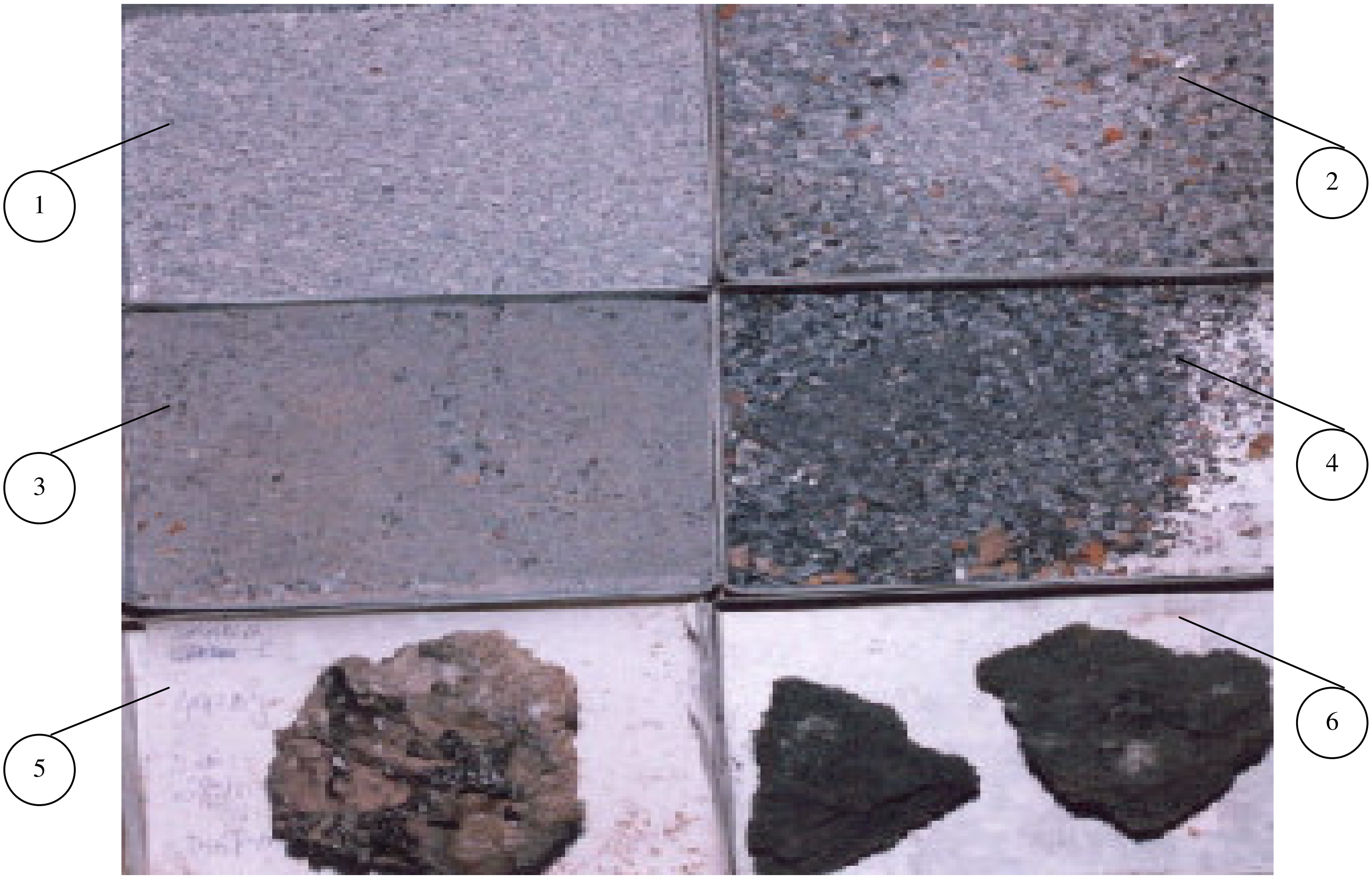


Fig.5.9 (1) shows dolomite. Fig.5.9 (2) Dolomite and ash with heavier particles. Fig 5.9 (3) fine ash Fig.5.9(4) Coarse particles removes from FBC. Fig 5.9 (5) solid rock like structure while burning rice straw alone. Fig.5.9 (6) Char coal formed while using rice husk and malee.

The source of energy in the system is the organic matter in the feed materials. For the system to be stable, the energy in must equal the energy Out. If the input is greater than the output, the temperature will increase. If the input is less, the temperature will decrease. The average bed temperature was 350°C-375°C which is shown in figure 5.10**(a,b,c)**. The system operated very well and stability was easy to obtain.

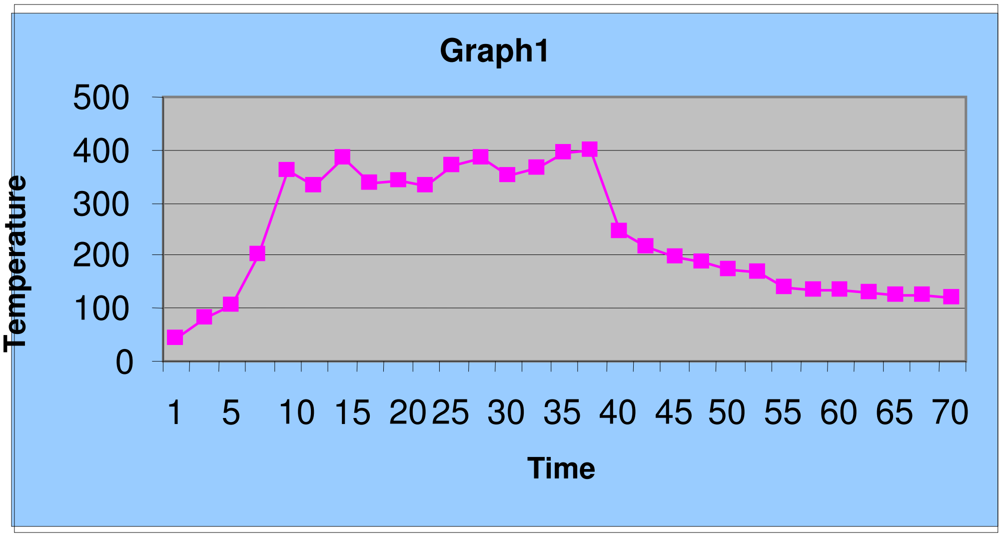


Fig. 5.10 (a): Average bed temperature

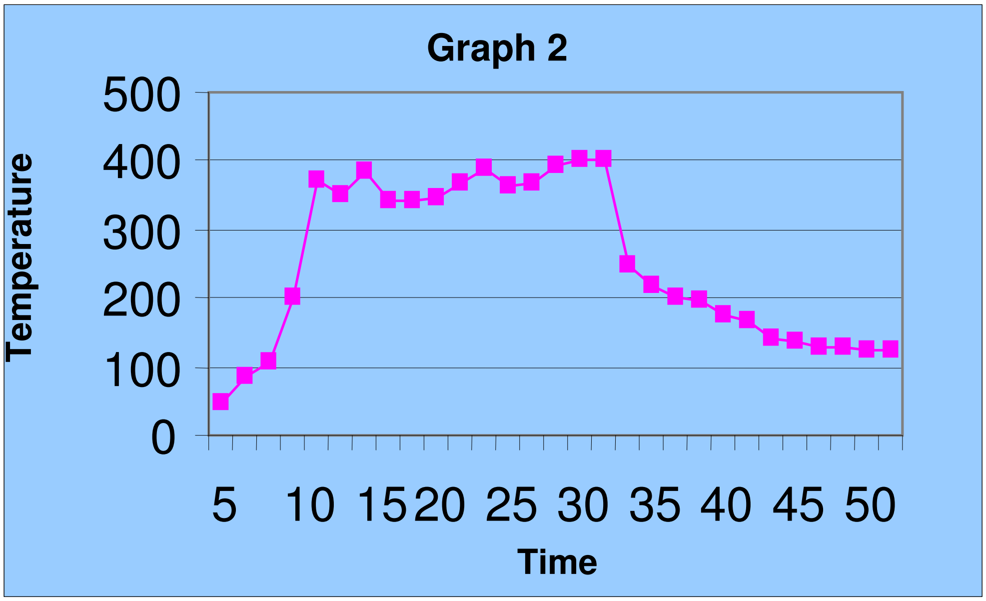


Fig. 5.10 (b) : Average bed temperature

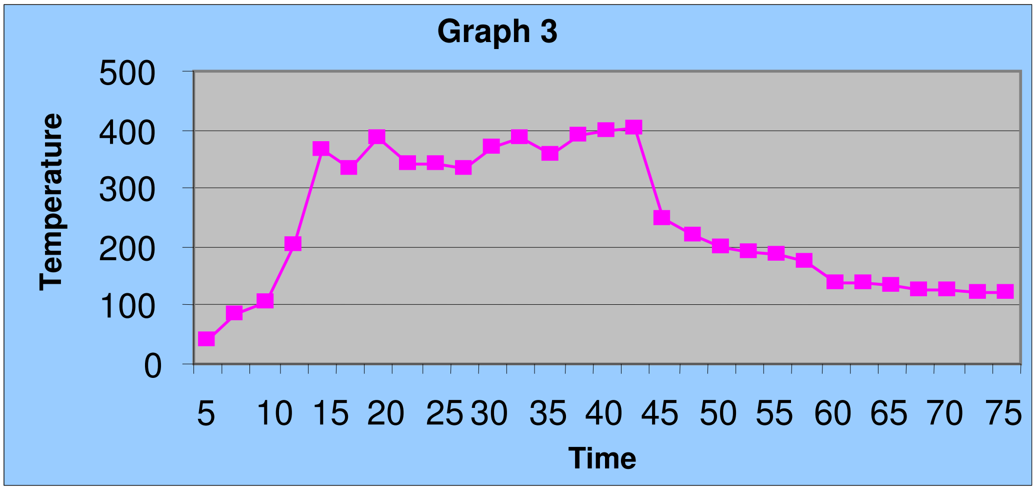


Fig. 5.10(c) : Average bed temperature

Exhaust gases from the fluidized bed combustor were analyzed for O_2, CO_2, CO and NO_x and are given in Table 5.5. The Tables 5.6 and 5.7 show the chemical analysis of bi-fuel and multi-fuel combinations.

Table 5.7: Gas Analysis Multifuel Samples

		MF 1	MF 2	MF 3	MF 4	MF 5	MF 6	MF 7	MF 8	MF 9
CO_2	%	11.0	6.0	5.9	5.8	5.8	5.9	6.0	5.8	5.8
O_2	%	15	14.2	6.4	6.5	5.4	6.4	14.2	6.5	5.4
CO	Ppm	100	180	160	140	281	160	180	140	281
SO_2	Ppm	47	31	30	30	30	30	31	30	30
NO	Ppm	114	45	-	47	200	-	45	47	200
NO_2	Ppm	45	42	40	30	16	40	42	30	16

Table 5.8: Chemical Analysis of Multifuel Samples

	Window 1		Window 2		Window 3		Window 4	
	FeO_3 % mass	**Na % mass**	**FeO_3 % mass**	**Na % mass**	**FeO_3 % mass**	**Na % mass**	**FeO_3 % mass**	**Na % mass**
Bed	49.0	5.0	45	4.0	45	3.0	40	3.2
Wall Deposit	0.2	24.0	0.2	20	0.1	18	0.2	18
Cyclone	1.8	15	1.4	13	1.2	12	1.1	10

5.9: Chemical analysis of Bi-fuel Samples

	Window 1		Window 2		Window 3		Window 4	
	FeO3 % mass	**Na % mass**	**FeO3 % mass**	**Na % mass**	**FeO3 % mass**	**Na % mass**	**FeO_3 % mass**	**Na % mass**
Bed	52	6	45	6	45	4	42	4
Wall Deposit	0.3	25	0.3	22	0.2	17	0.3	20
Cyclone	1.0	13	1.2	15	1.1	10	1.0	12

Windows (Refer. Fig. 5.6) : Testing of FBC

RESULTS

Eleven kgs of fuel was used for starting of the FBC system. The three plot between temperature and time shows that an average temperature of 350°C-375°C (Fig. 5.10) was obtained for bed. This bed temperature was obtained in 20 to 30 minutes and window 1 was termed as firing window. Multi-fuel samples MF1 to MF9 were fired from windows 1, 2, 3 and 4 after a gap of twelve hours so that the bed material gets cooled, removed and weighed. The gross contents of the bed after burning, net contents and unburnt contents of multifuels are shown in Tables 5.3and 5.4 in Sets 1 and 2

Similarly set 3 for bi fuels are given in Table 5.5

The FBC system was operated for 180 minutes. The samples of the material from the walls of the FBC system were scrapped and collected; similarly bed material was removed and sent to TCIRDC laboratory for chemical analysis and are shown in table 5.6and 5.7 Simultaneously gas analysis was carried out with the help of Orsat apparatus and gas analyzer*. The gases analysed are given in tables 5.7 for different windows (Ref. Fig. 5.6)

** Gas Chromatograph Model Nucon 5765*

Results of these analyses indicate that all organic matter combusted. The alkali component of the briquetted ash reacts with sulphur in the multifuel/bi fuel to form K_2SO_4 and $CaSO_4$. Sio_2 concentrations are very low and Fe_2O_3 concentrations indicate flakes of oxidized iron from FBC system wall material using the data presented in previous tables, it is indicated that the bed material consisted of bi/multi fuel residues. Flue gas analysis show, carbon remaining 5.8 – 11%, oxygen (O_2) 6-15%, SO_2 (200-500ppm), NO 40-114(150-200)]*. The flue gas temperatures also remain below bed temperature[80].

Obtained results indicate that FBC system technology can be used for combusting the briquettised agriwaste, further be used for steam generation. The top feed set up i.e. window 3 and 4 permit more stable operation.

*(*Figures in bracket are the permissible limits prescribed by Punjab Pollution Control Board (PPCB), Govt. of Punjab)*

CONCLUSIONS

A fluidized bed combustor has been developed for use in the incineration of agriwaste. The system has been tested extensively with agriwaste fuel (bi/multi) and provides robust operation and pollution control. The bi/multi fuels are able to control the alkali formation which was the main hindrance in case of single fuel i.e. rice straw. It has been proved experimentally that FBC operates between the temperature limits of 330°C – 750°C (Maximum temp. attained 950°C)[80]. Window firing also proved that it is efficient when used as 3rd and 4th place. Briquettes proved that there is negligible corrosion in the walls of the furnace as well as efficiency of the furnace improved by 27%.

CHAPTER: 6

RESULTS, DISCUSSION AND EPILOGUE

The study was initiated with the purpose of exploring the possibility of utilizing the agriwastes as fuel in various combinations, particularly for power generation purposes.

The study involved scanning for agriwastes for the main crops of the region; finding the calorific values and other related parameters for some of the materials used as fuel supplements and binders. Case study of the two agriwaste power generation plants; briquetting of agriwaste in various combinations and finding their related parameters; designing and fabricating a fluidized bed combustor and testing all the composite fuels prepared for their thermal efficiency that improved from 20-25% and environmental sustaining/improvement efforts.

The specific results for each of these steps have been given in their respective chapters. The broad inferences of the whole study are summed up here.

The study revealed that there is enough potential of agriwaste to be tapped to meet the gap in the energy requirements in the country as a whole and particularly in the Northern region i.e. Punjab, Haryana, Himachal, Uttaranchal, Rajasthan.

Proper exploitation of these resources can safely contribute upto 25% of the total electricity generation requirements of the region by 2020[6, 53, 76, 77, 78, 81, 82] (Ann. A & B1).

There are some agriwastes which have the potential to supplement the major agriwaste of the region but have almost remained unexploited. Some of these are the deoiled cake (DOC) spentwash, malee, tree leaves and grass. They are particularly useful in combination with the main crop residue [Table 3.1 pp 29].

The plants under study were operating between 65% - 85% plant load factors (PLF). The overall efficiencies of the power plants were between 16.10 – 25.10% (case study-I). The reported thermal efficiency of suitable plants in the developed countries is upto 35%. So a lot has to be done to improve the operational efficiency of the plants.

With respect to the economy of the process, the investment costs, the fuel price and the annual full load operating hours have been identified as the most important influencing factors. The kind of agriwaste used and the respective fuel price have a strong influence on the economy. In addition, at least 4,000 annual full load operating hours must be achieved from an agriwaste plant for an economic operation, 5,000 to 7000 annual full load operating hours are recommended for decentralized agriwaste plants in heat controlled operation. 2-10 MW is suitable capacity range for such projects. A 5 MW capacity project is the most viable having investment of Rs. 4.4 crores/MW against Rs. 6.6 crore/MW for 10 MW unit and Rs. 9.00 crore/MW for 2 MW unit. In case of areas with high population as well as crop density, 10 MW projects should be considered. On the other hand, in very thin population (kandi and border) areas, the more suitable alternative may be 2 MW station.

- The power plants based on agriwastes are in general technically and economically viable proposition. They need greater care at the operation stage (Case study I & II).
- The projects are more suitable as captive and/or as cluster projects (1 MW or 2 MW power plants for cluster of 20-30 villages). (Annexure-E, Refer to chapter-1 and case studies). They can supplement the power to the existing grids.
- The economic viability of the Plant is better if it is in private sector. The comparative performances of two plants under the case studies reveal the facts (presently Jalkheri Power Plant Ltd. And Nuchom Power Plant are working in private sector).
- Use of single fuels particularly rice straw results in agglomeration clinker formation and slagging due to alkaline nature of the fuel (case studies I & II and Operation manual of BHEL).
- The various Bi and Multi fuel combinations after application of linear programming for maximization of HHV and minimization of cost resulted in HHV range of 16800-21840 kJ/Kg (4000-5200 kCal/kg) and costs ranges were Rs.1550-2150 (US$ 35-48) per tonne

This proves economical as compared to Grade ‘C’ coal which has been taken as bench mark. 16800 kJ/kg (HHV 4000 kCal/kg) and cost range of Rs. 2500-3500 (US$ 56-78) per tonne depending upon the bulk).

- These fuel combinations provided better combustion results in the specifically designed and developed FBC at lower bed temperature (330°C) against recommended minimum temperature of 350°C (similar graphs could be obtained with different values of temperature and time).
- The ash contents of these combinations were also better than coal as they gave ash content of 5-18% against single fuels range of 8-22.5%. The ‘C’ grade coal (the bench mark)*** has ash content of 40%. There is also possibility of using this ash as a fertilizer.
- The overall temperature range attained in the FBC was 330°C - 950°C under our test conditions with negligible traces of alkali formation. This is against range of 350 °C - 750 °C in case of single fuels with alkali formation and related problems.
- The exhaust gas analysis of these combination fuels from FBC gave emission values much below the permissible limits. They were NO 40-114 ppm (150-200)* NO_2 2 ppm (200-300)*, SO_2 30-47 ppm (200-500)*. O_2 6-15% and CO_2 was 6%.

The projected 25% contribution [GOI, 81, 82] from agriwaste-power to electricity generation will go a long way to easing the grim power scenario within the region. The benefits could be multiple in terms of avoided environmental damage from substituted fossil fuel sources, rural development, employment generation, improved energy security, and in general terms a move to a more sustainable electricity production. Clearly, agriwaste will only be a component that is increasingly based on renewable resources. If good practices are followed and continued improvements in agriwaste based power production, logistics and conversion are obtained, the development of agriwaste power could be achieved with minimum environmental hazards and with increased economic viability. The ever increasing fossil fuel prices** further enhance the competitiveness of agriwastes as a source of electrical energy. The projected target of about 5000 MW of agriwaste power in the region by 2020 [76, 77, 78] will mean a tenfold increase in the agriwaste power capacity over next 15 years.

(Permissible limits prescribed by Punjab Pollution Control Board (PPCB)*
*(** Petroleum prices $58/- per barrel as on 24 June, 2005) *** Refer to line 23 page 3*

Under the current framework conditions the erection and operation of decentralized agriwaste plants is economically viable[76, 77, 78, 81, 82]. However, the heat related investment subsidies and the increased feed-in tariffs currently available are absolutely necessary in order to promote the market promotion of such system, to contribute to the fulfilment of national targets concerning electricity production from agriwaste. Agriwaste power will not grow without greater integration between energy, environment, agricultural and a carefully designed mix of incentives aimed at, agriculture and forestry sectors.

The support of agriwaste power is fundamental in developing sustainable, low-carbon options for the long-term incentives. Agriwaste power will tend to be more expensive than other renewable electricity sources, such as wind, but is likely to compete with future costs of electricity from fossil sources, in particular if environmental costs are also accounted [31. 36, 38, 54, 61, 64, 81, 82]. The decentralized nature of agriwaste power likely to result in savings and benefits with regard to electricity transmission and distribution. These need to be accounted through proper governmental electricity sector regulation.

Continued research development and demonstration (RD&D) related to improved crop types, management techniques and advanced conversion technologies (e.g. gasification and integration with gas turbines and fuel cells) is necessary for a gradual introduction of technically, economically and environmentally more efficient agriwaste power technologies.

Finally there is need for greater awareness. Governments need to establish agriwaste based industry and stake holder forums to identify the opportunities and needs of the industry, define targets related to research, development, demonstration and implementation, discuss barriers to market uptake and policy measures aimed at overcoming them. The outcomes of such forums then need to be translated into action plans.

Therefore, the support of decentralized agriwaste based power plants is very important. An appropriate approach can successfully be implemented in cluster of 30-40 villages in Punjab, Haryana, Uttaranchal, Uttar Pradesh, Himachal Pradesh, Rajasthan and plains of Jammu & Kashmir [76, 77, 78, 81]

Farmers can supply the agriresidue which may be collected at about five to seven centres for each of these plants. The agriresidue so collected will be briquettized, pelletized, shredded or bailed by department and stored at four to five sites other than the plant site. This process of collection will take about two to four months. The requirement of about two months will be kept at power house and the balance quantity will be kept at other centres to avoid fire hazard and the movement of fuel will be carried out from there to the site so as to replenish the quantity used.

It is indicated that one man day is required for transportation, loading and unloading of one tonne of crop residue [76, 77, 78, 81, 82]. With the utilization of bi or multi fuel, it is expected that employment to the tune of 1.4 lac, 3.5 lac and 7 lac man days will be created at the initial stage for 2 MW, 5 MW and 10 MW units respectively.

6.1 LIMITATIONS

- The data was mainly culled from the secondary sources, which have their own limitations of collection and computing.
- The non-availability of the some of the state of the art technology equipment[Gas analyzer] and research apparatus might have affected the results in their own way.
- Limitations of sources, especially the finances limited the quality of the fabricated equipment which in turn might have affected the study. This is perhaps on account of low priority for R&D in the country.
- Possibility of change in the crop pattern may change the availability of the intended agriwastes, affecting the study projections (*as suggested by the Johl Committee and accepted in principle by the State and Central Governments*). It can also alter the demand side of power.

6.2 SCOPE FOR FUTURE WORK

- Next logical step may be field tests of these combinations/samples after processing them through the commercial process (extrusion presses etc.)
- There is scope for further refinement of FBC specifically for agriwaste based fuels.
- The possibility of using the urban solid wastes in combinations with agriwaste be explored further.
- There is a scope for exploiting the multifuel combinations of some other agriwastes, agro industrial wastes and forestry wastes with higher calorific values for the other regions of the country.

6.3 EPILOGUE

Currently available information and data from studies conducted heretofore indicate that within a decade or so, it would be cost-effective to generate and supply electricity from renewable sources upto thousands of megawatts due to continued improvement in renewable energy devices seeking to increase efficiency and reduce cost. Besides augmenting the grid power supply, the renewable energy systems offer feasibility of decentralized power generation at or near the points of use, which can reduce peaking loads and save on costly up-gradation and maintenance of transmission and distribution networks while serving the growing demand.

Agriwaste based systems are the only energy generating system, which have the combined benefits of renewability, decentralization and availability on demand without need for separate storage. Taking into account the energy requirements and economics of collection, processing and conversion to the required form, agriwaste resource seems to assure a bright future from sustainability and conservation points of view.

A judicious coupling of energy production programme with planned agriwaste production is probably one of the few potential options with tremendous economical, environmental and social benefits. This close linkage provides the requisite economic reason for plantation activities to be commercially successful. A potential employment generation program for relatively weaker sections of the society can also be put in position through such projects. Agriwaste for power generation has already been recognized as an important component of the renewable energy programme in India and this is reflected in priority given to it by the Ministry of Non-conventional Energy Resources (MNES). There are important niches which promise substantial benefits from the use of agriwaste for power generation. Bagasse co-generation in sugar mills and power generation from waste from agricultural operations or agro-industries in concentrated geographical pockets are attractive proposals from this point of view. Broad estimates indicate that taking into account the demand for fodder etc, the agriwaste available in the country can optimistically support electric power based generating power plants aggregating to a total of 20000 MW[62].

From the foregoing, it is clear that there is an enormous untapped potential for energy generation from agriresidue. What is required is an immediate and urgent intensification of dedicated efforts in this direction, with a view to bringing down the unit energy cost and improving efficiency and reliability of agriwaste production, conversion and utilization, leading to subsequent saving of fossil fuels for other pressing applications.

The new initiatives in national energy policy are most urgently needed to accelerate the social and economic development of the rural areas. It demands a substantial increase in production and consumption of energy for productive purposes. Such initiatives are vital for promoting the goals of sustainability, cleaner production and reduction of long-term risks of environmental pollution and consequent adverse climatic changes in future.

Finally, there is a shimmering promise that the whole process of harvesting, collection, transport and economic processing and utilization of agriwaste can be made technically and economically more viable in future. Thus, the foregoing paras amply highlight the value of agriresidue as a prospective source of electric power, particularly for supplementing the main grid during the lean supply periods or peak load hours and also for serving the remote areas in the form of stand alone units. Its economic viability seems to be positive in view of its potential contribution to our economic and social development. This initiative needs to be backed and pursued vigorously for removing regional imbalances as well as strengthening the National economy.

REFERENCES

1. Amur, Ghulam Qambar, Bhattacharya, S.C., “Study of agriwaste as a source of energy in Pakistan”, RERIC International Energy Journal, V21 n1, 1999, pp.25-26.
2. Backman, R., “Melting Behavior of salt mixtures in the sytem (Na,K) (SO_4, CO_3, S, CL)”, Report 94-2, Abo Akademi University, Turku, 1994.
3. Baker, R.R., Jenkins B.M., and Baxter, L.L. “Boiler performance and furnance deposition during a full scale test with leached biomass”, Pergamon. 1977. pp. 97-510
4. Bauen, Ausilio, Woods, Jeremy, Hauls, Rebecca, “Bioelectricity Vision: Achieving 15% of electricity from Biomass in OECD countries by 2020” (April, 2004). E4tech (UK) Ltd
5. Baxter, L.L., “Task2. Pollutant emission and deposit formation during combustion of biomass fuels”, Quarterly report to National Renewable Energy Laboratory, Sandia National Laboratories, Livermore, California, USA, 1994.
6. Bhatnagar, A.P., “Combustion and Gasification of rice husk”, Proceedings of the International Conference February 1996 (New Delhi - India), pp.225-237, TERI.
7. Binning, Avtar, “Gas fired distributed energy resource technology characterisation” Review April 23/4/2002, California Energy Commission.
8. Burton Bill, Lighty JoAnn S., “Emissions from biomass combustion in a fluidized bed combuster and gas cleanup system” paper No. FBC 99-0051, proceedings of 15th International conference on fluidized bed combustion May16-19, 1999, Savannah, Georgia.
9. Catania, Peter, “China’s rural energy system and management”, Applied Energy, V64, n1, 1999, pp.229-240.
10. Cook, Jim; Beyea, Jan, “Bioenergy in United States: progress and possibilities”, Agriwaste and Bioenergy, V18, n6, 2000, pp.441-455.
11. Elaurica, J.C.; Quejas, R.E.T.; Cabrera, M.I.; Liganor, R.V.; Bhattacharya, S.C.; Predicala, N.L.J., "Agriwaste as source of energy in the Philippines”, RERIC International Energy Journal, V21, n1, 1999, pp.37-53.

12. Fodor-Csorba, Katalin, "Chromatographic Methods for the Determination of Pesticides in Foods", Journal Chromatography, 624, 1992. pp.353-367.
13. Ganesh, Anuradda; Banerjee, Rangan, "Agriwaste pyrolysis for power generation - a potential technology", Renewable Energy, V22 n1, Jan 2001, pp.9-14.
14. Gaoppi, G.; Tronconi, E.; Forzatti, P.; Berg, M., "Mathematical modelling of catalytic combustors fueled by gasified agriwastees", Catalysis Today, V59, n1, 2000, pp.151-162.
15. Gatlin, Jerry W., "Reclaim nitrogen from boiler flue gases : A new form of cogeneration", EIP 99094779322 Thomson Engineers, HPAC heating, piping, air conditioning V 71, n8, 1999, p2.
16. Gelatukha, G.G.; Martsenyuk, Z.A., "Energy potential of agriwaste in Ukraine", Heat Transfer Research, V29, n6, 1999, pp.433-437.
17. Ghaly, A.E.; Mansaray, K.G., "Comparative study on the thermal degradation of rice husk in various atmospheres", Dalhousie Univ., Halifax, NS, Can, Energy Sources V21 n10, 1999, pp.867-881.
18. Grahan, Robin L.; English, Burton C.; Noon, Charles E., "Geographic information system-based modelling system for evaluating the cost of delivered energy crop feedstock, Agriwaste and Bioenergy, V18, n4, 2000, pp.309-329.
19. Grover, P.D., "Agriwaste feed processing for energy conversion", Proceedings of the International Conference, 26-27 February 1996 (New Delhi), pp.177-195, RWEDP report No. 23, F&AO of United Nations, Bangkok, April 1996.
20. Gupta, P.K., and B.S. Panesar. Biomass gasification research at Punjab Agricultural University, Ludhiana. Proceedings of National Seminar on Energy for Better Tommorow – renewal and non-renewable energy sources (EFBET-97). Kavikulguru Institute of Technology and Science. Ramtek. India. December 26-28. 1997, pp: 197-206.
21. Gupta, P.K., and Panesar, B.S., "Thermal mode Testing of Cotton stalks gasifier", Proceedings of National Systems Conference- 97. January 23-24, 1998.
22. Gupta, P.K., Singh, Jaswinder and Jain, A.K., "Performance of 10 kW paddy husk gasifier" Proceedings of National Seminar on Renewable Energy: Challenges & Opportunity. Gujrat Agricultural University, Junagarh, India. Sep. 27. 1996, pp : 20-27.

23. Gupta, Y.P., “Pyrolysis as a means for using paddy straw as domestic fuel”, Proceedings of the International Conference (New Delhi), Feb. 1996,pp.196-201.

24. Gutierrez-Vera, Jorge, “Renewable trends in Mexico in the third millennium”, IEEE Power Engineering Review, V19, n11, 1999, pp.8-11.

25. Haider, S.W., “Agriwaste fuel consumption and formulation of household energy strategy in Pakistan”, Agriwaste Energy Systems, (Sec-1-Agriwaste Supply and Demand, and Policy issues), pp.73-89.

26. Hansen, P., “Deposit formation in coal/biomass fired CFB under load variations” ELSAM R&D project No. 348, 1997.

27. Hupa, M.,.”The role of alkali sulfates and chlorides in post cy-clone deposits from circulating fluidized bed coilers firing biomass and coal” Academic/Plenum Publishers, New York, ISBN 0-306-46126-9, 1999, pp. 525-540.

28. Hups, M., Kilipinen, P, Kallio, S., Konttinen, J., Skrifvars, B.J., Zevenhoven, M., Backman, R., “Prediciting the performance of different fuels in fluidized bed combustion” Proceedings of the ITIT symposium on effective utilization of low grade fuels by fluidized bed technology, Tsukuba, Japan, December 1-2. 1999, AISTNIRE-NEDO

29. Iniyan, S.; Suganthi, L.; Jagadeesan, T.R.; Samuel, Anand A., “Reliability based socio-economic optimal renewable energy model for India”, Renewable Energy, V19, n1-2, Jan-Feb 2000, pp.291-297.

30. Jagadish K.S. “Biogas from Leaf Biomass - Prospects and Problems”, Proceedings of the international conference 26-27 Feb. 1996 (New Delhi)” pp 361-367.

31. Jenkins B.M., Baxter, L.L. and Oden, L.L., “Boiler deposits from firing biomass fuels”. Bio-mass and Bioenergy 10(2-3): 1996. pp. 125-138.

32. Jiao, Qingyu; He,Yuan-bin; Bhattacharya, S.C.; Sharma, Mohan; Amur, Ghulam, Qamar, “Study of agriwaste as a source of energy in China”, RERIC International Energy Journal, V21, n1, 1999, pp.1-10.

33. Jones, J.M.; Pourkashanian, M.; Williams, A.; Hainsworth, D., “Comprehensive agriwaste combustion model”, Renewable Energy, V19, n1-2, Jan.-Feb 2000, pp.229-234.

34. Karaosmanoglu, Filiz, “Biobriquetting of rapeseed cake”, Energy Sources, V22, n3, 2000, pp. 257-267.
35. Khoa, TranMinh; Bhattacharya, S.C.; Amur, Ghulam Qambar, “Study of agriwaste as a source of energy in Vietnam”, RERIC International Energy Journal, V21, n1, 1999, pp.69-75.
36. Koopmans A; “Proceedings of the International Workshop on Biomass briquetting” FAO/RWEDP Bangkok; Report No. 23, 1996, pp. 123-133.
37. Kumaradasa, M.A.; Bhattacharya, S.C.; Salam, P., Abdul; Amur, Ghulam Qambar, “Study of agriwaste as a source of energy in Sri Lanka”, RERIC International Energy Journal V21, n1, 1999, pp.55-68.
38. Mann, Margaret K.; Spath, Pamela L., “Life cycle comparison of electricity from agriwaste and coal”, Proceedings of 3rd ACEEE Summer Study on Energy Efficiency in Industry ‘Industry and Innovation in the 21st century”, Saratoga Springs, USA, 15-18, June 1999, pp.559-569.
39. Mehta, G.D. Power Generation from Salinity Gradients and Waste Heat using Osmo-Hydro Power^{TM} Systems, Publication by Science Press, November 1979.
40. Mehta, G.D., “Power Generation from Salinity Gradient Systems” The International Conference on Alternative Energy and the offer of the Sun and the Sea, Invited Paper at Milan International Fair, Italy, 18-20 April 1980.
41. Mehta, G.D., “The Osmo-Hydro Power Heat Engine”, UNITAR (United Nations Institute for Training and Research) Conference on Long Term Energy Resources, Montreal, Canada, 26 November-7 December 1979.
42. Muller, C., Skrifvars, B-J., Backman, R., Nickull, S., Hupa, M., “Simulation of ash particle behaviour on surfaces of biomass fired fluidized bed boilers – Combination of Computational Fluid Dynamics and advanced ash analysis”, accepted for publication in the 16th FBC Conferences, to be held on May 2001, Reno, Vevada, USA.
43. Nielsen, H.P., Frandsen, F.J., Dam-Johansen, K., Baxter, L.L., “Implications of chlorine-associated corrosion on the operation of agriwaste-fired boilers”, Progress in Energy and Combustion Science, V26, n3, 2000, pp.283-298.

44. Nishiyama, Akio; Shibagaki, Gantaro, “Agriwaste burning technology utilizing circulating fluidized bed”, Kami Pa Gikyoshi/Japan Tappi Journal V53 n11, 1999, pp.33-41.
45. Ohman, M., Nordin, A., Skrifvars, B-J., Backman, R., Hupa, M., “Bed agglomeration characteristic during fluidized bed combustion of biomass fuels”, Energy and Fuels 14, Nr. 1, 2000, pp. 169-178,
46. Ohman, Marcus; Nordin, Anders, “Role of Kaolin in prevention of bed agglomeraion during fluidized bed combustion of agriwaste fuels”, Energy and Fuels, V14, n3, 2000, pp.618-624.
47. Panesar, B.S. and Gupta, P.K., “Agricultural System’s Modelling and the GIS” Journal of Research, PAU. Special issue released on the occasion of Third Agricultural Science Congress. March 12-15, 1997, 282-301.
48. Panesar, B.S. and Fluck, R.C., “Energy productivity of a production system: analysis and measurements”, Agricultural Systems, 1993, 43: 416-37.
49. Panesar, B.S., “Integrating spatial and temporal model – an energy example, In Agricultural Systems: Modelling & Simulation” edited by R.M. Peart & R.B. Curry, Marcel and Dekker Inc, USA, 1996, pp.: 32-42
50. Peltola, K., Hilltunen, M., Blomoqvist, J-P., Skrifvars, B.J., Kurkela, J., Latva-Somppi, J., Kauppinen. E., “Fouling of the cooling surfaces in Biofuel-fired fluidized bed boilers”, Proceedings of the ASME 15th FBC Conference, May 1999, Savannah, GA, USA.
51. Pilavachi, P.A., “Power generation with gas turbine systems and combined heat and power”, Applied Thermal Engineering, V20, n15, Oct. 2000, pp.1421-1429.
52. Potter, Philip, J., “Fuels and Combustion”, Power Plant Theory and Design, 2nd Ed., The Ronald Press Company, New York, Ch.5, 1959, pp.170-171.
53. Purvis, M.R.I., Tadulan, E.L., Tariq, A.S., “NOx emissions from the underfeed combustion of coal and agriwaste.”, Journal of the Institute of Energy, V73, n495, 2000, pp.70-77.
54. Rao, O.P., “R&D requirements in agriwaste combustion and gasification”, Proceedings of the International Conference, Feb. 1996 (New Delhi - India), pp.259-269 (TERI).

55. Rasul, M.G.; Ruddph, V., "Fludized bed combustion of Australian bagasse", Fuel, V79, n2, Jan. 2000, pp.123-130.

56. Sayigh, Ali, "Renewable energy - the way forward", Proceedings of the 19th International Energy Conference ENERGEX '98, Applied Energy V64 n1, 1999 pp.15-30.

57. Sharma, M.P., Sharma, J.D., "Bagasse based cogeneration system for Indian sugar mills", Renewable Energy, V.16 n1-4, Pt.2 Jan-Apr 1999, pp.1011-1014.

58. Sims, Ralph, E.H., "Bioenergy - a renewable carbon sink", Proceedings of world Renewable Energy Conference Perth, Australia, Feb. 1999, Renewable Energy, V22, n1, Jan. 2001, pp.31-37.

59. Singh, T., "Effect of supply and return air outlets on energy consumption" with J.B. Olivieri, Ashrac Transactions, 1982, No. 2665, RP 217, Vol. 88, Pt. 1.

60. Singh, T., "Rapid continuous Determination of Nitirc Oxide concentration in Exhaust Gases" Journal of air pollution control association, Vol. 18, pp: 102-105, 1968.

61. Singh, Bimal, P., Panigrahi, M.R., Ray, H.S., "Review of agriwaste as a source of energy for India", Energy sources, V22 n7 Aug. 2000 p.649-658.

62. Singh, N.P., "Agriwaste programme in India: an overview" Proceedings of the International Conference, 26-27 February 1996 (New Delhi), pp.65-72.

63. Skrifvars, B-J., Blomquist, J-P., Hup, M., Backman, R., "Predicting the ash behavior during biomass combustion in FBC conditions by combining advanced fuel analyses with thermodynamic multi-component equilibrium calculations", presented at the 15th annual International Pittsburgh Coal conference, Pittburgh, Pa, USA, September 1998.

64. Skrifvars, B-J., Zevenhoven, M., Backman, R., R. Ohman, M., Nordin, A., "Effect of fuel quality on the bed agglomeration tendency in a biomass fired fluidized bed boiler", Varmeforsk report No B8-803, ISSN 0282-3772, March 2000.

65. Skrifvars, M., Zevenhoven, A.C., Hupa, Jenkins, B.M., "The ash chemistry in fluidized is gasification of biomass fuel, Par I-III, *Submitted to Fuel.*

66. Splielhoff, H., Scheurer, W., Hein, K.R.G., "Effect of co-combustion of sewage sludge and agriwaste on emissions and heavy metals behaviour", Universitiaet

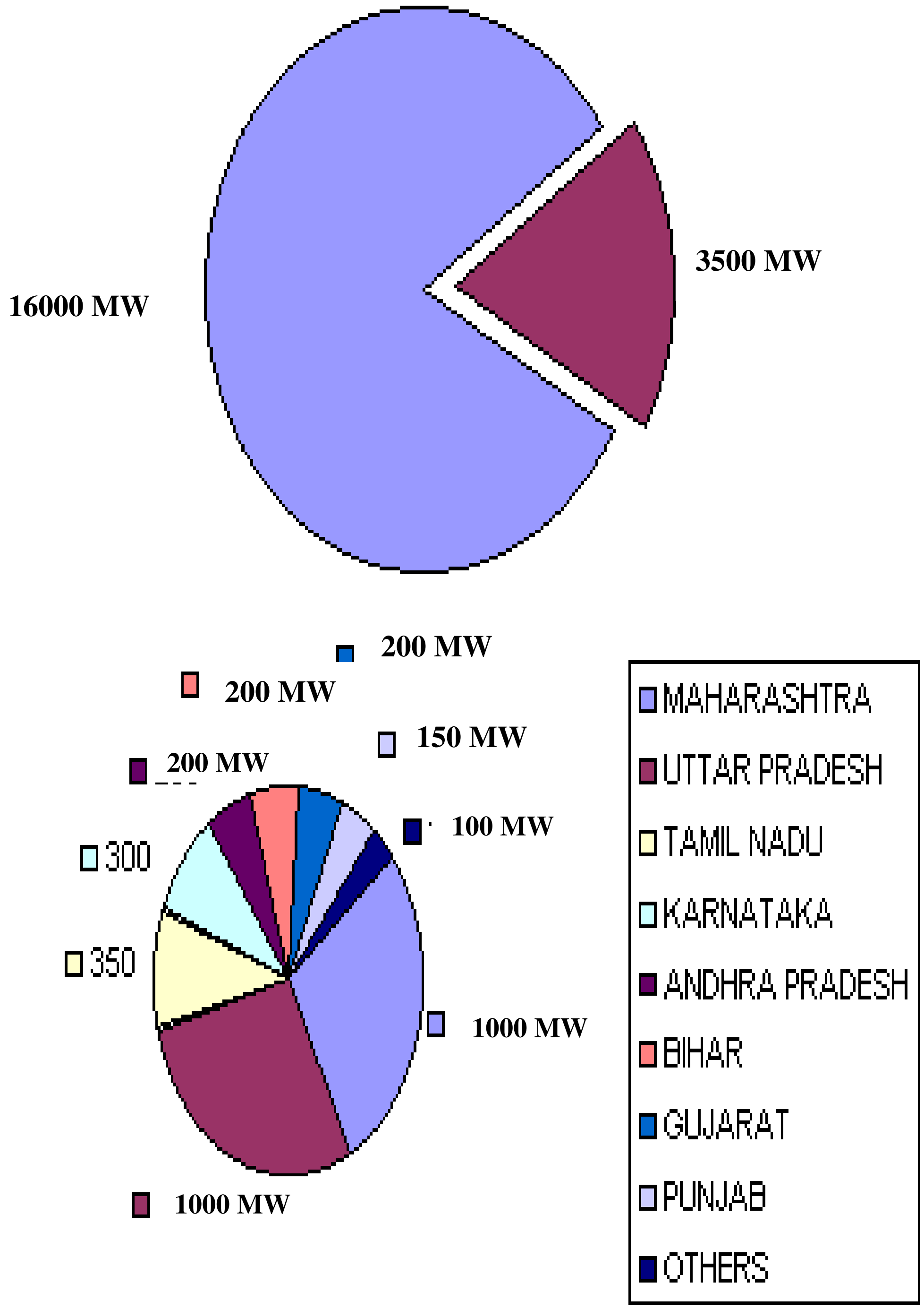
Struttgart, Stuttgart, Germany, Process safety and environmental protection : Transactions of the institution of chemical engineers, Part B, V78 n1, 2000, pp.33-39.

67. Tranuik, Anncharlotte E.; Sanati, Mehri; Zethracus Bjorn; Lyberg, Mats, "Study of the bed fouling problems in a agriwaste fired commercial CFB boiler", The 1999 International Joint Power Generation Conference and ICOPE '99, Burlingame, CA, USA, 25-28 July 1999. American Society of Mechanical Engineers, Fuels and Combustion Technologies.
68. Tripathi, A.K., Iyer, P.V.R., Kandpal, T.C., "Questionnaire based survey of agriwaste briquetting in India", MNES, New Delhi, International Journal of Ambient Energy, V21 n1 Jan 2000. pp.31-40.
69. Yokoyama, Shin-ya; Ogi, Tomoko; Nalampoon, Aman, "Agriwaste energy potential in Thailand", Agriwaste and bioenergy, V18, n5, 2000, pp.405-410.
70. Zevenhoven, M., Blomquist, J-P., Skrifvars, B-J., Backman, R., Hupa, M, "The prediction of behaviour of ashes from five different solid fuels in fluidized bed combustion, Fuel, Vol 79, 1353-1361-,2000.
71. Zevenhoven, M., Skrifvars, B-J Yrjas, P., Hupa, M, Nuutinen, R., "Searching for improved characterization of ash forming matter in biomass", accepted for publication in the 16th FBC Conference, to be held in May 2001. Remo, Nevada, USA.
72. Zevenhoven-Onderwater, M.; Blomquist, J.P.; Skrifvars, B.J.; Backman, R.; Hupa, M., "Prediction of behaviour of ashes from five different solid fuels in fluidized bed combustion", Fuel, V79, n11, 2000, pp.1353-1361.
73. Zhang, Bailiang, Li, Baoqian; Zhao, Chaohui; Xia, Zushang; Fu, Hantong "Application of BPB-1 biomass briquetting machine", Taiyangneng Xuebao/Acta Energiae Solaris Sinica, V20, n3, Jul. 1999, pp.234-238.
74. Zhou, Jiachun; Masutani, Stephen M., Ishimura, Darren M., Turn, Scott. Q, Kinoshita, Charles M., "Release of fuel-bound nitrogen during agriwaste gasification", Industrial and Engineering Chemistry Research, V39, n3, 2000, pp.626-634.
75. Zoelzer, K., "Advantages and disadvantages of fluidized bed illustrations for different applications", VGB Power Tech, V80, n1, 2000, pp.44-50.

76. Sidhu, B.S., “Energy conservation and Management in Pump sets for irrigation” – a report on Energy audit, conservation and renewable energy conversion, July 15-Aug 5, 2002, pp. 111-115.
77. Singh, Surendra, “Energy requirements, conservation and management in production agriculture” a report on Energy audit, conservation and renewable energy conversion, July 15-Aug 5, 2002, pp. 69-77.
78. Jain, A.k., “Biomass Characterization and utilization” a report on Energy audit, conservation and renewable energy conversion, July 15-Aug 5, 2002, pp. 27-34.
79. Howard, J.R., “Fluidized Beds” M.H. Associates, Southall, U.K. pp. 89-112.
80. Borislow Gruber, Dragoljub et al “Fluidized bed incineration tests of toxic liquid waste”, paper NO. FB99-0121 – Proceedings of the 15th International conference on fluidized bed combustion, May 16-19, 1999, Savannah Georgia.
81. Bhatnagar, A.P., Soni, Rajesh, “Paddy Straw based power generation in Punjab – A report” Report No. SE-49/93, October, 1993.
82. Grover, P.D., Mishra, S.K., “Regional Wood Energy Development Programme in India”, Proceedings of International Workshop on Biomass Briquetting, New Delhi (India), April 3-6, 1995.
83. Botterill, J.S.M., Toeman, Y. and Yurigir, K.R. Paper 2.4, Proceedings of XVIth ICMMT International Symposium Heat and Mass Transfer in Fixed and Fluidized beds, Dubrovnik, Yugoslavia, September 3-7, 1984.
84. Wen, C/Y. and Yu, Y.H., AiChE., J., 1966, 12, 610.
85. Zabrodsky, S.S., Antonishin, N.V. and Parnas, A.L. Can. J. Chem. Engg. 1976, 54, 52.S
86. Shubhen Kapila, Virgil Flanigan, Honglan Shi etal "Fluidized bed combustor for treatment of waste from livestock operations" Proceeding –waste research Technology -2002. Centre for Environmental Science and technology, University of Missouri- Rolla.
87. Hamdy. A .TAHA "Tora Optimization Systems-2004.

ANNEXURE – A

POTENTIAL OF AGRIWASTE



ANNEXURE – A

IDENTIFICATION, CLASSIFICATION & PRODUCTION DATA OF AGRIWASTE

I	II	III	IV	V	Vi	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
Name of Corp	Waste Component	Form of Use	Geographic Pockets of Availability	Level of Waste (% of total)	Mode of Collection From Fields	Current Storage System	Produce Per Acre in 100 kg	Existing Agro waste Power Plants	Capacity in MW	Calorific Value MJ/Kg	Residue	RPR	Moisture Content (s)	Ash Content	Bulk density Kg/m^3	Rs/per Tonne
Rice	Straw Husk Hull	Pulverised	PB, HR, HP,RJ, UP, AP, WB	33 to 50%	Manual & Mechanised	Open	24-26 Waste: Husk-18 Stalks-19	HR, PB, TN, AP, MP	4,10,2,1,5	Straw-15.5 Husk-15.3 Hull-16.8	Straw Husk	1.76 0.27	13 12	22.5	235 679	450 850
Wheat	Straw	Pulverised	PB, HR, HP,RJ, UP, AP, WB etc.	30 to 50%		Covered	18-22 Waste 6-8	--	--	Straw-18.9 Husk-17.2	Straw	1.75	15	3.5	180-320	800 950
Cotton	Stalks Seeds Seed Husk	Woody	PB, HR, RJ, GJ, AP, etc.	50%	Manual & Mechanised	Open Covered	30 to 50 Bales Waste 9-10	Haryana	4.0	Stocks-15.8 Seeds-17.4 Seed Husk-19.4	Stalks	2.755	12	3.01 5.01	79-304	400 1000 850
Sugarcane	Trash Bagasse	Pulverisable	PB, HR, HP, RJ, UP, UC, MH etc.	10 to 25%	Manual	Open	100-120 Waste 10-12	Maharashtra TN, UP, KT, AP, GT, MP	1.5x6 14 plants of varying capacity	Bagasse-19.0	Tops/ leaves	0.30 0.29	10 49	7.71 4.0	74-167	1200 1800
Sun Flower	Stalks Seeds Hulls Shells Kernels	Pulverisable	PB, HR, HP, RJ, UP, UC, MH etc.	30 to 50%	Manual & Mechanised	Open Covered	15 to 18 Waste 5-10	--	--	Stalks-21.0	Top steam	1.8 3.0	11 13	4.3	93 203	200 950
Ground Nut	Shells Husk Hulls	Pulverisable	PB, HR, HP, RJ, UP, UC, MH etc.	35 to 50%	Manual & Mechanised	Covered	15-20 Waste 5-10	--	--	Shells-19.7 Husk-20.0 Hulls-20.1	Straw Husk	2.3 0.48	15 8.2	3.10	120-180	2000 2200
Maize	Cobs Stalks Husk	Pulverisable	JK, PB,HP, HR, UP, UC, RJ, GJ, etc.	50%	Manual	Open	15-18 Waste 5-10	--	--	Cobs-18.9 Stalks-18.2	Stalks Cobs Husk	2.00 0.27 0.20	11% 7-8 11	2.49	304 391	400 800
Soyabean	Stalks Bagasse	Pulverisable	GJ, MP, MH, AP, etc.	50%	Manual & Mechanised	Open Covered	30% Produce 70% Waste	--	--	Bagasse-19.4	Staw + Pods	3.50	7%	4.5	440	500 900
Mustard	Stalks Khal	Pulverisable	PB, HR, HP, RJ, UP, UC, etc.	50%	Manual & Mechanised	Open Covered	30% Produce 70% Waste	Haryana	4.0	20.5	Stalks			8.00 5.40	150 - 200	1000 1600
Coconut	Shell Fibre Pith	Pulverisable	TN, K, GJ, WB, MH, MP,etc.	30 to 50%	Manual & Mechanised	Open Covered	30% Produce 70% Waste	Karnatka	1.0	Shell-20.1 Fibre-18.1	Husk Shell	0.42 0.12	10 8-9	4.60 6.31	79	1000 2000
Trees	Eucylptus Popular Kikar Sheesham	Woody/ Sheredded	JK, PB, HP, HR, UP, UC, RJ, GJ,etc.	30 to 50%	Manual & Mechanised	Open Covered	70% Produce 30% Waste	Gujrat	.50	Kiker-20.0 Popular-19.5 Eucylptus-20.0 Sheesham-21.0	Leaves Saw Dust		40 13	0.21 1.21 1.20 1.31	239 177 330	800 2000
Jowar Bazara Ragi Millets	Straw Straw Straw	Pulverisable	JK, PB, HP, HR, UP, UC, RJ, GJ,AP,etc.	15 to 30%	Manual & Mechanised	Open Covered	12-15 Waste 7-8	--	--	Straw-18.1 (approx)	Stalks husk		15 25	1.5 1.8 1.2 1.1	175 - 200	400 1200
Sorghum Bagasse			WB, HR, PB, UP etc	50%	Manual & Mechanised	Open Covered	10-12 Waste 6-8	--	--	Bagasse-18.9	Husk			7.40		500 800
			Total Annual Production				405 Million Tonnes Agri residue	--	--							

PB – Punjab, HR – Haryana, HP – Himachal Pradesh, RJ – Rajasthan, UP – Uttar Pradesh, JK – Jammu Kashmir, UA – Uttaranchal (All states of Northern India)
WB – West Bengal, AP – Andhra Pradesh, MP – Madhya Pradesh, GT –Gujarat, TN – Tamilnadu, KT – Karnataka

STATE-WISE/YEAR-WISE LIST OF COMMISSIONED AGRIWASTE POWER/CO-GENERATION PROJECTS IN MW (As on 30/06/2003)

		1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-2000	2000-01	2001-02	2002-03	2003-04	
1	Andhra Pradesh	--	--	--	--	1.00#	--	10.00	1.00	41.70	47.50	58.85	9.00	169.05
2	Chattisgarh	--	--	--	--	--	--	5.00	--	--	6.00	--	--	11.00
3	Gujarat	--	--	--	--	--	--	0.50	--	--	--	--	--	0.50
4	Haryana**	4.00**#	--	--	--	--	--	--	--	--	--	--	--	4.00
5	Karnataka	--	--	--	--	1.00	--	10.00	26.00	26.60	12.00	33.78	--	109.38
6	Maharashtra	1.50	--	1.50	4.50#	1.50	--	--	--	--	15.50	--	--	24.50
7	Punjab*	--	10.00*	--	--	--	--	--	--	2.00	--	10.00	--	22.00
8	Tamil Nadu	3.00	3.00	4.00	19.0	25.50	33.50	10.00	--	--	8.00	--	44.50	150.50
9	Uttar Pradesh***	--	--	--	6.50	--	8.00	8.00	24.00	--	--	--	--	46.50
	Total	**8.50**	**13.00**	**5.50**	**30.00**	**29.00**	**41.50**	**43.50**	**51.00**	**70.30**	**89.00**	**102.63**	**53.50**	**537.43**

* Rice straw fired plant, ** Mustered straw fired plant, *** Bagasse fired plants, # Year of installation

State-wise List of Agri-residue/Agriwaste Power Plants (MW)

S.N	State	Agri-waste exploited	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	Total capacity
1.	Andhra Pradesh	• Rice husk • deoiled bran • bagasse	-	-	-	-	1.0*	-	10.0	1.0	12.0
2.	Gujarat	• Fuel Wood	-	-	-	-	-	-	0.5*	-	0.5
3.	Haryana	• Cotton stocks • mustard straw • rice straw	4.0**	-	-	-	-	-	-	-	4.0
4.	Karnataka	• Coconut shell					1.0*	-	10.0	26.0	37.0
5.	Maharashtra	• Bagasse	1.5	-	1.5	4.5	1.5	-	-	-	9.0
6.	Madhya Pradesh	• Rice husk	-	-	-	-	-	-	5.0*	-	5.0
7.	Punjab	• Rice straw	-	10.0*	-	-	-	-	-	-	10.0

- *Year of installation* *Source: Biomass energy systems, V Ramana P Srinivas*

ANNEXURE - B

DELPHI SURVEY QUESTIONNAIRE

STUDIES IN TECHNO ECONOMIC ASPECTS OF POWER GENERATION FROM AGRIWASTE IN INDIA.

Focus: “The Future Scenario”
Please tick (✓) whichever option you feel is relevant

Q1. Hydropower will stay as a chief source of electric power in India even in future (2002-2012).

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q2. Coal /Fossil Fuels have no problems as a reliable future source of power in India in the ensuing future (2002-2010).

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q3. Nuclear power holds a good scope in the forthcoming decades(2002-2012).

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q4. Commercial Power from sun is yet a Pipe Dream.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q5. Presently there is hardly any scope for power generation from Agriwaste.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q6. Agriwaste will emerge as a viable source of electric power within a decade or so.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q7. Power Generation from Agriwaste can solve the twin problem of power shortage and air pollution due to stub burning, easily & economically.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q8. Viability of Agriwaste as a reliable & economic source of electric power in India has been well established by now.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q9. Though Agriwaste can come up fast as a viable alternative source of power in near future, we are not giving due attention & priority to its development.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q10. Lack of funds for R&D work in developing an economic solution of power ` generation from Agriwaste is a major impediment in our country.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q11. Power generation systems for more than 10MW capacity are not economically infeasible.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q12. Academics dismiss R&D work on conversion of Agriwaste into electric power as a dilute & low IQ persuit

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q13. Power generation from Agriwaste has a plus point as it can generate electricity by only a slight modification in the existing coal/ Fossil fuel based thermal power plants.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q14. The cost of Power generation from Agriwaste is much higher than that from coal/fossil fuels.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q15. Major issues involved in power generation from Agriwaste are heterogeneity of its type, location, bulkiness & its low Calorific Value.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q16. Problem of conversion of Agriwaste into an appropriate and handlable fuel-form is a major hurdle in developing this solution.

Strongly Agree	Agree	Can’t say	Don’t Agree	Strongly disagree

Q17. Fluidized Bed combustion approach for generating power from Agriwaste is a better option in view of its higher Thermal Efficiency.

Strongly Agree	Agree	Can't say	Don't Agree	Strongly disagree

Q18. Prospects of Power Generation from Agri-waste can be improved substantially by supplementing it with forest waste/energy plantation.

Strongly Agree	Agree	Can't say	Don't Agree	Strongly disagree

Q19. Decentralized Power generation is a dire necessity of our country for developing economy in rural & Tribal areas.

Strongly Agree	Agree	Can't say	Don't Agree	Strongly disagree

Q20. Power from Agriwaste will contribute substantially to the main grid, particularly during the lean period/peak load hours.

Strongly Agree	Agree	Can't say	Don't Agree	Strongly disagree

Any special comments you will like to make on the worth or problems of Agri-waste as source of electric power in India.

ANNEXURE B2

Ref. No.TI/MED/ 25 **Code No. _______________**

STUDIES IN TECHNO ECONOMIC ASPECTS OF

POWER GENERATION FROM AGRIWASTE IN INDIA

Focus: "The Future Scenario"

Q. No.	Strongly Agree (SA)	Agree (A)	Don't agree (DA)
1.	38	1	1
2.	36	--	4
3.	36	--	4
4.	34	3	3
5.	9	13	18
6.	35	2	3
7.	34	2	4
8.	32	2	6
9.	39	--	1
10.	31	7	2
11.	33	5	2
12.	31	1	8
13.	34	2	4
14.	32	4	4
15.	30	--	--
16.	35	1	4
17.	37	2	1
18.	40	--	--
19.	39	1	--
20.	34	4	2

Any special comments you will like to make on the worth or problems of Agri-waste as source of electric power in India.

Annexure B1, B2 (Delphi Survey)

As mentioned earlier 40 experts from various fields concerned with energy responded to the questionnaire. The basic issues involved were the possible alternative resources from energy in the region in the future. There was almost unanimous opinion of the experts that nuclear power and non-conventional energy sources have great role in potential for future energy requirements.

Among the non-conventional energy resources agriwaste was considered as a major contribution in this region (northern). There was further unanimity on the issues of decentralized power generation for the rural and tribal areas as well. The focused attention and priority for the development of agriwaste as the power source.

The respondents who had shown some reservations regarding the use of agriwaste as a alternative source of power generation were contacted in person and on telephone also agreed that a concentrated and focused effort will make the proposition viable and worth consideration.

There was again unanimous opinion that compaction of agriwaste for easy handling and compounding/mixing for higher calorific value will improve its use as source of power generation.

The opinion was near unanimous on the use of fluidized bed combustion for utilization of agriwaste which according to all of them are available in sufficient quantity.

The experts were also of the opinion that lack of funds for research and development for this purpose (use of agriwaste for power generation) is one of the major impediments using such a potential source of energy.

ANNEXURE C1

Table showing the values of agriwaste briquettes prepared natural drawing

Case-I		Case-II		Case-III		Case-IV		Case-V		Case-VI		Days
I (gm)	II (gm)	I (gm)	II (gm)	I (gm)	II (gm)	I (gm)	II (gm)	I (gm)	II (gm)	I (gm)	II (gm)	
122.39	123.59	91.12	400.00	76.18	92.94	133.51	126.64	98.97	111.00	130.25	137.81	0
120.50	122.25	89.00	397.00	71.00	88.00	128.59	119.81	94.27	106.25	128.26	132.61	1
119.65	121.08	87.67	393.25	69.55	93.76	123.10	114.18	89.91	102.50	121.86	128.60	2
117.24	118.18	85.28	389.32	69.43	91.76	115.00	107.00	88.31	100.70	116.00	122.32	3
114.60	115.38	85.10	386.20	69.20	90.51	112.20	104.50	86.64	98.80	113.40	125.32	4
111.62	112.47	86.82	382.35	68.95	89.15	108.80	102.00	85.19	96.91	110.75	122.82	5
108.92	109.57	85.25	378.50	66.95	87.55	105.60	99.50	83.57	95.04	108.06	120.52	6
106.69	107.32	83.75	374.68	64.37	86.19	102.50	97.14	82.31	93.02	105.19	117.92	7
104.33	104.47	82.25	377.79	62.95	84.66	102.90	94.55	80.66	91.35	102.32	115.58	8
101.63	101.67	80.67	366.84	60.45	83.41	101.14	91.86	79.04	89.49	99.74	114.36	9
98.65	98.77	78.69	362.99	60.21	82.165	100.29	89.32	77.41	87.68	96.87	111.86	10
96.00	95.57	77.10	359.47	59.46	80.06	96.60	86.76	75.81	85.86	94.02	109.32	11
93.65	92.57	75.60	355.49	58.61	77.85	93.39	83.76	74.18	84.05	91.06	106.72	12
91.25	89.59	74.125	351.91	58.32	75.62	90.70	80.56	72.50	82.29	88.21	103.82	13
88.62	86.69	72.56	348.22	58.15	72.26	87.72	77.56	71.00	80.51	85.39	100.92	14
85.66	83.81	70.54	344.30	57.28	71.00	84.51	75.06	69.48	78.76	82.59	99.72	15
83.30	81.01	68.54	340.33	56.43	69.75	81.26	72.52	67.85	76.78	79.89	98.42	16
80.10	78.11	66.96	336.44	56.03	68.50	78.81	70.26	66.22	74.80	77.04	96.82	17
77.10	75.11	65.38	332.57	55.11	67.14	74.87	67.90	64.51	72.84	74.19	95.22	18
74.18	71.91	64.13	328.77	54.19	65.78	71.73	65.65	63.05	70.89	71.29	93.22	19
71.019	68.91	62.57	324.59	53.30	64.53	68.64	63.44	61.57	68.95	68.59	90.86	20
68.31	66.06	60.62	320.57	52.30	63.29	65.19	61.06	60.12	67.00	66.19	87.96	21
65.35	63.11	58.77	316.57	51.10	62.04	62.63	68.86	58.92	65.04	63.99	85.07	22
62.40	60.24	57.27	312.68	49.90	60.79	59.83	56.66	57.67	63.08	61.06	82.46	23
59.20	57.26	55.07	308.79	48.70	59.25	57.70	54.56	56.42	61.28	58.39	79.46	24
56.20	54.26	53.07	305.60	46.70	59.95	55.56	52.46	54.92	59.48	56.09	76.45	25
54.20	51.38	51.17	302.59	45.70	56.69	53.42	50.46	53.72	56.58	53.59	70.45	26
51.35	48.48	49.37	298.57	44.70	55.45	49.28	48.56	53.58	56.38	51.39	67.86	27
48.60	45.88	47.95	294.69	43.80	54.20	47.78	46.66	51.58	55.24	50.19	66.85	28
45.70	42.90	46.50	290.80	43.00	53.88	47.25	45.21	50.25	55.14	50.08	62.84	29
43.00	40.00	45.00	287.00	42.00	53.75	47.00	45.00	50.00	55.00	50.00	58.00	30

Fig. No. 1

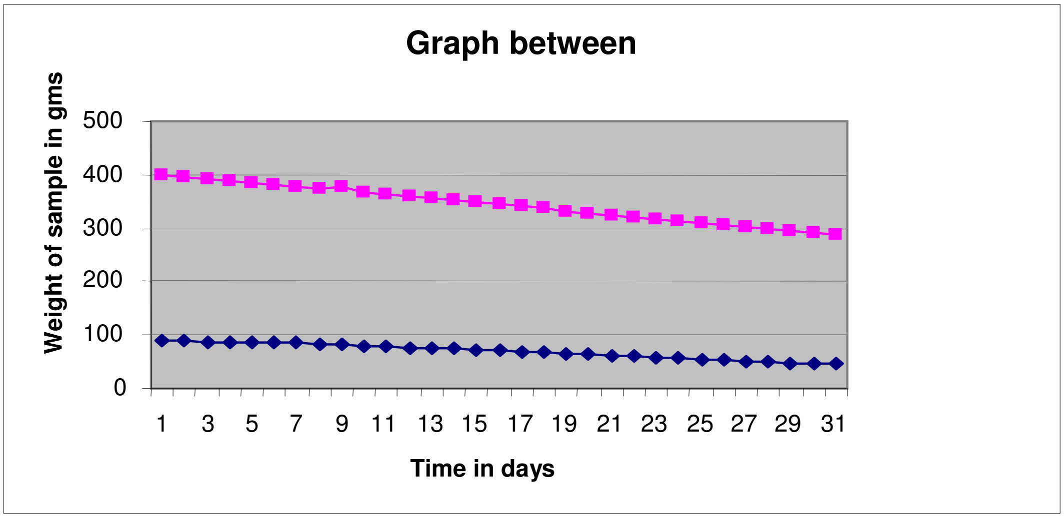


Fig. No. 2

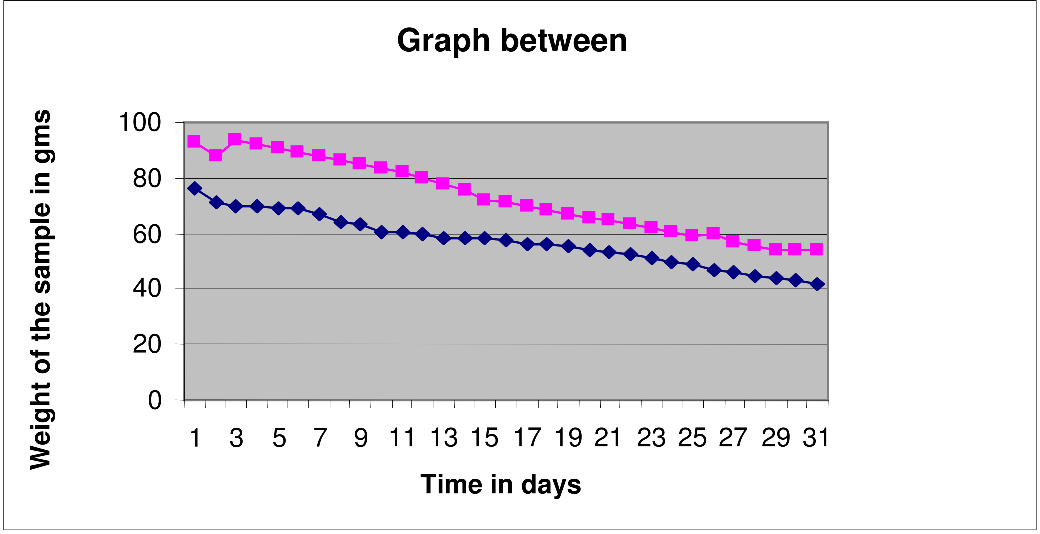


Fig. No. 3

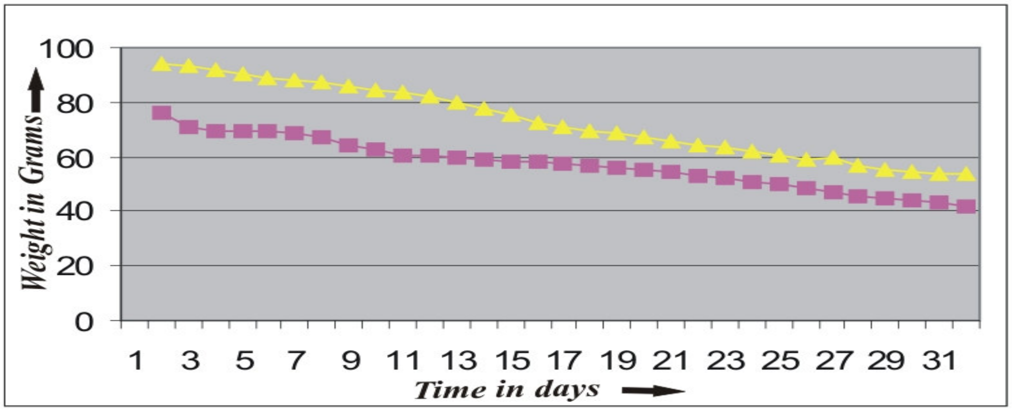


Fig. No. 4

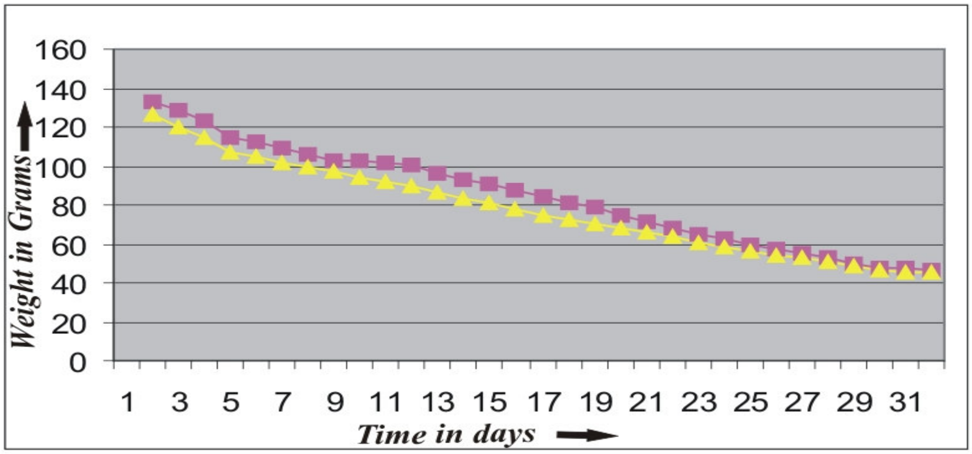
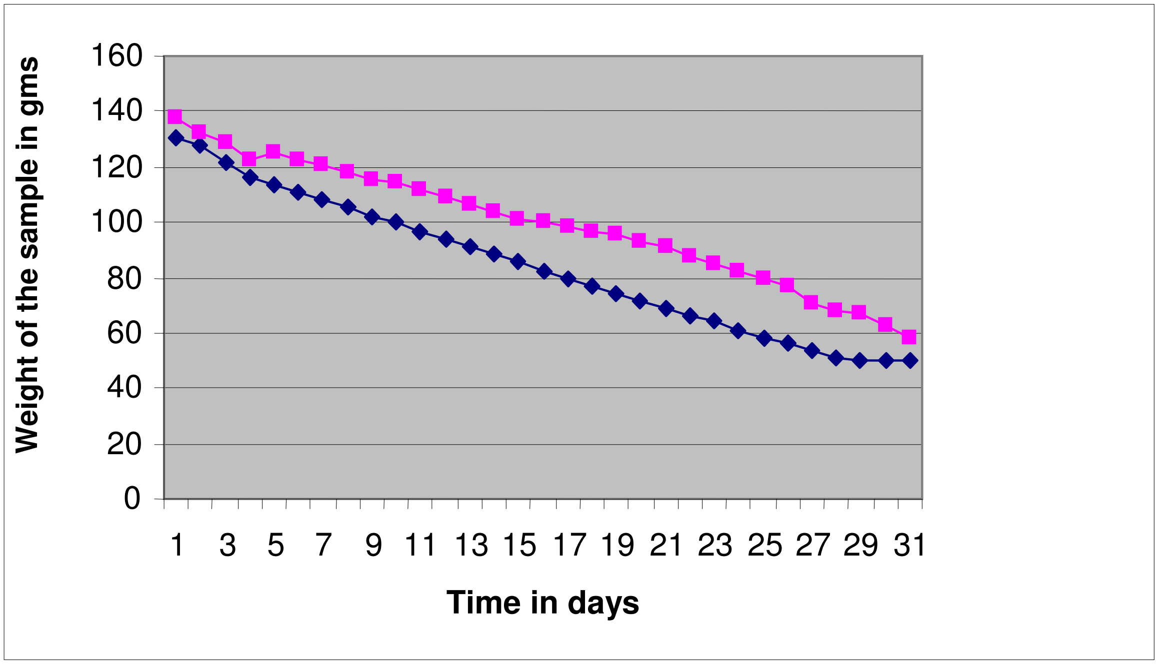


Fig. No. 5



ANNEXURE - D

C++ PROGRAMMING SHEET

```
#include<iostream.h>
#include<conio.h>
void main()
{
	clrscr();
	float rs,rh,sd,le,fl,wh,tr;
	float total_main_ct=0, total_trans_ct=0;
	float total_m_t, power_cost,main_cost,market_cost,total;
	cout<<"enter the percentage of rice straw:";
	cin>>rs;
	if(rs>0)
	{
		total_main_ct=total_main_ct+250;
		total_trans_ct=total_trans_ct+150;
	}
	cout<<"enter the percentage of rice husk:";
	cin>>rh;
	if(rh>0)
	{
		total_main_ct=total_main_ct+350;
		total_trans_ct=total_trans_ct+100;
	}
	cout<<"enter the percentage of saw dust:";
	cin>>sd;
	if(sd>0)
	{
		total_main_ct=total_main_ct+300;
		total_trans_ct=total_trans_ct+75;
	}
	cout<<"enter the percentage of leaves:";
	cin>>le;
	if(le>0)
	{
		total_main_ct=total_main_ct+10;
		total_trans_ct=total_trans_ct+20;
	}
	cout<<"enter the percentage of flowers:";
	cin>>fl;
	if(fl>0)
	{
		total_main_ct=total_main_ct+200;
		total_trans_ct=total_trans_ct+150;
	}
	cout<<"enter the percentage of wheet straw:";
	cin>>wh;
	if(wh>0)
	{
		total_main_ct=total_main_ct+400;
```

```
                total_trans_ct=total_trans_ct+100;
        }
        cout<<"enter the percentage of trees:";
        cin>>tr;
        if(tr>0)
        {
                total_main_ct=total_main_ct+0;
                total_trans_ct=total_trans_ct+75;
        }
        float clv;
        clv= 4.2*((rs*38)+(rh*42)+(sd*46)+(le*40)+(fl*42)+(wh*48)+(tr*46));
        cout<<"The caloific value of the combination is:"<<clv<<endl;
        cout<<"Total raw material cost for combination is:"<<total_main_ct<<endl;
        cout<<"Total transportation cost for combination is:"<<total_trans_ct<<endl;
        total_m_t=total_main_ct+total_trans_ct;
        cout<<"total raw material and transportation cost:"<<total_m_t<<endl;
        cout<<"enter the power & labour cost:";
        cin>>power_cost;
        cout<<"enter the maintaince cost:";
        cin>>main_cost;
        cout<<"enter the marketing cost:";
        cin>>market_cost;
        total=total_m_t+power_cost+main_cost+market_cost;
        cout<<"total cost is:"<<total;
        getch();
}
```

ANNEXURE-E

LINEAR PROGRAM – ORIGINAL DATA

Title : ____

	x1	X2	X3	X4
Minimize	450.00	250.00	200.00	350.00
Subject to				
(1)	4000.00	3800.00	3900.00	4200.00
(2)	500.00	250.00	250.00	0.00
(3)	450.00	250.00	200.00	350.00
Lower Bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

	x5	x6	x7	x8
	200.00	150.00	50.00	100.00
(1)	4700.00	4900.00	4000.00	4150.00
(2)	0.00	0.00	0.00	0.00
(3)	200.00	150.00	50.00	100.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

	x9	x10	x11	x12
	250.00	300.00	250.00	175.00
(1)	3850.00	4950.00	5000.00	4850.00
(2)	0.00	0.00	0.00	0.00
(3)	250.00	300.00	250.00	175.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

	x13		
	75.00		
(1)	4750.00	>=	52000.00
(2)	0.00	=	1000.00
(3)	75.00	<=	2800.00
Lower Bound	0.00		
Upper Bound	Infinity		
Unrestr'd (y/n)?	n		

SIMPLEX TABLEAUS (Two Phase Method)

Title : ____

Phase 1 (Iter 1)

Basic	x1	x2	x3	x4
z(min)	4500.00	4050.00	4150.00	4200.00
Rx15	4000.00	3800.00	3900.00	4200.00
Rx16	500.00	250.00	250.00	0.00
sx17	450.00	250.00	200.00	350.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x5	x6	x7	x8
z(min)	4700.00	4900.00	4000.00	4150.00
Rx15	4700.00	4900.00	4000.00	4150.00
Rx16	0.00	0.00	0.00	0.00
sx17	200.00	150.00	50.00	100.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x9	x10	x11	x12
z(min)	3850.00	4950.00	5000.00	4850.00
Rx15	3850.00	4950.00	5000.00	4850.00
Rx16	0.00	0.00	0.00	0.00
sx17	250.00	300.00	250.00	175.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x13	Sx14	Rx15	Rx16
z(min)	4750.00	-1.00	0.00	0.00
Rx15	4750.00	-1.00	1.00	0.00
Rx16	0.00	**0.00**	**0.00**	**0.00**
sx17	75.00	0.00	0.00	0.00
Lower bound	0.00			
Upper Bound	Infinity			
Unrestr'd (y/n)?	n			

Basic	sx17	Solution
z(min)	0.00	53000.00
Rx15	0.00	52000.00
Rx16	0.00	1000.00
sx17	1.00	2800.00

Phase 1 (Iter 2)

Basic	x1	x2	x3	x4
z(min)	500.00	250.00	250.00	0.00
x11	0.80	0.76	0.78	0.84
Rx16	500.00	250.00	250.00	0.00
sx17	250.00	60.00	5.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x5	x6	x7	x8
z(min)	0.00	0.00	0.00	0.00
x11	0.94	0.98	0.80	0.83
Rx16	0.00	0.00	0.00	0.00
sx17	-35.00	-95.00	-150.00	-107.50
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x9	x10	x11	x12
z(min)	0.00	0.00	0.00	0.00
x11	0.77	0.99	1.00	0.97
Rx16	0.00	0.00	0.00	0.00
sx17	57.50	52.50	0.00	-67.50
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x13	Sx14	Rx15	Rx16
z(min)	0.00	0.00	-1.00	0.00
x11	0.95	0.00	0.00	0.00
Rx16	0.00	0.00	0.00	1.00
sx17	-162.50	0.05	-0.05	0.00
Lower bound	0.00			
Upper Bound	Infinity			
Unrestr'd (y/n)?	n			

Basic	sx17	Solution
z(min)	0.00	1000.00
x11	0.00	10.40
Rx16	0.00	1000.00
sx17	1.00	200.00

Phase 1 (Iter 3)

Basic	x1	x2	x3	x4
z(min)	0.00	130.00	240.00	-280.00
x11	0.00	0.57	0.76	0.39
Rx16	0.00	130.00	240.00	-280.00
x1	1.00	0.24	0.02	0.56
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x5	x6	x7	x8
z(min)	70.00	190.00	300.00	215.00
x11	1.05	1.28	1.28	1.17
Rx16	70.00	190.00	300.00	215.00
x1	-0.14	-0.38	-0.60	-0.43
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x9	x10	x11	x12
z(min)	-115.00	-105.00	0.00	135.00
x11	0.59	0.82	1.00	1.19
Rx16	-115.00	-105.00	0.00	135.00
x1	0.23	0.21	0.00	-0.27
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x13	Sx14	Rx15	Rx16
z(min)	325.00	-0.10	-0.90	0.00
x11	1.47	0.00	0.00	0.00
Rx16	325.00	-0.10	0.10	1.00
x1	-0.65	0.00	0.00	0.00
Lower bound	0.00			
Upper Bound	Infinity			
Unrestr'd (y/n)?	n			

Basic	sx17	Solution
Z(min)	-2.00	600.00
x11	0.00	9.76
Rx16	-2.00	600.00
x1	0.00	0.80

Phase 1 (Iter 4)

Basic	x1	x2	x3	x4
z(min)	0.00	0.00	0.00	0.00
x11	0.00	-0.02	-0.32	1.66
x13	0.00	0.40	0.74	-0.86
x1	1.00	0.50	0.50	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x5	x6	x7	x8
z(min)	0.00	0.00	0.00	0.00
x11	0.74	0.42	-0.08	0.20
x13	0.22	0.58	0.92	0.66
x1	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x9	x10	x11	x12
z(min)	0.00	0.00	0.00	0.00
x11	1.11	1.30	1.00	0.58
x13	-0.35	-0.32	0.00	0.42
x1	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x13	Sx14	Rx15	Rx16
z(min)	0.00	0.00	-1.00	-1.00
x11	0.00	0.00	0.00	0.00
x13	1.00	0.00	0.00	0.00
x1	0.00	0.00	0.00	0.00
Lower bound	0.00			
Upper Bound	Infinity			
Unrestr'd (y/n)?	n			

Basic	sx17	Solution
Z(min)	0.00	0.00
x11	0.01	7.05
x13	-0.01	1.85
x1	0.00	2.00

Phase 2 (Iter 5)

Basic	x1	x2	x3	x4
z(min)	0.00	0.00	0.00	0.00
x11	0.00	-0.02	-0.32	1.66
x13	0.00	0.40	0.74	-0.86
x1	1.00	0.50	0.50	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x5	x6	x7	x8
z(min)	0.00	0.00	0.00	0.00
x11	0.74	0.42	-0.08	0.20
x13	0.22	0.58	0.92	0.66
x1	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x9	x10	x11	x12
z(min)	0.00	0.00	0.00	0.00
x11	1.11	1.30	1.00	0.58
x13	-0.35	-0.32	0.00	0.42
x1	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x13	Sx14	Rx15	Rx16
z(min)	0.00	0.00	Blocked	Blocked
x11	0.00	0.00	0.00	0.00
x13	1.00	0.00	0.00	0.00
x1	0.00	0.00	0.00	0.00
Lower bound	0.00			
Upper Bound	Infinity			
Unrestr'd (y/n)?	n			

Basic	sx17	Solution
Z(min)	1.00	2800.00
x11	1.00	1205.26
x13	0.00	9.26
x1	0.00	2.00

Phase 2 (Iter 6)

Basic	x1	x2	x3	x4
z(min)	0.00	3.42	55.00	-283.68
sx17	0.00	-3.42	-55.00	-283.68
x13	0.00	0.38	0.40	0.88
x1	1.00	0.50	0.50	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x5	x6	x7	x8
z(min)	-125.79	-72.63	13.16	-34.47
sx17	125.79	72.63	-13.16	34.47
x13	0.99	1.03	0.84	0.87
x1	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x9	x10	x11	x12
Z(min)	-189.21	-221.84	-171.05	-98.42
sx17	189.21	221.84	171.05	98.42
x13	0.81	1.04	1.05	1.02
x1	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr'd (y/n)?	n	n	n	n

Basic	x13	Sx14	Rx15	Rx16
z(min)	0.00	-0.02	Blocked	Blocked
sx17	0.00	0.02	-0.02	-0.77
x13	1.00	0.00	0.00	0.00
x1	0.00	0.00	0.00	0.00
Lower bound	0.00			
Upper Bound	Infinity			
Unrestr'd (y/n)?	n			

Basic	sx17	Solution
Z(min)	0.00	1594.74
sx17	1.00	1205.26
x13	0.00	9.26
x1	0.00	2.00

Phase 2 (Iter 7)

Basic	x1	x2	x3	x4
z(min)	-110.00	-51.58	0.00	-283.68
x7	110.00	51.58	0.00	283.68
x13	-0.80	-0.02	0.00	0.88
x3	2.00	1.00	1.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr’d (y/n)?	n	n	n	n

Basic	x5	x6	x7	x8
z(min)	-125.79	-72.63	13.16	-34.47
x17	125.79	72.63	-13.16	34.47
x13	0.99	1.03	0.84	0.87
x3	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr’d (y/n)?	n	n	n	n

Basic	x9	x10	x11	x12
Z(min)	-189.21	-221.84	-171.05	-98.42
sx17	189.21	221.84	171.05	98.42
x13	0.81	1.04	1.05	1.02
x3	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr’d (y/n)?	n	n	n	n

Basic	x13	Sx14	Rx15	Rx16
z(min)	0.00	-0.02	Blocked	Blocked
sx17	0.00	0.02	-0.02	-0.77
x13	1.00	0.00	0.00	0.00
x3	0.00	0.00	0.00	0.00
Lower bound	0.00			
Upper Bound	Infinity			
Unrestr’d (y/n)?	n			

Basic	sx17	Solution
Z(min)	0.00	1374.74
sx17	1.00	1425.26
x13	0.00	7.66
x3	0.00	4.00

Phase 2 (Iter 8)

Basic	x1	x2	x3	x4
z(min)	-97.50	-51.25	0.00	-297.50
sx17	97.50	51.25	0.00	297.50
x7	-0.95	-0.02	0.00	1.05
x3	2.00	1.00	1.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr’d (y/n)?	n	n	n	n

Basic	x5	x6	x7	x8
z(min)	-141.25	-88.75	0.00	-48.13
sx17	141.25	88.75	0.00	48.13
x7	1.18	1.23	1.00	1.04
x3	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr’d (y/n)?	n	n	n	n

Basic	x9	x10	x11	x12
z(min)	-201.88	-238.13	-187.50	-114.38
sx17	201.88	238.13	187.50	114.38
x7	0.96	1.24	1.25	1.21
x3	0.00	0.00	0.00	0.00
Lower bound	0.00	0.00	0.00	0.00
Upper Bound	Infinity	Infinity	Infinity	Infinity
Unrestr’d (y/n)?	n	n	n	n

Basic	x13	Sx14	Rx15	Rx16
z(min)	-15.63	-0.01	Blocked	Blocked
sx17	15.63	0.01	-0.01	-0.61
x7	1.19	0.00	0.00	0.00
x3	0.00	0.00	0.00	0.00
Lower bound	0.00			
Upper Bound	Infinity			
Unrestr’d (y/n)?	n			

Basic	sx17	Solution
z(min)	0.00	1255.00
sx17	1.00	1545.00
x7	0.00	9.10
x3	0.00	4.00

ANNEXURE-F

CALCULATION OF 5 MW

S. No.	Particulars	Unit	
1	Installed Capacity	kW	5 x 10^3
2	Cost of Project	Lacs	2200
3	Cost/kW 220000000/2 x 10^3	Rs.	44000
4	Interest on capital during const. @ 8% (2)	Lacs	176.00
5	Total of (2 + 4)	Lacs	2376
6	Cost/kW including interest charges (5/1)	Rs.	47520
7	Annual generation per kWh at 70% LF 7000 x 365 x 24	kWh	61320000
8	Ausciallary Consump @ of 5%of(7)	kWh	306.6
9	Units sent out (7 – 8)	kWh	5825.4
10	Weighed heat rate (10876.8 x 1.14)	kJ/kWh	14832
11	Fuel Consumption	Kg/kWh	1.14
12	Fuel Consumption per year kW (11 x 7)	Kg	6990.48
13	Annual fuel cost/kW installed @ 1500/tonne 599184x1500/1000	Rs	5941.908
14	Fixed Charges (a) Interest Charges @ 8% on 6 3801.6 (b) O & M charges @ 2.5% on 3 1100.0 (c) Dep. @ 3.5 % on 3 1540.0	Rs.	6441.6
15	Total fixed & running charges (13 + 14)	Rs.	12383.508
16	Cost/kWh generated (15/7)	Rs.	2.019
17	Cost/kWh at bus (15/9)	Rs.	2.12
18	Return on capital	Rs.	761.60
19	Profit/Unit sent6 out (18/9) 3850/4993.2	Rs.	0.130
20	Price/kW generated for sending out (17 + 19)	Rs.	2.250
	Fuel Required/Unit		
1	CV of the fuel	kJ/kg	14832
2	Boiler ηb		80%
3	Heat available 13596 x 0.80	kJ/kg	11865.6
4	Requirement of fuel/unit	Kg/kWh	1.14
5	Total annual generation at 70% LF	kWh	61.32x10^6kWh
6	Total requirement of fuel/year	MT	70000
7	Requirement of fuel/day	MT	191.780
8	Requirement of fuel/hr	MR	8 mt/h/MW

Heat Rate = 11865.6 x 1.14 = 13526.784 kJ/kg

CALCULATION OF 10 MW

S. No.	Particulars	Unit	
1	Installed Capacity	kW	10 x 10^3
2	Cost of Project	Lacs	6600
3	Cost/kW 220000000/2 x 10^3	Rs.	66000
4	Interest on capital during const. @ 8% (2)	Lacs	528
5	Total of (2 + 4)	Lacs	7128
6	Cost/kW including interest charges (5/1)	Rs.	71280
7	Annual generation per kWh at 70 LF 7000 x 365 x 24	kWh	61320000
8	Ausciallary Consump @ of 5%0f(7)	kWh	306.6
9	Units sent out (7 – 8)	kWh	5825.4
10	Weighed heat rate (10876.8 x 1.14)	kJ/kWh	14832
11	Fuel Consumption	Kg/kWh	1.14
12	Fuel Consumption per year kW (11 x 7)	Kg	6990.48
13	Annual fuel cost/kW installed @ 1500/tonne 599184x1500/1000	Rs	5941.908
14	Fixed Charges (a) Interest Charges @ 8% on 6 5702.4 (b) O & M charges @ 2.5% on 3 1650.0 (c) Dep. @ 3.5 % on 3 2310.0	Rs.	9662.4
15	Total fixed & running charges (13 + 14)	Rs.	16303.356
16	Cost/kWh generated (15/7)	Rs.	2.641
17	Cost/kWh at bus (15/9)	Rs.	2.78
18	Return on capital	Rs.	761.60
19	Profit/Unit sent6 out (18/9) 3850/4993.2	Rs.	0.1307
20	Price/kW generated for sending out (17 + 19)	Rs.	2.91

Fuel Required/Unit			
1	CV of the fuel	kJ/kg	14832
2	Boiler ηb		80%
3	Heat available 13596 x 0.80	kJ/kg	11865.6
4	Requirement of fuel/unit	Kg/kWh	1.14
5	Total annual generation at 70% LF	kWh	61.32x10^6kWh
6	Total requirement of fuel/year	MT	70000
7	Requirement of fuel/day	MT	191.780
8	Requirement of fuel/hr	MR	8 mt/h/MW

Heat Rate = 11865.6 x 1.14 = 13526.784 kJ/kg

Cost of Electricity produced Rs./kWh

Fuel Price	2 MW	5 MW	10 MW
Rs. 450/tonne	Rs. 2.932	Rs. 1.776	Rs. 2.328
Rs. 850/tonne	Rs. 3.410	Rs. 2.250	Rs. 2.910
Rs. 950/tonne	Rs. 3.532	Rs. 2.410	Rs. 2.928
Rs. 1500/tonne	Rs. 4.252	Rs. 3.095	Rs. 3.644
Rs. 2050/tonne	Rs. 4.851	Rs. 3.865	Rs. 4.248
Rs. 3200/tonne	Rs. 6.214	Rs. 5.110	Rs. 6.195
Firing rate : 8 mt/h/MW			

Experiment **ANNEXURE G1**

Title :
Proximate analysis

Objective:

- (a) Determination of Moisture content.
- (b) Determination of Volatile matter.
- (c) Determination of Ash Content.
- (d) Determination of Fixed carbon.
- (e) Determination of approximate calorific value using Goutel formula.

Requirements:

Porcelain silica capsule (7/8'' in depth and 1.75'' in diameter) with aluminium cover or platinum crucible, alcohol, platinum crucible (diameter 2.5-3.5cm, capacity 10-20ml) with close fitting lid which has vent for escape of volatile matter.

Determination of inherent moisture content of coal:

If the coal sample appears to be wet, spread it on tared pans, weigh and dry it in a moisture oven at 10-15^0 C in an oven until the difference in weight between tow readings five hour apart is not nor than 0.5%. The loss in weight gives free moisture. Quickly crush and grind the sample in air tight all mill, to pass through a no. 60 mesh (ASTM). Transfer approximately 1 g of this sample to a porcelain silica capsule (7/8'' in depth and 1.75'' in diameter) with aluminium cover or platinum crucible (previously heated to temperature at which the sample is to dried ignited, and weighed), Close in tightly fitted cover and weigh.

Inherent moisture content = (B-C)/ (B-A)* 100
Where
A = Wt. of empty capsule/crucible, g
B = Wt. of sample + crucible before drying, g
C = Wt. of crucible + residue after drying, g

Determination of Ash content:

The useless and incombustible during burning of the organic matter is known as ash. Place the porcelain/silica capsule or platinum crucible containing dried coal (From the inherent moisture test), without cover in muffle furnace at low temperature and gradually raise the temperature to 700^0 C. Stir the residue or nichrome wire (to hasten ignition) and ignite for half an hour at temperature between 700^0C and 750^0 C. Moisten the residue with a drop or two of alcohol. If black articals minutes. Cool in a desiccator and weigh. Recent the process of ignition, cooling and weighing until difference in weights between two successive weighing is less than 1 mg.

Ash content (Air dry basis) = (D-A)/(B-A)* 100%
Ash content (Oven dry basis) = (D-A)/(B-A)* 100%
Where,

A = Wt. of empty & previously ignited capsule, g
B = Wt. of capsule + Air dried sample, g
C = Wt. of capsule + Oven dried sample, g
D = Wt. of capsule + Residue after ignition, g

Determination of volatile matter:

Weigh exactly about i g of sample in a previously dried (at 950 $+20^0$ C) and weighed platinum crucible (diameter 2.5.-3.5.cm, capacity 10-20 ml) with close fitting lid which has bent for escape of volatile matter. Spread the matter evenly, close with lid and place in muffle furnace maintained at 950± 20^0 C and shut the door. After heating exactly for 7 minutes take out the crucible and first bring down its temperature to room temperature rapidly (to avoid oxidation if its contents) by placing on a cold iron plate and then transfer warm crucible to desiccator to bring it to room temperature. take the final weight of crucible and contents.

% volatile matter = [(B-C)/(B-A) * 100 - % moisture]
where,
A = Wt. of empty crucible, g
B = Wt. of crucible + sample before heating, g
C = Wt. of crucible + sample after heating, g

Fixed Carbon:

The residue remaining after volatile matter of coal has been expelled, contains the mineral matter originally present and non volatile or fixed carbon. The fixed carbon of coal is thus calculated as follows:

% Fixed Carbon = 100 – (%moisture + %Ash+ % volatile matter)

Calorific value of coal:
The following empirical relationship (Goutel's formula) holds true for high ranking coals :

$$Q = 82\,(FC) \;+\; \alpha\,(VM)$$

FC = % fixed carbon

VM = % volatile matter

α = A factor whose value depends upon the nature of coal and its value increases with rise in volatile matter, 80-85.

Experiment **ANNEXURE G2**

Experiment: Determination of calorific value of a fuel sample using bomb calorimeter.

Apparatus: Oxygen cylinder, pressure gauge on stand, pellet press, ignition wire, benzoic acid (as standard fuel), fuel of unknown calorific value, Beckman thermometer.

Theory:

A known amount of sample is burnt in a sealed chamber. The air is replace by pure oxygen. The sample is ignited electrically. As the sample burns, heat is produced. The rise in temperature is determined. Since, baring loss of heat, the amount of heat produced, burning the sample must be equal to the amount of heat absorbed y the calorimeter assembly, a knowledge of water equivalent of the calorimeter assembly, and rise in temperature enables one to calculate the heat of combustion of sample if:

W	Water equivalent of the calorimeter assembly in calories per degree Centigrade.
T	Rise in temperature registered by a sensitive thermometer in Degree centigrade.
H	Heat of combustion of material in calories per gram
M	Mass of burnt sample in grams.

W.T. = H.M.

In first step of the experiment water equivalent of calorimeter is calculated by using a standard sample whose caloric value is known.

In the second step of experiment the "Calorific value" (H) is calculated for the provided sample; easily since W, T and M are known.

Observations:

(i) Determination of water equivalent or calorimeter.

* Calorific value of the standard sample (H) = ……. Calories per gram
Mass of the standard sample in grams (M) = …….. Gram
Corrected temperature rise in (T) = ………degree centigrade

$$W = (HM) / T$$

= ………. Calories per degree centigrade

(ii) Determination of calorific value of fuel:

Initial reading of Beckman thermometer (t1) = ………^{o}C
Final maximum reading of Beckman thermometer after the ignition (t_2) = ^{o}C
Rise in temperature as registered by Beckman thermometer (t_2-t_1) = ….^{o}C

H = (WT) / M = Calories per gram

Calorific value of Benzoic aid = 6319 Cal/Gram

C.F. of benzoic acid = 6319 Cal/gram

Procedure:

1. **Attaching the fuse and thread:**
   All manipulations prior to closing the bomb should be performed by holding the bomb lid in support stand. Cut a single length of fuse wire 10cm long and attach it to electrodes and suspend one 30 cm cotton thread fuse wire to sample surface.

2. **Filling the bomb with oxygen:**

   Prepare a pellet of less than one gram of fuel sample. And place it carefully in the cup with thread touching its surface. Now close the lid of the bomb tightly. Ensure the continuity by using the test switch on the pane after connecting the terminals. Connect copper tube from cylinder to pressure gauge, pressure gauge to filling tube and filling tube to bomb. Open the filling connection of control value slowly. Observe the gauge and allow the pressure to rise until the required pressure is reached. Then close the connection of the gas control valve and remove the bomb. If required the pressure of the bomb could be decreased by releasing through the value provided on the bomb.

3. **Assembly of calorimeter parts:**

   Place the star support at the bottom of the jacket and set it so that two pins provided inside the jacket do not allow it to be displaced. Place the bucket on the star supporter. Lift the bomb with hook and place it inside the bucket containing 2000 gm of water. Attach the supply connection to electrode provided on the lid of bomb.

4. **Firing of bomb**:

   Attach the supply connection to electrode provided on the lid of bomb. Measure the initial reading of the Beckman's thermometer, which is suspended in the bucket surrounding bomb. Push the button marked "Fire" on the panel for 10 seconds. Observe the “Ammeter” needle on the panel which shows high deflection and then returns to zero. This confirms the ignition inside the bomb.

Weight he temperature rise on Beckman scale and not the maximum attained value.
Same procedure is repeated for the fuel of unknown calorific value.

Precautions:

1. Bomb calorimeter is so designed that nor more than 10,000 calories should be liberated in any test and it is advisable to work with amass liberating 7000 calories.
2. Solid sample before use should be air dried and ground till all the particle pass through 60 mesh size otherwise the burning may be incomplete.
3. The loop of fuse should be placed just above the surface of sample.
4. Non volatile liquid may be tested in the crucible but volatile liquids must be tested in gelatine capsules and correction must be applied for combustion of gelatine.

LIST OF PUBLICATIONS

PAPERS PUBLISHED IN JOURNALS

National

1. **B. Lonia, Dr. N.K. Nayar, Prof. P.L. Bali**; Performance improvement of a high pressure lignite fired power plant boiler: A case study, Engineering Today; Vol.4, Issue 2, Feb. 2002; pp. 23-34.

2. **B. Lonia, Dr. N.K. Nayar, Prof. P.L. Bali;** Power from Agriwaste: Prospects, problems and ways out; Engineering Today, Vol. 4, Issue 6, June 2002; pp. 01-11.

3. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh**; Bio Briquettization of Bio-agriwaste. Bull. Bio. Sci. Vol. 1 (2004) p.p. 37-43

4. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh**; Energy Resources Vs Environment. Bull. Env. Sci. Vol. 1 (2004) p.p. 45-51.

PAPERS PRESENTED IN CONFERENCES

International:

1. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Bio-briquettization of Bio-agriwaste, International Conference/Workshop organized by NESA, Jamia Hamdard at New Delhi April 24-26, 2004.

2. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Power generation economics, **International Conference,** Bhubneshwar, 19-21 Dec. 2003.

3. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Energy resources Vs Environment, International Conference/Workshop organized by NESA, Jamia Hamdard at New Delhi April 24-26, 2004.

4. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Applications of WDM, International Conference/Workshop organized by NESA, Jamia Hamdard at New Delhi April 24-26, 2004.

5. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Techno-economic aspects of power generation from agri-waste, FBC-170 International Conference, USA held during May 18-21, 2004.

6. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Technological Approaches for Environmental Restoration, Bio-Convergence 2004, at TIET, Patiala November 18-20, 2004 – 191.

7. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Combining Environmental Economic & Social Imperatives of Development for Bio-Convergence 2004 at TIET, Patiala November,18-20, 2004 –192

National:

8. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** One solution for Twin Problem: Meeting Electric Power Shortage and Disposal of Agriwaste, NCME 2003, pp. 234, TIET, Patiala.

9. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Fluidized Bed Furnace Model for Agriwaste in India, NCME 2003, pp. 259, TIET, Patiala.

10. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Agriwaste a Non-conventional source of energy, NCME 2003, 249, TIET, Patiala

11. **B. Lonia, Prof. P.L. Bali;** Meeting electric power shortage and economic disposal of agriwaste; One solution for Twin Problem, 5th Punjab Science Congress, Feb 7-9, 2002; pp. PHP-19, TIET, Patiala.

12. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Techno economic aspects of power generation from agriculture waste in India, Proceedings: All India Seminar, REC, Murthal, Feb 20-21, 2003, pp. 394-403.

13. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Critical study of GHTP Lehra Mohabbat Bhatinda : A case study; Proceedings : All India Seminar, REC, Murthal, Feb 20-21, 2003, pp. 318-320.

14. **B. Lonia, Dr. N.K. Nayar,** Composite Materials: The potential for small-scale power plants, NCMRT 2003, TIET, Patiala.

15. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Agglomeration in fluidized bed combustion – a case study**,** NCMRT 2003, TIET, Patiala.

16. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Value of engineering for Objective and responsive power generation in India, Engineers' Day at Ambala, 15th Sept. 2003, Institute of Engineers.

17. **B. Lonia, Dr. N.K. Nayar, Dr. S.B. Singh;** Air pollution – a case study of various power generating systems, TICE, TIET, Patiala.

18. **B.Lonia, Dr. P. K. Bansal, Dr. S. B. Singh, Dr. N. K. Nayar**, Role of Cryptography in Data Security. Presented in All India Seminar on E-Security ,dated 25th-26th May, 2004.Held at G.T.B.K.E&T Chhapianwali, Malout-152107 (Punjab)

19. **B. Lonia, Dr. N. K. Nayar, Dr. S. B. Singh** A Simulation Model for Briquettised Agriwaste , presented in National conference CCadm-2005, April 08-09 2005 pp148

20. **B. Lonia, Dr. N. K. Nayar, Dr. S. B. Singh** Briquttised Agriwaste:A bio-degradeable Polymer, presented in national conference held from 06-07 May, 2005, Organised by Chemical Engg. Deptt. T.I.E.T. Patiala pp BP103(1-13)

21. **B. Lonia, Dr. N. K. Nayar, Dr. S. B. Singh** FBC System Design For biodegradeable Polymer, presented in national conference held from 06-07 May, 2005, Organised by Chemical Engg. Deptt. T.I.E.T. Patiala pp BP104(1-13)

Annexure-B1

Ref. No.TI/MED/ 25

Code No. _______________

STUDIES IN TECHNO ECONOMIC ASPECTS OF POWER GENERATION FROM AGRIWASTE IN INDIA

Focus: "The Future Scenario"

Panel of experts →

Q. N.↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	A	SA	A	CS	A	SA	SA	DA	CS	A	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA
2	DA	SA	DA	A	SA	A	SA	A	A	DA	SA	DA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	SA	A	SA
3	A	A	A	DA	SA	DA	A	A	DA	DA	A	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	SA	A	SA
4	SA	DA	A	A	A	DA	A	A	DA	A	CS	SA	SA	SA	SA	SA	SA	CS	SA	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	SA	SA	SA	A	CS	SA	SA	SA	SA	A	SA
5	DA	SD	DA	DA	A	SD	DA	DA	CS	DA	AG	DA	SA	A	CS	DA	CS	CS	SA	SA	A	CS	DA	CS	DA	DA	A	DA	DA	DA	CS	CS	A	CS	CS	A	CS	CS	DA	CS
6	A	SA	A	A	DA	A	SA	SD	A	A	DA	A	SA	A	SA	SA	CS	SA	SA	SA	A	SA	SA	SA	SA	A	A	SA	SA	SA	A	SA	SA	CS	SA	A	SA	SA	SA	A
7	SD	A	CS	CS	SA	A	DA	DA	A	A	DA	A	SA	A	SA	A	SA	SA	SA	SA	A	A	SA	SA	SA	SA	A	A	SA	SA	A	SA	A	SA	A	A	SA	A	SA	A
8	DA	A	A	CS	A	A	DA	DA	DA	CS	DA	DA	SA	A	SA	A	SA	SA	SA	SA	A	A	SA	SA	SA	A	A	A	SA	SA	A	SA	A	SA	A	A	SA	A	SA	SA
9	A	A	A	A	A	SA	A	SA	SA	A	DA	A	SA	A	A	SA	SA	A	SA	SA	SA	A	A	SA	A	SA	SA	A	SA	SA	A	SA	A	SA	A	A	SA	A	SA	SA
10	CS	DA	CS	CS	SA	A	A	CS	CS	CS	DA	A	SA	SA	A	SA	A	A	SA	A	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	A	SA	A	SA	A	CS	SA	A	SA	SA
11	DA	CS	CS	CS	SA	A	SA	CS	A	DA	CS	A	SA	SA	SA	SA	A	A	SA	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	SA
12	DA	A	DA	DA	A	DA	A	CS	DA	DA	DA	A	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	DA	SA	SA	SA	A	SA	SA	A	SA	SA
13	A	A	A	CS	DA	A	DA	DA	A	CS	DA	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	SA	A	SA	SA
14	CS	A	CS	DA	A	DA	DA	CS	CS	DA	A	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	S	SA	SA	A	SA	A
15	SA	A	A	A	A	SA	A	A	A	A	A	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	SA	A	SA	A
16	SA	DA	DA	A	A	A	SA	SA	DA	DA	A	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	CS	SA	SA	A	SA	SA	A	A	A
17	A	A	SA	A	CS	SA	A	A	A	A	A	A	A	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	DA	A	CS	SA	A	SA	SA
18	A	SA	A	A	A	SA	SA	SA	SA	A	A	A	SA	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	SA	A	A	SA
19	A	SA	A	A	A	SA	SA	SA	SA	SA	CS	A	SA	SA	SA	SA	SA	SA	A	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	A	SA	SA	A	SA	A

20	A	A	A	CS	DA	A	A	CS	A	CS	DA	CS	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	A	SA	A	SA	SA	A	SA	A

Nomenclature: SA = Strongly Agree; A = Agree ; CS = Can't say; DA = don't agree; SD = Strongly agree