HYDRAULIC TRANSPORTATION OF GROUNDED BOTTOM ASH FOR BACKFILLING OPERATION

A

THESIS

Submitted in partial fulfillment of requirements for the award of degree of

Master of Engineering (M.E)

In

Thermal Engineering

Submitted by

Chandan Kishor

Registration No.: 801783002

Under the Supervision of

Dr. Satish Kumar

Associate Professor, MED

NIT, Jamshedpur-831014

Mr. Sumeet Sharma

Associate Professor, MED

TIET, Patiala – 147004

MECHANICAL ENGINEERING DEPARTMENT

THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY, PATIALA

CERTIFICATE

I hereby declare that this minor project report entitled **"Hydraulic Transportation of Grounded Bottom ash for Backfilling Operation."** is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering** in **Thermal Engineering** at **Thapar Institute of Engineering & Technology, Patiala** under the supervision of **Shri Sumeet Sharma** (Associate Professor, Mechanical Engineering Department, Thapar Institute of Engineering and Technology, Patiala) and **Dr. Satish Kumar** (Associate Professor, Mechanical Engineering Department, NIT Jamshedpur), No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

Chandan Kishor

Date: 8/7/2019

Chandan Kishor

801783002

TU, Patiala

It is certified that the above statement made by the student is correct to the best of our knowledge and belief.

Dr. Satish Kumar
Associate Professor, MED
NIT, Jamshedpur-831014

Shri Sumeet Sharma
Associate Professor, MED
TIET, Patiala – 147004

ACKNOWLEDGEMENT

First and foremost, I would like to give my sincere thanks to my parents, the source of my life and hope for giving me the strength and wisdom to complete the research work.

I would like to express my gratitude Shri Sumeet Sharma (Associate Professor, Mechanical Engineering Department, Thapar Institute of Engineering and Technology, Patiala) and Dr. Satish Kumar (Associate Professor, Mechanical Engineering Department, NIT Jamshedpur), for his valuable guidance, support and for sharing his pearls of wisdom with me during my research work. Many times, his patience and constant encouragement has steered me to the right direction.

I am also thankful to Dr. Vikrant Khullar, coordinator of Master's Program and to all other teaching and non-teaching staff members of Mechanical Engineering Department for providing me all the instruments required for carrying out my research work.

Last but not least I am always grateful to my family members for their unconditional support, encouragement and best wishes, without which I have not come this far.

Chandan Kishor

(Chandan Kishor)

ABSTRACT

Coal is a major source of energy. It contributes approximate 55% of total energy production. In India, about 70% electricity produced by combustion of pulverized coal in thermal power plants.

In India, fly ash and bottom ash are hydraulically transported from thermal power plant to ash pond by pipelines. The production of bottom ash in the thermal power plants increases day by day and causes disposal and environmental problems. The objective of the present study was to investigate the physical, chemical, rheological and leaching characteristics of grounded bottom ash at high solid concentration with an additive of Nirma detergent. Bottom ash samples used for characterization were collected from the ash pond of two thermal power plants namely Rajiv Gandhi thermal power plant, Hisar, Haryana and Deenbandhu Chhotu Ram thermal power plant, Yamuna Nagar, Haryana, India. The environmental risk analysis of disposal ash was carried out to predict various critical issues associated with disposal of ash. The leaching characteristics of bottom ash were determined at liquid to solid ratio of 20:1. From the leaching result data of original and grounded bottom ash, it is observed that tracing element of Mn, Mg, Cr, Zn, Ni, Pb, Fe and Cu are most abundant while Co is the least abundant element. The tracing elements Co, Ni, Pb and Cu show under the prescribed limits in both original and grounded bottom ash.

The rheological characteristics of grounded bottom ash slurry suspension were determined at different solid concentration (10-50%). Moreover, this study is also carried out to investigate the effect of additives on rheological behaviour of grounded bottom ash slurry suspension at higher precision. The Nirma detergent was used as additive and added in proportion of 0.1, 0.2 and 0.3% (by weight) at each concentration of grounded bottom ash slurry suspension. Both grounded bottom ash slurry suspension show Newtonian behaviour at 30% solid concentration (by weight) beyond this it depicts non Newtonian flow characteristics. The addition of additives Nirma detergent help to reduce the pressure drop effectively. The maximum reduction in pressure drop rate of grounded bottom ash was found with 0.2% addition of Nirma detergent whereas marginal reduction was observed with 0.1% and 0.3%. The present study can be useful for transporting grounded bottom ash with the addition additive at higher concentrations, through pipelines for mine backfilling purpose.

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LIST OF SYMBOLS

τ	Shear Stress, Pa
μ	Viscosity. Pa.s
$\gamma, \frac{du}{dy}$	Shear rate. 1/s
n	Flow index
k	Flow parameter
V_C	critical velocity, m/sec
Φ	volume fraction of solids
d	Weighted mean diameter of solid particle, m
D	Pipe diameter, m
ρ_s	density of solid particles, Kg/m^3
ρ_f	density of carrier fluid (Kg/m^3)

CHAPTER 1

INTRODUCTION

Coal is used as primary energy source for generation of electricity. Coal is a combustible substance and its composition depends on earth crust. Coal from different regions shows different properties. Coal have different ranks and grades, as per its quality and carbon contents. Anthracite coal have higher carbon content followed by bituminous and lignite. Anthracite coal is hard to ignite whereas bituminous and lignite coal easily ignite. In Indian thermal power plants low rank (lignite or sub-bituminous) coal is used which has high ash content (34 to 49%) with lower calorific value.

Indian coal is low grade coal with high ash content between 40 – 48 % and therefore huge amount of ash is being produced in coal fired Thermal Power plants in the country, which is the source of air and water pollution. Presently 170 million tons per annum of coal-ash is generated in India from more than 70 thermal power stations. It is expected that during 12^{th} & 13^{th}Plans, power generation capacity is likely to be increased by 1, 00,000 MW which doubles the coal ash generation by 2022.

Ash is disposed in ash pond in the form of slurry and overflow ash from dyke used to be discharged in nearby water bodies. This requires huge area for disposal and will cause air and water pollution. However, recommendations by Corporate Responsibility were implemented in the year 2003 for Environmental Protection (CREP), power plants have been informed to stop overflow water discharge from ash pond and recycle for different usages within power plant.

1.1 THERMAL POWER PLANTS

Thermal power plants based on coal are leading energy sources, which provides about 70% of electricity in India. Coal fired thermal power plant is a complex energy generation system which deals with many sub-systems namely coal handling system, steam generator, power generation unit, condensation unit, water-cooling system and ash conveying etc.

Thermal power plant works on Rankine cycle in which heat is produced from the combustion of fuel for the generation of steam. Superheated steam fed to the turbine where its heat energy is converted into mechanical energy which further makes the generator to run and produces electricity. This is forecasted that electricity generation by coal-based thermal power plants in year

2020 and 2050 to be 6.1 and 16.7Mwh (billion) respectively. According to Ministry of power, India the installed status of thermal power plants in India shown in Figure 1.1.

- Total installed capacity (MW) in India is 298059.97 MW.
- Current installed capacity of thermal power is 210675.04 MW which is 70.68% of total installed capacity as shown in Figure 1.1.
- Current installation of coal-fired thermal power is 185172.88 MW which is about 87.89 of thermal power and 62.12% of total installed base.

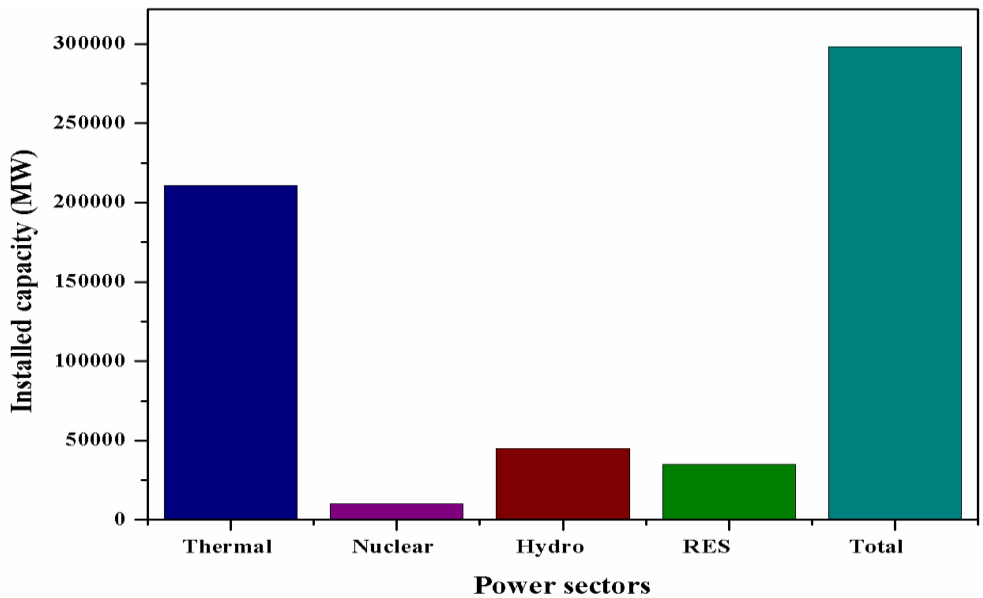

Figure 1.1: Current installed capacity of power plants in India (Source: Central Electricity Authority, New Delhi, and March 2016)

1.2 GENERATION OF BOTTOM AND FLY ASH IN THERMAL POWER PLANTS

Bottom and fly ash are produced after the combustion of coal in thermal power plants. Basically, combustion of coal takes place in the boilers chamber in which hot air is blow through nozzles of combustion bed. Generation of heat after ignition produces byproducts i.e., ash, flue gases, coal slug etc. Heat is extracted with the help of boiler tubes, which results in lowering down the temperature of molten material and formation clinker and slag. It is non-combustible solid residual made of minerals of coal. The large size clinker or slag are crushed in finer particles known bottom ash. Fly ash is produced after the vaporization and condensation followed by coagulation through various modes during the combustion or gasification of coal. The formation of ash is specified with a mechanism shown in Figure 1.2.

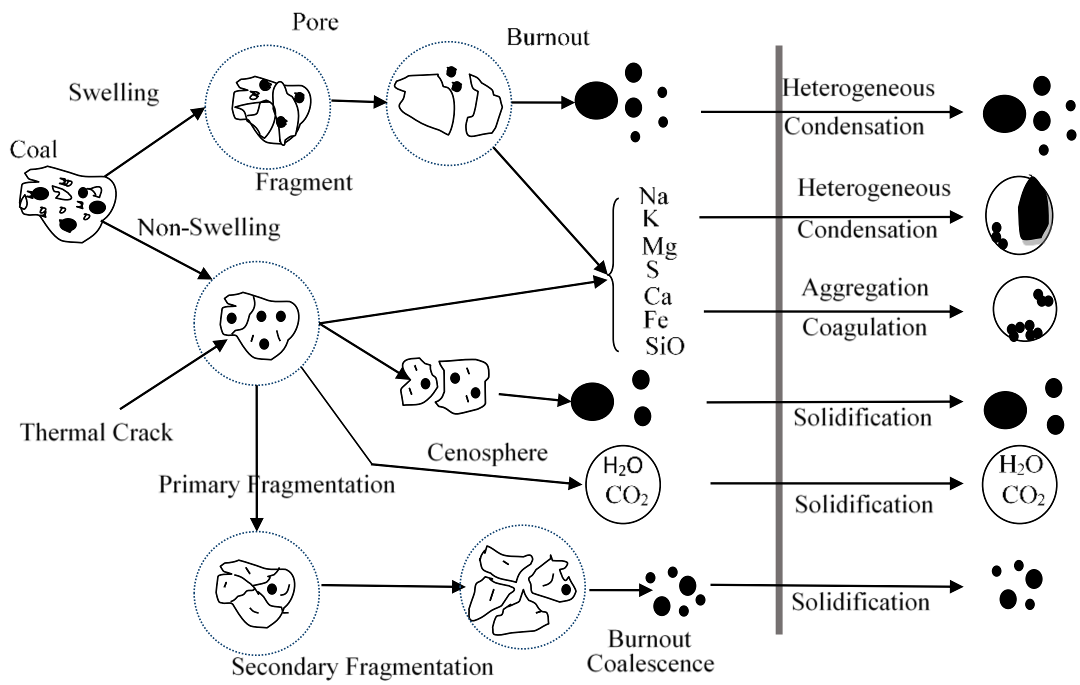

Figure 1.2: Ash formation mechanism

Bottom ash is referred as the coarser particles, irregular morphology with amorphous surfaces which can be collect under the hoppers of combustion chamber, whereas the finer ash particles called as fly ash which can be collected from electrostatic precipitator with the help of flue gases. Mainly, coal ash consists of SiO_2, Al_2O_3, Fe_2O_3 and CaO, that exist in form of crystalline oxides and amorphous.

On the basis of chemical compositions two class of fly ash are F and C type. In the comparison of Class F type fly ash, Class C has high concentration of Ca content. Class F ash is generated by combustion of harder bituminous coal. It consists of glassy silica and alumina. The total sum of SiO_2, Al_2O_3 and Fe_2O_3 in class F is more than 70% however in case of Class C it lies in the range of 50-70%. After combustion of sub- bituminous coal which consists of SiO_2, Al_2O_3 and Fe_2O_3 more than 50%, Class C type fly ash is formed. The total fraction of unburnt carbon should be up to 6% in ash sample.

1.2.1 Ash handling system

According to the Central Electricity Authority annual report (New Delhi-2016, Ministry of power India), coal based thermal power plants are about 62.12% of total power plants installed across the country. In other words, currently power generation in India is mainly coal based. Combustion of coal produces enormous amount of ash (about 200 million tons annually). Out of this, approximate 130 million ton is fly ash and remaining is bottom ash. A strong ash handling system is required in a coal-fired thermal power plant, for the proper utilization and disposal of coal ash. A typical coal ash handing system consists of following units:

- Bottom ash handling unit
- Fly ash handling unit
- Economizer (Coarser ash handling unit)
- Air pre-heater
- Slurry disposal unit

A slurry disposal system deals with preparation of slurry in large slurry tank and conveys it to the dyke area. The layout of ash conveying or handling system is shown in Figure 1.3. Ash from economizer hopper evacuates continuously with the help of flushing boxes. Continuous generation of bottom ash in economizer feed out into respective hopper pipes (placed at slope) by gravity. Whereas, the ash generated in air pre-heater hopper evacuates by vacuum conveying system which is connected with Electrostatic Precipitator (ESP) hopper. Fly ash extracts by vacuum pump and collects in ESP hopper which is located before induced draft fan and mounted at outlet of the furnace. Generally, fly ash is transported pneumatically to storage silo whereas coarser particles (mainly bottom ash) are pumped from ash slurry sump to the disposal site (dyke). Long pipeline and large amount of water requires for the transportation of bottom ash to the disposal site (dyke).

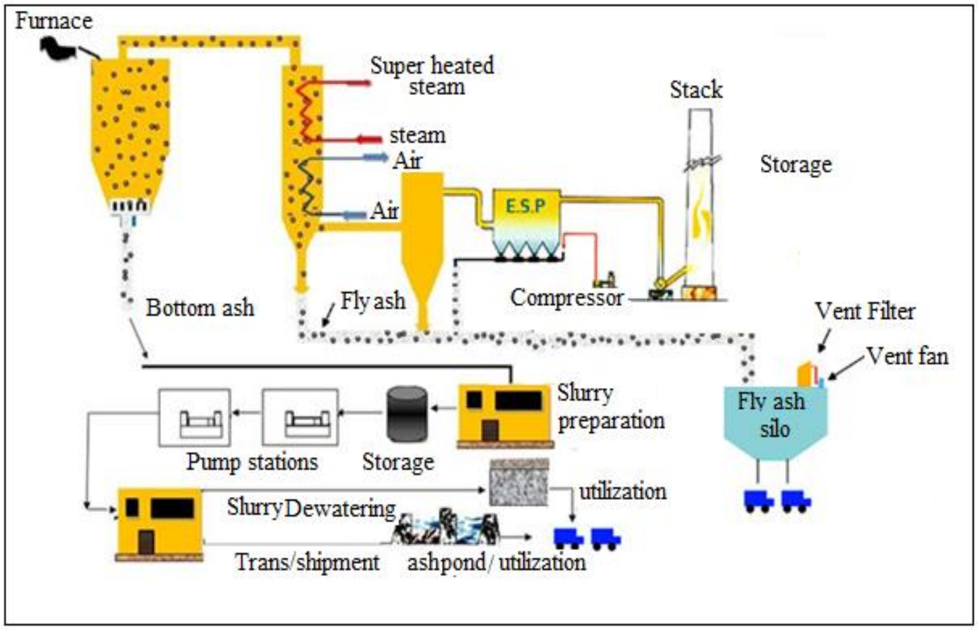

Figure 1.3: Ash handling system of coal fired thermal power plant

Conventionally, Lean Concentration Slurry Disposal (LCSD) systems have been used to transport the ashes which had the following limitations. These system requires high power consumption, leads to wastage of water, allows contamination of ground water and needs large land area for ash disposal etc. In order to overcome the limitations, ash disposal system has lead towards use of High Concentration Slurry Disposal (HCSD) systems. HCSD systems uses high potential head pump to dispose the high concentration ash through pipelines. However, these systems also have some drawbacks as many of components such as pump, pipes, tees, reducers, valves in HCSD system fails during the rapid operation of ash disposal. This failure mainly occurs due to the action of scaling, erosion, corrosion, and erosion-corrosion. Many industries along with thermal power plants such as mining and manufacturing industries are also facing similar type of problem.

1.2.2 Components of ash disposal system

Ash conveying of a coal based thermal power plant consists of various components as shown in Figure 1.3. The pumps and pipeline are two major components of an ash disposal system. Normally, centrifugal pump is used to dispose the ash from a coal based thermal power station. A centrifugal pump consists of impeller, volute casing, shaft sleeve and liners. Universally used pumping materials are cast iron, hard iron and stainless steels. Another important part of an ash disposal system is pipelines. Pipelines are made up of different materials such as mild steel, case hardened steel, heavy wall steel, heat treated alloy steel, cast iron, solid basalt or lined, AISI 304, AISI 304L, AISI 316, AISI 1020, AISI 440C, SS 304. Stainless Steel is commonly used for the manufacturing of pipe elbows or bends, pump cashing, shaft sleeves and impeller. As the major concern in pipeline is erosion wear, the next section provides brief discussion about erosion wear in slurry pipeline.

1.3 ENVIRONMENTAL IMPACT OF BOTTOM AND FLY ASH

In India, around 100 and 190 million tons of bottom and fly ash are transported hydraulically every year from thermal power plant to dyke through pipelines at many individual thermal power plants situated across the country. The huge amount of toxic elements poses negative environmental effect on environment and human health. Coal ash from different locations shows different physico-chemical properties depending on properties of parent coal. The coal ash contains heavy tracing elements like As, Pb, Hg, Cd, Cr, Al, Mo, Mg, Co, Mn, Ni, Cu, Zn etc.

Environmental Protection Agency (EPA) reported that the people have high risk near the dyke area of thermal power plant. It is also reported that unlined ash pound are responsible for series health hazardous by contamination of ground water i.e., cancer, lung disease, cognitive deficits, birth defects, kidney disease damage nervous system etc. Among the elements present in coal ash, Arsenic is considered as most dangerous pollutant followed by cadmium, lead, and other toxic metals. Mainly improper disposal and leaching of coal ash allows these elements to enter in the living beings through drinking, eating or inhaling. This can be minimizing by the use of dry landfills and use of composite liners for prevention from leaching in ash pond. Now-days the disposal of fly and bottom ash disposal is serious environmental issues faced by the world due to the leaching of heavy toxic tracing elements from it.

Trace elements emitted from thermal power plants present in coal ash voyage to surface and ground water and soil over a span of time. The toxic metal elements production in ash disposal system of thermal power plants have negative environmental effects on plants and human health. In India, the river water also polluted due to toxic element discharge from the thermal power plants. As far as tracing elements are concerned, it has negative impact on the human health like blockage of cardiac, lung tumors, breakdown of nervous systems and liver failure etc., as shown in Table 1.1.

Table 1.1 Health Effects of Heavy Metals of Fly Ash

Heavy Metals	Health Effects
Zinc	Anorexia Nervosa , Dizziness, Respiratory system Disorder, Dermatitis
Iron	Choroiditis , Conjunctivitis , Siderosis
Calcium	Kidney stones, Scierosis of Kidney, Osteoporosis
Cadmium	Diarrhea, Lung Damage, Kidney Damage, Psychological disorder
Cobalt	Lung Effect, Asthma, Pneumonia, Vision problem, Thyroid damage
Nickel	Lung cancer, Larnyx Cancer, lung embolism, Birth defect
Copper	Liver damage, Kidney Damage, Stomachaches, Dizziness
Lead	Swelling of the brain, Male reproductive problems, Hearing impairment, Hemoglobin Damage, Nervous system Damage, High blood pressure
Manganese	Fatness, Skeleton disorder, Birth defects, Neurological Symptoms
Chromium	Respiratory Disorder, Lung Cancer, Kidney damage

1.4 ENVIRONMENT IMPACT OF FLY ASH

1.4.1 Groundwater Contamination

Since coal contains heavy trace elements such as boron, cadmium, chromium, barium, arsenic, beryllium, molybdenum, mercury, thallium and selenium that is why trace metal is absorbed by its ash and so it cannot be reserved or drain where trace metal can percolate by rain water.

1.4.2 Divulge of mass depository

Mass depository of fly ash is done in watery form rather than moist free because of fugitive dust can get reduced. Generally in solar ponds or in land filling fly ash is deposited in mass. Generally solar ponds are very big and stable for long time, but any breakage of their bund walls will be effect the surrounding area rapid and on a massive scale.

1.4.3 Fly ash Contamination

Heavy metals and other substances which are produced in fly ash that are known to be hazardous to health above the higher range amounts. Heavy elements in coal including arsenic, barium, cadmium, beryllium, lead, chromium, nickel, mercury etc. are potentially toxic. High contaminant levels in many coal combustion residue (CCR) percolates may create ecological and human health concerns, according to The National Academy of Science noted in 2007.

1.4.4 Fly ash Exposure Concerns

Toxic chemicals using with crystalline silica and lime (Cao) are exposure to coal fly ash through particulate matters inhalation and drinking water detrimental to human health. Fly ash contains silica in crystalline form which cause lung disease, lime (Cao) is other component concern of fly ash. Lime reacts with water to produce calcium hydroxide [Ca(OH)2], giving fly ash a pH a medium to strong base in between 10 and 12, also cause lung disease if present in plenty.

1.5 TRACING ELEMENTS OF FLY ASH & ITS ENVIRONMENTAL, HEALTH EFECTS

1.5.1 Zinc (Zn)

Zn is shiny bluish white metal. Zn is the 23rd most available element available on the earth crust. It’s brittle and crystalline at ambient temperature. But when it is heated at temperature (110°C-150°C) it becomes malleable and ductile. It is literally reactive when it comes in the contact with oxygen and other non – metals. When it react with diluted acids it release Hydrogen. Water is highly contaminated with Zn due the higher concentration of Zn in industrial waste water and combustibles. When the waste sludge is directly dumped in the pond without any precautionary measures it may contaminated the above ground soil and underground water also. Zn also increases the acidity of the river water as well as underground water which is very dangerous for the marine life.

The WHO (World health organization) stated a limit of Zn in water is 5mg Zn^{2+}/L. If the Zn is found in the higher range in soil only a limited plants are able to survive. That's why where the Zn industries are located there is not to much plant diversity. Zn is trace element and very necessary for the human health. When human absorb little quantity of Zn can experience of decreased sense of smell and taste, a loss of appetite or hunger and skin sores. With the shortage of Zn birth defects are occurring.

Even the human body can handle with large quantity of Zn. The higher range of Zn also creates the health problem such as skin irritation, anemia, vomiting etc. Very high level of Zn can disturb the protein metabolism cause arteriosclerosis, damage the pancreas and also effect the new born baby health.

1.5.2 Iron (Fe)

It is 10^{th} clement which is mostly available in the universe. Fe is shiny, malleable, ductile and silver grey metal. It is exist in the four form of crystalline. It lusts in moist air but not in dry air Iron dissolve quickly of readily in dilate acids. Fe is almost essential for the living things i.e. microorganism to humans. Human body can absorb Iron from see food instead plant foods.

Iron is important parameter for hemoglobin. Iron is the red color agent in blood that supplies oxygen through the bodies. Iron can cause choriodities (the pigmented vascular layer of eye ball between retina and sclera) retinitis, etc. if it contacts the issues. Excessive inhalation of Iron oxides or dust may create the problem of siderosis (lung disease) which is observed by an X-ray change. Excessive inhalation may also increase the risk of lung cancer. 50% of marine animal death may occur due to exposure to the Iron by any route other inhalation.

The deficiency of Iron leads to anemia instead of normal brain functioning depends upon the Iron. Iron may hazardous for the environment special attention for the plant air and water. Generally plants contain between 200 to 300 ppm Iron (dry mass) when soil contains little iron, or little Iron concentration in water then there is problem persist in to plant growth. Plant growth does not depend only upon the percentage of Iron content in soil, it also depends on the pH values because if pH is higher, it leads with iron precipitation. Iron is harmful if its content less than the limit (5-20ppm) at the time of feeding to plants. When Iron exceeds to the higher limit it is stored in liver then bone marrows have higher amount of Iron. When Iron deficit in human bodies leads to anemia, loss of concentration, causes of concentration disorder. The permissible limit of Iron in water is 200 ppm.

1.5.3 Calcium (Ca)

Ca is the most available metal in the earth crust. Ca is softer than aluminum and harder than sodium It is lesser chemically reactive as compare to other alkaline metals when it contact with air make oxide and nitride coating it prevents corrosion.

Calcium is present in very large quantity in the human body. It is the main content of teeth as well as for bones. Calcium has several metabolic functions. It is necessary component for Skelton preservation and teeth. Leak of Calcium may leads to Osteoporosis diseases related to bones becomes slowly porous and heal. Calcium phosphide is toxic in nature and very harmful for the aquatic plants. Calcium is important parameter for the water harness. It is mainly stabilize the pH of water due to its buffering quality.

1.5.4 Cadmium (Cd)

Cadmium is a lustrous very malleable ductile and silver, which is very soft metal even though to be easily cut with simple Knife. But it tarnish when it explore to air 'It is easily soluble in acids but not is alkaline. Human uptake this element mainly through the sea foods.

People those are living in industrial Area or near hazardous waste sites they are mostly suffering from lung disease if higher content of cadmium may occur in body if will accumulate in kidney and then damage the filtering mechanism. Health effect from cadmium are damage the central nervous system, DNA damage Psychological disorder etc.

Cadmium may enter to the soil through burning of fossil fuels and waste combustions. Cadmium may cover longer distances when it absorb by sludge. This Cadmium rich sludge or soil may pollute the underground and surface water.

Cadmium may absorb by soil, presence of cadmium in soil is highly dangerous for growing plants and for animals two those are depending upon or vegetative foods. Cadmium found in very high amount in cows because they are eating multiple plants. Salt water organism is grater resistant to cadmium poisoning as compare to fresh water.

1.5.5 Cobalt (Co)

It is hard, brittle, shiny, silver white element like Fe it can magnetized. This element is highly chemically active making many compounds. As cobalt is highly dispersed in environment human may be take it through air drinking and eating. Cobalt is not freely present in environment but when its particles are not found with soil it may take up by plants or animals Cobalt stimulates the production of red cells in blood.

By higher concentration of plant various diseases are occur like Vomiting, vision problem, Heart problem, thyroid damage. Some other diseases are also occurring due to ratio above Cobalt isotopes this can cause hair loss, sterility, bleeding etc. Cobalt may settle or the land through wind which contains Cobalt dust and also enters to water when water rain water pass through the rock or soil containing Cobalt. Cobalt can't be destroyed if it enters to the environment. It may reacts with other elements absorb by water, soil easily.

1.5.6 Nickel (Ni)

It is malleable and ductile metal. It is used for the coating purpose. It is good conductor of electricity and heat. It forms complex compound i.e. generally bluish or green. Nickel slowly dissolves in diluted acids. People may expose with nickel through the drinking water, air inhalation, Skin contact, vegetables those are grown on polluted soil. Plants can accumulate nickel.

In small quantity nickel is essential for human but higher quantity may be problematic for human health. Intake of large quantity of nickel may create the various problems such as lungs embolism, heart disorder, asthma, birth defects and respiratory failure. Nickel is released in the atmosphere through power stations and incinerators. It will than settle down on ground then reaction with rainwater. It will contaminate ground water, it will highly mobile in acidic water. It also impacts the marine life also. Nickel tetra carbonyl is insoluble in water. Generally Ni is soluble in water at temperature (20°C). Nickel chloride is highly soluble in water. Nickel is required nutritional diet for many organisms. But it may be toxic if it persists in larger quantity.

1.5.7 Copper (Cu)

Cu is reddish metal having cubic crystalline structure and good conductor of heat and electricity with low chemical reactivity. When it contact with moist air it creates a coating on it in green color known as patina. Long term contact with Cu can create the irritation on the nose, eyes and mouth. Excessive concentration of Cu may lead damage to liver and kidney. Cu may travel long distances in surface water. It cannot break down in environment due to that it accumulates in animals and plants when it exists in soil. On rich Cu soil only limited number of plants can survive. Due to this reason very low greenery persist near the Cu disposing industries. Its serious threat for the production of farmlands.

1.5.8 Lead (Pb)

Lead is a lustrous metal, which is ductile and malleable. It is resistant to corrosion but tarnish when it contacts with the moist air. Pb may have the most harmful effect on human health. The food like

Sea food, vegetables, meat, grains, wine etc. contain huge amount of lead. By corroded pipe line of drinking water as well as of supply water pile lead can enter in the ground water. It is mostly happen when the water is acidic in nature.

Due to this reason the water treatment plants are required to adjust the pH level of water. By high value of lead uptake may create the several unwanted effects such as Anemia, Blood pressure problem, Miscarriage, Kidney failure, Sperm damage. It is also create the problem among the diminishing of learning ability among the children. It can also effect the nervous system of new born baby by entering through the placenta of mother.

Lead may enter in water and soil mostly through the pipe lines. Lead mostly accumulates in soil organism as well as in water organisms. With the interference of lead the functioning of Phytoplankton can disturb. Phytoplankton is very important source of oxygen supply in larger sea animals. Near highways and industrial area higher concentrated lead soil found. This type of soil organism may suffer from the lead poisoning.

1.5.9 Manganese (Mn)

Mn is very hard and brittle metal. It is pinkish grey in appearance. It is easily oxidized but very hard to melt. If it is used in powdered form it is burn in the presence of oxygen. It dissolves in the diluted acids. It act as iron (highly rusted) when it reacts with water.

When manganese presence in higher limits in human body then survival for human life is very difficult. It can effect in the brain and respiratory tract. It can also effect the central nervous system of the human which may cause of permanent disability.

Due to shortage of manganese some other effects may occur such as skin problem, birth defects, Neurological symptoms, Blood clotting etc. Manganese compound naturally exists in soil and little particle of Mn found in water. Manganese contents found in air due to industrial pollution. When Mn used as pesticides then it is enter in the soil. Mn is essential for the animals for their metabolism bone formation. By many laboratory test it is prove the higher side of Mn may poisoning even though also create the tumor among the animals. When pH of soil is low Mn deficiency found in the soil.

1.5.10 Chromium (Cr)

Chromium is lustrous, brittle and hard metal. It is not tarnish in air and gives green chromic oxides when it is heated. It is impermeable with oxygen and protect the metal. Chromium contents are higher in the environment due the industrial applications (Textile, Leather, Chemical

Manufacturing etc.). Through the combustion of coal, waste disposal is enter in the soil and through soil it is enter in ground water.

During in presence of water is absorb on sediments become immobile. Cr naturally persist in vegetables, fruit, grain, meat etc. when food is stored in steel tank then the percentage of chromium is higher. Those people working in steel textile, steel manufacturing industries may have to exposure to Cr. The health problems occur due to Cr, such as Lung cancer, Kidney and Liver damage, Respiratory problem and skin rashes, etc.

1.6 Backfilling operation

In general, Backfill meaning is to refill an excavation unit to store the former ground surface and or to preserve the unit and make it recognizable as having been excavated. Backfilling is one of the important practices in coal mining which is performed with various techniques like paste backfill, pneumatic backfill and hydraulic backfill or stowing.Hydraulic stowing is one of the important techniques used for backfilling in underground coal mine voids, where slurry made of different material is send to the mine voids. Easy and quick dewatering or drainage is one of the essential features of hydraulic backfill technique. In the absence of this, there is a possibility of liquefaction or collapse of the filled material, in some instance it may rupture the barricades used in this technique.

Backfill is useful in preventing fires, improving stability of the rock, mine ventilation as well as for environmental and economic factors. Hydraulic Backfilling helps to minimize underground mine fires. When preparation plant reject is used as stowing material, backfilling can be used as an alternative coal refuse disposal method.

1.6.1 Backfill method used for transport solid-liquid slurry

- **Paste Backfill:** Paste backfill is a technique in which slurry at solid concentration above >65% by weight is pumped to the underground mine void. The paste has a homogenous in nature and produces a considerable slump when it released from a cone shape slip mold. Paste backfill does not require dewatering process when it is deposited underground mines or voids.
- **Hydraulic sand fill:** Hydraulic sand fill is sand mixed with binders and hydraulically pumped in to the voids. As the sand settled and gain strength then the excess.

- **Cemented fill:** Cement fill method consists of ores tailings and waste rock filled in underground mines void. This method is used when waste rock storage is necessary and the left over voids need filling. Tailing mix with cement pour over the waste rock to fill the voids. Cemented fill is beneficial when small volume of cement slurry is vital to bind backfill material.
- **Dry rock fill:** Dry rock fill method consists of rock waste, sand, gravels and dried tailings. In this method the fill is either drops down into an open stope by dump trucks.

1.6.2 Backfill design for transportaion of solid- liquid slurry through pipeline

- Selection of backfill method according to requirement.
- Exploration of source, quantities and qualities of potential backfill materials.
- Analyze the physical and chemical properties of backfill material like specific gravity of solid, angle of internal friction, water holding capacity, pH, porosity of settled fill, SEM-XRD.
- Preparation of filling slurry, storage, addition of fly ash and cement, transportation of slurry through pipe line form backfill pant to the mined out area. Method of fill system, drainage system, quality control, monitoring and keeping record of the following: cement, fly ash, bottom ash quantities, concentration, fill stability etc.
- Economic estimation of overall plant, cost savings, etc.
- For a new Back fill system a detailed engineering construction with documentation and routine fine tuning is required. Implementation of monitoring all data in the computerized form and training is required.

1.6.3 Backfill system current status in India

In recent years, the backfill system is being adopted by an Indian resource (IRL) flagship, the Sudra copper mine, East Singhbhum (Jharkhand) India. It is an integral part of the mine filling and most of stopping activities use horizontal cut and fill method, it leaves void progressing out of reach of mining during cutting and needs to be filled with tailing which provides platform for mining activities.

Backfill also provides constancy and fills voids between foot and hanging wall. The maximum open span is 5m, after this mining ceases until filling is complete to within 1-2 m of solid rock. For the design of the backfill system solid-liquid slurry transports from the ground surface to the underground mine. So, characterization of the slurry flow needs to study some physical and chemical characterization of coal ash like particle size distribution, electron dispersive X-ray, X-ray diffraction, scanning electron microscopy, specific gravity, porosity, water holding capacity, bulk density, plasticity, pH, settling, thermal gravimetric analysis, etc. The above properties are discussed in the next chapter.

Computational fluid dynamics is a powerful graphical tool which is very useful to simulate the pilot test loop system for the backfill system. To test different types of backfill material on experimental loop, it become too expensive and time consuming. Now a days, CFD used for the designing of such system provides an approximate and fast results.

In backfilling system CFD plays an important role in which we can predict the pressure drop, erosion rate, internal flow behavior, heat transfer rate, etc. So, the motivation of the present thesis work is to develop a CFD model for backfill system to predict the pressure drop, velocity profile and solid concentration profile in slurry pipeline.

CHAPTER 2

LITERATURE REVIEW

Coal is a major source of energy. The ash content in Indian coal varies 34 - 39 % while in imported coal it varies 10 -15% only (Kumar et al. 2000; Chandel et al. 2009). During the combustion of coal an abundance of inorganic residues is produced in the thermal power plants are bottom ash, fly ash, slag and desulfurization byproducts of flue gas. The hydraulic ash transportation system of thermal power plant have consist of three system as pump, pipeline and slurry preparation system.

The pipeline and pump are key components of slurry transportation system. The performance of slurry transportation system depends upon the design and operating parameter. The design of pipeline and rheological behavior of slurry suspension play very significant role in effective operation of slurry transportation system. At present lean (up to 20 % concentration) slurry transportation system is used to disposal of coal ash **(**bottom ash and fly ash**)** from thermal power plant to dyke.

The other problems associated in the pipe line are excessive wear due to high transportation velocity of the ash water mixture which reduces their working life. This data emphasizes the need of investigation on slurry transportation system for the flow of solid-liquid mixture at high concentration. Attempts have been made to study the various parameters influencing performance of slurry pipe line and piping material. A critical review of significant work carried out in this field has been presented in this chapter to give an understanding into the present state of knowledge.

2.1 CHARACTERIZATION OF COAL ASH

Kumar et al. (2000) collected fly ash sample from three different coal based thermal power plants to study various properties. They found that fly ash consists of SiO_2, Cao, Al_2O_3, MgO and Fe_2O_3 oxide in major proportion (96.5-98%) with small amount of other element. They noticed that fly ash samples have significant difference in their chemical composition. They suggested that lower bulk density and water holding capacity makes it useful for used in civil construction. The fly ash can be applicable in cement, road and fly over and other construction.

Sarkar et al. (2005) studied various properties of collected fly ash sample from various location of thermal power plant situated in Eastern Indian. They study the various physical properties of collected fly ash sample for utilization in various application. They reported that wide variation in particle size distribution was found from sample to sample. They suggested that finer particle of fly ash can be used in construction works.

Stanislav et al. (2005) carried out experimental study for determine the various physico-chemical mineral properties of fly ash samples. During the experimentation various small scale laboratory test was conducted to determine different properties of fly ash. X-ray diffractometry was used to find out mineral phases in solid sample. They reported that the physico-chemical properties of fly ash contributes in its utilization for various applications.

Sarkar and Rano (2007) analyzed the variation of different properties of soil by adding of fly ash. They found that fly ash increase the level of nutrient which are essential for the growth of plant. Most of Indian fly ash have alkaline nature which can be used to neutralization of acidic soil They found that as percentage of ash was change from 10 to 30% (by weight) neutralization of soil is increase. There was a significant improvement in yield crop and change pH of soil.

Erol et al. (2008) investigate the physical and mechanical properties of ash. They noticed that fly ash consists of various oxides such as $Al2O3$, $Fe2O3$, $SiO2$ and CaO. They reported that fly ash can be utilized for the fabrication of glass ceramics and glass products.

Chindaprasirt et al. (2008) determined variation in geopolymer properties with addition of fly ash. It was noticed that fly ash have lower reactivity with high concentration of calcium oxide. Blending of collected sample was done with active fly ash for increasing the rate of reaction used in geopolymer. The sodium silicate and sodium hydroxide was used as additive for the synthesis of polymer at relevant temperature. They suggested that fly ash geopolymer were used with PCC-fly ash to increase strength and workability of polymer.

Mahale et al. (2012) investigated the usage of fly ash in soil to increase yield of crops. Investigate the effect of addition of fly ash for agriculture production of wheat, mung bean and urad bean. They found that seed generation rate was increased with addition of fly ash. They also reported that 10-20% increase in yield production of mung and urad bean by the addition of fly ash.

Lee et al. (2014) investigated the utilization of fly ash in tailing application. They reported that ingress of water was reduced with addition of fly ash. Results show that fly ash comes in contact with water results in hydration. Electric conductivity of mine tailing with addition of fly ash was reduced and helps in minimize leaching of trace elements.

Tang et al. (2014) investigated the effect on mechanical properties of mortar with addition of bottom ash. They investigated physico-chemical properties of mortar with addition of bottom ash. They reported that with addition of finer bottom ash particles compressive strength and flexural of mortar was improved. They also found that compressive strength is function of curing time.

Latifi et al. (2015) performed experimental investigation to assess the effect of addition of bottom ash (BA) in fly ash on morphological, physic-chemical and strength of mortar. They also determined the effect of curing time on compressive strength with addition of BA. They noticed from SEM analysis the addition BA in fly ash increase the percentage of irregular particles compared to original bottom ash sample. They also reported that significant change in chemical composition was found with addition of fly ash. They concluded that with addition of bottom ash modulus of elasticity reduced from 30-70% with any significant impact of shear strength.

Baite et al. (2016) performed the experimental study to determine the effect of addition of bottom ash as coarser particle in mortar. The amount of bottom ash in sand was change from 0-100% (by volume) for manufacture of mortar. The properties namely as porosity, bulk density, thermal conductivity etc. of sand was alter with addition of bottom ash. They found that porosity of sand mixture was increased which lead to increase water holding capacity during curing of mortar.

Singh et al. (2017) studied various physic-chemical properties of bottom ash taken from four different power station situated in northern region of India. They crushed the bottom ash sample as pass through 250 μm sieve to prepare grounded bottom ash. They noticed that physical properties alter with grounding of bottom ash without major modification in chemical composition. Cementing properties of bottom ash also increased after grounding the bottom ash sample and helps in utilization for various application. They also noticed that specific gravity of grounded bottom ash was increased as compared to original samples.

2.2 RHEOLOGICAL BEHAVIOUR OF SLURRY

The study of flow behavior and deformation of fluid under the effect of external force is known as rheology.

Mishra et al. (2002) carried out the rheological investigation to study the impact of temperature and concentration on coal ash slurry. They noticed that coal ash slurry suspension show pseudo plastic nature. They also reported that viscosity of coal ash slurry is depends on temperature, concentration and pH.

Boylu et al. (2004) carried out and experimental study to investigate the rheology of coal-water suspension influenced by volume fraction, particle size distribution and rank. Results show that as the higher rank of coal has low apparent viscosity.

Verma et al. (2006) carried out an experimental study on impact of particle size distribution on rheological behaviour of coal ash slurry suspension at higher concentrations. The experimentation was carried out by taking different size sample and each sample of different concentration. They noticed that fly ash more than 40% show non-Newtonian nature.

Senapati et al. (2010) carried out an experimental investigation to analyze the rheology of fly ash suspension at higher concentrations. Experiments were conducted by taking five sample of fly ash with volumetric concentration 0.32 to 0.4945. They found that viscosity of fly ash suspension is depends upon concentration and particle size.

The researcher (Senapati et al. 2010; Kumar et al. 2013; Kumar et al.2014) reported that behaviour of fly ash suspension depends upon concentration of fly ash. They also found that the rapidly enhancement in viscosity and yield stress of fly ash suspension as solid concentration is increased. The above review shows that no universal correlation has been devolved to predict the rheological behavior of slurry suspension. This is due to the fact that rheological of slurry suspension is governed by large number of parameters like volume fraction, shear rate, viscosity and other properties of solid particles.

2.3 INVESTIGATION OF PRESSURE DROP CHARACTERISTICS OF COAL ASH IN SLURRY PIPELINE

Pressure drop is the most important technical parameters to be ascertained while designing a hydraulic transportation system. In the absence of any universal correlation for pressure drop prediction , head loss is generally estimated by carrying out pilot plant studies and the data collected are then scaled up for prototype pipelines. These studies also lead to a better understanding of the flow mechanism, which eventually may lead to development of an appropriate correlation. The pioneer work in this area was done by **Durand and Condolios (1952)** in the early fifties.

Kumar et al. (2000) investigated the rheological properties of bottom ash, fly ash and with addition of bottom ash as additive. They noticed that rheological characteristic of fly ash suspension was improved with addition of bottom ash.

Gillies et al. (2004) studied the pressure drop of heterogeneous sand slurry flow at high velocities. The test loop used to conduct experiments was of 0.09 and 0.27 mm in median diameter and 0.103 m of length. They measured the pressure drop with the help of calibrated transducers and velocities with the help of calibrated magnetic flux flow meter. The calibration of magnetic flux flow meter was verified during experiments. Results show that friction losses were low at high velocity of slurry flow. They also developed a correlation to predict the friction generated by heterogeneous slurries at velocities.

Chandel et al. (2009) carried out an experimental study on the effect of additives on rheological characteristics and pressure drop of fly ash slurry by using pilot plant test loop. The pilot plant test loop was consisting of 40 mm diameter straight pipeline of 50 m length. The concentration of ash slurry was kept high (above 60% by weight) and mixture of Henko detergent and sodium carbonate was used as an additive. The flow rate inside pipeline was measured by calibrated electromagnetic flow meter. The results obtained from experiments showed reasonable agreement with analytical results calculated from the algorithm given by Darby and Melson (1981). They also found that the pressure drop gets reduced with the addition of soap solution in high concentrations fly ash slurry.

Chandel et al. (2010) carried out an experimental study on rheological characteristics and pressure drop of coal ash (fly and bottom ash) slurry at high concentration by using pilot plant test loop. The pilot plant test loop was consisting of 42 m diameter straight pipeline of 50 m length. The concentration of ash slurry was kept high (50-70% by weight). A Roto flow pump was used to the flow the high concentration slurry. The flow rate inside pipeline was measured by calibrated electromagnetic flow meter. The fly and bottom ash is mixed in 1:4 ratio by weight. Results show that with increase in solid concentration the pressure drop increases at a particular flow velocity.

Chen et al. (2010) carried out an experimental study on wall slip flow behavior of coal water slurries with the help of pilot scale slurry transportation system. The pilot plant test loop was consisting of 25, 32, 40 and 50 mm diameter straight pipeline of 2200 mm length. A screw pump was used to the flow the slurry at rate of 16 m^3/h **by** adjusting the speed of electromagnetic motor. Results show that increase concentration, temperature and particle size tends towards the decrease in the wall slip velocity. Also, the increase in concentration and decrease in temperature/particle size resulted in increase of critical wall shear stress.

Pavel and Zdenek (2011) performed an investigation on flow behavior of high concentration slurries influenced by particle size distribution and concentration. By the experimental investigation, flow behaviour and pressure drop of dense complex slurries which contain sand of different particle size, mean diameter ranging (0.20 to 1.40 mm) and inner diameter ranging (17.5 to 26.8 mm). The solid concentration of sand, sand-dust and stony dust-sand slurry lied in range 6-40%, 26-48% and 45-51% respectively. It was found that the sand slurry with coarser particles have high gradient than sand slurry with fine particles. They found that flow resistance of fine-grained stony dust slurry was reduced by adding coarse-grained material.

Mika (2012) performed an investigation on rheological behavior and pressure drop in sudden contractions and expansions of pipeline due to flow of ice slurry at low fraction. Experiments were performed at six different pipe contractions and expansions ratios (0.813, 0.800, 0.769, 0.650, 0.615 and 0.500). They analyzed the structure of ice slurry flow and found the minimal flow velocity of the ice slurry in range of 0.11 to 0.32 m/s.

Cimzmadia et al. (2013) predicted the friction factor in straight pipe line for Bingham plastic fluid and the power law fluid using experiment and simulation. The solution they have taken contains 0.13% carbopol 971, 0.05%NaOH and 99.82% water. The experimental setup consists of pipe diameter 20mm and length of pipe 298 mm long. Computational fluid dynamics approach has been used to validate the experimental data. CFD code ICEM has been used to develop the geometry which consists of 32000 elements and length of pipe was 10m. Turbulence model was SST model used to simulate the model. They analyzed the Headstrom number for Bingham fluid at different viscosity and keeping the other parameter constant like pipe diameter, density and yield stress. They observed that as there is increment in the yield stress in the Bingham plastic fluid the laminar segment shifter towards right with increase in Headstrom number in the moody chart i.e. as the friction factor increases the laminar-transition appear at higher Reynolds number. Now the CFD modeling found to be good agreement with the experimental data and we can predict the losses or friction factor for a non-Newtonian fluid.

Mishra et al. (2014) studied the characterization of coal ash and coal ash-water slurries for hydraulic disposal in underground mine. They have taken three samples of coal ash from ash pond and studied the required variable for hydraulic transportation of ash-water slurries at different solid concentration ranges of 45-65% by weight. Physical-chemical properties, self-heating of pond ash has been discussed by author and compared the different empirical correlation to find out the critical velocity and the slurry viscosity of the pond ash. Morphology of these samples shows that the pond ash consists of spherical particles which lead to improve the flow of slurry in which particles behaves as a ball-bearing and results in a frictionless flow with less wear and tear in pipeline during hydraulic transportation. They observed that the Thomas's equation predicts the viscosity of pond ash very well. The viscosity variation predicted by empirical model of particle size 0.29 and 0.48 mm indicates exponential increase in viscosity for concentration 45% and 65% while beyond 50% concentration of particle size 0.33 mm there was a steep increase in viscosity. Higher the slurry viscosity higher would be the pressure drop. The critical velocity of slurry has been evaluated with different concentration and pipe diameter ranges of 80-200 mm. The results show an increasing trend with increasing pipe diameter and slurry concentration.

Panda et al. (2014) studied the fly ash and fly ash-Bottom ash mixtures slurry through pipeline transportation at higher concentration by hydraulic means. They have taken coal ash sample of Fly ash and Fly-bottom ash mixtures in the ratio (3:2). Particle median diameter for fly ash and bottom ash is 20μm and 250μm respectively. They observed that the fly ash- water slurry at higher concentration above 60% behave as a Bingham plastic and while adding Bottom ash to fly ash slurry then the behavior changes from Bingham to Pseudo plastic. Bingham plastic model was used for fly ash to calculate the Friction factor for laminar flow by evaluating the Headstrom number and Bingham Reynolds number. Darby and Melson empirical correlation was used for turbulence flow of fly bottom ash slurry.

Wu et al. (2015) studied the pressure drop characteristics of solid-liquid flow in pipe line using Computational fluid dynamics code COMSOL Multiphysics. They have taken coal mixture of coal gangue, cement, fly ash as a solid material. The mixture solid concentration varied from 78-79.5% concentration by weight at different flow rate (60, 70, 80 and 90 m^3/h). They employed a test loop pipeline system of 120 mm diameter with 35 m total length to study the pipe flow behavior of suspension. They observed that the fluid solid-liquid mixture behaves as a Bingham Fluid at high solid concentration. CFD Model was carried out to compare the outcomes of simulated results with loop test. They observed that the partial pressure drop and total pressure drop increase with increasing the slurry flow rate leads to increase the Darcy friction factor (f_D) and the frictional resistance loss. If there is increase in inner diameter of pipe then the slurry velocity will decreases which leads to decrease in pressure drop, on the condition maintaining the same volumetric flow rate. The obtained results have shown a good accord between the loop test and model simulation.

Kumar et al. (2017) performed an investigation on pressure drop characteristics bottom ash slurry with and without addition of additive. They have taken Henko detergent and sodium sulfate as an additive. The additive added in bottom ash suspension by weightage of 0.2, 0.4 and 0.6%. The solid concentration of bottom ash suspension was kept in range of 10-60%. They found that the 0.4% addition of additive in slurry results in maximum pressure drop due in the pipeline. From the available prediction tools for pressure drop, it is observed that none of the available methods is directly applicable to all commercial slurries operating in heterogeneous regime. Therefore, there is a need for concerted effort in this area to produce a prediction tool for pressure drop which will be applicable to all types of commercial slurries having wide particle distribution.

2.4 LEACHING CHARACTERISTICS OF COAL ASH SUSPENSION

Leaching deals with the removal of soluble components exists in solid. Leaching of any solid is dependent on its mineralogical as well as physico-chemical characteristics. Also, the pH value and surface area of solid, solubility of chemical compound and composition of leachate decides the leaching of any substance. A review of literature available in this area has been presented in the following paragraphs to discuss the present state of knowledge.

Georgeakopoulos et al. (2002) determined trace and major leachants elements in fly ash sample of Ptolemaist coal-fired power plant (Northern Greece). Leaching experiments were carried out with help of one stage and column procedures. Experiments were carried out to characterize the relative mass leached from fly ash and time dependent elemental behavior. Results show that Sr and Mo were lost during leaching.

Ugurlu et al. (2004) investigated the leaching behavior of fly ash samples collected from Kemerkoy Power Plant (Turkey). Leaching experiments were performed on the fly ash collected from electrostatic precipitators and dyke area. They found the pH value of fly ash in range of 11.9-12.2 which represents the alkaline nature of both fly ashes. They found that Calcium, sodium, potassium, manganese, iron, sulphur and lead were major leachants and cadmium, magnesium, copper, chromium and cobalt were minor leachants.

Ahn et al. (2006) analyzed the municipal incineration of bottom ash for the investigation of leaching properties of Cu, Pb and for the stabilization of both elements. They concluded that by interaction with carbon dioxide with bottom ash both elements were more stabilized by carbonation reaction. The pH quickly dropped and heavy metal depended on pH extraction solution.

Sushil and Batra (2006) investigated the leaching behavior of bottom and fly ash samples gathered from investigated three different North Indian power plants. Leaching tests were conducted to find the tracing element namely Cr, Mn, Pb, Zn, Cu, Ni and Co. They found the element Cr and Zn shows maximum concentration and Co shows minimum leachate concentration.

Tsiridis et al. (2006) analyzed the toxicity of fly ash sample. According to their study compound contained in fly ash easily be transferred to liquid with the effective leaching procedure. Heavy metals concentration was higher in the TCLP test results as compared with ASTM method. The pH of leaching media is most significant factor for the extraction of heavy metal toxicity medium.

Snigdha et al. (2006) investigated the leaching behavior of fly ash samples to determine the tracing element of Cr, Mn, Pb, Fe, Cu, Ni and Co. They found the element Cr and Zn shows maximum concentration and Co shows minimum leachate concentration. They proposed the ash pond lining to control the leaching of ash.

Zhang et al. (2008) studied about the effects of different parameters such as L/S ratio, leaching time, pH etc. on heavy metal extractions from municipal solid waste bottom ash. They observed that extraction rate of heavy metal rapidly influence with liquid to solid ratio. Leaching concentration also partly depends upon the absorption reaction.

Prasad et al. (2008) analyzed the leaching potential of heavy elements in of fly ash sample with variation of pH value. They concluded that leaching of heavy element is strongly function of pH of fly ash sample solution.

Popovic et al. (2009) investigated the leaching behaviour of coal ash by verifying pH values. They found that the environment threat of most recently deposited fly was too much greater than the older deposited dump coal ash because it had already lost its pollution potential. They have also concluded that rate of extraction of heavy element are directly proportional to the acidity of extraction.

Dutta et al. (2009) investigated the leaching behaviour of fly ash collected from four different thermal power plants situated in West Bengal, India. Leaching experiments were performed on leaching of ten elements i.e. Iron, manganese, calcium, sodium, potassium, copper, chromium, zinc, arsenic and lead. The initial value of pH for leaching solutions was varied as strongly acidic-to-basic. Experiments were performed to obtain leaching patterns for pH variation along with analysis of solid–liquid ratio. Results were indicating the higher mobility of the elements at low pH.

Baba et al. (2010) investigated the leaching behaviour of fluidized bed combustion fly ash. They conducted the toxicity test for their study. Their result showed the pH value, temperature, quality of lime stone were the most significant factors for the leaching properties. Concentration of toxic element was higher on higher temperature range and when pH<5. At pH=5 there was no detection of heavy metal presence in fly ash. Concentration of As and S was found most leachates than the other heavy metal element.

Sarode et al. (2010) performed an experimental study on leaching of heavy metals from fly ash collected from a thermal power plant. The samples were collected from different areas of thermal power plants. They used batch leach test and toxicity characteristic leaching procedure (TCLP) for extraction of various heavy metals like zinc, nickel, copper, iron, lead, manganese, magnesium and cadmium. They had checked the possibility of ground water contamination. The element of Mg, Mn, and Fe were leached in higher concentration as compared to Zn, Cu, Pb and Ni. The element Cd was not leached in any sample. They found that concentrations of zinc, iron, manganese, magnesium and cadmium in groundwater samples were lie within the permissible limits whereas nickel and lead were found over the WHO permissible limits.

Popovic et al. (2011) studied the leaching characteristics of trace and major elements of six composite samples of filter fly, bottom and dump coal ash from "Obilic" power plant. They have used sequential extraction procedure to study the leaching characteristics. They observed that Cd was not extracted from coal filter fly ash samples, while Pb was present only in the fifth, sample. Mn was not extracted from the first and second ash sample.

Singh et al. (2012) analysed the leaching characteristics of fly ash. They noticed that the higher leachability of Ni and Cr is extracted solution as compare to buffer and aqueous solution. They noticed that the leachability in both solutions (aqueous and extracted) of Cu whereas in aqueous and buffer solution leachability of Cd was increased was increased with time.

Akar et al. (2012) studied the leaching characteristics of alkaline ash samples. They observed that the particle size of ash sample is the most influencing parameter of leaching characteristics. The element of Mn and Fe shows lower leaching characteristics where Ca shows higher leaching rate. The concentration of Cr found more than the permissible limit.

Cheng et al. (2012) investigated the extraction of aluminum of coal ash by using high acid pressure leaching method. They found that particle size of fly ash affected the extraction efficiency of aluminum. They proposed that the acidic pressure leaching method is suitable for extracting of aluminum.

Popovic et al. (2013) studied the trace element characteristics in filter lignite fly ash. They found the leaching of Si, Cu, Ni, Fe and Mg was highly affected by ionic strength of water. While other elements like Cd, Al, Cr, K, Pb, Mn were not affected by ionic strength of water when it was contacted with fly ash.

Komonweeraket et al. (2015) performed the leaching experiments to determine influence of pH on leachate concentration. Batch water leach test procedure was used to examine leaching characteristics of Cr, Fe, Zn, Cu, Al, and Mn from soil–fly ash mixture used for construction work. Type C fly ash was used for the investigation using six different types of soils. The concentration of Mn was decreased with increase in pH whereas leachate concentration of other elements was increased. The leachate concentration of tracing elements can be controlled by hydroxide and oxide.

Kumar et al. (2016) investigated leaching behaviour of fly ash by varying liquid-to-solid ratio from 20:1 to 60:1. The standard leaching testing method TCLP was used to estimate leachate concentration of Mn, Mg, Zn, Co, Fe, Ni, Pb, Cr, Mo and Cu from present in fly ash sample. They found that leachate concentration of tracing elements depends upon pH and liquid-to solid ratio. They reported that tracing elements Mg, Cu, Mn, Cr, Ni, Fe and Pb were found slightly higher than WHO permissible limit for drinking water.

Pani et al. (2016) analyzed the leaching characteristics of fly ash sample collected from two Indian coal based thermal power plant. Batch leaching test and TCLP procedures were used to investigate leaching of Cu, Zn, Ni, Co, Pb, Cd, As and Hg from fly ash with addition of additive. Sodium silicate, banana leaf, reetha fruit, active carbon and aloe vera juice were used as additive. They found that addition of small amount of sodium silicate was increased the pH of aqueous fly ash suspension which helps to reduce the leachate concentration of tracing elements.

Singh et al. (2016) studied the leaching characteristics of fly ash by using ASTM leaching method. Sodium bi-carbonate was used as additive with 0.2-0.6% solid concentration (by weight). They found that tracing elements Mn, Mg, Cr, Zn and Cu show higher leaching rate as compared to other elements present in fly ash sample. The tracing element Fe showed lowest leachability whereas Mn showed higher leachability from among all other tracing elements present in fly ash. They addition of additive was effective in reduction of leachate concentration of tracing elements.

Kumar et al. (2017) analyzed the leaching behaviour of bottom ash collected from four different thermal power plants of India. TCLP method was used to determine the leachate concentration of tracing elements for the liquid-to-solid ratio range of 20:1 to 60:1. They found that tracing elements Fe, Pb, Co and Mo showed lower leaching rate as compared to other elements present in bottom ash. They also examined that leachability of tracing elements highly affected by the pH of extraction media and liquid-to-solid ratio.

CHAPTER: 3

CHARACTERIZATION OF GROUNDED BOTTOM ASH

Bottom ash samples used for characterization were collected from the ash pond of two thermal power plants namely Rajiv Gandhi thermal power plant, Hisar, Haryana and Deenbandhu Chhotu Ram thermal power plant, Yamuna Nagar, Haryana, India. The bottom ash samples were crushed and passed through 250 µm sieve to prepare the grounded bottom ash. The grounded bottom ash samples are labeled as S-I and S-II.

3.1 EXPERIMENTAL METHOD

Various bench scale tests were carried out to determine the physical and chemical characteristics of the grounded bottom ash samples. The particle size distribution of bottom ash was determined with the help of Malvern 3601 particle size analyzer. The bulk density and specific gravity of ash samples were determined as per IS: 2386 (Part III) with the help of water pycnometer. ASTM D-2434 standard was used to find out the coefficient of permeability by constant head permeameter. The water holding capacity of the ash samples were determined with the help of Keen's box method. The static settled concentration of slurry suspension is representing the maximum value of solid concentration, which can be determined by gravitational settling method. A digital pH meter was used to determine pH value of the coal ash slurry suspension at any given solid concentration. The pH meter electrode was first moistened with distilled water and then calibrated with known pH value of buffer solution.

It was cleaned with distilled water and then immersed in the slurry suspension of coal ash sample whose pH value was to be determined. The morphology, chemical composition and LOI (loss of ignition) of the grounded bottom ash samples were determined by using scanning electron microscopy-energy dispersive X-ray spectroscope (Model: JEOL, 6510LV).

3.1.1 Particle size distribution (PSD)

Particle size distribution (PSD) is used to measure the variation in size of particles in powdered sample. Particle size distribution affects various properties of solid sample like bulk density, physical stability and permeability. By the selection of particle size, it is feasible for aggregate to attain high bulk density and physical stability with low permeability. Generally, two different types of methods namely sieve analysis and hydrometer analysis are available to determine the particle size distribution.

Hydrometer method deals with finer particles (<75 µm) whereas sieve analysis method with coarser particles (>75 µm). For sieve tests, firstly the particulate material is dried in an oven and separated through a set of standard sieves of size. The sample is dried properly by maintaining a high temperature. The sieves are adjusted in a column with decreasing mesh size i.e. higher mesh size kept on top and lower mesh size placed at bottom level called as receiver or round pan. A well-known weight of sample pours into the top sieve which has higher mesh size. Then adjust timer of mechanical sieve shaker for 10-20 minutes and calculated weight of sample received through each sieve. The percentage of retained sample in any sieve is calculated by using equation 3.1:

$$\frac{\text{Weight of solid particle retained}}{\text{Total weight of solid particles}} \times 100 \qquad (3.1)$$

3.1.2 Specific gravity

The ratio of substance density to the reference substance density is called as specific gravity. The term 'density' denotes the mass of a unit volume. In the present study, the specific gravity of grounded bottom sample is determined. Firstly, a properly cleaned fix volume bottle of 50 ml is taken and kept it in oven for the purpose of removing moisture. After an hour, the bottle is taken out from the oven and noted its weight (W_b) when cooling down completely. Now, it is filled with some solids (over dried) about 30 grams and weighted again (W_{bs}). Afterwards, distilled water is slowly poured into the bottle and shaked regularly till the filled solid get completely wet. The bottle is closed with thumb and shaked properly for 5 minutes. Then, it is kept for an hour to ensure that there should be no air bubble in it. Afterwards, bottle is filled with water and corked before weighted (W_{bsw}). Now, emptying the bottle and cleaned with tissue paper. Further, it is dried and filled with distilled water. The weight (W_{bw}) is noted down to calculate the specific gravity of bottom ash samples by using equation 3.2.

$$\text{Specific gravity} = \frac{(W_{bs} - W_b)}{\{(W_{bw} - W_{bsw}) + (W_{bs} - W_b)\}} \qquad (3.2)$$

Where,

W_b = Weight of beaker

W_{bs} = Weight of beaker and solid

W_{bw} = Weight of beaker and water

W_{bsw} = weight of beaker, solid and water

3.1.3 Static settled concentration

The highest limit of solid concentration in the slurry suspension can be determined by static settled concentration or by gravitational settling. In current study, static settled concentration has been calculated by preparing slurry sample of specific concentration. This sample is allowed to be settled down in a proceeded jar until the solid level doesn't become constant. Thus, the settled portion of solid in proceeded jar is known as static settled concentration.

In order to determine the settling rate, slurry level is checked regularly at fixed time intervals during process of slurry setting. The value of static settled concentration is influenced by properties of carrier fluid as well as solids. To measure static settling characteristics of slurry, firstly mixture of different concentration is prepared and put in a 100 ml graduate jar. Initial level of mixture is noted and properly mixed slurry is allowed to be settled down.

As the solid material settled without interruption state, the level of settled slurry is recorded at regular time intervals. Preliminarily, the readings are taken at regular short time interval while time interval is increased as the rate of settling slow down. After a passage of time, the settled slurry level becomes nearly constant. The optimal value of concentration for solids transportation ranges from 5-10% i.e. lesser than value of static settled concentration. Method of calculating the static settled concentration is described as below:

Let the volume of water taken= V_l

Mass of solid taken=W_s

Density of solids= ρ_s

Density of liquid=ρ_l

Initial concentration of slurry= $\frac{W_s}{\rho_l V_l + W_s}$ (3.3)

Initial volume of slurry=V_{mi}

Volume of settled, slurry at any given time = V_m

Volume of water in the settling slurry = V_l - (V_{mi}-V_m) (3.4)

Then concentration of solids in the settled slurry = $(C_w)_{ss}$= $\frac{W_s}{\rho_l V_{lm} + W_s}$ (3.5)

Settled concentration of slurry by volume = $(C_w)_{ss}$= $\frac{(C_w)_{ss}}{[\rho_l[1-(C_w)_{ss}] + (C_w)_{ss}]}$ (3.6)

Equation 3.5 and 3.6 are used to measure settled concentration (by weight) and settled concentration (by volume) respectively.

3.2 PHYSICAL AND CHEMICAL CHARACTERIZATION

The physical and chemical properties of the grounded bottom ash samples are given in Table 3.1 and 3.2. From the Table 3.1, it is observed that, after the grinding process, the particle size distribution of bottom ash gets reduced and ash particles become finer in nature. Only 11.17 and 11.80 % particles are coarser than 90µm in the samples S-1 and S-II. More than 45.75 and 54.20% particles are finer than 53µm.

Table 3.1: PSD of grounded bottom ash

Particle Size Distribution (µm)			**d_{10}**	**d_{20}**	**d_{30}**	**d_{40}**	**d_{50}**	**d_{60}**	**d_{70}**	**d_{80}**	**d_{90}**	
		S-I	7.82	12.13	18.35	24.55	33.12	43.50	53.08	72.34	101.21	
		S-II	6.45	8.42	13.04	18.82	21.86	33.55	42.60	57.85	88.90	
Particle Size(µm)		**250**	**150**	**106**	**90**	**75**	**53**	**26**	**21**	**15**	**11**	**6**
% Finer	**S-I**	100	96.26	90.62	88.83	80.48	69.78	45.75	35.67	25.40	17.67	8.89
	S-II	100	94.78	92.34	88.20	84.20	72.67	54.20	43.50	33.30	26.30	13.05

The particle diameters d_{10}, d_{20}, d_{30}, d_{40}, d_{50} d_{60}, d_{70}, d_{80} and d_{90} of samples S-1 were determined as 7.82, 12.13, 18.35, 24.55, 33.12, 43.50, 53.08, 72.34, 101.21 µm and of samples S-II were determined as 6.45, 8.42, 13.04, 18.82, 21.86, 33.55, 42.60, 57.85, 88.90 µm respectively. The final value of static settled concentration of grounded bottom ash slurries were found as 57.50 and 53.48% (by weight) respectively.

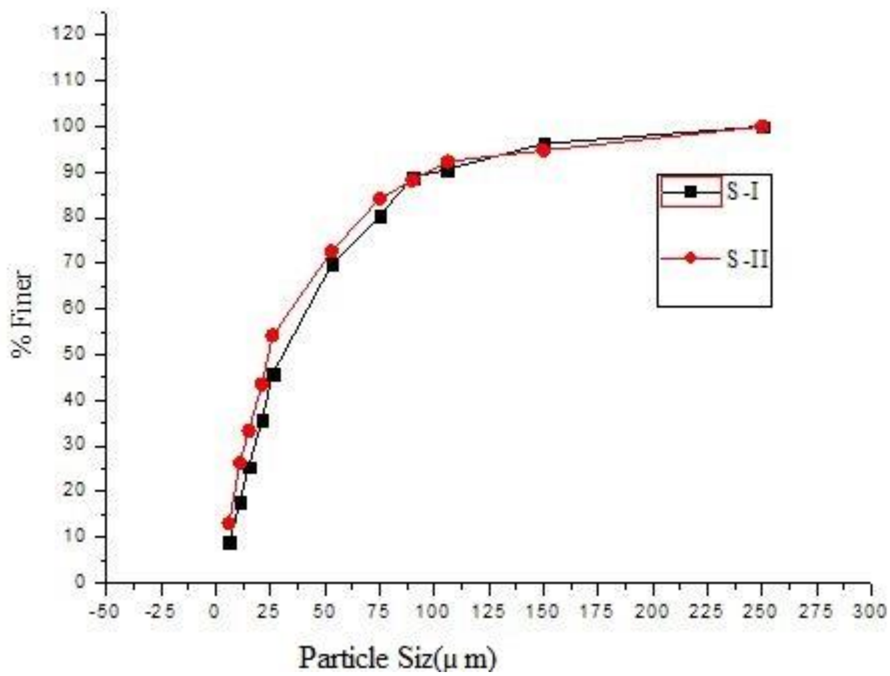

Figure 3.1: % finer-particle size curve of grounded bottom ash sample S-I and S-II

Table 3.2: Properties of grounded bottom ash

	Specific Gravity	**Bulk density**(gram/cm^3)	**Porosity (%)**	**Water Holding Capacity (%)**
S-I	2.30	1.45	31.56	36.80
S-II	2.23	1.34	28.89	33.37

The specific gravity of the ash samples S-1 and S-II were determined as 2.30 and 2.23 respectively. Whereas bulk density of ash samples were found as 1.45 and 1.34 gram/cm^3 respectively. The porosity and water holding capacity of the samples S-1 and S-II were determined as 31.56, 28.89 and 36.80, 33.37 respectively.

3.2.1 Potential of Hydrogen (pH)

pH test were performed to study the nature of aqueous solution or slurry i.e. acidic or basic. pH of samples are determined by using pH meter (manufactured by: Orino 5 Star; pH ISE Cond DO Benctop) associated with a glass electrode. Firstly, electrode was sprinkled over with distilled water and then adjusted with respect to an aqueous solution of known pH value. Then, it was washed by distilled water and engrossed in the ash slurry sample to determine pH value. When equilibrium value of slurry suspension is attained, the pH value can be noticed through digital display unit. The pH value of ash slurry is determined by the Digital electrode pH meter. The pH values of grounded bottom ash slurry is shown in table 3.3.

Table 3.3: Physical properties of grounded bottom ash

pH values at different concentrations	**Concentration (%)**		10	20	30	40	50
	Value	**S-I**	7.67	7.58	7.52	7.47	7.40
		S-II	7.69	7.59	7.55	7.48	7.40

The pH values have been measured at various concentrations in the range of 10 to 50% (by weight). The pH value of both grounded bottom ash varies in the range of 7.67- 7.40respectively.

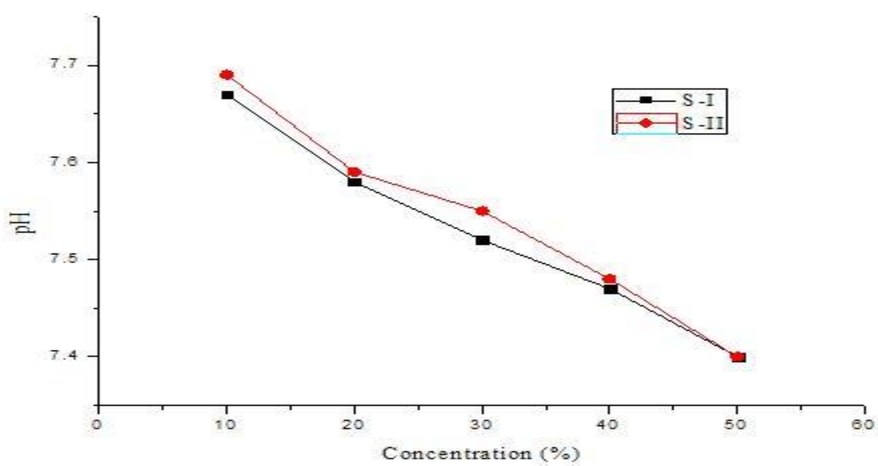

Figure 3.2: pH-Concentration(%) curve of grounded bottom ash sample S-I and S-II

The pH values of different concentrations of grounded bottom ash varying from 10 to 50% (by weight) varies in the range of 7.67 to 7.40. The pH values of samples depict non-reactive nature of all the ash slurries. It can be inferred that the concentration of the grounded bottom ash slurries has negligible effect on pH value.

3.3 MINERAL AND MORPHOLOGICAL CHARACTERIZATION

3.3.1 Scanning electron microscopy (SEM)

In order to visualize the shape of solid particles, SEM is useful technique. Basically, it utilizes a high resolution microscope that scans the sample through high-energy beam of electrons and generates images simultaneously. Scanning electron microscopy can be performed at or above unit nanometer. Sample can be keep at high vacuum, low vacuum and in dry condition also. The interaction of atoms (sample) and electrons (beam) generate signals which further provide information regarding sample's composition, surface topography and other properties. A small quantity (i.e. mg) of coal ash sample is taken from the sample and ash surface is coated with the gold to make it conducting in vacuum medium. The interaction of atoms (sample) and electrons (beam) generate signals which further provide information regarding crystallography, shape and size of the particles. Scanning electron microscope of JEOL, 6510LV model is used and results images are captured with X100 magnification. The scanning electron micrograph (SEM) of the original and grounded bottom ash samples at ×100 magnification are shown in Figure 3.3 and 3.4.

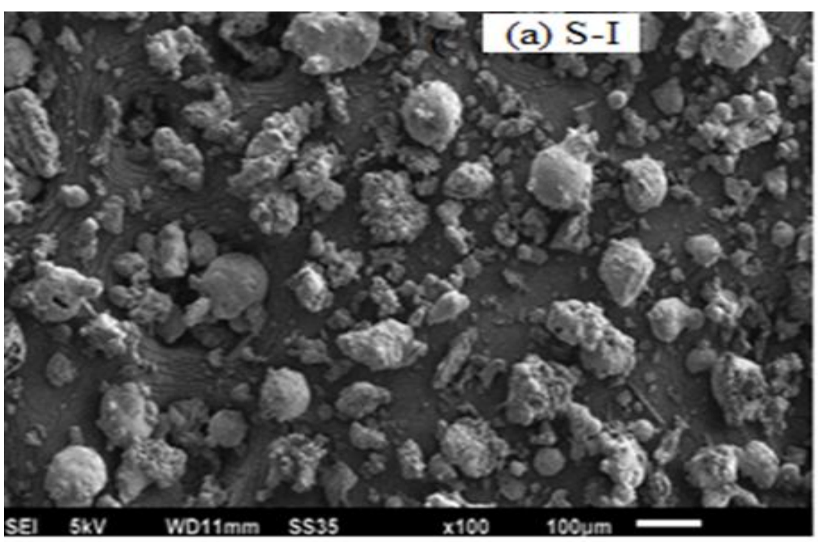

Figure 3.3: SEM image of grounded bottom ash sample S-I

From the micrograph, it is seems that grounded bottom ash having finer particles, dark grey in color due to the presence of unburned carbon, smooth surfaces, almost regular in shape and spherical morphology along with cenospheres (hollow spheres).

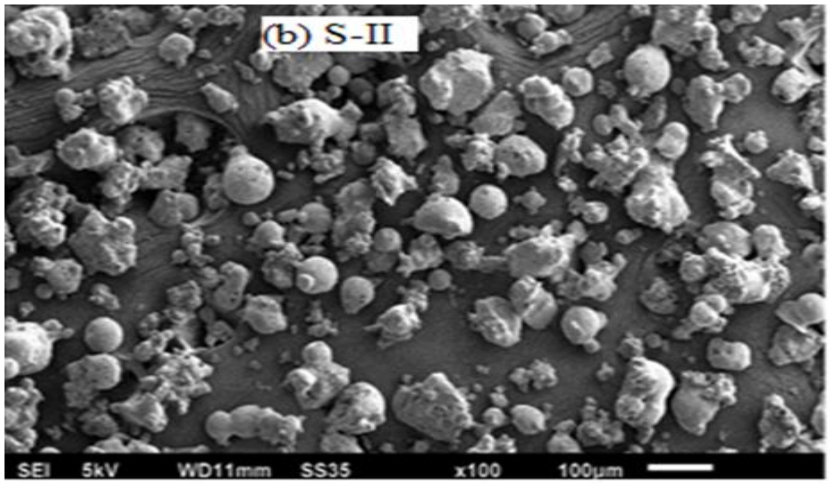

Figure 3.4: SEM image of grounded bottom ash sample S-II

It is also observed that some of the finer particles like cenospheres were agglomerates of coarser particles. These cenospheres present in ash samples facilitate to develop lightweight concrete and structural materials with sound absorbing property (Sharma et al.2015; Zhao et al.2015).

3.3.2 Chemical composition

Energy-dispersive X-ray spectroscopy (EDX) is used to find percentage composition of elements present in samples (also known as energy dispersive X-ray analysis). This works on the principle of spectroscopy. According to this principle, every existing element have its individual atomic structure which permits a distinctive set of peaks on its electromagnetic emission spectrum. This method allows the interaction between source of X-rays excitation and sample specimen. X-rays beam of high-energy strikes at the sample to stimulate the emission of X-rays from a specimen. The surface of sample produces different number and level of energy by striking X-rays which are further measured by an energy-dispersive spectrometer. The coinciding (overlapping) peaks on spectrum may decrease the accuracy of EDS spectrum and it also affected by the nature of sample.

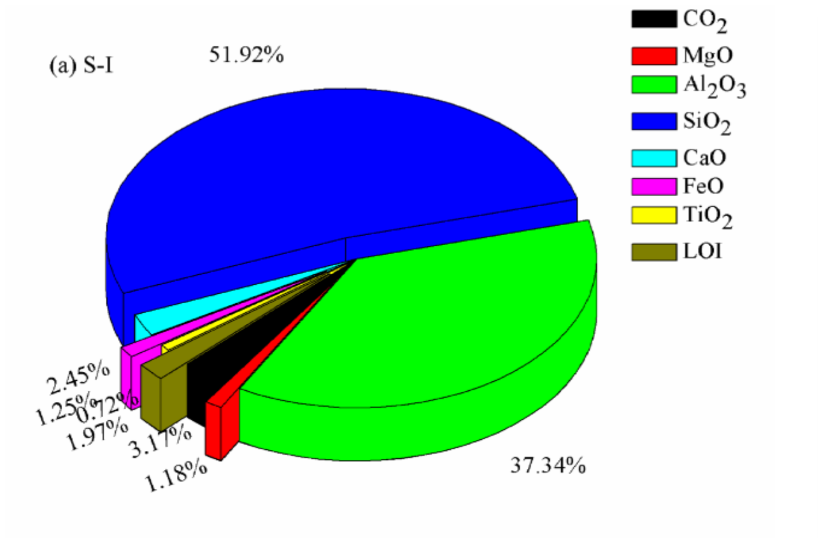

Figure 3.5: Chemical composition of grounded bottom ash sample S-I

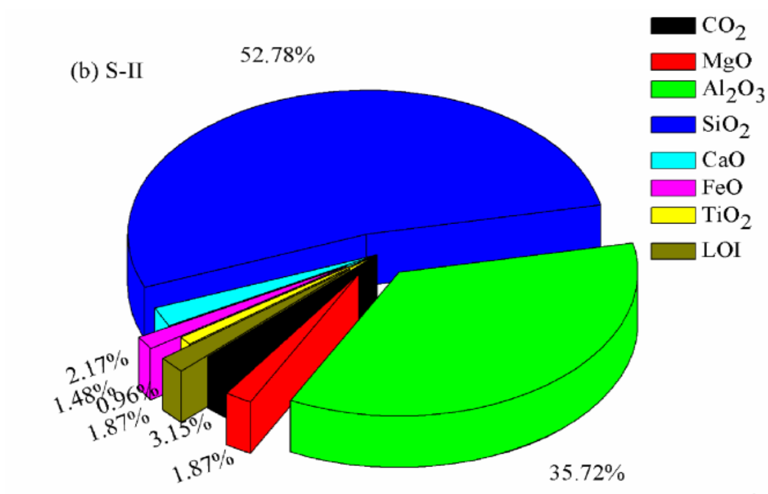

Figure 3.6: Chemical composition of grounded bottom ash sample S-II

From which it is observed that in the both samples, the proportion of aluminum oxide and silica oxide are more as compared to other elements like iron, titanium, potassium, calcium, magnesium, zinc etc. The presence of silica oxide, aluminum oxide, Iron oxide and calcium oxide in samples S-I are 51.92, 37.34, 1.25 and 2.49% respectively. Whereas in sample S-II, elements are present in the percentage of 52.78, 35.72, 1.48 and 2.17 % respectively. Similar observation was also drawn by many investigators (Kumar et al.2014; Singh et al.2016) with fly ash slurry. The sum of SiO_2, Al_2O_3 and Fe_2O_3 in grounded bottom ash sample S-1 and S-II is calculated as

90.32 and 89.98 % of the total chemical composition. The loss of ignition (LOI) is less than 5%, confirm as F type of ash according to BS 3892-1(1997).

The F type of coal ash shows very good pozzolanic properties (Ramadosset al.2014; Sharma et al.2015; Zhao et al.2015). Cement product formed by reaction of hydrate lime or moisture with silica and alumina, which are present in coal ash having fine particulates. Experimental investigations (Zhao et al.2015; Singh et al.2016; Kumar et al.2017) reported that finer coal ash can be utilized as raw material for production of blended cement products.

The presence of silica as a major proportion in the form of quartz, improves the strength of the support materials and presence of CaO enhanced cementing properties further used as stowing material in underground coal mines (Kim, 2015; Zhao et al.2015). The head loss of slurry suspension in pipeline is reduced due to presence of spherical particles in grounded bottom ash as compared to coarser bottom ash. Similar observation also drawn by (Kumar et al.2014) with fly and bottom ash slurry.

3.3.3 X-ray diffraction (XRD)

X-ray diffraction is universally accepted for unknown crystalline materials and phases identification present in the sample. This study is conducted by using X-ray diffractometer which mainly consists of specimen holder, X-ray tube and detector. Electron beam is generated by using X-ray tube while fixed specimen rotates with angle 'θ' where X-ray detector rotates angle '2θ'. Another instrument used to set angle and rotate the sample is called as 'goniometer'. In this technique, whenever electrons beam impacts on the surface of sample and fulfills the Bragg equation, peak in intensity occurred.

The locations (angles) and intensities of the diffracted X-Rays are measured. A detector records X-ray signal firstly and change them into a count rate which further used to recognize the presence various phases. The spacing between crystals plane represents the wavelength of X-rays and used to produce the diffraction pattern (1–100 A°). A Philips X'Pertdiffractometer (Model: PW 1710) is used to acquire the X-ray diffraction patterns of ash samples. It is operated with 40 kV and 30 mA utilizing Cu Kα radiation (λ=1.542 Å). In grounded bottom ash samples quartz and mullite have same chemical composition as in original bottom ash samples. XRD of grounded bottom ash samples are shown in figure 3.7 and 3.8.

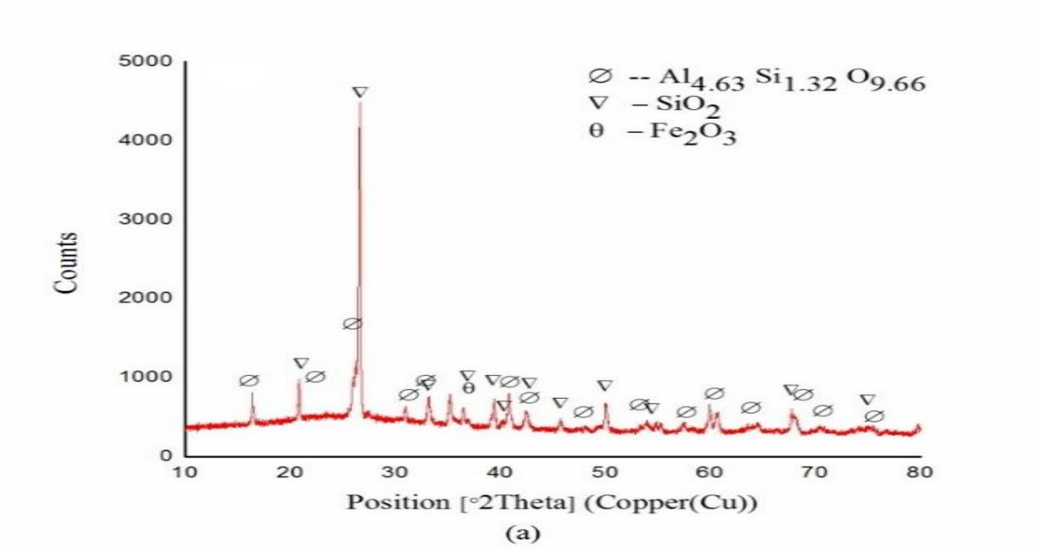

Figure 3.7: XRD of grounded bottom ash sample S-I

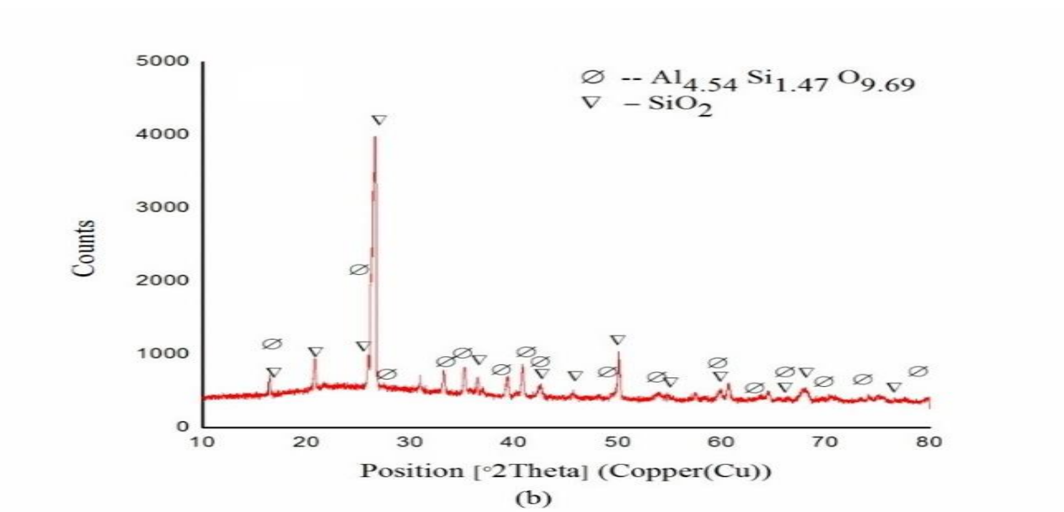

Figure 3.8: XRD of grounded bottom ash sample S-II

The quartz presence in the grounded bottom ash samples S-I and S-II are 54.90 and 53.5% respectively whereas the presence of mullite are 42.10 and 46.5%. The strongest peaks of quartz are in proximity of 26.45° and 26.53° whereas mullite peaks are in proximity of 26.24° and 26.28° in grounded bottom ash samples S-I, S-II respectively.

Grounded bottom ash has similar composition to that of original bottom ash sample. The diffraction peaks intensity of quartz and mullite phases for grounded bottom ash are stronger as compared to original bottom ash samples and the crystal structures of quartz and mullite phases do not change after being grounded, which may be due to variation of amorphous thickness layer of grounded ash particles. However on the basis these results, it is hard to conclude that the crystalline structure of original bottom ash is more amorphous than grounded bottom ash samples. The presence of silica and mullite make it more feasible to be used in the building materials particularly for stowing purpose.

3.4 LEACHING CHARACTERISTICS

Leaching is a process of tracing metal elements extraction from a solid by dissolving them into liquid. The leaching can be performed through industrial process as well as naturally. This process deals with realization of organic and inorganic contaminants of water under the impact of desorption and mineral dissolution. This further affected by pH range, micro biological activity and organic matter dissolved in it. The uniqueness of process makes it broadly applicable, as every material or tracing element exposed in contact of water will leach out from its interior surface. So, it is essential to examine the leaching behavior of coal ash and to detect its harmful effects for surrounding environment mainly on those locations where large amount of ash is disposed in water. Leaching is an industrial process. There are number of factors that affect leachability like temperature adjustment, selection of solvent and liquid-to-solid contact.

3.4.1 Leaching Testing

US Environmental Protection Agency (US EPA) had established the precise standards for two different extraction procedures called Extraction procedure (EP) and Toxicity Characteristic Leaching Procedure (TCLP, Method-1311), after establishment of Resource Conservation and Recovery Act (RCRA) of 1976. Nevertheless, US ASTM (American Society of Testing and Materials) has also developed a method (D-3987) by avoiding acids for extracting medium or used distilled water. However, another procedures have been established which are applied by different other agencies but this is far away from the scope of present study. Commonly the following three procedures are employed for extraction of tracing or leaching elements from thermal power plant waste.

3.4.1.1 Extraction Procedure (EP- 3050 B)

This method is established to categorize hazardous solid waste which is based on different type of organic and inorganic elements labeled in the US Federal Register (1980). The relevant US legislation registered a list of contamination with specified value and a solid waste called ‘EP toxic' only when the extract shows similar or higher value than the specified value for a concentration. EP method is favorable for the leaching of barium and selenium as compare to other element. TCLP has replaced the extraction procedure (EP) for predicting toxicity characteristics. The process involves mixing of a well-known amount of water in residue sample and agitation properly by using acetic acid before adjusted pH range from 4.8 to 5.2.

3.4.1.2 TCLP (1311) Method.

Basically this method is commonly used as a supplement of EP method (includes toxicity etc.) for categorization of hazardous wastes. The testing conditions for TCLP method are more trivial than earlier one (EP method). In this method, waste classifications are based on extended version of organic and inorganic compound's list and cover a wide range of waste types. TCLP method favors the leaching of Ag, Ar, and Cr however leaching of barium is comparative nonviolent. Alike EP method, TCLP method is used for leaching of selenium also.

3.4.1.3 ASTM (American Society for testing and material) D-3987

ASTM (American Society for testing and material) also prepared an extended extraction method named as D-3987. ASTM Method includes the use of distilled water for extraction purpose means that there is no need of adjusting pH by adding glacial acetic acid. This method is useful to determine the leaching potential of a material being exposed to normal precipitation.

3.4.2 LEACHING CHARACTERIZATION OF ORIGINAL AND GROUNDED BOTTOM ASH

The results of leaching test for the original and grounded bottom ash samples are presented in Figure 4-5. ASTMD-3987 method is used to detect the tracing elements like Mn, Mg, Pb, Fe, Cr, Zn, Cu and Ni. The (L/S) ratio was accepted as 20:1. In the original bottom ash sample S-I', leaching order for heavy tracing element have been found as Mg> Mn > Cr > Zn > Cu > Ni > Pb > Fe > Co > Mo whereas in the sample S-II' the order of tracing element found as Mn > Mg > Zn > Cu > Cr > Ni> Pb> Fe > Co > Mo respectively. In the sample S-I' the maximum leachability observed as Mg whereas in sample S-II' Mn found as maximum leachate element. The heavy metal element Mo showed minimum leaching concentration in all the bottom ash samples.

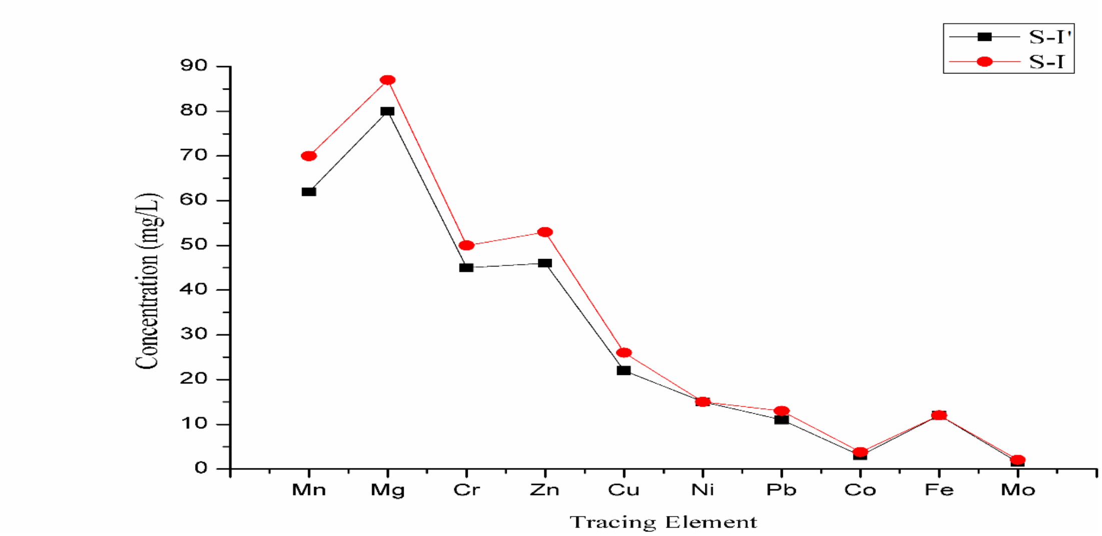

Figure 3.9: Toxicity characteristic leaching procedure (TCLP) of sample S-I

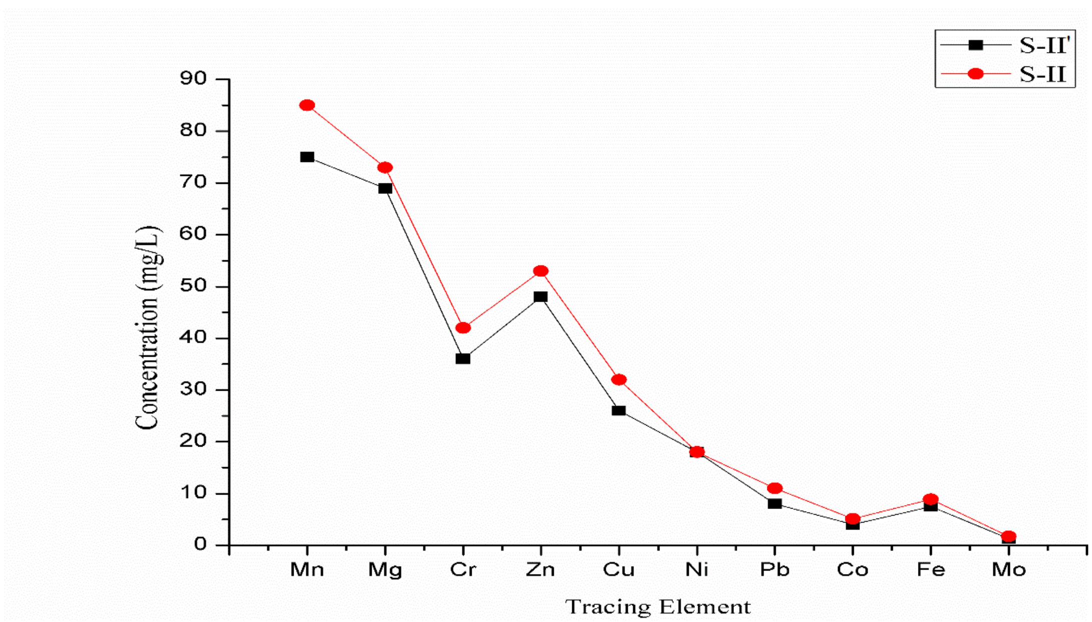

Figure 3.10: Toxicity characteristic leaching procedure (TCLP) of sample S-II

The tracing element characteristics of grounded bottom ash show similar trends as original bottom ash samples. The leachate concentration of tracing element in all samples is increasing after the grounding the bottom ash. From the leaching result data of original and grounded bottom ash, it is observed that Co is the least abundant element whereas, tracing element of Mn, Mg, Zn, Ni, Pb, Cr, Fe and Cu are most abundant. The tracing elements Ni, Pb, Co, and Cu appeared under the recommended limits in both the grounded and original bottom ash, while the elements Mg, Mn, Zn, Cr, and Fe have navigated the standard limits. Currently, leaching data result appears favorable aggregation with the results assertion by researchers on coal ash from power plants. The tracing elements raise a very serious health issues such as liver failure, lung tumor, heart attack, and nervous system damage etc. By adopting high concentration ash disposal system rather than conventional ash disposal system and also by using coal of good quality and with restriction of temperature during combustion, the toxic metal element leaching concentration can be overwhelmed. The controlling of pollution by of toxic heavy metals of the bottom ash disposal in surrounding of power plants is also by adopting green technology.

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CHAPTER 4

RHEOLOGY OF GROUNDED BOTTOM ASH SLURRY

Rheology deals with the study of complex fluid and slurry suspension, due to the effect of applied shear force. Generally, rheology is specified for the behaviour of non-Newtonian fluid. Due to the effect of external forces (shear stress), slurry suspension undergoes plastic deformation continuously. Those materials which can be deformed under the action of external force like coal ash slurry or mud, for those material investigation is carried out by the rheological characterization. Since many years, due to large industrial practice, the study of flow properties of slurry suspension has been focused. The role of flow characteristics in designing of slurry transportation system is already highlighted in pervious chapters. After addition of solid particles, flow behaviour of fluid changes because the study of flow properties of solid-liquid suspension is complex phenomena. The flow behaviour of slurry suspension gets affected due to the physical properties of solid particles.

When slurry is subjected to shear forces and allows dissipation of external energy, deviation in flow behaviour of slurry suspension is mainly arise. The dissipation rate of solid rely on different factors like viscosity of slurry, solid volume fraction, physical properties of solid and shear rate. The fluid behaviour may alter from Newtonian fluid to Non-Newtonian because the addition of solid in liquid leads to increase in the viscosity.

Recently, coal ash is transported through pipelines at very low solid concentration in thermal power plants. This leads to utilization of huge amount of electricity and water. The convey of ash slurry at higher concentrations have need of thorough study of rheological behaviour of solid suspension at distinct solid concentrations and flow conditions. Available literature affirms that there are many parameters which play major role to obtain the rheological behaviour of solid suspension like particles size, viscosity, solid concentration etc. The performance or operation of slurry suspension at various parameters is evaluated with the device called as Rheometer.The designers need extensive data covering all aspects of two-phase solid –liquid flow, for the hydraulic design of the slurry system. The substantial literature exhibit that sufficient data is not available to assist the design methodology for all solid materials. Thus, it is mandatory to initiate the flow characteristics of a particular slurry flow for making the design methodology acceptable for it. The flow properties data has been generated by conducting the experiments, for any slurry suspension.

Present work was focused to investigate the rheological characteristics of grounded bottom ash slurry suspension at different solid concentration (10-50%). Moreover, this study was also carried out to investigate the effect of additives on rheological behaviour of grounded bottom ash slurry suspension at higher precision. The Nirma detergent was used as additive and added in proportion of 0.1, 0.2 and 0.3% (by weight) at each concentration of grounded bottom ash slurry suspension.

4.1 TYPES OF FLUID

Fundamentally, in the transportation of slurry, fluid is considered as a carrier medium. For ash water slurry suspension system, water is used as a carrier medium. Fluids accomplished to transport the solid material exhibits different types of behaviour as explained below:

4.1.1 Newtonian fluids: Fluids in which shear stress (τ) is directly proportional to shear rate of deformation are Newtonian fluids. Newton' law of viscosity is express in equation 4.1:

$$\tau = \mu \frac{dU}{dx} \qquad (4.1)$$

Whereas, dU is change in velocity of fluid layers which are at a distance dx from each other, and $\frac{dU}{dx}$ is velocity gradient equation 4.1 can be expressed as below when is $\gamma = \frac{dU}{dx}$

$$\tau = \mu\gamma \qquad (4.2)$$

A fluid that obeys equation 4.1 is known as Newtonian fluid. Newtonian fluid obeys Newton's law of viscosity. Viscosity is the function of temperature only and independent of velocity gradient and time. Newtonian fluids have constant viscosity, which is independent of shear stress and linearly depends to the strain rate. Also, Newtonian fluid is defined as the coefficient of viscosity under some special condition. Only few group of fluids exhibit constant viscosity and these are known as Newtonian fluids. There are many common fluids such as water, diesel, petrol, kerosene, ethyl alcohol, methyl alcohol, air, light oils and gasoline are Newtonian fluids under some normal conditions.

4.1.2 Non-Newtonian fluids: In this shear stress is not directly proportional to deformation rate are non-Newtonian. Some fluids are not described by Newtonian constitutive relation (equation 4.1), and are commonly encountered in wide variety of industrial applications, called non-Newtonian fluids. Newton's law of viscosity (i.e. linear law) is not applicable for non-Newtonian fluid. Figure 4.2 shows variation of shear stress with shear strain rate for non-Newtonian fluids. For non-Newtonian fluids viscosity changes as the shear rate is varied. Non-Newtonian fluids are two types i.e. time independent and time dependent fluid. The time independent fluids are dilatant (shear thickening fluid), pseudoplastic (shear thinning fluid) and bingham plastic fluid (also known as ideal plastic fluid). The time independent fluids are discussed below.

4.1.3 Pseudoplastics fluids: In pseudoplastic (shear thinning) fluids, the apparent viscosity decreases with increasing deformation rate (n < 1). Pseudoplastics fluids have an extremely small shear stress which is adequate to initiate motion. Flow behaviour of Pseudoplastic is come across in slurries where fine particles turn loose aggregates. Pseudoplastic behaviour of fluid is not easy to estimate precisely, but different empirical equations has been developed. At least one exponent empirical factor is involved by these equations. Thus, pseudoplastic slurries are often called power-law slurries. The shear stress in pseudo plastic slurries is a function of shear rate according to the following equation (4.3)

$$\tau_w = k\left(\frac{dy}{dt}\right)^n \tag{4.3}$$

Where k = Power law consistency factor, n = Power law behaviour index and dy/dt = Shear rate characteristic

For pseudoplastic slurries, n is < 1. By using a rheometer, the empirical factors can be determined in laboratory testing.

4.1.4 Dilatant fluids: Dilatant fluid is also called as shear thickening fluid. The dilatant fluid behaviour is reverse of pseudoplastic. As shear rate increases, the viscosity of dilatant fluids also increase. Thus, as the shear rates increases dilatants fluids becomes 'thicker'. Both dilatants and pseudoplastic fluids can be describe by using same equations 4.3, for dilatants fluids , power law flow behaviour index is > 1 in special case.

4.1.5 Bingham plastics fluids: Bingham plastic is also known as ideal plastic fluid which are necessary for Newtonian fluids with a yield stress (Pascal) that needs to be come out to initiate motion. Until the yield stress, it behaves like solid and then exhibit linear relationship between shear stress and rate of shear strain. Though, viscosity is referred to as η(cP) and is called the coefficient of rigidity or plastic viscosity in the case of Non-Newtonian fluids. Bingham plastics can be characterized the viscosity curve with equation (4.4). by

$$\tau_w - \tau_o = \eta \frac{dy}{dt} \tag{4.4}$$

Whereas: τ_W = Shear stress at the wall, dy/dt = Shear rate characteristic,

For Bingham flow characteristics, the value of yield stress also increases with the concentration. As the solid concentration of slurry increases, a relatively larger numbers of solid particles were present in the suspensions and hence a high value of shear stress is required to start the shearing process. The value of yield stress can vary from as low as 0.01 Pascal for sewage sludge to as high as 1000 MPa for asphalts and bitumen. The coefficient of rigidity, or plastic viscosity, can also be vary drastically, from the viscosity of water to 100 Pascal of some paints and much higher for asphalts and bitumen.

4.2 RHEOLOGICAL MEASUREMENT

The rheological behaviour of grounded bottom ash slurry suspension were determined with the help of standard rheometer (Anton Paar, Manufactured by: Rheolab Q-C, APC Ltd. Germany). The schematic diagram of rheometer used in present work is represented in Figure 4.1. Specification of rheometer and sensor system used in present study are tabulated in Table 4.1. It consists of bob and cylindrical cup assembly both are made up from zirconia coated stainless steel. The slurry sample (50ml) of coal ash is poured into outer stationary cylinder.

To control the temperature of slurry suspension, a thermal jacket is mounted over the cylinder which is used for circulation of water. Inductive position sensors are used to measure speed of inner cylinder during shearing of slurry. Rheological testing of slurries was determined by determining shear stress at shear rate ranging from 0-300 s^{-1}. At fixed shear rate for all slurry samples, the various flow properties such as viscosity, shear stress were measured at each concentration.

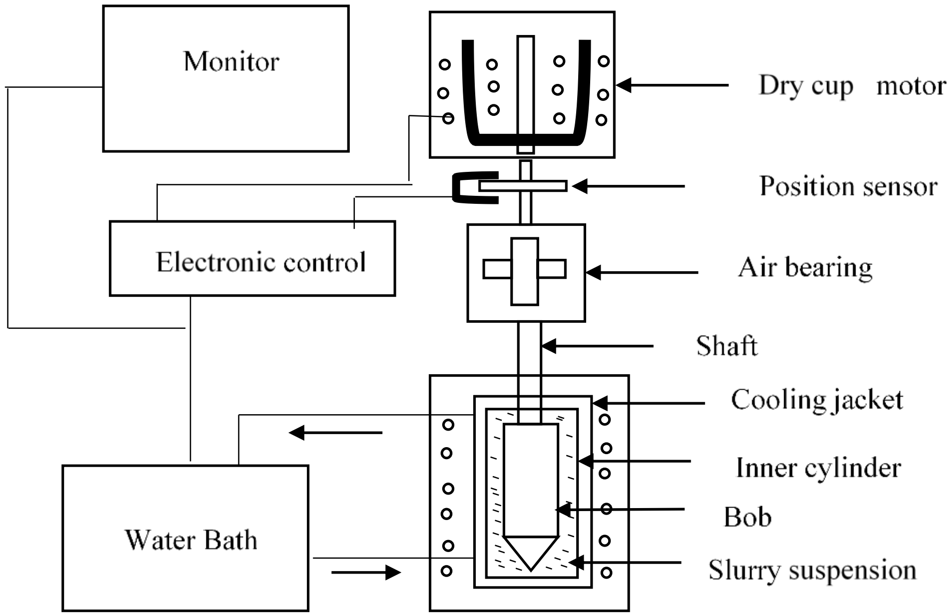

Figure 4.1: Schematic diagram of rheometer used for rheological experimentation

Table 4.1: Specification of rheometer (Rheolab QC)

S. No.	Component	Specification
1	Motor type	Synchronous EC motor
2	Speed range	0.01 to 1200 (min^{-1})
3	Shear stress range	0.5 to 3 x 10^4 (Pa)
4	Shear rate range	0.01 to 4000 sec^{-1}
5	Viscosity range	1 to 10^9 (mPa.s)
6	Temperature range	-20 to 180 (^oC)

4.2.1 Preparation of the Slurry Samples

For rheological tests, 50 ml coal ash slurry was prepared by proper mixing of essential quantity of water with coal ash. Single pan balance of electronic type with (least count ±0.001 mg), was used to measure the weight coal ash. A glass rod was used for proper mixing of slurry suspension. Prior from laboratory testing, the rotating bob and cup assembly is fixed with the help of locking device. The slurry suspension was poured into cup (cylinder) till the specified mark. Rheological tests were commenced by changing the shear rate value (0 to 300 s-1) at constant temperature with varying concentrations 10 to 50 (% by weight) for all samples.

The experimental study was conducted with slurries of grounded bottom ash with and without additives. Nirma detergent was used as additive to improve rheological properties of coal ash slurry suspension. The concentration of additives was varied from 0.1 to 0.3 (% by weight). Each experiment was done three times for coal ash slurry suspension to ensure the precision of measured data.

4.2.2 Range of Parameters

The rheological experiments were carried out with the slurry suspension of grounded bottom ash with and without additives. The rheology of the grounded bottom ash slurry suspension was measured in the solid concentration range of 10 to 50% (by weight) all coal ash samples collected from different thermal power plants. The additive of Nirma detergent was added in the proportion of 0.1, 0.2 and 0.3% (by weight) at each concentration of grounded bottom ash slurry.

4.3 RHEOLOGICAL CHARACTERIZATION

The rheological experiment was carried out with the slurry suspension of grounded bottom ash. The rheology of ash slurry was measured in the solid concentration range of 10 to 50% (by weight). The shear stress - shear rate data for above range of solid concentration were obtained for each ash sample.

To evaluate the viscosity of all the slurry suspensions, a straight line equation was fitted to all sets of data. The shear stress-shear rate data of ash at different concentrations are presented in Figure 4.2 and 4.3. In view of the observed experimental rheology data, different plots representing the variation of shear stress with shear strain at different solid concentration. From Figure 4.2 and 4.3, it is observed that shear stress increases linearly with increase in shear strain rate at all slurry suspension of ash.

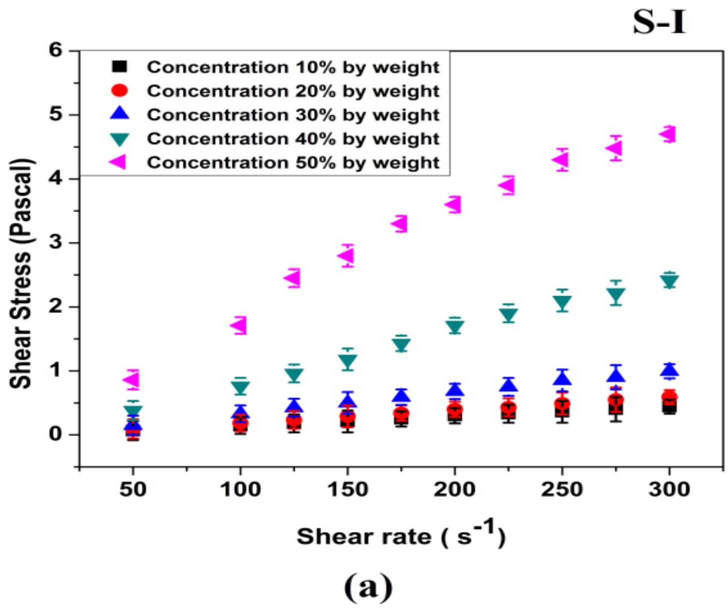

Figure 4.2: Shear stress-strain rate curve of grounded bottom ash sample S-I

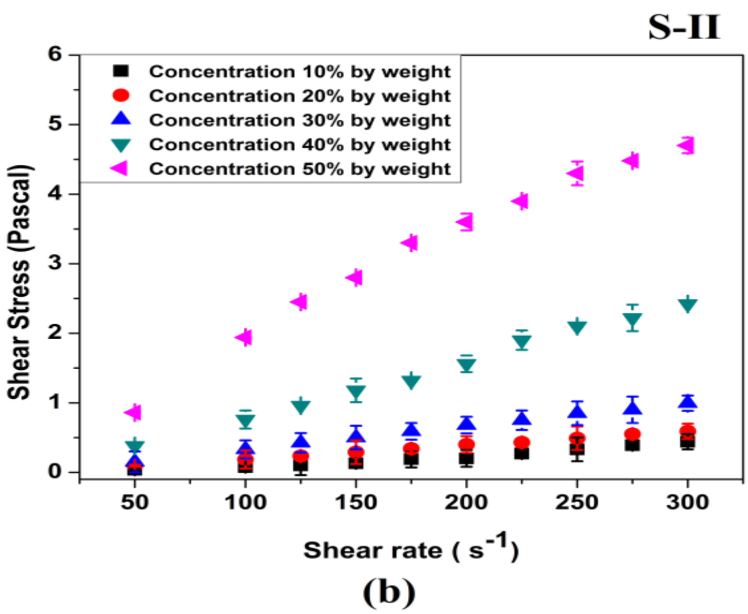

Figure4.3: Shear stress-strain rate curve of grounded bottom ash sample S-II

The value of τ_y is zero for suspension of ash slurry at 30% solid concentration (by weight). This implies that both grounded bottom ash slurry suspension show Newtonian behaviour at 30% solid concentration (by weight) beyond this it depicts non Newtonian flow characteristics. The results also indicated that slurry viscosity of the suspension is a function of solid concentration.

The variation in relative viscosity is less at lower solid concentration up to 30% (by weight) and more at higher concentration.

4.4 EFFECT OF SOLID CONCENTRATION ON VISCOSITY OF GROUNDED BOTTOM ASH SLURRY

The relative viscosity of grounded bottom ash samples are shown in Table 4.2. The rheological results shows that relative viscosity of grounded bottom ash highly dependent on solid concentration of their respective slurry suspension. The relative viscosity of grounded bottom ash sample S-I and S-II was determined as 1.44 and 1.5 at 10% solid concentration whereas 15.7 and 16.6 respectively at 50% concentration.

Table 4.2: Rheological behaviour of Grounded bottom ash

Cw (%)		**10**	**20**	**30**	**40**	**50**
Relative Viscosity of Grounded Bottom Ash Samples	**S-I**	1.44	1.96	2.93	5.82	15.7
	S-II	1.5	2.1	3.1	6.2	16.6
Nature of Samples		**Newtonian**			**Non-Newtonian fluid**	

It was noticed that with increase in solid concentration relative viscosity increases. Moreover, at higher solid concentration relative viscosity of grounded bottom ash suspension was increased hastier as compared to lower solid concentrations.

As the solid concentration was increases the number of solid particles per unit volume in slurry suspension was also increases. Thus for starting the shear process, a high shear stress was required. The experimental results indicated that grounded bottom ash slurry suspension follows time independent suspension behaviour. Same type of phenomenon had been noticed by researchers (Gandhi et al. 2000; Seshadri et al. 2008; Chandel et al. 2009; Senapati et al. 2010; Naik et al. 2011 and Kumar et al. 2014) with coal ash slurry.

4.5 EFFECT OF ADDITIVES ON THE RHEOLOGY OF GROUNDED BOTTOM ASH SLURRY

The additives are compound of chemicals or minerals which can improve the rheological behaviour of slurry suspension. In present investigation Nirma detergent was used as an additive. Nirma detergent was used as an additive in the fraction of 0.1, 0.2 and 0.3% (by weight) of total solid concentration of grounded bottom ash suspensions. The solid concentration varied within the range of 10-50% (by weight). In order to investigate the effect of additive on the rheology of grounded bottom ash suspension, the extensive experimentation has been repeated. The value of shear stress for grounded bottom ash suspension (S-I) with addition of additives at shear rate of 0-300 s^{-1} is shown in Figure 4.4(a-e).

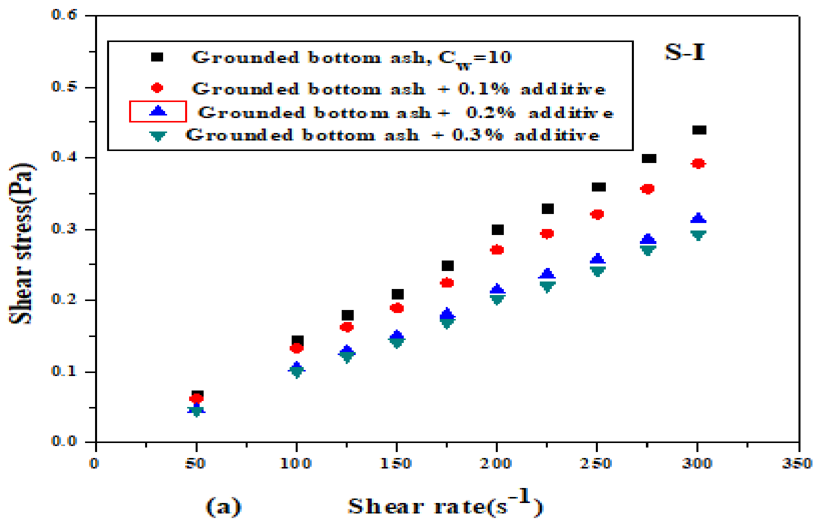

Figure 4.4(a): Shear stress-strain rate curve of grounded bottom ash sample S-I with additives

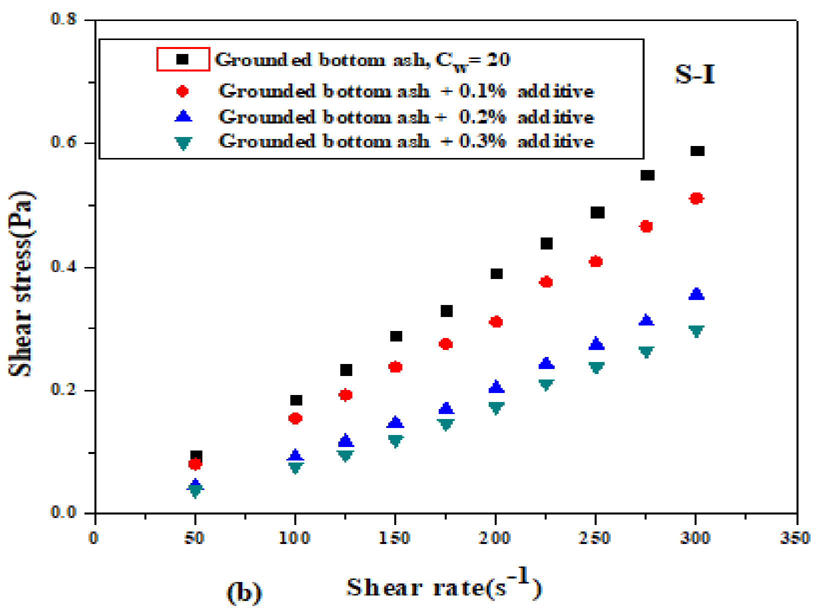

Figure 4.4(b): Shear stress-strain rate curve of grounded bottom ash sample S-I with additives

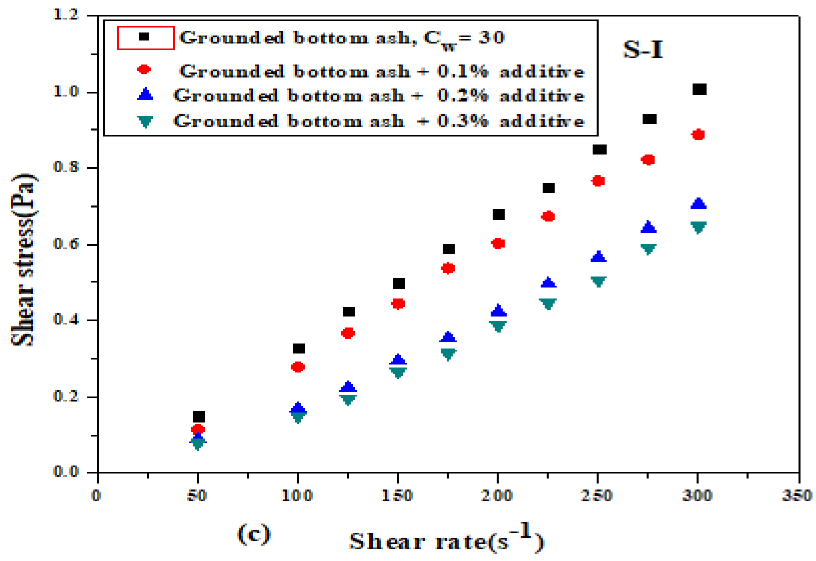

Figure 4.4(c): Shear stress-strain rate curve of grounded bottom ash sample S-I with additives

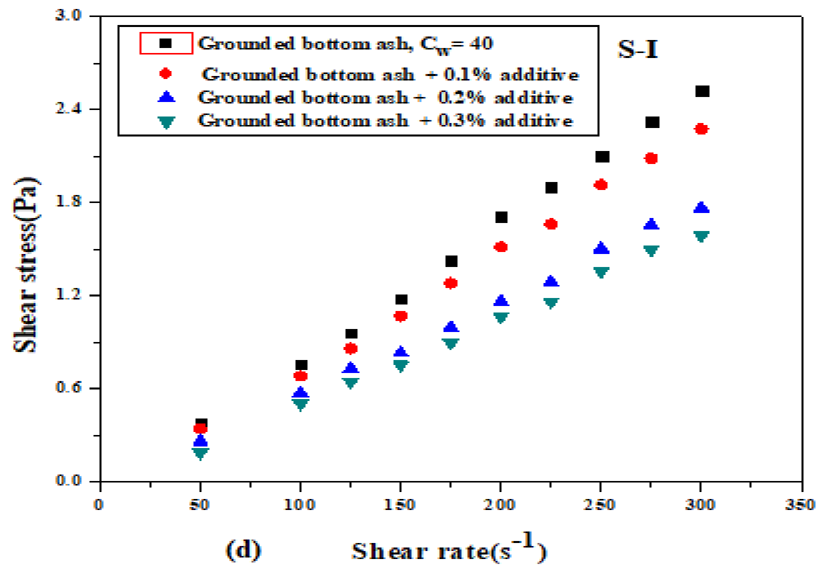

Figure 4.4(d): Shear stress-strain rate curve of grounded bottom ash sample S-I with additives

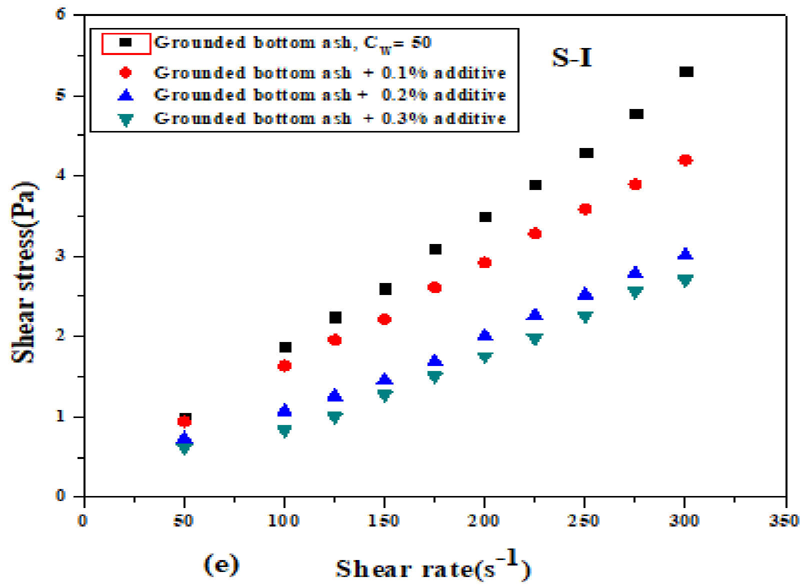

Figure 4.4(e): Shear stress-strain rate curve of grounded bottom ash sample S-I with additive

The addition of additive helps to decrease the viscosity of grounded bottom ash slurry suspension due to reduction in drag forces between adjacent layers. At shear rate of 300 s^{-1}, the value of shear stress was reduced from 0.44 to 0.39, 0.39 to 0.31 and 0.31 to 0.29 Pascal respectively with 0.1, 0.2 and 0.3% addition of additive at 10% solid concentration while 5.31 to 4.19, 4.19 to 3.01 and 3.01 to 2.70 Pascal respectively at 50% solid concentration.

The value of shear stress for grounded bottom ash suspension (S-II) with addition of additives at shear rate of 0-300 s^{-1} is shown in Figure 4.5(a-e). In S-II at shear rate of 300 s^{-1}, the value of shear stress was reduced from 0.46 to 0.39, 0.39 to 0.30 and 0.30 to 0.27 Pascal respectively with 0.1, 0.2 and 0.3% addition of additive at 10% solid concentration while 4.96 to 4.47, 4.47 to 3.61 and 3.61 to 3.17 Pascal respectively at 50% solid concentration.

4.6 CALCULATION OF CRITICAL VELOCITY IN PIPE

The correlation developed by Wasp in 1977 is mostly used to calculate the critical velocity of slurry suspension in pipeline, which is expressed in equation 1.

$$V_c = 3.116\phi^{0.186}[2gD\left(\frac{\rho_s - \rho_f}{\rho_f}\right)]^{1/2}(\frac{d}{D})^{1/6} \tag{4.5}$$

Where ϕ =volume fraction of solids, D= Pipe diameter (m), ρ_s= density of solid particles (Kg/m^3), ρ_f= density of carrier fluid (Kg/m^3), d= Weighted mean diameter of solid particle (m) and V_C= critical velocity of slurry suspension (m/sec). The solid concentration of grounded ash slurry suspension varies from 10 to 50% (by weight). The pipe diameter taken as 50, 75, 100,125 and 150 mm for the calculation of critical velocity in slurry pipeline.

The density of grounded ash samples S-1 and S-II taken as 2300 and 2230 Kg/m^3. The critical velocity of grounded bottom ash slurry in hydraulic stowing operation was evaluated with variation of solid concentration and diameter of the pipe, which is shown in Figure 4.5 and 4.6. It is observed that critical velocity of the grounded bottom ash slurry increases with increase in solid concentration and pipe diameter.

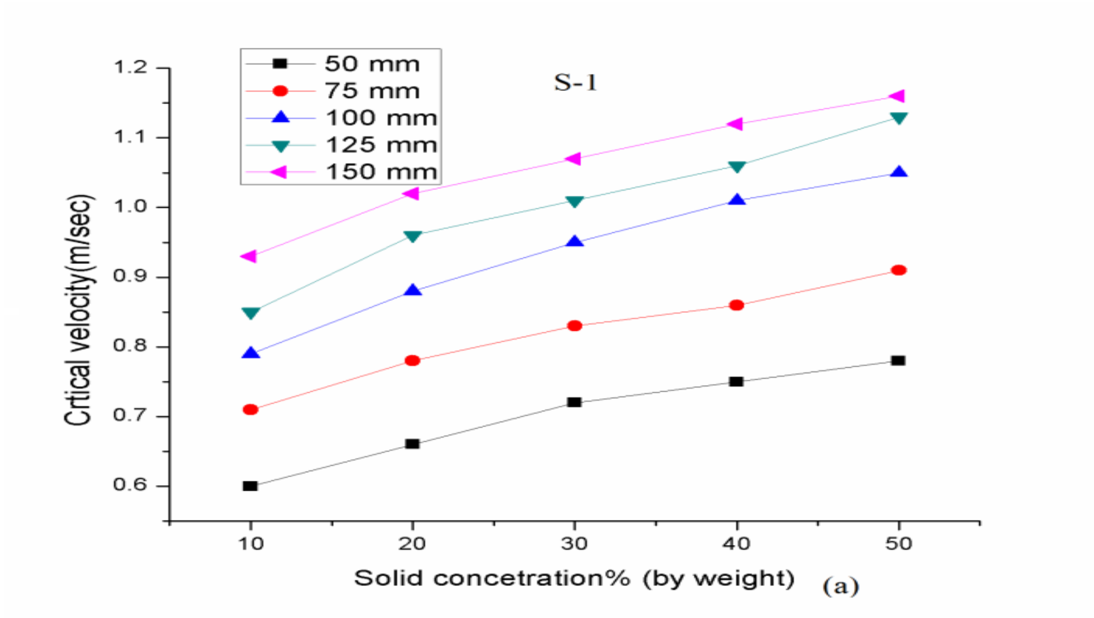

Figure 4.5: Critical velocity variation with solid concentration

The critical velocity of grounded bottom ash samples S-I and S-II are increases from 0.60 to 0.93 and 0.55 to 0.89 m/sec respectively with the increase in pipe diameter from 50 to150 mm at 10 % (by weight) solid concentration. Similar trend of increase in critical velocity observed at the remaining concentrations of 20, 30, 40 and 50% in both samples, it increases from 0.66 to 1.02, 0.72 to 1.07, 0.75 to 1.12 and 0.78 to 1.16 respectively in sample S-I. Whereas in sample S-II critical velocity increases from 0.61 to 0.97, 0.67 to 1.04, 0.71 to 1.09 and 0.75 to 1.15 respectively.

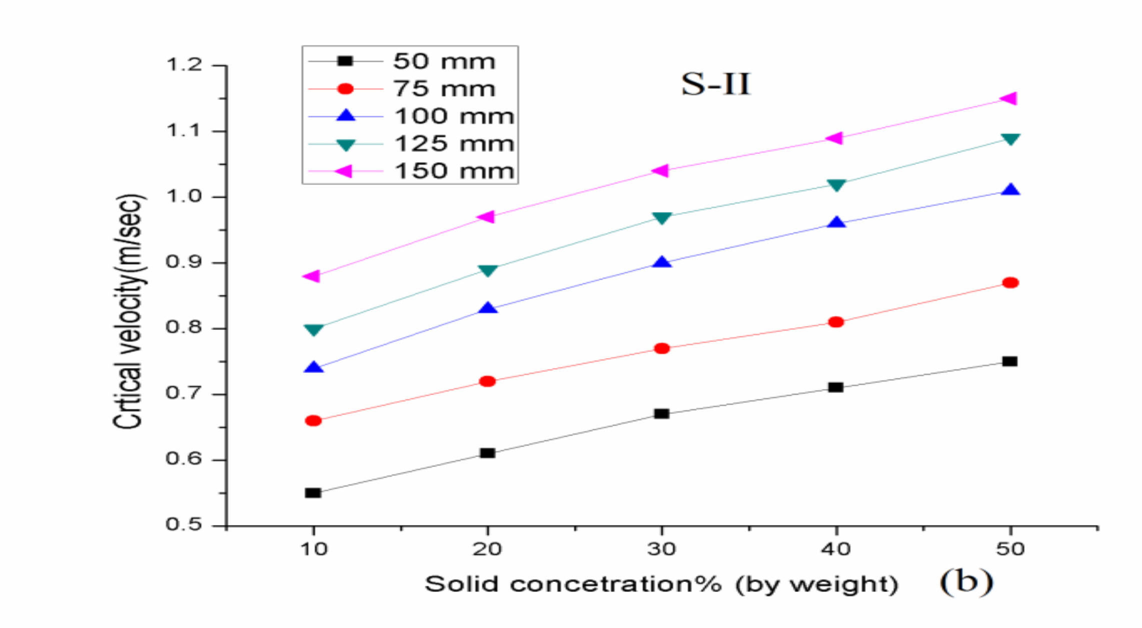

Figure 4.6: Critical velocity variation with solid concentration

Result data shows that, higher critical velocity required for stowing of grounded bottom ash slurry in the slurry transportation system at higher concentrations with larger pipe diameter.

The particles of grounded ash remain in suspension only when they flow above the critical velocity at given concentration and pipe diameter that leads to minimum pressure drop. The flow of slurry suspension maintained above the critical velocity to overcome blockage and settling of solid particles. The result data also helps to design the slurry pipeline system for the hydraulic stowing of grounded bottom ash slurry at any concentration and pipe size.

CHAPTER 5

PRESSURE DROP CHARACTERISTICS OF GROUNDED BOTTOM ASH SLURRY

The design of slurry pipelines consists of the calculation of pressure drop which can be determined by performing rheological tests. However, the multisized particles present in slurry makes the rheological experiments quite difficult and complex. The ashes produced in different locations have different physical properties like specific gravity, bulk density and particle size distributions. Therefore, in order to design the slurry pipeline, it is essential to identify the optimal parameters with the help of correlation. The present investigation pilot plant loop has been used for experimental investigation of pressure drop .Results obtained from the study are beneficial for the design of slurry pipeline with high precisions.

5.1 EXPERIMENTAL PROCEDURE

The pressure drop in horizontal slurry pipelines of pilot-plant testing loop (100 mm NB) is calculated with the help of the pressure transducer. A pilot test loop used measured pressure drop is shown in Figure 5.1. The major component of test loop are slurry pump, flow meter, pressure transducer, flow control values, measuring tank, stirrer, motor, observation chamber, preparation tank and pipeline etc. Electromagnetic type flow meter and pressure transducer is used to measured flow, inlet head and delivery head. The total length of loop is about 60 meters. Coal ash slurry was prepared in slurry preparation tanks of conical shape. To avoid settling of coal ash slurry in tank a stirrer is provided. A screw type cavity slurry pump is used to transfer coal ash slurry from slurry tank to pipelines to measure pressure drop in pipeline. The actual concentration of coal ash slurry was determined by taking sample from sampler. The collected sample was dry and then calculated the weight of ash to determine actual concentration of solid pass through the pipeline. Before start the experiment with coal ash slurry, initial loop was run with water and its pressure drop was measured.

To measure the pressure drop, grounded bottom ash is used to prepare the coal ash suspension. During the experiments solid concentration (C_w) of coal ash was fixed i.e. 50 % (by weight). The slurry was continuous circulate in pipeline till the experimentation was completed at different flow velocity.

Figure 5.1: Slurry pump pilot-plant test loop

After completion of experiment slurry was drain by opening drain valve. The water was supply from water tanks to clean the test loop to avoid and blockage by solid ash in loop. The pressure drop is presented as a function of flow velocity in terms of mWc/m of pipeline estimated from pilot-plant test loop.

5.1.1 Range of parameters

The present study was carried out with pilot plant test loop. The experiment of pressure drop was carried out for the flow of grounded bottom ash suspension at 50% (by weight) solid concentrations. The effect of addition of additive (Nirma detergent) on pressure drop was also determined by changing solid concentration of additive from 0.1-0.3% (by weight). Measurements of pressure drop was measured for flow velocities in the range of 0.5 to 3.5 ms^{-1}.

5.2 Results and discussion

Experimental investigation was carried out to determine the pressure drop of grounded bottom ash slurry with and without addition of additive at 50% (by weight) solid concentration. Nirma detergent was used as an additive for grounded bottom ash slurry with concentration range of 0.1-0.3% (by weight). In order to measure the pressure drop grounded bottom ash slurry suspension with additive, a separate experimentation was performed.

The additive (Nirma detergent) with dosage proportion 0.1, 0.2 and 0.3% (by weight) was added in grounded bottom ash slurry. The effect of additive addition at different flow velocities of grounded bottom ash suspension is shown in Figure 5.2. The pressure drop results show that additive addition automatically affect the pressure drop. The pressure drop was increased as the flow velocity increased. Moreover, considerable pressure drop reduction was observed with additive addition. In another words, the pressure drop was decreasing with increase in additive concentration in both grounded bottom ash slurries. The additive addition of slurry suspension reduce the inter-particle particle friction. This should considerably effect on pressure drop in slurry pipeline.

5.2.1 Effect of solid concentration on pressure drop characteristics of grounded bottom ash

The pressure drop forecast was made in 100 mm diameter pipe with grounded bottom ash slurry for concentration (C_w) varying from 10-50% (by weight). The pressure drop was determined in meter of water column pipeline, at each concentration. Figure 5.2 shows the significance of solid concentration on pressure drop for the flow of grounded bottom ash slurry. It was found that the increase in solid concentration tends towards the increase in pressure drop at a stated velocity. Increase in solid concentration results in step increase in density and viscosity of the slurry due to the fact. Similar type of phenomenon was observed by researchers (Verma et al. 2006: Seshadri et al. 2008; Chandel et al. 2009; Senapati et al. 2010; Kumar et al. 2017).

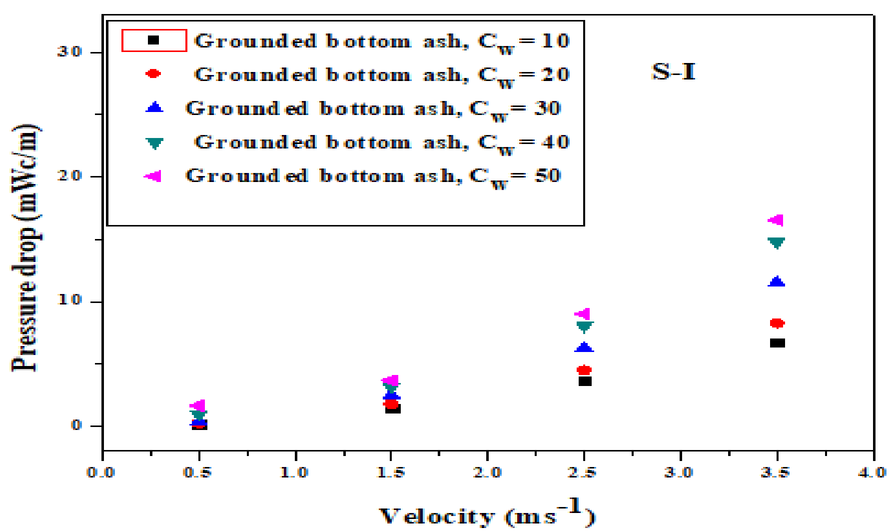

Figure 5.2: Effect of solid concentration on pressure drop for grounded bottom ash suspension

It was seems that pressure drop increased from 6.73 to 8.27, 8.27 to 11.52, 11.52 to 14.8 and 14.8 to 16.55 mWc/m with increase in value of C_w from 10 to 20, 20 to 30, 30 to 40 and 40 to 50 % at a flow velocity of 3.5 ms^{-1} respectively. Pressure drop versus solid concentration (C_w) curve of grounded bottom ash suspension follows similar trend as for fly ash suspension.

5.2.2 Effect of addition of additive on pressure drop for grounded bottom ash slurry

In order to measure the pressure drop grounded bottom ash slurry with additive, a separate experimentation was performed. The additive (Nirma detergent) with dosage proportion 0.1, 0.2 and 0.3% (by weight) was added in grounded bottom ash slurry. The effect of addition of additive at different flow velocities of grounded bottom ash slurry suspension is shown in Figure 5.3.

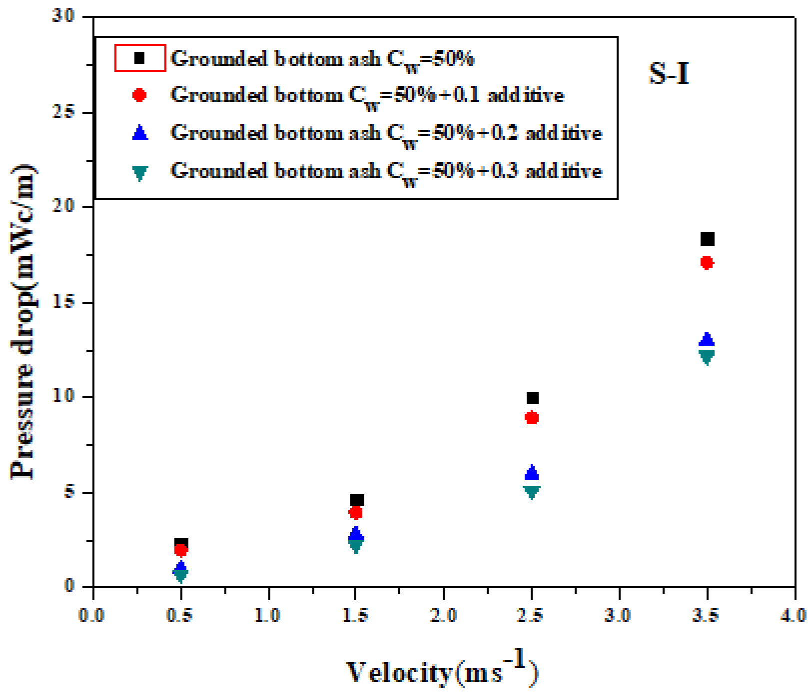

Figure 5.3: Effect of addition of additive on pressure drop for grounded bottom ash suspension

The pressure drop results shows that addition of additive significantly affect the pressure drop. The pressure drop was increased as the flow velocity increases. Moreover, considerable reduction in pressure drop was observed with addition of additive.

In other words, the pressure drop was decreases with increase in concentration of additive in both grounded bottom ash slurries. The addition of additive in coal ash slurry tends to increase the pH of the slurry suspension and also highly soluble into water. The addition of additive in slurry suspension reduce the inter-particle particle friction. This should considerably effect on pressure drop in slurry pipeline. The pressure drop reduction for grounded bottom ash slurries were found as 43, 56.62 and 59.44% with addition of 0.1, 0.2 and 0.3% additive. The experimental results found to be good aggregate with the results reported by researchers (Chandel et al. 2002; Seshadri et al. 2008; Kumar et al.2017). For a given solid concentration, suspension of grounded bottom ash slurry suspension maximum pressure drop reduction was found with addition of 0.2% additive.

5.2.3 Effect of velocity on pressure drop characteristics of grounded bottom ash

At different solid concentration (C_w) up to 50% (by weight), pressure drop in slurry pipeline has been obtained for the range of flow velocity 0.5-3.5 ms^{-1}. From figure 5.4, we can observe that pressure drop is increasing with increase in slurry velocity for a given solid concentration. Higher velocity leads to high pressure drop as compared to low flow velocities. It can be observed that lower velocities (0.5 to 1.5 ms^{-1}) showed laminar flow whereas higher flow velocities showed turbulent flow.

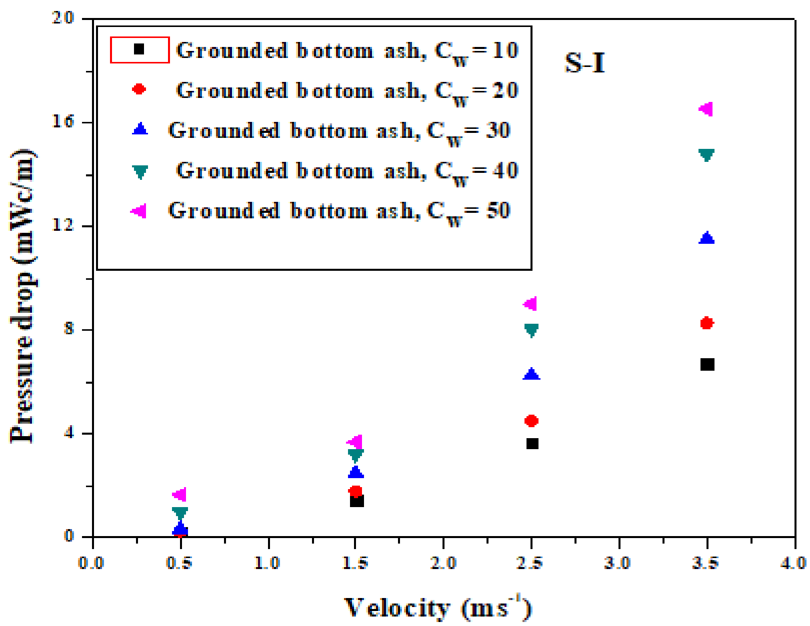

Figure 5.4: Effect of velocity on pressure drop for grounded bottom ash suspension

Similar observations are drawn by investigators (Verma et al. 2006; Chandel et al. 2009). It was noticed that pressure drop was increased from 1.65 to 3.68, 3.68 to 9.01 and 9.01 to 16.55 mWc/m with increase in flow velocity from 0.5 to 1.5, 1.5 to 2.5 and 2.5 to 3.5 ms^{-1} respectively at 50% solid concentration. Pressure drop characteristics of grounded bottom ash slurry in pipeline shows similar trend as fly ash slurry whereas the pressure drop attains higher values for the flow of grounded bottom ash as compared to fly ash. Maximum value of pressure drop is found at velocity 3.5 ms^{-1} while least value is observed at flow velocity 0.5 ms^{-1} for a given solid concentration of grounded bottom ash suspensions.

CHAPTER 6

CONCLUSIONS

Based on the present investigation result data, the following conclusions can be made:

- The grounded bottom ash possesses approximate similar physico-chemical, mineral and properties as fly ash.
- The F type grounded bottom ash possesses very good pozzolanic properties, favorable for stowing in coal mines.
- Potential utilization of grounded bottom ash helps to reduce the transportation cost as well as reduces environmental hazard.
- The relative viscosity of grounded bottom ash slurry is the function of solid concentration.
- The result data obtained for critical velocity helps to design the slurry pipeline system for the hydraulic stowing of bottom ash slurry at any solid concentration and pipe size.
- The addition of additives Nirma detergent help to reduce the pressure drop effectively. The maximum reduction in pressure drop rate of grounded bottom ash was found with 0.2% addition of Nirma detergent whereas marginal reduction was observed with 0.1% and 0.3%.

FUTURE SCOPE WORK

The design of slurry transportation system is dependent on large number of parameters and focus of present study is on hydraulic parameters of the slurry pipeline. Following aspects of work need greater attention for better understanding of the flow mechanism of highly concentrated slurry through pipes and pumps:

- Flow field analysis of the solid–liquid flow through slurry pipeline using sophisticated instrument like Laser Doppler Velocimeter (LDV) etc.
- To investigate the performance of slurry pump at higher concentration of grounded bottom ash with addition of other suitable additives
- To study the performance characteristics of progressive cavity screw pumps with solid materials of different properties in order to establish the relationship between particle size distribution, head and efficiency ratio of screw pump.

PUBLICATION: Chandan Kishor, Satish Kumar, Sumeet Sharma & Anil Kumar Singh (2019): Effective utilization of F-type bottom ash by enhancement of pozzolanic properties, Energy Sources, Part A: Recovery, Utilization, and Environmenta-l Effects, DOI: 10.1080/15567036.2019.1587072

To link to this article: https://doi.org/10.1080/15567036.2019.1587072

Published online: 01 Mar 2019.

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