Formulation, analysis and plant design for coal water slurry fuel blended with wastewater

By

Mueed Akhtar

Reg # : NUST201463513MCES64114F

Session 2014-16

Supervised by

Dr. Muhammad Zubair

A Thesis Submitted to the U.S. – Pakistan Center for Advanced Studies in Energy in partial fulfillment of the requirements for the degree of

MASTERS of SCIENCE in

ENERGY SYSTEMS ENGINEERING

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THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by Mr Mueed Akhtar, (Registration No. NUST201463513MCES64114F), of U.S. – Pakistan Center for Advanced Studies in Energy has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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Certificate

This is to certify that the work in this thesis has been carried out by Mr. Mueed Akhtar and completed under my supervision in Biofuels Lab, USPCAS-E, NUST, Main Campus, Sector H-12, Islamabad, Pakistan.

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Dedication

I dedicate this endeavor to my father for his advice, inspiration and faith

&

To my mother for her love, care and support

Abstract

Coal is an important and vital fossil fuel. It has been underutilized due to its complex mining procedures, transportation constraints and environmental impacts. Pakistan has vast amount of coal reserves and at present these reserves are not yet fully exploited due to the complications in underground coal gasification and mining. The proposed innovative technology of coal water slurry fuel can make the utilization of coal more easy and environment friendly. Finely ground coal particles are blended with water and additives to formulate a liquid fuel having properties comparable to the heavy fuel oils. Another novel idea is to use industrial wastewater instead of fresh water in preparation of coal slurry fuel. Major industries in Pakistan are facing problems of energy curtailment and wastewater disposal. Both the challenges can be effectively addressed by employing the proposed concept of coal slurry fuel together with the wastewater. The effects of blending pulverized coal in wastewater and fresh water were investigated in terms of properties such as heating values, sulfur content and ash content. Pulverized coal was obtained from "Pioneer Cement", having average particle size 90 µm, heating value of 6260cal/g, 16.22% ash content and 0.69% sulphur content. Wastewater was collected from Noon Sugar Mills distillery having a pH of 3.92, brix 13.2, COD 101000 mg/l and BOD 35000 mg/l. Two samples of coal slurry fuel were prepared, one using fresh water and other using wastewater of alcohol distillery. Heating values were analyzed on dry basis, in case of wastewater sample the heating value decreases by a non-noticeable margin, the new value is 6014 cal/g and in case of fresh water sample it was 6245 cal/g. Sulphur in the fuel is increased to 0.96 due to presence of sulfur containing compounds in wastewater but for fresh water sample it is 0.83%. Further, ash content of the wastewater coal slurry fuel was 17.86% as compare to the fresh water sample, which was 16.72%. Both sample slurries can be fired in boilers in replacement of expensive heavy fuel oils. But in case of wastewater some post treatment is suggested in order to reduce Sulphur contents. All the parameters are in normal ranges so no post treatment is required.

Keywords

Coal; spent wash; Coal Water Slurry Fuel; Coal Spent wash Slurry Fuel

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List of Abbreviations

MTOE	Million Tonnes Oil Equivalent
GSP	Geological Survey of Pakistan
CWSF	Coal Water Slurry Fuel
CSF	Coal Slurry Fuel
IUPAC	International Union of Pure and Applied Chemistry
NaNSF	Sodium Naphthalene Sulfonate Formaldehyde
TOE	Tonnes of Oil Equivalent
Mbbl	Million Barrels
GHG	Green House Gasses
GCV	Gross Calorific Value
ADB	Air Dry Basis
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TS	Total Solids
TPH	Tons Per Hour
BARA	BAR Absolute
MPKR	Million Pakistani Rupees
NSMD	Noon Sugar Mills Distillery
HMC	Heavy Mechanical Complex
ISO	International Standards Organization

List of Publications

i. Mueed Akhtar, Muhammad Zubair, ***Preparation and investigation of coal slurry fuel blended with industrial wastewater for use in thermal power generation***, **17th International Pakistan Oil and Gas Energy Expo(POGEE), 17 May, 2016**. (Accepted)*

ii. Mueed Akhtar, Muhammad Zubair, ***Preparation of coal slurry fuel blended with industrial waste water to replace furnace oil and LNG in industrial boilers and furnaces***, **1st international conference on emerging technologies for waste water and alternative energy processes**, June 01-02, 2016, organized by University of Gujrat, Gujrat, Pakistan. (Accepted)**

* Annex I

* Annex II

Chapter 1: Introduction

1.1 Pakistan Energy Mix

Pakistan is remained as an agriculture based economy but in the past decade, there has been a major development in the industrial sector. The industrial development means more economic activity with greater energy requirements. In Pakistan, total installed capacity of electricity is 22,000 MW. Average supply of energy is almost 16,000 MW and the shortfall of energy lies between 5,000 MW to 6,000 MW [1]. In Pakistan commercial energy supply is mostly generated by using oil and gas. Total 81% of the supply in the energy mix of Pakistan is dominated by oil and gas combined. In fiscal year 2013-2014 energy production from oil was 23,006,510 TOE which was 34.4% of the total energy mix. From gas total of 30,964,868 TOE was produced in the same year and it was 46.3% of the total energy mix. From coal 3,590,386 TOE were generated and it was 5.4% of the total energy mix. Besides fossil fuels the other major source of energy is hydel from which total of 11.4% of the total energy mix. Rest is obtained by nuclear and other resources like renewables and LPG etc.[1].

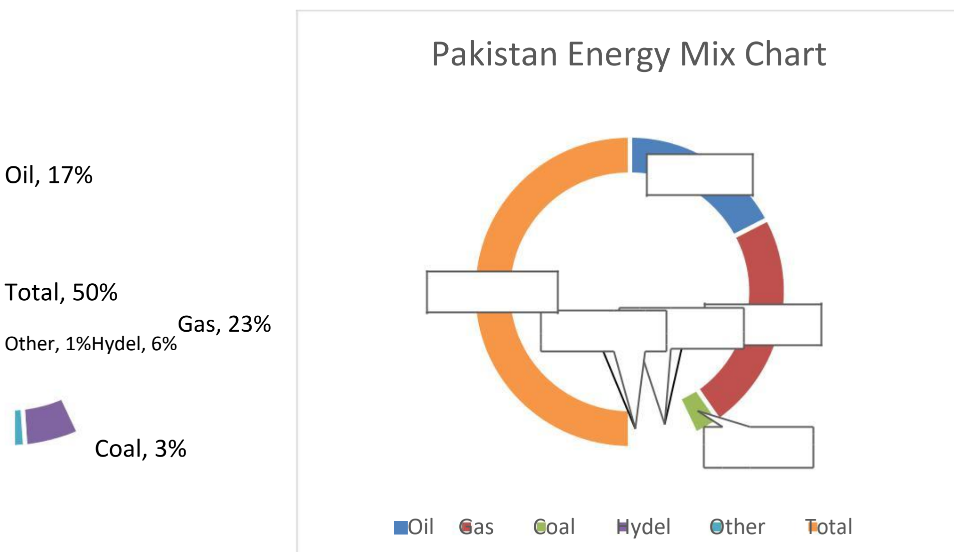

Figure 1: Pakistan energy mix

There is a significant share of oil and gas in world's energy mix as compare to coal . Pakistan does not have enough indigenous resources of oil and gas. According to a survey by HDI Pakistan, annual production of oil is 23.94 Mbbl with reserve to production ratio of 14.

Annual oil production is 1.40 TCF with reserve to production ratio of 21. Similarly coal production is 4.95 MTons with reserve to production ratio of 678[2]. These statistics clearly indicate that the production of oil and gas is not sufficient to fulfill national needs; therefore, considerable cost is incurred on imported crude oil. The import cost of these fuels definitely increases the cost of electricity generated. In Pakistan, almost 46% percent of energy requirements are fulfilled by using Natural gas. Despite of higher efficiency of thermal power plants, Combined Cycle Power plants are termed as the latest trend because of greater output power and better efficiency. But indigenous production of gas is not enough. Recently, government of Pakistan has signed a project to import LNG from Qatar. Besides, government is also focusing on starting such feasible projects with neighboring countries which include Pak-Iran gas pipeline, LNG terminal at port Qasim. Importing LNG is a short term solution for shortage of gas but consumer cost will increase eventually.

On the other hand, Pakistan has a large amount of coal reserves. These reserves are neglected due to various political and technological policies. To overcome our energy crisis and produce low cost energy, we have to focus on indigenous energy resources available in our country. To develop sustainable energy resources by considering their pros and cons, and to work on the policies feasible enough to cater the energy demands of the country, is need of the hour.

1.2 Coal in Pakistan

Pakistan has considerable coal reserves. According to an analysis held by Private Power and Infrastructure Board, coal reserves with their respective calorific values are as follows[3] :

Province	**Reserves (Mtons)**	**Calorific value (BTU/lb)**
Sindh	1,84,623	5,219-13,555
Baluchistan	217	9,637-15,499
Punjab	235	9,472-15,801
KPK	91	9,386-14,217

AJK	9	7,336-12,338
Total	185,175	

Table 1: Coal reserves in each province

Pakistan can generate 100,000 MW of electricity for around 30 years from existing coal reserves. It is imperative to discuss the quality of coal province wise.

1.2.1 Sindh

The coal present in Sindh coal mines is classified as 'Lignite'. In Sindh, there are following reserves of coal[3]:

Coal Field	Reserves (Mtons)	Calorific value (BTU/lb)
Thar	175,506	6,244-11,045
Lakhra	1,328	5,503-9,158
Sonda-Jherruck	5,523	5,129-13,555
Meting-Jhimpir	473	5,219-8612
Indus East	1,777	7,782-8,660
Badin	16	11,415-11,521
Sub-total	1,84,623	

Table 2: Coal Reserves in Sindh

It is clear that the largest coal reserve in Sindh is Thar coal which comprises of 175.5 billion out of 184 billion of total reserves of Sindh. Among all these coal fields, Lakhra coal field is most developed one with coal reserves of about 146 million tons. Coal from Lakhra field contains high amounts of sulphur. The Thar coal has low sulphur and low ash contents but it contains more moisture. Another major issue is that Thar coal is difficult to mine due to large water bed. Thar coal was discovered by GSP in 1992 [3]. Until now, it has not been fully utilized because of its complicated mining procedures. The composition of Thar coal is given below**.**

Moisture (%)	29.60-55.50
Ash Content (%)	02.90-11.50

Volatile matter (%)	23.10-36.00
Fixed Carbon (%)	14.20-34.00
Sulfur	00.40-02.90
Heating Value (Btu/lb)	
As Received	6,244-11,045
Dry Basis	10,723-11,353

Table 3: Analysis of Thar coal

1.2.2 Baluchistan coal

Baluchistan has also a number of coal fields. Major coal fields are named as follows:

1. Sor Range
2. Degari
3. Sharigh
4. Harnai
5. Ziarat
6. Mach
7. Duki

Total coal reserves are 217 million tons out of which 32 million tones are considered mineable. The classification of coal is sub-bituminous to bituminous. Heating values are in the range of 9,637-15,499 Btu/lb with low ash contents but high sulfur contents.

1.2.3 Punjab

Punjab also has substantial amounts of coal resources. It has two major coal mines, one is located between Jhelum and Sargodha districts of Punjab. This mine is spread over an area of 260 sq. km. The total reserves of salt range coal mine are estimated to be 213 million tons. Out of these 213 million tons only 30 million tons can be extracted or mineable[3]. The quality of coal is classified as sub-bituminous. It contains low moisture but high ash and sulphur quantities. Estimated calorific value of the coal is in between the range of 9,472-15,801 Btu/lb.

The second coal field Makarwal coalfield located in the Mianwali district of the Punjab province. It is spread over an area of 75 km, near Makarwal 13 km west of Kalabagh. The total coal reserves are reported to be 22 million tons. It has relatively low moisture, ash content and sulfur content than salt range coal mine. Quality of coal is also qualified as sub-bituminous coal.

1.2.4 KPK

Total potential of coal in KPK is yet to be explored. Two major coalfields are known at this point.

1. Hangu
2. Cherat

Their combined reserves are estimated to be 91 million tons. Coal of both mines is reported to be sub-bituminous with heating values in the range of 9,386-14,217 Btu/lb. Coal from both mines have low sulphur and ash contents also with low moisture contents.[3]

1.3 Environmental issues

Pakistan, being an under-developed country, pays greater attention towards accelerating its economic growth. With increased population, demand for more energy, consumer products and industrial growth has also increased. The economic growth is accompanied by unsustainable production and consumption pattern, which not only alarms for significant threats on resource consumption but also leads to cause more stress on environment. Pakistan is facing serious environmental issues related to energy crisis, water scarcity, air and water pollution besides depletion of these natural resources.

Various textile and sugar mills, cement and fertilizer plants, consumer products industry, food and beverage industries in the country don't cater for the environmental pollution caused by their wastes.

Fossil fuels form a major role in current energy share of Pakistan while at the same time; renewables energy resources do not get enough focus by government.

Apart from environmental pollution, Pakistan has also failed to stop rapid growth in population. With this increased rate of population, problems such as unemployment, wage rates, illiteracy and social backward infrastructure are also getting out of hand. Government needs to make a clear policy for development of new industrial setups, in a way to improve the environmental conditions of industrial area.

To have a long-term sustainable better economy, environmental challenges need to be addressed effectively. These environmental issues include industrial waste water, municipal waste water, chemical spills in clean water, soil erosion, deforestation, salinity, water logging, fresh water pollution, just to name few.

Majority of the population does not have proper supply of fresh drinking water. Also our government is neglecting this major issue.

Urbanization and implementation of modern technologies is also causing the pollution of water. According to the research conducted by Pakistan Medical Research Council, majority of the diseases in common population is caused by drinking of substandard or polluted water.

1.3.1 Effects of water pollution

Water pollution however produced by any means causes serious consequences. Clean drinking water is becoming scarce. Industrial wastewater pollution is carcinogenic. The water pollution is effecting the ecology. When polluted water is provided for agriculture it results in toxicities in fruits, vegetables and grains. Miss use of insecticides and pesticides contaminated the fresh underground water resources. Bad and faulty sewage water disposal system contaminates the supply of fresh water. All these things are responsible of water scarcity and causing a number of diseases.[4]

1.4 Problem statement

As discussed earlier Pakistan's sole energy production system relies on the fossil fuels like oil and gas. Pakistan, being a not major producer of these two resources, has to import both of these. It is a difficult to maintain supply chain management for both these commodities. As international market is unstable, it makes the patterns of prices of these commodities more unpredictable. The import cost, in reference to production cost per unit of electricity, has also increased in recent era.

Therefore, there must be a reliable solution with appropriate modifications and improvements which, in the start, can be executed on a small scale for better analysis. An environmentally friendly solution must be devised to make the industrial sector capable of better energy management and generation systems and to ensure an efficient waste to energy development.

1.5 Introduction to Coal Slurry-Fuel

Back in the period of World War 2, coal mining and usage of coal used to be at its peak. A water plus coal mixture left during processing of dry coal, was deemed unusable and was wasted. In the late 1950s, the soviets started working on developing more efficient ways of coal production, usage and transportation. The idea to use this remaining coal plus water mixture was worked on and a protocol was developed by addition of some dry coal in this mixture. This operation formed the slurry and initially, it was used to transport coal from one place to another. Later on, more experimentation on this lead to development of better way of transporting this coal in the form of pipe lines.

Also there are some reports which indicates that in 1940's, coal was used to transport to marine vessels by making a slurry. After slurry is pumped to the ship, it is dried and the coal was fired in boilers to run the ship.

Back in 1983, US Marine corps was tasked to develop a burner technology to burn Coal Slurry-Fuel directly into boilers without drying it. This task was given in order to replace Coal Slurry-Fuel with expensive petroleum products[6].

Now with the passage of time there are numerous technological advancements regarding the Coal Slurry fuel and its use. Scientists have developed new ways of preparing and utilizing coal slurry-fuel. New burner technologies have made its use easier and more efficient.

Coal Slurry-Fuel has numerous advantages over orthodox coal burning. Due to the presence of water SOx are absorbed and flushed along with ash. Coal Slurry-Fuel burns at low temperatures so low NOx is produced. Due to slurry formation and better fluid dynamic better combustion efficiencies are achieved. Also it is easy to handle, transport and store[7].

1.6 References

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Chapter 2: Literature review

2.1 Various forms of using Coal Slurry Fuel

In contrast to initial use of CSF for transportation purposes, later on developments were made in regard to use CSF for burning in the furnaces and in diesel engines. After the energy crisis in 1973 and in 1979 many countries started working on CSF to use as a replacement fuel for oils in furnaces. In 1973, a combination of companies was formed in USA. This company was named as General to develop a technology comprising of Coal Slurry Fuels. The US department of energy supported this project. They presented their first report later in 1976, stating that CSF can be used as a viable fuel in the furnaces as a replacement of oil and gas.[8]

In 2011, a research experiment was conducted to study the effects of using CSF in a diesel engine instead of diesel. Purpose of the study was to reduce the usage of diesel and also to reduce GHG emissions in the atmosphere. Fuel produced had a viscosity of 27 cP. The desired viscosity was (<100 cP). The fuel gave little delayed ignition but showed higher calorific values which raised the ignition temperature from 300°C to 450°C. Top combustion pressure and 100% load was achieved at 1200 rpm. Higher heat delivery was observed, for diesel it was 145j/crank cycle and for CSF it was 180j/crank cycle.[9]

2.2 Composition of Coal Slurry Fuel

In literature, we can find various compositions for the preparation of coal slurry fuels. But the most common ratio in which coal Slurry fuel is prepared is 55-70% coal and 45-30% water with an addition of 1% additives[10]. These ratios are adjusted according to the desired results. For low viscous slurries less quantity of coal is used and for highly viscous slurries more coal is used. Similarly, low viscous slurries have less heat content per unit as compared to high viscous slurries. Although low viscous slurries are easy to use and cause less wear and tear as compared to high viscous slurries. Low viscous slurries are also easy to handle as compared to highly viscous slurries[11].

2.3 Effect of coal properties on Coal Water Slurry Fuels

The coal properties have a dominant effect on the properties of coal water slurry fuels. The first parameter that affects the properties of CWSF is the particle size of coal. More finely pulverized the coal the better chances of homogenized mixing of the slurry. Usually the particle size recommended is between 30-60 µm. but the size must not surpass 60µm[11]. The particle size also effects the slurry-ability of coal water slurry fuel and its viscosity. Also the parameter like Sulphur content, ash content, volatile matters and moisture content will affect directly to the quality of slurry fuel formed. These parameters will effect in both ways. the pre-combustion and the post combustion of the fuel formed.[12]

2.4 Effect of chemical additives on Coal Water Slurry fuel

Different additives are added in CWSF to enhance different characteristics of the fuel. Different chemicals are used for different purposes. Their functions may include giving stability to the slurry, increase slurry-ability, control the suspension state, improve the rheology of the slurry, improve the shelf life of the slurry etc. For this purpose, many synthetic and natural chemicals are developed. The main two types of chemicals used are classified into two categories.

Stabilizers

Dispersants

2.4.1 Stabilizers

These chemicals are used to stabilize the already suspended coal particles in the slurry form thus enhancing the slurry-ability of the fuel formed. Addition of these chemicals enhance the rheological properties of the fuel formed. This also increases the grind ability of coal and reduces the viscosity of CWSF. These chemicals may be synthetic or natural. The efficiency of the synthetic stabilizers is better than natural stabilizers. The synthetic stabilizers have polymeric structures which helps in providing better stability. These stabilizers may include NaNSF (Sodium Naphthalene Sulfonate Formaldehyde Condensate) and PSS (Polystyrene Sodium Sulphonate)[13].

2.4.2 Dispersants

The main action of the dispersants is the proper distribution of coal particles in the slurry form. These dispersants are derived from the lignin and these are mostly naturally made compounds. Although the main purpose of these compounds is to disperse the coal particles in the slurry but besides that these compounds helps to decrease viscosity and provide better rheological characteristics of the slurry formed. Dispersants like wheat straw alkali lignin, Sodium lingosulphide, Calcium lignosulfide are very common in this practice.[14]

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Chapter 3: Experimentation

3.1 Objectives:

The main objective of this research is to devise a fuel strategy by which the coal produced by various resources can be utilized with characteristic of having best possible efficiency. Besides, to stimulate the innovative resources to reduce the toxicity and control waste management, keeping under consideration the importance of renewable energy resources, is also the key prospective of the research.

3.2 Scope:

Scope of this research lies in the development of fuel ensuring the use of coal in Pakistan and it also lies great focus on reducing the environmental impacts of industrial waste water. Strategy, therefore, fits in with all the environmental and industrial accordance of capital planning by defining the scope of efficiency of coal slurry technology in various technological operations.

3.3 Approach Used:

To address the charge of objectives of this research, use of coal slurry technology to fit our current energy crisis in Pakistan, is the key factor. This research is followed by analyzing all the relevant aspects of utilization of natural resources of the country and eliminating the hazards of waste water management, by critically considering all the subsequent energy uncertainties.

3.4 Materials

Materials required for the experiment include coal, stabilizer, dispersant and water/waste water. All the materials were obtained from various industries. All these materials were industrial grade. The qualities, origin and specifications of materials are described as follows:

3.4.1 Coal

Coal was obtained from ‘Pioneer Cement PVT Ltd.’ The basic purpose of obtaining coal from cement industry, was to obtain already pulverized coal. In that plant, coal is used to fire the kiln and is pulverized to an average particle size of 60 microns. They pulverize coal using horizontal bed type roller mills. Analysis and characteristics on composition of the cement taken under experimentation, done by Quality control department located at ‘Pioneer Cement PVT Ltd.’ along their ISO standards, is given as follows:

Sr. No.	Analysis/Parameter	Value	ISO Standards
1	% Inherent Moisture	-	ISO 11722
2	% Total Moisture	3.12	ISO 11722
3	% ASH Content	16.22	ISO 11721
4	% Volatile Matter	30.69	ISO 351
5	% Sulphur	0.69	ISO 351
6	Gross Calorific Value (cal\gm)ADB	6260	ISO 1928

Table 4: Analysis of coal

3.4.2 Sodium lignosulfide

Sodium lignosulfide is used as dispersant. The main purpose of dispersant is to disperse or distribute the finely pulverized coal particles equally into the slurry to maintain rheological properties. It is also used as viscosity adjuster. Sodium lignosulfide was obtained from Jinan Yuan sheng Chemical Technology Co., Ltd, China.. Purity of the chemical obtained was 90%. Following are the specifications of sodium lignosulfide.

3.4.2.1 Specifications

IUPAC Name

disodium;3-(2-hydroxy-3-methoxyphenyl)-2-[2-methoxy-4-(3sulfonatopropyl) phenoxy] propane-1-sulfonate

Molecular formula

$C_{20}H_{24}Na_2O_{10}S_2$

Physical Appearance

Light tan powder

3.4.2.1.1 Physical and Chemical Properties

Molecular Weight	238.2597 g/mol
Hydrogen Bond Donor Count	1
Hydrogen Bond Acceptor Count	4
Rotatable Bond Count	1
Exact Mass	238.02998 g/mol
Monoisotopic Mass	238.02998 g/mol
Topological Polar Surface Area	79.8 A^2
Heavy Atom Count	16
Formal Charge	0
Complexity	293
Isotope Atom Count	0
Covalently-Bonded Unit Count	2

Table 5: Physical and Chemical Properties of Sodium Lignosulfide

3.4.3 Sodium Naphthalene Sulfonate Formaldehyde condensate

Sodium Naphthalene sulfonate or simply known as NSF is an anionic surfactant. The main purpose of NSF is to increase the timing of suspension of solid particles in solution. In this case the solid particles are finely pulverized coal particles and the solution is the coal water slurry fuel. It increases the particle retention time and provides better viscosity profile for the slurry. It helps in increasing the shelf life of the slurry and make transport of the slurry easier. This particular chemical was obtained from SHANDONG WANSHAN CHEMICAL CO. Ltd., China. Major specifications of the chemical are given below.

3.4.3.1 Specifications

IUPAC Name

formaldehyde naphthalene-2-sulfonic acid

Molecular Formula

$C_{11}H_{10}O_4S$

Physical appearance

Light tan powder

3.4.3.2 Physical and chemical properties

Molecular Weight	238.2597 g/mol
Hydrogen Bond Donor Count	1
Hydrogen Bond Acceptor Count	4
Rotatable Bond Count	1
Exact Mass	238.02998 g/mol
Monoisotopic Mass	238.02998 g/mol
Topological Polar Surface Area	79.8 A^2
Heavy Atom Count	16
Formal Charge	0
Complexity	293

Covalently-Bonded Unit Count	2

Table 6: Physical and Chemical Properties of Sodium Naphthalene Sulfonate

3.4.4 Waste water

For this experiment, wastewater from three different industries was used. These industries include Alcohol Distillery, Dairy and Textile. Alcohol distillery wastewater or spent wash was obtained from Noon Sugar Mills Distillery located in Bhalwal, District Sargodha. Waste water from former Noon Pakistan and now known as Fauji Foods located in Bhalwal district, Sargodha was obtained. The last one was obtained from Sapphire textile mills limited located in Lahore. Key characteristics of the wastewaters are given below.

3.4.4.1 Alcohol distillery

Key characteristics of spent wash obtained from Distillery are tabulated below these were tested by NOON Sugar Mills Distillery laboratory.

Parameter Tested	**Spent Wash**
Temperature (^{o}C)	**60**
pH	**3.92**
Density(gm /cc) at 25^{o}C	**1.05**
Brix (%)	**13.20**
COD (mg / l)	**101000**
BOD (mg / l)	**35000**
TVA (mg / l)	**1200**
TDS (mg / l)	**100500**
TSS (mg / l)	**9500**
TS (mg / l)	**110000**

Ash (%)	**4.10**

Table 7:Analysis of waste water

3.4.4.2 Dairy

Key characteristics of spent wash obtained from Dairy are tabulated below these were tested by Fauji Foods laboratory.

Parameters tested	Dairy Waste Water
COD (mg / l)	2000-6000
BOD (mg / l)	1200-4000
Suspended Solids (mg / l)	350-1000
Volatile Suspended Solids (mg / l)	330-940
Total Fatty Matter (mg / l)	300-500
PH	8-11

Table 8: Poperties of Dairy waste water

3.4.4.3 Textile

Key characteristics of spent wash obtained from Textile are tabulated below these were tested by Sapphire textile mills laboratory.

Parameters tested	Textile Waste Water
PH	2-13
COD (g/m^3)	10-61900
TSS (g/m^3)	5-7630

Turbidity (NTU)	1-200
Conductivity (mS/cm)	0.2-115.2
Color Absorbance average	0.001-218.8

Table 9: Analysis of Textile waste water

3.5 Method

All the raw materials were collected and brought to the Bio Fuels lab at USPCAS-E NUST, Islamabad Pakistan. Two major types of slurries were prepared. One was prepared by using fresh water and other was prepared by using waste water. For both types of slurries solid loading was kept 65% and liquid ratio was kept 35% by weight. 1% additives was added, both in equal quantities. 400g samples of both slurries were prepared in a mixer driven by 800w variable speed motor. 260g of coal, 139g of water, 0.5g of NaNSF and 0.5g of sodium lignosulfite were added into the container and then mixed at 1357 RPM for 30 minutes. After 30 minutes the coal water slurry fuel (CWSF) was collected into sample bottles. The same procedure was repeated with waste waters to make coal waste water slurry fuels (CWWSF) under ambient conditions.

Figure 2: Blender for the experiment

3.6 Analysis

After preparation of samples. These samples were again sent to Pioneer Cement Pvt. Ltd. There the same analysis as previously done for raw pulverized coal, were done on these samples. These samples were first dried. Drying was done according to the procedure internationally adopted. These samples were dried in an air circulated furnace by maintaining temperature at 40◦c. After sample preparation these samples were analyzed for inherent moisture, total moisture, volatile matter, Sulphur content, ash content and gross calorific value. All these analyses were carried out on the same ISO standards as before. The following results were obtained.

Sr. No.	Analysis	Coal	Coal Water Slurry Fuel	Coal Waste Water Slurry Fuel (Textile)	Coal Waste Water Slurry Fuel(Alcohol Dstillery)	Coal Waste Water Slurry Fuel (Dairy)
1	**% Inherent Moisture**	-	2.46	1.77	1.42	1.48
2	**% Total Moisture**	3.12	38.94	39.45	35.54	38.22
3	**% ASH Content**	16.22	16.72	16.56	17.86	16.80
4	**% Volatile Matter**	30.69	30.64	27.01	28.41	26.99
5	**% Sulphur**	0.69	0.81	0.83	0.96	0.85
6	**Gross Calorific Value (cal\gm)ADB**	6260	6245	6228	6014	6209

Table 10: Analysis of the Fuel Prepared

All the samples prepared are viable fuel for power production in boiler furnaces.

Chapter 4: Plant Design

After successful preparation of fuel comprising of coal and waste water. The next step is to develop a procedure or design a plant, which can utilize this type of fuel. Due to lack of knowledge regarding mechanical engineering a proper boiler and other system could not be designed. For this purpose, a collaboration was done with Noon Sugar Mills. They needed a power production system for running their distillery during non-crushing season. They are currently using natural gas for running their low pressure boilers and diesel for the production of electricity. They needed a permanent solution for both producing steam and producing power.

They have a specific need of 10-14 tons of steam per hour to keep their distillery operations going and also need to produce around 1 MW of electricity to run electrical operations. So there must be a solution which attends to both their needs. So one simple solution to this problem was to use a high pressure boiler and a back pressure turbine generator set. In this ways both problems can be addressed by installing a single mechanism. All these thing only exist in theory not in practical.

4.1 Process

First almost 25mm particle size coal is needed to be reduced using a ball mill or a roller mill. After size reduction of the coal particles to fine pulverized coal it is needed to be mixed with water/waste water. for this purpose, a mixer can be used but the economical way is to use a roller mill in which wet milling can be done. In this way energy and time both can be conserved. In wet milling coal, additives and waste water can be added into same mill. This process can be a batch process or it can be a continuous process. It totally depends which type of roller mill is used. After preparing the fuel it is needed to be stored. It can be directly pumped to furnaces. But storage makes it safer. If there is any problem in the milling section, then surge storage makes it possible to run the process without any stoppage. This provides continuity to the process. After that the fuel is pumped to the boiler at a specific rate to produce steam. Here fuel is mixed air to maintain an air to fuel ratio for maximum burning efficiency. This air is provided by using an air compression unit. After producing steam, the steam then goes into turbine and the rotates generator. The generator in turn produces electricity. As in our case a back pressure turbine is used which means steam used to produce electricity is not condensed at all but loses pressure and is viable for use again so this steam is then again send for use in distillery operations and then condensate is again used in boiler operations.

4.2 Process Flow diagram

After finalizing the process, the next step in line is to develop a process flow diagram. This diagram gives the detail about the process equipment and flow of materials.

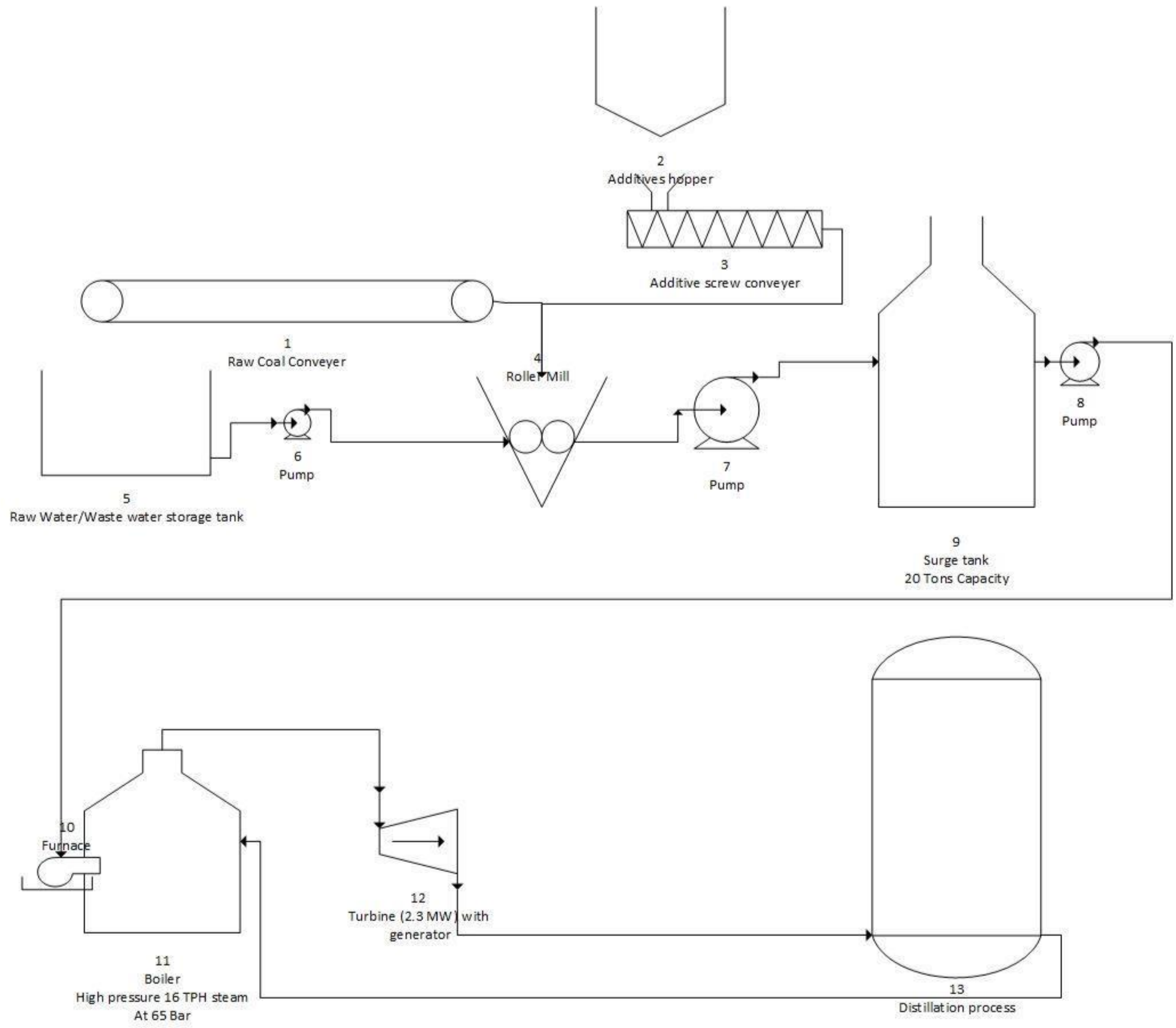

Figure 3: Process Flow Diagram

4.2.1 List of equipment

In the above given process flow diagram the equipment and their coding is given below.

Sr #	Equipment name	Code\Nomenclature
1	Raw Coal Conveyor	CC100

2	Additives Hopper	AH100
3	Additives screw conveyor	SC100
4	Roller Mill	RM100
5	Raw water Storage tank	ST100
6	Pump	P100
7	Pump	P101
8	Pump	P102
9	Surge Tank	ST101
10	Furnace	F100
11	High pressure boiler	B100
12	Turbo generator set	ST100
13	Distillation process	DP100

Table 11: List of equipment

4.3 Material balance

The next step in plant design is to apply material balance on all the equipment selected. The material balance is applied by back calculation. Our major demand or end product should be 17 TPH steam to be utilized in the distillery process. So by back calculation we have calculated the amount of material required for keeping the process running. In this way we have calculated the amount of all the raw materials required and all the products formed. Material balance is applied on all the equipment individually. So further below there is a breakdown of all the individual material balances on all the equipment.

In the present scenario there are a number of components are involved. These components are listed below.

Coal

Waste water

Additives

Coal water Slurry Fuel

Steam

Raw water

These components are considered main components in this process and material balance is applied on all the equipment keeping in view all these components. The operation is divided into two stages keeping in view the nature of process which is continuous and batch. In the first stage the roller mill is operated in batch process and in the next stage the boiler and turbine are operated in continuous phase. The capacity of the roller mill is selected slightly higher than the required capacity to produce enough fuel to fill the surge tank and to keep the process going. Below is the given material balance on all the equipment.

Material Balance										
Equipment	**Roller mill**		**Surge tank**		**Boiler**		**Turbine**		**Distillation Process**	
Component	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
	TPH	**TPH**	**TPH**	**TPH**	**TPH**	**TPH**	**TPH**	**TPH**	**TPH**	**TPH**
Coal	2.58									
Waste Water	1.38									
Additives	0.04									
Coal Water Slurry		4	4	2.79	2.79					

Fuel										
Steam						17	17	16	13.82	13.82
Raw Water					17					
Total	4	4	4	2.79	19.79	17	17	16	13.82	13.82

Table 12: Material Balance

Here it is clear that 4 TPH CWSF is produced per hour but only 2.79 TPH is the consumption. This is solely because that to keep the process up and running we must have enough fuel present at all times. So that is why a surge tank is installed. Also there are phase changes during the process.

These phase changes are tabulated below.

Phase Changes										
Equipment	**Roller mill**		**Surge tank**		**Boiler**		**Turbine**		**Distillation Process**	
Phase	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
Component										
Coal	S									
Waste Water	L									
Additives	S									
Coal Water Slurry Fuel		L	L	L	L					
Steam					G/L	G	G	G\L	G\L	G\L
Pressure(BARA)						65	65	2.4	2.4	

Temperature (◦c)						480	480	147.2	147.2	30
Raw Water					L					
Pressure(BARA)										
Temperature (◦c)					115					

Table 13: Phase temperature and pressure changes

4.4 Energy balance

Now the next step in designing of a plant is to apply chemical energy balance on the plant. In our present scenario, there are only 3 equipment on which energy balance could be applied. The main components which involve in this energy balance are listed below.

Steam

Raw water

Coal water slurry fuel

The three main equipment on which energy balance is applied are also listed below.

Boiler

Turbine

Distillation process

CWSF enters into the furnace of the boiler burns and produces energy which is then transferred to the water for making steam, under 65 BARA pressure. This steam is moved forward to the back pressure turbine where electricity is generated and through back pressure steam at the pressure of 2.4 BARA sent to the process. Here it loses all temperature and pressure and water is recycled back to the boiler where it is mixed with some of the steam from turbine collected in deaerator. When steam mixes with the process water it raises its temperature. Thus 16 TPH water again enters the boiler at 115◦c.

In the table below the main energy balance is given.

Energy balance										
Equipment	**Roller mill**		**Surge tank**		**Boiler**		**Turbine**		**Distillation Process**	
Component	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
	KJ\Ton	**KJ\Ton**	**KJ\Ton**	**KJ\Ton**	**KJ\Ton**	**KJ\Ton**	**KJ\Ton**	**KJ\Ton**	**KJ\Ton**	**KJ\Ton**
Coal										
Waste Water										
Additives										
Coal Water Slurry Fuel					46188800					
Steam						3369000	3369000	2760100	2760100	0
Raw Water					7715200					
Total					53904000	3369000	3369000	2760100	2760100	0

Table 14: Energy Balance

4.5 Equipment selection

After applying the material and the energy balances, the next step is to design or select the specific equipment. This is done keeping in mind the material and energy balances.

This task was done with the help from Noon Sugar Mills Distillery. At that particular industry they wanted a solution for their ongoing problem. They have to run to the distillery around the year. During the crushing season the can use the steam from the sugar plant. But after the crushing season when there is a shut down on the sugar plant there is a deficiency of steam generation. In crushing season, they are using bagasse as a fuel. But after crushing season the bagasse is available for some time, but after that they have to use natural gas for steam generation and diesel generator as a power source. It is also not feasible to run sugar mill boiler for both these purposes. So they were in need of a solution to this problem.

They were already looking for a solution. One possible solution they thought were to use bagasse as a main fuel, produce 2.3 MW of energy, and get 13.92 TPH steam for process. But logistics of bagasse in the off season remains the problem. Another problem they were facing was the proper disposal of the distillery spent wash. So after a lot of discussion and technical sessions a solution for them was derived. This solution comprised of using coal water slurry fuel as a replacement of bagasse. Also waste water to be replaced as fresh water in coal water slurry fuel.

They already had the specifications and plant design for the High Pressure Cogeneration system. We just needed to modify it. Addition of roller mill, slurry pumps and other raw material handling material was done. In this way we can modify any existing system installed into CWWSF based system. Further it is discussed about how the selection of particular equipment was done.

4.5.1 Roller mill

According to the material balance total of amount of fuel required is 4 TPH. The main equipment for producing the fuel is the roller mill. For this purpose, a roller mill having a capacity of 4 TPH was selected. All the design specifications were obtained from Fabcon engineering LTD, Lahore. Further specifications are given in Table 15 in **Appendix I**.

4.5.2 Boiler

For this particular operation a high pressure boiler was selected. High pressure boilers have better efficiency. They consume less fuel. The steam is at high pressure which is good for CO generation systems. Different boilers from different manufactures were considered but a 17 TPH boiler was selected, designed and manufactured by HMC, Taxila. Boiler description and specifications are given in Table 16 in **Appendix I**.

4.5.3 Turbine

For this specific operation involving co-generation of electricity and steam, a back pressure turbine was selected. The turbine from Trivani Turbines china was selected. The main reason was because this particular turbine was giving maximum electricity generation besides the production of 13.82 TPH steam for distillery operations. Specifications of the turbine are given in Table 17 in **Appendix I**.

Chapter 5: Economic analysis

The next step in plant design is to study the economics of the plant to be installed. There are two main steps involved in this analysis. First one is to calculate the capital cost of the plant to be installed and the other one is the estimation of the operational cost.

5.1 Capital cost estimation

Capital cost estimation is the amount of money required to purchase and install the plant. If we talk about the plant, then it includes all the necessary equipment, auxiliaries and utilities. Also the amount of money is estimated to run the plant for the first time. Capital cost is the sum of fixed capital investment and working capital. Fixed capital investment includes direct and indirect costs. Direct costs are the ones which are essential for starting the project. For instance, it may include the cost of main equipment to be installed. They may also include the cost of constructing any building or any auxiliaries required. The in direct costs are the one which are required to start or support the project as it goes on.

5.1.1 Direct cost

Direct cost of the plant is the amount of basic equipment to be installed. Bare cost estimation is done by getting real quotations from the manufacturers. All those procedures were followed which noon sugar mills do for acquiring any new system or plant. The table below gives us the detail about the bare capital cost of the plant.

Equipment Number	Type of Equipment	Equipment Specifications	Materials of Construction	Equipment Cost in PKR, Oct 2015	Installation factor	Installed cost (PKR)
	Comments					
B100	High pressure Boiler & Boiler	65 bar, 17 TPH, 485°C		135000000	8%	146002500
STG100	Back Pressure Turbine	1500 RPM, 2370		5500000	20%	6600000

	and generator set	KWH		0		0
CSRM10 0	Coal waste water Slurry Roller mill	4 TPH, 22 KW x 2	Carbon Steel	4000000	25%	5000000
CC100	Coal Conveyors(50mx0.609mx 1.650m)	(50mx0.609mx1.6 50m)		8800000	25%	1100000 0
	Boiler Ash Removal System			1100000 0	0%	1100000 0
LCT100	Lube Oil Cooling tower	(4mx4mx15m)		3000000	0%	3000000
					Total	2168000 00

Table 15: Bare Capital Cost

In the above table all the bare cost of all the equipment is given. All these costs were directly collected from the manufacturers directly by Noon Sugar mills limited, Bhalwal. The price of boiler was obtained from HMC, Taxila. It includes all the foundations and instrumentation equipment also. Similarly, the quotation of back pressure turbine and turbo generator set is obtained from Triveni Turbines, China. Design parameters and quotation of roller mill including two 22 KW motors and gear boxes was obtained from Fabcon Engineering LTD, Lahore. Coal conveyors will be assembled in Noon Sugar Mills, Bhalwal, so it was their own estimate. Boiler ash removal system is basically the part of boiler so its quotation was also received from HMC, taxila. Lube oil cooling tower was basically a part of turbine so its quotation was also received from Triveni Turbines, China. So the total bare cost of the plant is 216.8 Million PKR.

5.1.2 Other Direct Costs

These are the costs which include the cost of things, buildings or equipment other than the main equipment. Usually it includes Instrumentation, electrical wiring and instruments installation, buildings or services or facilities costs. In our case, the quotation of instrumentation cost was included with the equipment quotation. An electrical wiring is required to supply the produced power to the grid. As the plant is the extension of an existing so no new buildings or offices are required. Other civil work like the civil work of boiler, turbine and generator and other such equipment is already included in the equipment quotation. The other thing in other direct cost is the services. It includes all the engineering and non-engineering services you get to get the job done. For instance, it may include some third party labor or some consultancy regarding designing. In the below table all the other direct costs are given.

Classification	Description	Comments	Percentage of bare cost	Amount in PKR
Electrical installations	12 % of purchased equipment		12%	26016000
Cost of building including services	7% of purchased equipment	As project is an addition to already present project	7%	14092000
Service facilities	20 % in this case with some existing utilities		20%	43360000
		Total PKR		83468000

Table 16: Other Direct Costs

From the above table it is concluded that total other direct cost is 83.468 Million PKR.

5.1.3 Indirect cost

As discussed earlier indirect costs are the one which are required to run the plant as the foundations are laid. These costs may include the funds required to start the project as it is installed. These costs may also include the fund incase anything is cut off short or anything bad happens. Also this cost may include the fund for engineering services or supervision of the project. For the present base case all these costs were assigned the percentage values according to the peter & timmerhaus approach. The table below show the assigned percentages of indirect costs.

Description	Comments	Percentage	Amount in PKR
Engineering and supervision	15 % of purchased equipment cost	15%	32520000
Contingency	10% of direct cost	10%	32547050
Start-up cost	20% of direct cost	20%	65094100
	Total indirect cost		**130161150**

Table 17: Indirect Costs

So the total indirect cost for our project is 130.161150 Million PKR.

5.1.4 Fixed capital investment

As we know that, the fixed capital investment is the sum of direct cost and in direct cost.

Fixed capital investment = Direct Cost + Indirect Cost

= **455.631650 Million PKR**

5.1.5 Working Capital

It is the cost required to keep the things going as soon as the project is finished and about to start. It may include the raw material procurement funds or it may include wages. For our base case this value is considered 15% of the total capital investment.

5.2 Total capital investment

The total capital investment is calculated in the table below.

	% of TCC	MPKR
Fixed capital investment	85%	**455.631650**

Working Capital	15%	80.405585
Total Capital investment		536.04

Table 18: Total Capital Investment

5.3 Operating cost estimation

The next step in economic analysis is to estimate the operating cost or manufacturing cost. The manufacturing cost is the sum of the contributing costs related to the operations. It may include the cost of procuring all the raw materials, wages of all the employs, administrative costs. It may also help to calculate in how much time we can recover the capital investment. It also helps to determine the final price of the product at which best payback period is achieved. The total operating cost or manufacturing cost is divided into two portions.

Production cost

General expenses

Production cost is further divided into following costs.

Direct cost

Fixed charges

Plant overheads

The plant will be available for 82% of the year. Annual plant operation period is considered 7201 hours.

5.3.1 Total operating cost break up

In the table below the total breakup of the operating cost is presented.

TOTAL OPEX							
PRODUCTION COST						**GENERAL EXPENCES**	
DIRECT	MPK	FIXED	MPK	PLANT	MPK	GENERAL	MPK

PRODUCTION COST	R/yr	CHARGES	R/yr	OVERHEAD	R/yr	EXPENCES	R/yr
Raw Materials	77	Local Taxes	1.207	Purchasing/Warehousing		Sales & Marketing	
Other Materials	0.00	Insurances	1.207	Site Overhead		Distribution	
Utilities	38.24	Rent		Medical Services		Quality Management	
Maintainance & Repairs	21.44			Safety & Protection		engineering Services	
Operating Labor	4.1	CAPITAL CHARGE		Cafetaria & Recreation		Research & Development	
Supervision	2.7	Interest		Laboratories (QC)		Finance & Administration	
Laboratory Charges	0.3	Depreciation	46.73	Logistic Services		Personel & Organisation	
Operating Supplies & Packaging	2.68			Administrative services		Management Services	
Patents& Royalty	0						
Carbon Credits & Waste	0			Total	7.51	Total	2.88
Total	146	Total	49.14				

Table 19: Total Operating Cost

Total operational cost is estimated to be 206 MPKR. The maximum amount of total operating cost is the cost of raw materials. Total raw material cost is 89% of the total operational cost. As there are no other materials required so no cost. Utilities cost, maintenance cost and other production cost are 2%. Total labor cost is 3% of the total operational cost. Other production cost and plant overheads are 1% each. The percentages of costs are presented in the figure below.

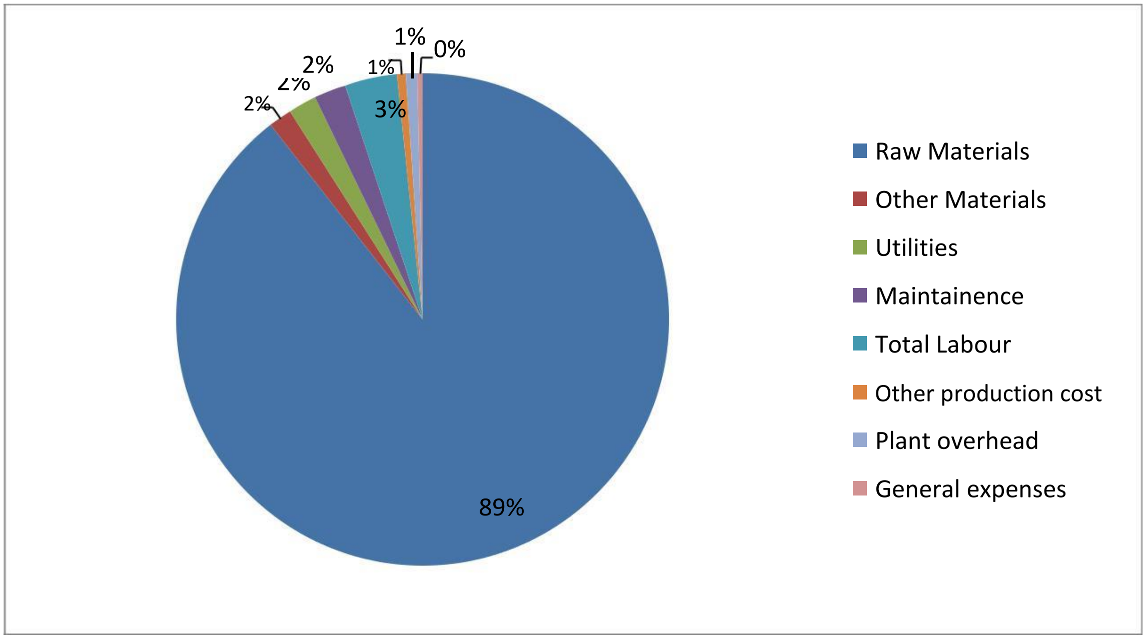

Figure 4: Operating Cost Breakup

5.4 Direct production costs

It includes all the cost direct cost related to the production. For instance, it may include price of raw materials, other raw materials, utility costs and total labor cost. In the base case there is no other raw materials cost because none are needed. Below given tables contains the details of raw material cost, utility cost and total labor cost.

Raw Materials					
Stream	**Amount**	**Unit**	**Price**		**Cost (MPKR/yr)**
Waste water	0.96255	tonne/hr			
Coal	1.80	tonne/hr	5700.0	(PKR/ton)	73.86
Sodium Lignosulphite	0.01	tonne/hr	28296	(PKR/ton)	3

Sodium Sulphonae formaldehyde	0.01	tonne/hr	13.1	(PKR/ton)	0.00132
			Total		76.70

Table 20: Cost of Raw Materials

Utility Costs								
				No of units				
Type	amount	Actual	unit			Price	unit	Cost (KPKR/yr)
Electricity			KWH	400	KWh/h	13	PKR/KWh	37444
Water	17		tonne/yr	122412.2	tone/yr	6.5	PKR/Tonne	795.7

Table 21: Utility Costs

LABOR COST						
Type	nr. Of units	workers/unit/shift	nr. Of workers	h/yr	Cost (kPKR/yr)	%
Boiler	1	5	15	36004	2250.225	33
Turbine	1	2	6	14401	900.09	13
Ball Mill	1	1	3	7201	450.045	7
Roller mill	1	1	3	7201	450.045	7
Total Operating Labor Cost					4100	60
supervision	9	% of OLC		21602.16	2700	40
Total Labor Cost					6800	99

Table 22: Labor Cost

The remaining production costs are presented in the table below, generally excepted portions of the total capital investment for maintenance & repairs and operating supplies & packaging are applied. As well as for operating labor cost for laboratory charges. Patents and royalties cost is not considered.

5.5 Fixed Charges

Fixed charges include the costs that are virtually not affected by the production capacity. For both Local taxes and insurances 1% of the FCI is used. Assuming that the plant's property is bought, therefore no rent is considered. For depreciation and interest, capital charge is calculated by taking interest rate 15 % over the period of 10 years. Calculated capital charge is 20% of FCI per year for 10-year time. In our case these charges were calculated and provided by NOON Sugar Mills Distillery.

5.6 Plant Overheads

The plant overheads are the costs related the production operation. These include Purchasing/Warehousing, Site Overhead, Medical Services, Safety & Protection, Cafeteria & Recreation, Laboratories (QC), Logistic Services, Administrative services, etc. a general figure for this cost is 50-70% of the total expenses for operating labor, supervision and maintenance labor cost.

5.7 General Expenses

General expenses are classified into administrative costs, distribution and marketing costs and research and development costs according to Peter & Timmerhaus, table below shows the contributions of these subjects to the general expenses. A relatively low factor has been chosen for distribution as the materials and products are distributed by already present pipe-lines. 0.3 % of operating cost estimation was considered for research and development as this is a new process technology. Not that these are very low fractions but because of the high total operating cost estimation the total general expenses would inflate too much.

Other production costs					
Maintenance & Repairs	**wages**	2%	% of CAPEX	10720744.71	PKR
	materials	2%	% of CAPEX	10720744.71	PKR
Operating Supplies & Packaging		0.50%	% of CAPEX	2680186.176	PKR
Laboratory Charges		8%	% of OLC	328000	PKR
Patents & Royalties		0	% of OPEX		
Plant Overhead		70%	% TLC & Maintainance wages	7509281.294	PKR
General Expences	Administrative	0.2	% of OPEX	2880163.15	
	Marketing, Sales & Distribution	0.2	% of OPEX		PKR
	Research & Development	0.3	% of OPEX		

Table 23: Other Production Costs

5.8 Profitability analysis

In the development of a new project, a lot of investment is required. Therefore, the analysis of profitability of the project at the stage of conceptual designing is very important. This provides adequate data for making the decision either the project is feasible or not. This decision is taken in different types of measures. These measures include (Break-even analysis, payback period time, return on investments and discounted cash flow). For our base case that is the production of 2370 MW co-generation system, profitability analysis is done. The table below shows the revenue of selling 2370 MW into the grid.

REVENUE					
Stream	Amount	Unit	Price	Unit	Revenue (MPKR/yr)
Electricity	17065706	KWH/yr	15.853	PKR/KWH	270.5

Table 24: Revenue

5.9 Break-even point

It is a point at which the costs and sales are equal. Thus at this point there is no loss or no profit. Below the break-even point the plant is in loss and above it the plant is profitable.

The *manufacturing cost* consists of variable cost (VC) and fixed cost (FC). Variable cost is the cost directly related to the capacity of the production. When the plant is not running, the variable cost will be zero. On the other hand, fixed cost is not related to the capacity of production. Even though the plant is not running (Capacity = 0), fixed cost still occurs.

$$\text{Marginal profit per unit} = \frac{\text{Annual Sales}}{\text{Capacity}} - \frac{\text{Annual VC}}{\text{Capacity}}$$

In the break-even point, total marginal profit (break-even production rate x marginal profit per unit) is equal to the variable cost. Thus, the break-even production rate can be calculated with the following equation:

$$\text{Break} - \text{even production rate} = \frac{\text{Annual FC}}{\frac{\text{Annual Sales}}{\text{Capacity}} - \frac{\text{Annual VC}}{\text{Capacity}}}$$

In addition, the marginal profit contribution in the sales is calculated:

$$\text{Relative contribution} = \frac{\frac{\text{Annual Sales}}{\text{Capacity}} - \frac{\text{Annual VC}}{\text{Capacity}}}{\frac{\text{Annual Sales}}{\text{Capacity}}}$$

The base case is evaluated and results in break-even production rate of **1150 KWH/yr** and relative contribution of 0.69. This means that when the plant runs below **1150 KWH/yr**, the plant will be in loss, and when it operates above **1150 KWH/yr**, profit is gained.

Break-even analysis can also be represented by a graph, such as in figure below. The intersection between the sales revenue and the production cost line is the break-even point. In agreement with the calculated value of **1150 KWH/yr**, the break-even production rate of the base case is **1150 KWH/yr** or 40% of the full production capacity.

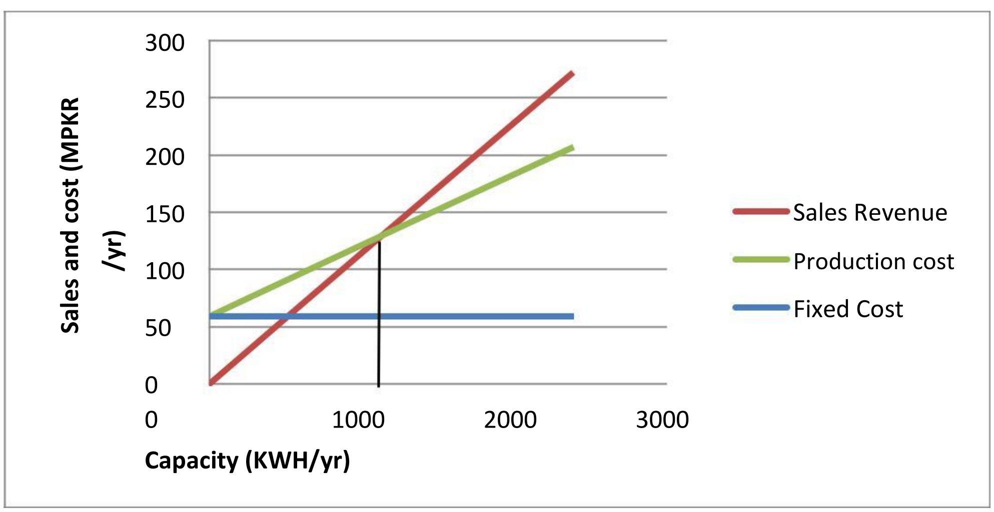

Figure 5: Break-Even Point

5.10 Payback Period

Payback period stands for the period (amount of years) that is takes to return the capital investment by the annual cash flow. The payback period (PBP) is calculated from Equation given below, where W is the total capital cost minus the working capital, land cost and salvage value. CF_{avg} is the average cash flow. The payback period for this design is **8.2** years, from the start of production.

= ——— = .

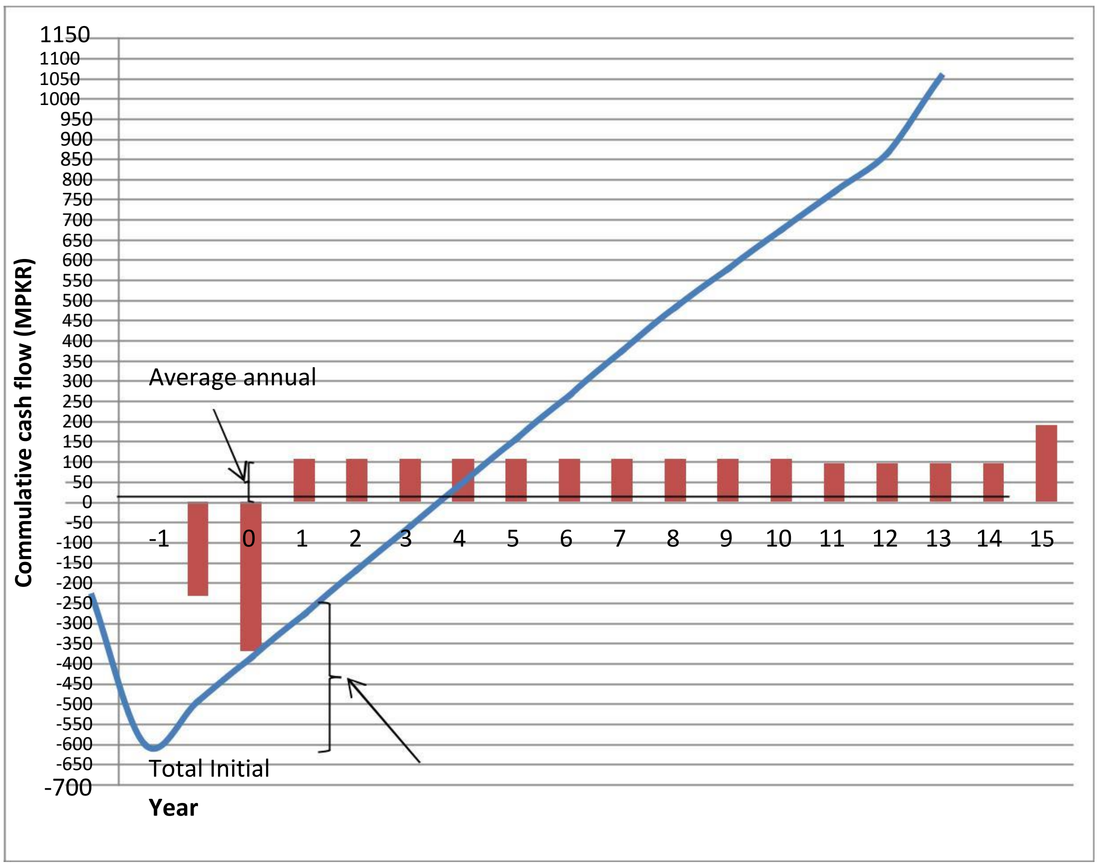

Figure 6: Cumulative Cash Flow

5.11 Discounted Cash Flow Analysis

The method of approach for a profitability evaluation by discounted cash flow takes into account the time value of money and is based on the amount of the investment that is unreturned at the end of each year during the estimated life of the project. A trial-and-error procedure is used to establish a rate of return which can be applied to yearly cash flow so that the original investment is reduced to zero during the project life.

Figure below shows the cash flow and the present value the project for a life time of 15 years. In the two years before production, the plant is build which requires the investment of the total capital. In year 0 the start-up and working capital are added to the investment. The cash flow for the years 1 till 15 is calculated using equation below. The interest/depreciation is taken for the period of 10 years.

$$\text{Cash Flow} = (\text{Revenue} - \text{OPEX} - \text{Depreciation}) - \text{Tax} + \text{Depreciation}$$

Where the Tax is 28% and depreciation/interest is 12% capital charge per year of FCI. In the final year of the project the working capital, land cost and salvage value is recovered. The cash flow is discounted using equation below with and a discount rate of of i=0.1% and 0.6%.

$$\text{Present Value} = \text{Cash Flow} \cdot (1+i)^{-n}$$

$$NPV_n = NPV_{n-1} + PV_n$$

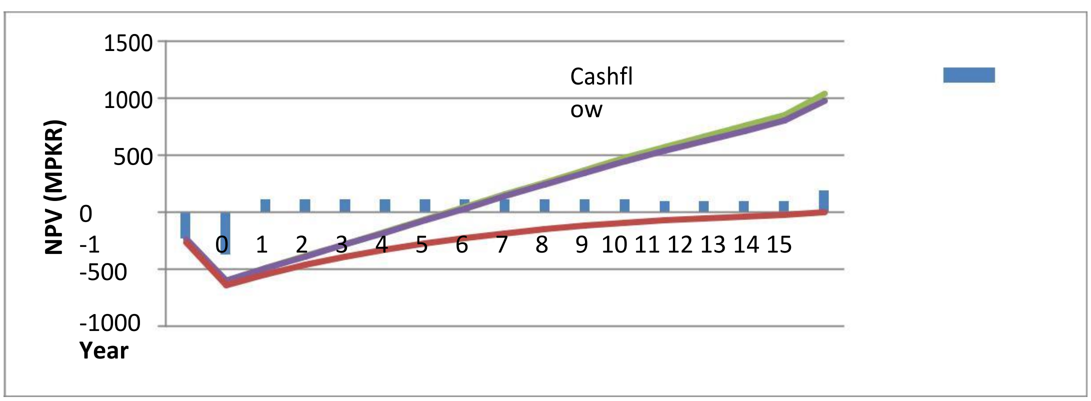

Figure 7: Net Profit Value

The *net present value* (NPV) was calculated using equation above. From the sum of the present values (NPV) a payout time of about **8.2** years can be realized for **i=0.00101** and **9.6** years for **i=0.006**. The *internal rate of return* at NPV=0 is **15%** for this case of the project.

5.12 Sensitivity and Risk Analysis

Both the project NPV and the IRR depend on the cash flows associated to the project, which at the same time depend on many factors: the initial investment required, the revenues and their evolution in time, the discount interest rate, which depends on the required return on the project, the inflation and the uncertainty component, etc.

Many times the variables underlying the project's cash flows or the interest rate for discount purposes are not known with certainty; therefore, companies estimate them and use the best guessed values to perform the necessary project analysis. Any change in one of these variables compared to the estimated value can affect the project NPV or whether the IRR is greater than the cost of capital.

Therefore, it is necessary to assess the degree of the forecasting risk for these variables and to what extent they might affect the profitability, as well as to identify the key variables linked to the success or failure of the project.

5.13 Sensitivity analysis

provides information about what happens to the NPV and IRR when one or more variables change. For that purpose, it has been done for many scenarios in Excel sheet, where all the variables are frozen except the one analyzed and then it is checked how much sensitive are the NPV and/or the IRR to changes in particular variable.

This analysis is first performed for the variables sales revenue, manufacturing cost and capital cost. To do this, each item is varied as a percentage relative to the base case. The variations for each scenario are shown in table below. We may emphasize that it is taken as a base case the first year of operation in which the plant operates at full capacity utilization.

Scenarios	Lower limit		Base case		Upper limit	
	%	MPKR	%	MPKR	%	MPKR
Sales revenue	-30%	189.9	0	270.2	30%	351.3
Manufacturing cost	-30%	99.9	0	142.7	30%	185.5
CAPEX	-30%	325.3	0	464.7	30%	604.1

Table 25: Senstivity Analysis

The considered items, manufacturing cost and CAPEX may be subjected to some degree of error that makes these values vary considerably. Therefore, it is assumed that a variation of 30% in these cases because of the uncertainly in the calculations and the lack of information. Furthermore, it must take into account that the product comes from coal, so due to the significant fluctuations in its price, it is decided to vary the sales revenues also with 30%. The figure below shows the graphical analysis of the sensitivity analysis. The figure also shows the effect of fluctuation on the NPV value.

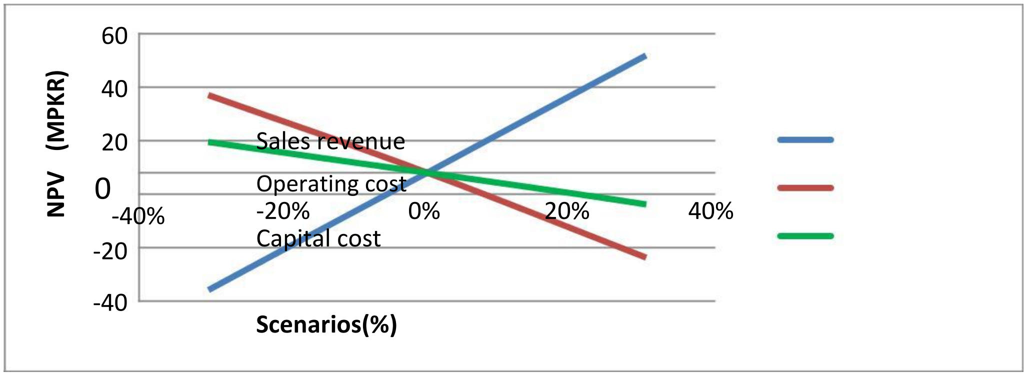

Figure 8: Sensitivity Analysis

Chapter 6: Results and conclusions

To discuss the results and conclusions, let us have a quick review. We have developed four different fuels. Coal water slurry fuel and coal waste water slurry fuel (Dairy, Textile, and Distillery). All the samples were analyzed. All the results were collected. Based on these results, some theoretical studies were conducted. A plant design was done in collaboration with NOON Sugar Mills limited. After plant design economic analysis was done. Following results can be concluded from the results collected and theoretical studies done.

All the samples formed and analyzed were in range and are feasible to use in the boiler furnaces.

Sulfur content in all four samples were below 1% that is why these fuels can be used in boiler furnaces.

Some modifications are required to use this fuel in the furnace.

Burner design can be modified according to this fuel.

Internal furnace lining should be changed before using this fuel.

This fuel produces low Sox and NOx.

Low Sox due to the presence of water in the fuel. Which produces acids as soon as the Sox are produced. Due to this reason internal lining of the boiler and furnace should be anti-corrosive.

Low NOx is due to the low burning temperatures of the fuel. It is burnt around 680◦c.

A Co-generation system was designed on the basses of this fuel.

The plant was original designed for bagasse and biogas. However, when converted to coal water slurry fuel or coal wastewater slurry fuel the revenue is less and payback period is more but the plant is feasible.

Accurate analysis is not done because there were no facilities regarding combustion testing of the fuel. Due to this reason we have to assume the efficiency of the fuel by doing literature survey.

Actual amount of Sox and NOx can be found by doing proper combustion and flue gas analysis.

If the logistics of the coal is promised, then this method or procedure can help small scale industries to produce surplus energy and help improving the energy crisis.

The total cost of the plant is 536 MPKR approximately. This cost may vary because cost of boiler and turbine were obtained in October 2015.

Total operational cost estimation of the plant is 206 MPKR

And revenue generated at the cost of unit price at 15.83 is around 270 MPKR.

This revenue can be increased if the system in not Co-generation and it is totally power generation.

By this also better efficiencies can be achieved and better revenues can be generated.

Appendix I

Parameter	Specification
Capacity	4 TPH
Feed size	25mm
Product size	60 microns
Feed Rate	4 TPH
Diameter	5 feet
Length :	6.25 Feet
Angle of elevation	35 Degrees
Power per mill	44 KW per hour
Solid loading	80%
Number of rods	45
Mill critical rpm	70
Charge filling	40%
Rod Filling	40%
Volume of the Rods	1.09 ft cube
Radius of rods	0.63Ft

Table 26: Roller Mill Specifications

Parameter	Specification
Capacity	17 TPH
Pressure	65 BARA
Temperature	480◦c
Drum Height	130m
Drum Dia	1m
Drum length	3m

Table 27: Boiler Specifications

Parameter	Specification
Inlet steam	16 TPH
Outlet Steam	16 TPH
Power Generated	2.3 MW
Inlet Pressure	65 BARA
Inlet Temperature	480◦c
Outlet Pressure	2.4 BARA
Outlet Temperature	147◦c
RPM	1500

Table 28 Turbine Specifications

Annex I

Preparation and investigation of coal slurry fuel blended with industrial wastewater for use in thermal power generation

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Abstract

Coal is an important and vital fossil fuel. It has been underutilized due to its complex mining procedures, transportation constraints and environmental impacts. Pakistan has vast amount of coal reserves and at present these reserves are not yet fully exploited due to the complications in underground coal gasification and mining. The proposed innovative technology of coal water slurry fuel can make the utilization of coal more easy and environment friendly. Finely ground coal particles are blended with water and additives to formulate a liquid fuel having properties comparable to the heavy fuel oils. Another novel idea is to use industrial wastewater instead of fresh water in preparation of coal slurry fuel. Major industries in Pakistan are facing problems of energy curtailment and wastewater disposal. Both the challenges can be effectively addressed by employing the proposed concept of coal slurry fuel together with the wastewater. The effects of blending pulverized coal in wastewater and fresh water were investigated in terms of properties such as heating values, sulfur content and ash content. Pulverized coal was obtained from "Pioneer Cement", having average particle size 90 μm, heating value of 6260 cal/g, 16.22% ash content and 0.69% sulphur content. Wastewater was collected from Noon Sugar Mills distillery having a pH of 3.92, brix 13.2, COD 101000 mg/l and BOD 35000 mg/l. Two samples of coal slurry fuel were prepared, one using fresh water and other using wastewater of alcohol distillery. Heating values were analyzed on dry basis, in case of wastewater sample the heating value decreases by a non-noticeable margin, the new value is 6245 cal/g and in case of fresh water sample it was 6014 cal/g. Sulphur in the fuel is increased to 0.96% due to presence of sulfur containing compounds in wastewater but for fresh water sample it is 0.81%. Further, ash content of the wastewater coal slurry fuel 17.86% as compare to the fresh water sample which was 16.72%. Both sample slurries can be fired in boilers in replacement of expensive heavy fuel oils. But in case of wastewater some post treatment is suggested in order to reduce Sulphur contents. The analysis shows environmental friendly utilization of coal as slurry with wastewater due to reduced ash contents and maximum thermal energy extraction even by the use of low quality coal.

Keywords

Coal; spent wash; Coal Water Slurry Fuel; Coal Spent wash Slurry Fuel

1. Introduction

The main purpose of discussing in detail all the factors is to draw the attention of scientists, engineers and industrialists towards an economical and environmental friendly solution to two major problems. One is the energy crisis and other is the waste water treatment or waste water disposal. The solution is to prepare a fuel comprising of coal and waste water. If we replace industrial waste water with the fresh water part in Coal Slurry Fuels then we will be solving two problems at the same time. We are producing energy and disposing waste water at the same time. Plus we are saving fresh water. In this way organic matter from waste water can be utilized into power production[1]. These volatile organic compounds present in in waste water can be utilized in the form of energy or they can provide energy because they have their specific calorific or heating values. Thus the increase the overall heating value of the fuel[2]. Coal water slurry fuel can be used in ordinary boilers operating on heavy fuel oils. No or minor modifications are required to have the new fuel firing the boilers[3]. This coal water slurry fuel can also be used for gasification for producing syn gas and further production of energy. At present multiple gasification technologies are present like GE energy (Texaco), opposed multi-burner process etc.[4], [5].

Coal water slurry fuel comprises of coal, water and additives. Properties of coal can affect the properties of slurry produced. For example, if brown coal is used for making coal water slurry fuel then there will be some other results and if black coal is used the results will be some other. With brown coal fuel formed will be of low heating value and Sulphur content will be more. For black coal fuel will have high heating content and low sulfur values. Usually the coal content in coal water slurry fuel is known as solid loading and it is kept 55-70% and the rest 30-45% is water part. Its ignition temperature is 800-850^{o}c. and combustion temperatures are recorded to be 950-1150^{o}c. Its viscosity is recorded between 1.15 mPa and 1.2 mPa depending upon the solid loading. The heating value of coal slurry fuel depends upon the type of coal used. If brown coal is used then heating values will be in range of 3700-4500 cal/g and if black coal is used then its range is from 5800-6500 cal/g[6]. The fuel formed is a good replacement of furnace oil and heavy marine oils. It can be replaced in ordinary furnace oil boilers by simply making some minor modifications.

The most noticeable and desirable advantages of coal water slurry fuel are it high solid loading, good stability, good rheological properties, intermediate viscosity, low ash formation and relatively higher calorific values. Apart from coal and water some additives are also added in the coal water slurry fuel. The purpose of these additives is to disperse the coal particles in the water and to stabilize the formation[7]. Usually NaNSF (Sodium Naphthalene Sulfonate Formaldehyde) is used as a dispersant/ surfactant. Other surfactants are also used but NaNSF is the common one[8].

The other main issue is the treatment and proper disposal of waste water. Either the technologies developed are too expensive or there in ill management or poor implementation of protocol. There are numerous industries in Pakistan. As discussed earlier sugar industry, textile industry, leather industry and dairy industry are some common industries in Pakistan. These industries have two major common issues. Energy production and waste water treatment or management. For example let's discuss the sugar industry.

In the crushing season of sugar cane, the sugar industry utilizes sugar cane and produce multiple products which includes sugar crystals, molasses (liquid leftover after crystallization of sugar) and bagasse. Bagasse is the solid part of the sugar canes outer crust and is utilized as fuel for power production for the whole crushing season. The other thing produced is molasses. Molasses is considered to be waste product of sugar mills. But it still contains significant amount sugar present in it. This sugar can be further utilized to produce alcohol. So now with most of sugar mills in Pakistan alcohol plants are also installed.

Alcohol production is alcohol distilleries majorly consists of four simple steps. Namely feed preparation, fermentation, distillation and storage. Molasses coming out of sugar mill has varying brix/density. It mostly depends how much sugar is extracted from it before. After molasses reaches the distillery its brix is tested and according to present brix it is diluted accordingly to prepare it for fermentation. Then it is loaded with sulfuric acid, urea and yeast. Now it is ready for fermentation. Step two, in fermentation the mesh formed is allowed to ferment for 30-40 hours. The main products formed are alcohol and carbon dioxide. Carbon dioxide is readily separated. Now the mesh is send for distillation, third step. During distillation alcohol is separated from spent wash (left overs). This spent wash is now the problem[9], [10]. This spent wash includes many impurities like organic pollutants, traces of alcohol, COD and BOD. Presence of BOD suggest that it can be further degraded biologically. So we can again ferment it and produce bio gas from it. But again some leftover is present which must be disposed of properly. Total 26 distilleries are working in Pakistan.in the year 2013-2014 492.24 million liters of alcohol were produced. On average 1 liter of alcohol 8-15 liters of spent wash are produced[11]. So the remedy to this problem is making coal slurry fuel using spent wash. Replacing water part of coal slurry fuel with spent wash.

2. Materials

Coal is the basic raw material. Coal was procured from Pioneer Cement Pvt. Ltd. Plant located near Khushab district, Pakistan. Pioneer Cement Pvt. Ltd. procured this coal from Waterberg coal field located in South Africa. The coal obtained was already milled and pulverized. The average particle size was 90µm. This coal was mixed with spent wash(waste water from distillery) obtained from Noon Sugar Mills Distillery Pvt. Ltd. located in Bhalwal near Sargodha district, Pakistan. Properties of spent wash are listed in Table 1. An ionic surfactant named as sodium naphthalene sulfonate formaldehyde condensate was selected as dispersant which was imported from SHANDONG WANSHAN CHEMICAL CO. Ltd., China and Sodium lingo-sulfite was selected as the stabilizer which was imported from Jinan Yuan sheng Chemical Technology Co., Ltd, China.

Parameter Tested	**Spent Wash**
Temperature (^oC)	**60**
pH	**3.92**
Density(gm /cc) at 25^{o}C	**1.05**
Brix (%)	**13.20**
COD (mg / l)	**101000**
BOD (mg / l)	**35000**
TVA (mg / l)	**1200**
TDS (mg / l)	**100500**
TSS (mg / l)	**9500**
TS (mg / l)	**110000**
Ash (%)	**4.10**

Table 29 Properties of spent wash

3. Method

All the experimentation was performed in the Bio Fuels lab in United States Pakistan Center for Advance Studies in Energy located in National University of Science and Technology, Islamabad

Two slurries were produced one was with water (Coal Water Slurry Fuel (CWSF)) and with spent wash (Coal Spent wash Slurry Fuel (CSSF)) for both slurries solid loading was kept 65% and liquid ratio was 35% by weight. 1% additives in equal ratio were also added in equal proportions. 500g samples were prepared each time. A mixer was used. No milling was required because coal procured was already pulverized. 322.5g of , 172.5g of water/spent wash, 2.5g of sodium naphthalene sulphonate formaldehyde and 2.5g of sodium lignosulfite were added into a mixer. The mixer has an 800w motor and mixing was done at 1300 rpm. Both sample were prepared at ambient conditions.

4. Results and Discussion

After the preparation of both samples. These samples were sent off site for analysis. All the analysis were done at Intertek Pvt. Ltd. Karachi. Each sample were tested for heating value, ash content and sulfur content.

Heat contents were found on dry basis and analysis was followed by ASTM standards (ASTM D-5865). For CWSF heat contents found were 6245 cal/g and for CSSF it were 6014 cal/g.

These heating values found are relatively close to the heating values of coal slurry fuels found in literature and no abnormality was found. It is also found that organic pollutants in the waste water or in this case spent wash have their own heating value. This heating value contributes in the overall heating value of the fuel[2]. Spent wash contains ethanol and higher alcohols and other volatile compounds, which helps in boosting the heating value of CSSF. Also the formation of CSSF is not affected by any of the compound present in spent wash. Both these heat content values are obtained on dry basis, but in future if advance studies are done with more scientific methods the increased heating value of the slurries can also be verified.

(CAL/G)

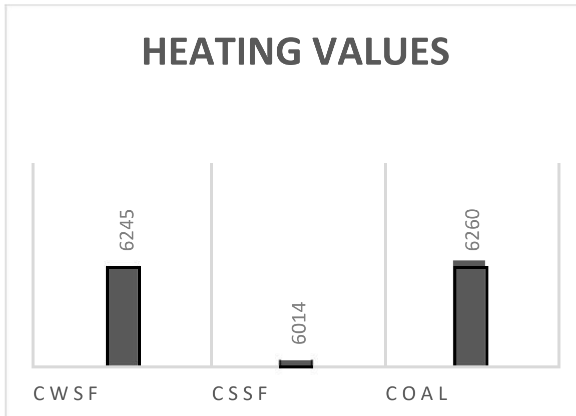
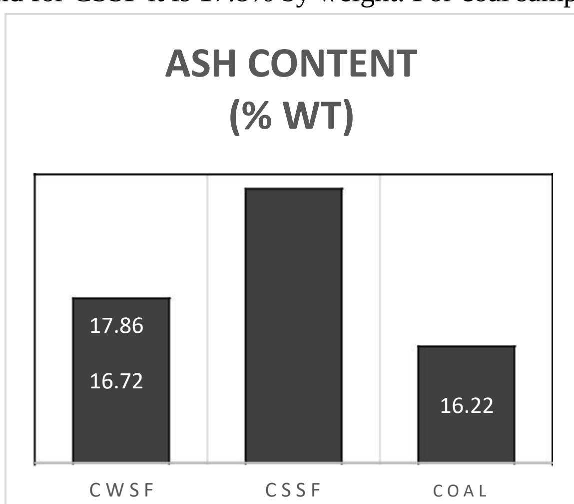


Figure 1: relation between heating values.

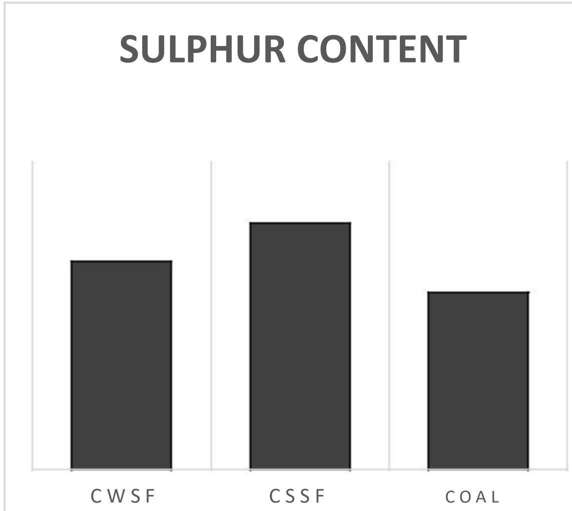
Ash content of both samples were tested at ASTM standard (ASTM D-3174) and were found to be 16.72% by weight for CWSF and for CSSF it is 17.8% by weight. For coal sample it was



16.22% by weight

Figure 2: Ash content

Next and final analysis was sulfur content. It was performed at ASTM standard (ASTM D-3177). In CWSF it was found to be 0.81% by weight. In CSSF it was 0.96% by weight. In coal it was found to 1.67% by weight. It is reported that Sulphur content in CSSF is increased due to the presence of sulfuric acid added to start fermentation process during the production of alcohol. But this hypothesis in not valid for other type of waste waters. The may not contain



(% WT)

Sulphur like spent wash.

Figure 3: Sulphur content

5. Conclusions

Energy production and waste water treatment are two major issues in the world and especially for Pakistan. Energy production from coal is avoided due to its environmental hazards. But according to the depleting conditions of other two resources (oil and gas). We need to divert the production of energy from oil and gas to coal. To balance it out and to make it somewhat sustainable.

Coal gasification, coal to liquid technologies are some of the greener technologies but they are very expansive. Instead of them Coal Slurry fuel technology is much cheaper and feasible and if we use waste water instead of fresh water then we will also remedy the solution for waste water treatment or waste water disposal. From the experiments conducted following points can be concluded.

Heating values of CWSF and CSSF are in accordance with Coal Slurry fuels, so both fuel are viable.

Capital investment is required for retrofitting the existing systems and acquiring new systems.

Ash formed is best fit to be used as filler in the production of concrete.

Elevated sulfur levels can be reduced by crushing some lime with coal and then preparing CSF.

According to literature per MW cost for the production of energy from CWSF is less than furnace oil and natural gas[12].

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Annex II

Preparation of coal slurry fuel blended with industrial waste water to replace furnace oil and LNG in industrial boilers and furnaces

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Abstract

Pakistan is currently facing severe energy crises. Most of the power production in Pakistan is thermal based with major share of fossil fuel, and coal accounts only 5.4% in energy mix. According to a survey,185,175 million tons of coal reserves are present in the country. Out of which 184,623 million tons of coal is present in Sindh. With this amount of coal Pakistan can produce 100,000 MW of energy for around 30 years. Coal slurry fuels are being used for power production from 1960’s. it is a cleaner and green technology. This type of fuel has less emissions. In slurry form coal slurry fuel is easy to handle. It also gives better efficiencies.

The proposed innovative technology of coal water slurry fuel can make the utilization of coal more easy and environment friendly. Finely ground coal particles are blended with water and additives to formulate a liquid fuel having properties comparable to the heavy fuel oils. Another novel idea is to use industrial wastewater instead of fresh water in preparation of coal slurry fuel.

The effects of blending pulverized coal in wastewater and fresh water were investigated in terms of properties such as heating values, sulfur content and ash content. Pulverized coal was obtained from “Pioneer Cement”, having average particle size 90 µm, heating value of 6260cal/g, 16.22% ash content and 0.69% sulphur content.

Wastewaters were collected from Noon Sugar Mills distillery, Fauji Foods and Sapphire textile mills. Four samples of coal slurry fuel were prepared, one using fresh water and others using wastewaters from textile, distillery and dairy. Heating values were analyzed on dry basis, in case of wastewater sample the heating value decreases by a non-noticeable margin, the new value is 6228, 6014, 6209 cal/g respectively and in case of fresh water sample it was 6245 cal2/g. Sulphur in the fuels prepared by waste water are 0.83, 0.96, 0.85 % respectively but for fresh water sample it is 0.81%. Further, ash

content of the wastewater coal slurry fuels was 16.56, 17.86, 16.80 % respectively as compare to the fresh water sample which was 16.72%. Both sample slurries can be fired in boilers in replacement of expensive heavy fuel oils. But in case of wastewater some post treatment is suggested in order to reduce Sulphur contents. All the parameters are in normal ranges so no post treatment is required.

Key words

Coal, Coal slurry Fuel, waste water.

1.Introduction

Pakistan is majorly an agriculture based economy but in the past decade there has been a major development in the industrial sector. This industrial development results in more energy requirements and more consumption. In Pakistan total installed capacity of power generation is 22,000 MW. Average production of power is almost 17,000 MW and the shortfall of energy lies between 5,000 MW to 6,000 MW. Total 80.7% of the supply in the energy mix of Pakistan is dominated by oil and gas combined. In fiscal year 2013-2014 energy production from oil was 32% of the total energy mix. From gas 34% of the total energy mix is produced. From coal 3,590,386 TOE were generated and it was 0.1% of the total energy mix. Besides fossil fuels the other major source of energy is hydel from which total of 30% of the total energy mix. Rest is obtained by nuclear and other resources like renewables and LPG etc.[1]

In Pakistan vast quantities of coal are present. Each province has got substantial amount of coal reserves. Reserves and their calorific values are show in the table below.

Province	Reserves (million tons of coal)	Calorific value (BTU/Lb)
Sindh	1,84,623	5,219-13,555
Baluchistan	217	9,637-15,499
Punjab	235	9,472-15,801
KPK	91	9,386-14,217
AJK	9	7,336-12,338
Total	185,175	

From the above data it is crystal clear that Pakistan has more than enough coal resources. With these resources Pakistan can generate 100,000 MW of energy for more or less 30 years. In Pakistan most of the coal found has either high sulphur values or high moisture content. If the coal has perfect quantities of all the components, then the coal is in very little quantities. It is clear that the largest coal reserve in Sindh is Thar coal which 175.5 billion out of 184 billion of total reserves of Sindh. But it contains 29.60-55.50% moisture. Total coal reserves in Balochistan are 217 million tons out of which 32 million tones are considered to be mineable. The classification of coal is sub-bituminous to bituminous. Heating values are in the range of 9,637-15,499 Btu/lb with low ash contents but high sulfur contents. Now talking about Punjab, the total coal reserve is reported to be 22 million tons. It has relatively low moisture, ash content and sulfur content than salt range coal mine but still not up to mark the optimum quality coal. Quality of coal is also qualified as sub-bituminous coal. In KPK, there are combined reserves estimated to be 91 million tons. Coal of both mines is reported to be sub-bituminous with heating values in the range of 9,386-14,217 Btu/lb. Coal from both mines have low sulphur and ash contents also with low moisture contents. .[2]

1.1 Environmental issues

Pakistan is a developing country. In Pakistan there are multiple industries, growing day by day. Also the population of Pakistan is increasing day by day. Pakistan is now the home of more than 200 million people. Increased population means more energy requirement, more consumer products, more industrial growth, also more municipal waste and industrial waste. Pakistan is basically an agriculture based economy but now this economy is shifting towards industry. There are textile mills, sugar mills, cement plants, fertilizer plants, consumer products industry, food and beverage industry. All these industries use water for processing. If water is used for processing, then obviously there is some water wastage.

Pakistan is a country where most of its energy is produced from fossil fuels like oil and gas. A very less amount of energy is produced from renewable. In the recent years there is a remarkable shift in the government's policy, to make the process of making energy efficient, green, cleaner and sustainable.

To have a long term sustainable better economy, Pakistan must address the environmental challenges which comes along with the better and stable economy. These problems include industrial waste water, municipal waste water, chemical spills in clean water, soil erosion, deforestation, salinity, water logging, fresh water pollution, just to name few.

1.1.1 Water pollution

In Pakistan, water gets polluted by a number of means. Mainly these are classified into following classes. Water pollution due to raw sewage.

Water pollution due to industrial waste water. Water pollution

due to agriculture run-offs.

All these pollutions have driven fresh water supply to a limited amount. Majority of the population does not have proper supply of fresh drinking water. Urbanization and implementation of modern technologies is also causing the pollution of water. According to the research conducted by Pakistan Medical Research Council, majority of the diseases in common population is caused by drinking of substandard or polluted water. This water pollution is causing many diseases like typhoid, cholera and other gastric diseases. This polluted water when seeps through the soil, mixed with pockets of fresh underground water also makes it polluted. [3]

1.2 Coal Water Slurry Fuel

CWS is a fuel which consists of finely ground (less than 20 micrometers in diameter) coal particles suspended in water in the presence of emulsifying agents/oil. CWS usually consists of 55-70% of fine dispersed coal particles and 30-45% of water. Coal-water slurry fuel classified based on following properties: ignition temperature 800—850 °C, combustion temperature 950—1150°C, and calorific value 5800-6500 kcal/kg. This fuel can be used to fire boilers for steam production. Another application for this type of slurry is gasification. At present there are multiple gasification processes developed to utilize this technology like GE energy (Texaco), opposed multi-burner process etc.[4]

The most desirable features of CWSF are high solid loading, good stability, good rheological behavior, low viscosity, low ash content and relatively high heating values. Usually CWSF is prepared by maintaining a solid to water loading of 70% and 30% respectively. These ratios may vary from 70:30 – 60:40. If water is added above 40% then heating value of the fuel will be decreased. A small percentage (up to 1%) of additives is also added for better dispersion, uniformity and stability of solid loading.[5]

2. Materials and methods

Coal was obtained from Pioneer Cement Pvt. Ltd. Plant located near Khushab district, Pakistan. They imported the coal from Waterberg coal field located in South Africa. The coal obtained was already pulverized and the average particle size was 90µm. This coal was mixed with three different industrial waste waters. Spent wash was obtained from Noon Sugar Mills Distillery Pvt. Ltd. located in Bhalwal near Sargodha district, Pakistan. Similarly, waste water was obtained from Fauji Foods located in Bhalwal near Sargodha district, Pakistan and Sapphire textile mills limited located in Lahore, Pakistan. An ionic surfactant named as sodium naphthalene sulfonate formaldehyde condensate was selected as dispersant which was imported from SHANDONG WANSHAN CHEMICAL CO. Ltd., China and Sodium lingo-sulfite was selected as the stabilizer which was imported from Jinan Yuan sheng Chemical Technology Co., Ltd, China. All the raw materials were collected and brought to the Bio Fuels lab at USPCAS-E NUST, Islamabad Pakistan. For both types of slurries solid loading was kept 65% and liquid ratio was kept 35% by weight. 1% additives were added, both in equal quantities. 400g samples of both slurries were prepared in a mixer driven by 800w variable speed motor. 260g of coal, 139g of water, 0.5g of NaNSF and 0.5g of sodium lignosulfite were added into the container and then mixed at 1357 RPM for 30 minutes. After 30 minutes the coal water slurry fuel (CWSF) was collected into sample bottles. The same procedure was repeated with waste waters to make coal waste water slurry fuels (CWWSF) under ambient conditions.

3. Results and Discussions

After preparing samples of all the slurries, these samples were sent to Pioneer Cement for testing. Three types of tests were performed on both the samples. The tests carried out were focused on finding out the qualities of the fuel in order to determine whether or not it could be used effectively.

A number of tests were performed to determine the quality of coal. These tests include % total moisture (ISO 11722), % Ash content (ISO 1171), % Sulphur (ISO 351), % inherent moisture (ISO 331), % volatile matter (ISO 351) and Calorific value (ISO 1928). All the samples were prepared at Pioneer Cement. As all of them were prepared from finely pulverized coal. So now size reduction for the preparation of samples were needed. All the samples were dried by placing them in an air circulated furnace a 40 degree Celsius. After performing the analysis, the following analysis were obtained.

Sr. No.	Analysis	Coal	Coal Water Slurry Fuel	Coal Waste Water Slurry	Coal Waste Water Slurry Fuel(Alcohol Dstillery)	Coal Waste Water Slurry

				Fuel (Textile)		Fuel (Dairy)
1	% Inherent Moisture	-	2.46	1.77	1.42	1.48
2	% Total Moisture	3.12	38.94	39.45	35.54	38.22
3	% ASH Content	16.22	16.72	16.56	17.86	16.80
4	% Volatile Matter	30.69	30.64	27.01	28.41	26.99
5	% Sulphur	0.69	0.81	0.83	0.96	0.85
6	Gross Calorific Value (cal\gm)ADB	6260	6245	6228	6014	6209

Table 1: Analysis of Coal, CWSF and CWWSF samples.

In the above table there are given the properties of five samples. One being the coal and other four are coal slurry fuels. Coal is marked as a basic standard and all other values are for comparison. All the samples of coal slurry fuel have inherent moisture. This is due to the presence of water in the form of fresh water or in the form of waste water. also due to this same reason the total moisture in the coal slurry samples is higher.

Ash contents of all the samples are almost same as that of coal sample except the CWWSF (Alcohol Distillery). This is because of the properties of alcohol distillery spent wash. Spent wash already contain solid material. Volatile material in CWSF is in accordance with the coal sample. But for CWWSF sample the levels are different. This is again due to the different properties of different waste waters. Sulphur content in coal sample is 0.69%. This value is perfect for use in in thermal power generation. It should be less than 1%. In CWWSF sample this value is different but all the values are within the range. Coal sample has the maximum GCV, all CWWSF samples have lowered GCVs but this difference is negligible.

On the basis of all these discussions it is obvious that all the samples CWWSF are feasible for use in thermal power production.

4. Recommendations

On the basis of all the above discussions it is obvious that all the samples CWWSF are feasible for use in thermal power production. This solves many problems. The Coal Slurry fuels are easy to handle. They have better combustion efficiencies. Ash formation after combustion is less. SOx emissions after combustion is also low. This is because of its composition. It contains water which forms acids with sulphur. Due to these acids formation there are low SOx emissions. Also NOx emissions are reduced. Due to the presence of water in the slurry. The slurry is combusted at lower temperatures. NOx are produced due to the combustion at high temperatures. This is the only reason of low NOx productions.[6] But there is also a down side. We need to make modifications in the internal design of the existing and new boiler\steam generation systems. Corrosion is accelerated due to the production of acids during combustion. This is a serious problem. It shortens the life of equipment increases wear and tear. If not inspected and evaluated, it may cause serious damage to internal parts of the boiler/steam generator.it also makes maintenance of equipment more difficult. To prevent this, we need to preinstall an anti-corrosive coating on the internal parts of the boiler/steam generator. Plus, if we replace this fuel in existing systems. We need to make major modifications in the design. For example, if the existing system is on furnace oil the we need to install a new CSF based burner. Also some modification is need to extract ash from the system. Same modifications are needed if Natural gas based thermal systems are installed. Mostly if natural gas based systems are installed they use gas turbines instead of boilers/ steam generators. Some modifications are also required in the process. The wet milling equipment is required to prepare the slurry. Also some slurry pumps are required for pumping and transport. A suggested flow sheet diagram is shown below.

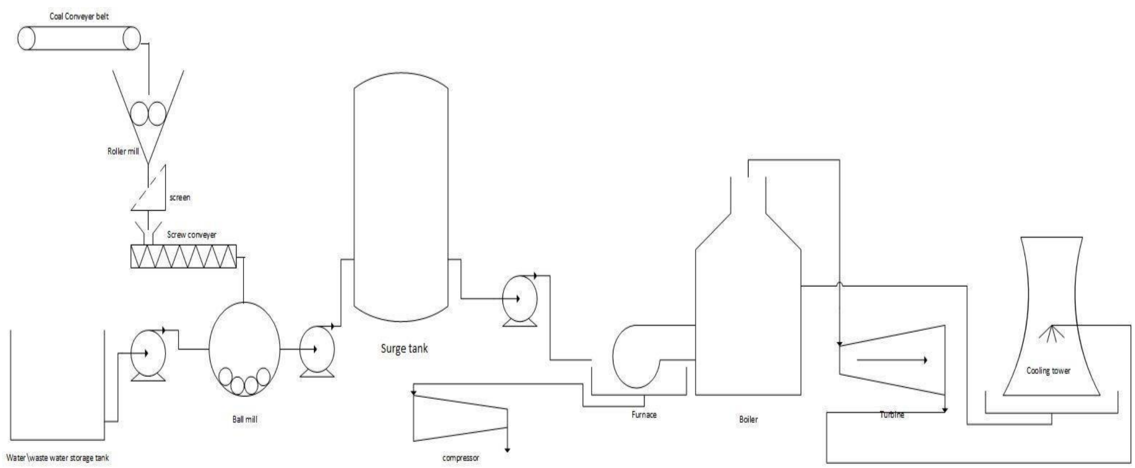

Figure 1: Flow sheet diagram

According to some literature energy production from CWSF is cheaper than Furnace oil and Gas.

Sr. No	Fuel	Price\MJ (PKR)
1	Furnace oil	2.6
2	Natural Gas	0.63
3	CWSF	0.42

Table 2: Cost comparison

Although there is a very small difference between Natural gas and CWSF, but gas reserves in Pakistan are depleting. Government is trying to import LNG as a solution but it is expensive. So this difference will not be very little if compared with LNG.[7]

5. Conclusions

Energy production and waste water treatment are two major issues in the world and especially for Pakistan. Energy production from coal is usually avoided due to its environmental hazards. But according to the depleting conditions of other two resources (oil and gas). We need to divert the production of energy from oil and gas to coal. To balance it out and to make it somewhat sustainable.

Coal gasification, coal to liquid technologies are some of the greener technologies but they are very expensive. Instead Coal Slurry fuel technology is much cheaper and feasible and if we use waste water instead of fresh water then the problem can be addressed for waste water treatment or waste water disposal. From the experiments conducted following points can be concluded.

All the properties of CWWSF are in accordance with coal sample. Which means the CWWSF are viable for use in thermal power production.
Some capital investment is required for retrofitting the existing systems and acquiring new systems.
Ash formed is best fit to be used as filler in the production of concrete.
Per MJ of energy cost of production from CWSF is less than when produced from furnace oil and natural gas.
Less Sox and NOx emissions are recorded by using this fuel.

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