Research Journal of Applied Sciences, Engineering and Technology 9(6): 460-465, 2015
DOI:10.19026/rjaset.9.1426
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: October 13, 2014 Accepted: November 3, 2014 Published: February 25, 2015

Research Article

The Case of Coal Water Slurry Fuel for Industrial Use in Pakistan

[1]Muhammad Irfan, [2]Mohammad A. Irfan, [3]Afzal Khan, [4]Irfan Ullah and [5]Noman Wazir
[1]Sarhad University of Science and Technology, Peshawar, Pakistan
[2]Qassim University, Saudi Arabia
[3]University of Engineering and Technology, Peshawar, Pakistan
[4]Taibah University, Saudi Arabia
[5]FF Steel Industry, Industrial Estate, Hayatabad, Peshawar, Pakistan

Abstract: This research presents the case for design and development of Coal Water Slurry (CWS) Plant for industrial use in Pakistan. After exclusive comparison between coal quality quantification for CWS it was found that Darra mines at Pakistan provide best coal for CWS. Highly volatile, A and B Bituminous coal and Sub-Bituminous coal is selected for making CWS because of its low Sulfur contents, Ash contents and high heating value through experimentation. The purpose of this research was to present a complete blue print for the production of coal water slurry fuel in Pakistan. The measured viscosity and heat contents of the tested CWS are of the order 490 mPa-sec and 23.8 KJ/kg, respectively.

Keywords: Coal water slurry fuel, heat contents, quantification of coal, viscosity

INTRODUCTION

Energy is the fundamental part of daily life, in this industrially advanced world, the demand of energy is increasing day by day. The main sources of energy so far are coal and oil but will be used up with the passage of time. As the world is now heading fast towards a major energy crisis. Natural gas, coal and oil meet 85% of the world's energy supply in 2008. Lee *et al*. (2007) estimated that at the current rate of utilization, the entire estimated range of recoverable oil in the world can be fully exhausted by the year 2025.

Pakistan is plagued with energy crisis, much of its energy generation depends on imported oil. For industrial production the energy supply has been unreliable and intermittent. Pakistan has rich coal resources and has a shortage of oil and natural gas. Donnelly (2004) mentioned coal reserves in Pakistan at the intersection of Karakoram Himalaya and Hindu Kush mountain ranges. The coal deposits there are sedimentary and tectonized.

Bhutto and Karim (2005) suggested coal gasification for sustainable development of energy sector in Pakistan. Saeed *et al*. (2006) presented a characterization of Thar coal. The Thar coal deposits are estimated to be the sixth largest reserve in the world. Fixed carbon was found to be low (27%) as compared to volatile matter, suggesting its rank between peat and lignite.

Mushtaq *et al*. (2012) studied the coal fired power generation potential of Baluchistan. The mentioned that currently the share of coal fired power is merely 1%. Balochistan coal reserves are 217 MT including 32 MT mineable, of sub-bituminous to bituminous rank, heating value ranges from 9,637 to 15,499 Btu/lb, coal seam thickness ranges from 0.3 to 2.3 m. The unexploited coal resources of Pakistan can generate more than 100 GW of electricity for the next 30 years. Nawaz *et al*. (2012) reviewed gas to liquid technology for coal in Pakistan.

Naveed *et al*. (2013) studied gasification of Pakistani Coal. Samples form chakwal coal mines were collected and analyzed for proximate, ultimate and thermogravimetric analyses. The results indicated that Chakwal coals have manageable quantity of moisture (3-6%), high volatile matter and high has (10-30%). The calorific value was estimated to be between 18.8 and 25.5 MJ/kg.

Most of the above studies relate to coal gasification or GTL technology. Very little work has been done on Coal Water Slurry in Pakistan. About 55-70% fine coal particles with a typical size of each coal particles less than 200-300 micrometers are added with 30-45% of water to produce Coal Water Slurry. The CWS fuel in its liquid form is like heating oil, a very competitive alternative to heating oil, gas and diesel no. 2 for use in Diesel Electric Locomotives.

Coal-Water Slurry (CWS) is comparatively a low cost alternative energy source as compared to oil. It has the advantage of its availability from the worldwide market, fluidity and good viscosity properties. So,

Corresponding Author: Muhammad Irfan, Sarhad University of Science and Technology, Peshawar, Pakistan

Design and Development of Coal Water Slurry for industrial process heating can be a substitute of furnace oil and gas in Pakistan.

Coal water slurry fuels have been inquired since the 19th century, but economic restrictions have kept it from becoming a major energy source by Kesavan (1985). Interest in coal water slurry developed whenever local or short-term oil availability was in doubt, such as in periods during both world wars and again in the energy crises of 1973 and 1979. Much of the research during these time periods was dedicated to coal-oil fuels, which could quickly and readily replace oil or liquid fuel in furnaces and boilers. However, since 1980, the focal point of research has largely been coal water slurry for the entire replacement of oil and natural gases for the industrial use, such as steam used in industrial boilers and utility boilers and oil used in diesel engines, blast furnaces and process kilns (Gao *et al*., 2012).

Cheng *et al*. (2012) used recycled cotton seed and blended with pulverized huangling coal to prepare Coal Water Slurry (CWS) fuel. The physicochemical microstructures, slurriability and combustion properties of black liquor CWS were investigated. They found that cottonseed black liquor is superior to deionized water in preparing quality CWS with high concentration and low viscosity. The highest solid concentration of black liquor CWS is 63.7% when apparent viscosity is 1000 m Pa·s. Dai and Gao (2012) injected the aromatic ring skeleton structure such as hydroxyl, ether and carbonyl oxygen radicals, into active group A which enhanced dispersibility of Shenhua coal in the synthesis process. They found that the CWS concentration can be improved from 60.9% to 63.0% and the slurry has good stability (http://www.gsp.gov.pk/index.php?option = com_content and view = article and id = 30: thar-coal and catid = 1: data).

Das *et al*. (2013) explored the use of a surfactant mixture of natural and synthetic surfactants as additives in stabilizing Coal-Water Slurry (CWS) formed from low rank Indian coals. A considerable decrease in viscosity of CWS was observed on the addition of saponin to the synthetic surfactants, CTAB/SDS (at 50:50 (w/w) for saponin: CTAB; 60:40 (w/w) for saponin: SDS systems) (http://www.nepra.org.pk/ Tariff/Upfront/ Notification%20upfront%20Tariff% 20imported-local%20coal.PDF). Gao *et al*. (2012) added Blast furnace sludge to coal to prepare CWS. They found that with the addition of BFS at 24%, the slurrying ability and calorific value of CWS can meet industrial requirements (http://www.ogra.org.pk/ images/data/downloads/1377505682.pdf).

Ghanooni *et al*. (2013) investigated the effect of particle size distribution in CWS. They found that that the optimal ratio was obtained when the coarse to fine ration was approximately 10 located at a coarse coal content of 70% wt (http://www.psopk.com/products _services/product_prices.php). Deng *et al*. (2012) evaluated the erosion of ceramic nozzles in CWS system. They found that laminated structures in nozzles are an effective way to improve erosion wear resistance in Industrial CWS boilers. Liu *et al*. (2012) studied the effects of coal blending on slurriability. They elucidated that coal blending is a simple operation and low coast method to improve the slurriability of low rank coal. They found that the maximum solid concentration of CWS can be increased by 6% when the proportion of HuanNan coal reached 70%.

Ruan *et al*. (2012) experimented on the influence of coal quality and blending on slurriability. They studied the relationship between inherent moisture, ash content and oxygen content on the slurriability of CWS. They found that the mixtures indicated a very complicated and nonlinear relationship. Slaczka and Wasilczyk (2012) studied the effects of chemicals on the rheology of highly loaded CWS. They studied the influence of chosen detergents on CWS (60% wt.). They observed that the same surfactant, depending on the type of coal, may give the CWS of different rheological behavior. It was found that besides of electrostatic and dispersing forces the steric affect plays a significant role in the CWSs fluidity. Wang *et al*. (2010) characterized CWS prepared by two kinds of Inner Mongolia raw brown coal. The solid concentration of CWS prepared by two kinds of raw brown coal respectively is low, when it given the apparent viscosity at 1.0 Pa·s, the maximum solid concentration is only 52.06%.

Coal Water Slurry fuels have been used in United States, Russia and China. According to BP statistical review of world energy, Pakistan's recoverable coal reserves are estimated at 2070 Million tonnes, with a share of 0.2% of world total and at current productions rates the supply is enough to last for more than 500 years. The Geological Survey of Pakistan has discovered over 175 billion tons of Ignite coal in Thar desert in 1992. Currently in Pakistan coal slurry fuels is also being used at Ceramic Industry Shaidu (Nowshehra), but the technology has been imported from China. The purpose of this research is to provide the blue print for the development of CWS technology in Pakistan and to indigenously design, develop and install Coal Water Slurry Plant at Frontier Foundry Steel Industry, Industrial Estate Hayatabad Peshawar. This paper presents one of the first studies to make coal water slurry in Pakistan.

MATERIALS AND METHODS

Coal is the raw material for making the coal water slurry fuels. For producing good quality of CWS fuel, coal is characterized through analysis. Coal samples were analyzed, in which three taken from different areas of Pakistan including Dara Adam Khel coal mines, Muzafar Abad coal mines and Quetta coal mines and two samples were taken from international market from Indonesia and South Africa for the comparison of its quality. The basic objective of the coal analysis was to select the acceptable quality coal for the coal water slurry fuel preparation. In the experimentation part different samples should be analyzed to select the optimum coal for the coal water slurry fuel.

To determine heat or energy contents, volatile matter, amount of moisture contents and ash contents of the coal samples is the fundamental objective of proximate analyses of coal. Proximate analysis is an important quality control parameter for coal and coke. The proximate analyses are carried out by the TGA 4000 equipment. TGA doing such type of analyses that consists of variations occurs relative to changes occur in temperature. The analyses are done for all the coal samples with the help TGA. These analyses are highly precise for three parameters such as weight, temperature and changes occur in temperature provides a convenient method for carrying proximate analysis generally in a short amount of time.

ASTM specifies techniques for the determination of proximate analyses, where heat is supplied to a constant weight of coal samples. This procedure takes time and requires a significant amount of laboratory equipment. An alternative method for proximate analysis is Thermo Gravimetric Analysis (TGA). In TGA the mass of a substance is a function of time and temperature and the specimens of all samples are exposed to a controlled temperature program in a controlled atmosphere. It substantially reduces the analysis time as well as the equipment that is necessary for proximate analysis.

The objective of coal ultimate analysis is to determine the carbon and sulfur contents in the samples of coal. The coal water slurry fuels based on this coal analysis were tested for heat contents with the help of Bomb Calorimeter at the chemistry laboratory in Sarhad University of Science and Technology, Peshawar (Pakistan). The viscosity measurements were carried out with the help of Ford Cups and Viscometers at Pakistan Mineral Development Corporation.

Design of hydraulic circuit for coal water slurry plant: The main objective of this study is to propose a workable model for the coal water slurry plant. Figure 1 shows a schematic of the CWS system installed at FF steel. The essential systems of the Coal Water Slurry Plant consist of three main systems:

- Preparation of the coal water slurry
- Fuel supply and control system
- Air supply system

Preparation of coal water slurry: Coal water slurry fuel preparation consists of three major stages:

- Dry grinding of coal up to the size 30-40 μm
- Wet milling and homogenization
- Storage of the fuel

A continuous loop of coal particles in a specific quantity is supplied to the coal mill with the help of conveyors belt as a raw material for the fuel. A coal mill for CWS fuel specially designed for both dry and wet grinding is used to reduce the bulk sizes of coal into the fine coal particles and the sieves are used to allow only the fine coal particles (size 20 to 30 μm in diameter) for the mixture.

The CWS mixture is usually made by mixing 55-70% coal and 30-45% of water. The rotating blades of the coal mill are used to achieve a stable mixture. The coal and water is supplied through two inlets, one from the water tank and the other for the coal from the conveyors belt. The dry and wet grinding of coal and water is taking place inside the coal mill till the homogeneous mixture of the CWS fuel is developed. This fuel was developed in FF Steel Industry, Industrial Estate, Hayatabad, Peshawar and the preparation procedure is explained below.

For the preparation of CWS fuel, first a suitable coal type was selected to maintain the coal stability in the CWS. The quality of fuel depends upon quality of coal. The coal for CWS fuel was selected on the following parameters:

- Coal with high energy value
- Stability during combustion
- Coal with low Sulfur and Ash contents

Based on the above criterion, the bituminous and sub-bituminous type coal was very suitable for CWS. After the coal selection, next step was the preparation of coal water slurry fuels. The two main factors considered here were the size of the coal particles and the quantity of coal in CWS fuel. With a particle size of about 30 to 40 μm. 55% of coal was added to 44% of water to obtain good flow characteristics and to avoid coagulation specifically at the nozzle. The limitation of coal concentration is the fluidity of CWS which is measured in its viscosity. The maximum the quantity of coal in CWS, the maximum is the viscosity which results in flow rates of CWS, that is low. On the other hand, the minimum amount of coal in CWS lowers the viscosity and stabilizes the fluidity but lowers the heat contents of the coal water slurry fuels.

The CWS fuel prepared consists of 55% of the coal, 44% of water and 1% of the chemical additive of Soda Ash (sodium silicate) as a stabilizer. The efficiency of combustion was high and was approximately equal to 23.8 MJ/kg as compared with the experimental data discussed in results and discussions.

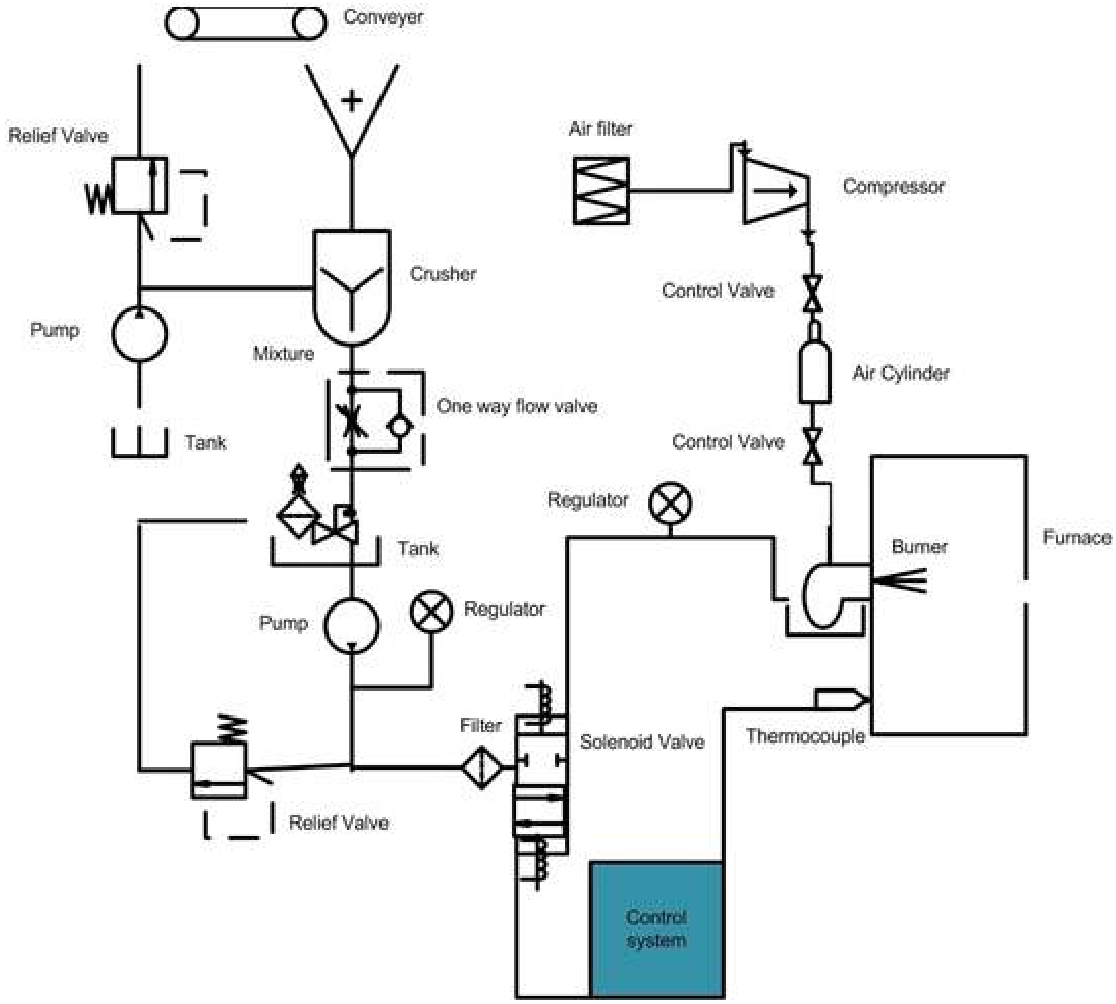

Fig. 1: Hydraulic circuit diagram for coal water slurry plant

Fuel supply and control system: Once the CWS fuel is prepared, using a flow controlled valve it is poured into a vested open tank as a reservoir for a constant supply of the fuel further ahead. A flow directional control valve is used to permit regulate or restrict the flow of the slurry into the pivot float operated tank (vested tank).

A constant delivery specially designed pump usually a centrifugal pump of impeller type is used to supply the fuel. A pressure relief valve is used for the safety purpose throughout the system to avoid structural damage to the system at the high pressure areas. The relief valve which opens into the slurry tank is used to provide the excess amount of slurry back into the slurry tank. A filter is used to filter out any impurity or large particles before the controlled directional solenoid valve.

The quantity of fuel for the high performance required must be introduced into the furnace. As the fuel injection in the furnace varies widely, so it is important to introduce an electronic fuel system to control the supply of fuel. A feed-back controlled solenoid valve is used to direct and control the flow of slurry in to the burner. A programmable logic controller is designed to regulate the flow and the respective burner flame and temperature. The electrical signals from the thermocouples attached with the furnace/ burner housing are the feedback signals for the control unit. The quantity/volume flow of the slurry is the output of the control unit. The fuel injection timing and proper atomization has a very important effect on the combustion. Therefore, a controlled fuel injection system is essential for attaining assuring high performance.

Air supply system: Efficient atomization of coal water mixture plays a key role before the combustion process. By designing a consistent burner system and atomizer, a good atomization can be accomplished. To enhance and to assure the complete combustion of the CWS fuel, an air supply system also works simultaneously (Das *et al*., 2013). The air is filtered through filter and then the air is compressed in compressor and supplied for combustion in the burner as per requirement. The supplied air would help in atomization and combustion of the CWS fuels.

Table 1: Proximate analysis of coal

Coal analysis	Darra (K.P.) coal	Sor-range (Quetta) coal	Muzzafar Abad (AJK) coal	Indonesian coal	South African coal
Moisture %	9.89	12.050	10.890	9.250	8.000
Volatile matter %	11.72	42.440	16.300	34.700	22.780
Ash %	16.01	15.330	16.000	14.630	15.250
Heating value (Btu/lb)	11.78	11.824	11.782	11.709	11.792

Experiments conducted at quality control and R and D department, Cherat cement factory

Table 2: Ultimate analysis of coal samples

Coal analysis	Darra (K.P.) coal	Sor-range (Quetta) coal	Muzzafar Abad (AJK) coal	Indonesian coal	South African coal
Sulfur %	2.06	1.89	1.41	0.90	0.61
Carbon %	60-65	60-65	55-65	60-70	65-75

Experiments conducted at quality control and R and D department, Cherat cement factory

RESULTS AND DISCUSSION

The experiments for coal analysis were performed in the Quality Control and R and D Department of Cherat Cement Factory certified by ISO 9001:2000 located in Khyber Pakhtunkhwa. Proximate Analysis was determined by thermo gravimetric analysis using TGA Instrument and the results are shown in Table 1.

Ultimate Analyses were carried by an Instrument, SC 144 DR Sulfur/Carbon Deaterminator and the results are shown in Table 2.

The objective of the coal analyses was to determine the suitable quality of coal for the coal water slurry fuels. The coal extracted from Darra Coal mines, Khyber Pakhtunkhwa was found to be the most suitable coal for CWS and therefore it was selected. The CWS fuels were prepared in the ratio of 55% of coal, 44% of water and 1% chemical additive. The quality parameter of the slurry selected made from coal sample is shown in Table 3. In the experimentation, CWS sample was analyzed for heat contents and viscosity. The experiment for testing the heat contents of CWS fuel was performed in the Chemistry Lab, Department of Mechanical Engineering, Sarhad University Peshawar using a bomb calorimeter and testing of viscosity of CWS fuel was performed in the R & D Department of Pakistan Mineral Development Corporation (PMDC). The viscosity of CWS fuel was determined by ford cups and viscometer and both results are in agreement with each other.

Table 4 presents an interesting comparison of cost for some fuels used for industrial process heating. The figures have been taken from government websites, more details can be found out in the given references. Although CWS poses a huge benefit over oil but its price is comparable with that of using gas. It must be noted that the table presents typical values, otherwise there can be a considerable variation of these values based on many factors. Since in Pakistan the intermittent load shedding of gas and electricity has a crippling effect on industries, CWS poses an alternate fuel over which the industrialist has complete control. CWS plants can easily be set up within the industry and hence lessen the dependence on government controlled gas and electricity.

Table 3: Heat contents and viscosity of 55-45% CWS fuel

CWS testing	Heat content K Cal/kg	Heat content MJ/kg	Viscosity mPa-sec
CWS 55-45%	5700	23.8	490

Experiments conducted at Sarhad University and PMDC Pakistan

Table 4: Comparative cost of CWS with other fuels used for industrial heating

	Cost/MJ
Light speed diesel oil	USD 0.025/MJ (23)
Gas	USD 0.006/MJ (24)
CWS	USD 0.004/MJ (25)

Environmental impact of using CWS: For any industry, the decision of switching over to CWS as a preferred fuel for industrial heating involves a careful consideration of the environmental impact. Two major factors have to be studied in considering the environmental impact. First the carbon emissions and second the water consumption. Countries have to pass mandatory laws for emission controls and caps. Industries using CWS have to use technologies to capture and dispose particulate emissions as well as CO and CO_2 emissions.

Pakistan being an agricultural country has to use its water resources carefully. Although it is naturally blessed with many rivers and rains, much of this water is needed for agriculture and domestic use. A careful study has to be done on water management and the magnitude of impact of using water for the production of CWS.

CONCLUSION

Local coal quality quantification was successfully carried out and it was found that Darra coal mines provide the most suitable coal for coal water slurry fuel in Pakistan. The acceptable coal for CWS fuel was selected and it was found that Bituminous type coal is well suited for CWS. Complete blue print is presented for the preparation of coal water slurry fuel. Viscosity measurements have been successfully carried out and are of the order of 490 mPa-sec for the prepared slurry.

Heat contents measurement have been successfully carried out and are of the order of 23.8 MJ/kg. The hydraulic circuit for the coal water slurry plant has been successfully designed and presented. It was also pointed out for countries to mandatory control carbon emission and judiciously weigh the impact of using water for the preparation of CWS.

REFERENCES

Bhutto, A.W. and S. Karim, 2005. Coal gasification for sustainable development of the energy sector in Pakistan. Energ. Sust. Dev., 9(4): 60-67.

Cheng, J., Q. Peng, A. Wang, J. Liu, J. Zhou and K. Cen, 2012. Fuel property of coal water slurry made from cottonseed black liquor. Proceedings of the Chinese Society of Electrical Engineering 32(35): 53-58.

Dai, C.S. and X.L. Gao, 2012. The synthesis of coal water slurry additive for Shenhua coal from lignin. J. China Coal Soc., 37(6): 1034-1038.

Das, D., U. Dash, J. Meher and P.K. Misra, 2013. Improving stability of concentrated coal-water slurry using mixture of a natural and synthetic surfactants. Fuel Process. Technol., 113: 41-51.

Deng, J.X., Y.Y. Chen and Y.Q. Xing, 2012. Erosion wear resistance of CWS laminated ceramic nozzles. Adv. Mater. Res., 538-541: 1915-1919.

Donnelly, L.J., 2004. Geological investigations at a high altitude, remote coal mine on the Northwest Pakistan and Afghanistan frontier, Karakoram Himalaya. Int. J. Coal Geol., 60(2-4): 117-150.

Gao, Z.F., L.S. Li, Z.J. Wu, X.R. Wu, X.H. Wu, S.H. Su *et al*., 2012. Preparation and rheology of coal water slurry blended with blast furnace sludge. Chinese J. Process Eng., 12(4): 564-568.

Ghanooni, N., Y.K. Leong and D. Zhang, 2013. Mixing narrow coarse and fine coal fractions: The maximum volume fraction of suspensions. Adv. Powder Technol., 24(4): 764-770.

Kesavan, S., 1985. Stabilization of coal particle suspensions using coal liquids. M.S. Thesis, University of Akron, Akron, OH.

Lee, S., J.G. Speight and S.K. Loyalka, 2007. Handbook of Alternative Fuel Technologies. CRC Press, Taylor and Francis Group, Boca Raton, London, New York, ISBN: (13) 978-0-8247-4069-6.

Liu, J.Z., Y.J. Yu, J.H. Zhou, C. Du, L. Ye, J. Cheng and K.F. Cen, 2012. Study on the effects of coal blending on the slurry ability of Shenmu coals. Adv. Mater. Res., 383-390: 3011-3016.

Mushtaq, F., A. Qadeer, F. Mir and A. Aftab, 2012. Coal fired power generation potential of balochistan. Petrol. Coal, 54(2): 132-142.

Naveed, S., A. Malik, M. Akram, M. Deary and A.P. Roskilly, 2013. Gasification perspective of pakistani coal. J. Energy Inst., 86(1): 1-7.

Nawaz, Z., N. Ramzan, S. Nawaz, S. Naveed and M. Bilal Khan, 2012. Green processing of coal to liquid fuels: Pakistan's perspective. Proc. Pak. Acad. Sci., 49(3): 165-172.

Ruan, W., J.Z. Liu, Y.J. Yu, X.Z. Cao, J.H. Zhou and K.F. Cen, 2012. Influence of coal quality and blending on the slurriability. J. Chin. Soc. Power Eng., 32(2): 165-176.

Saeed, K., M. Ishaq, I. Ahmad, M. Shakirullah, S.Y. Park, H. Khan and N. Ali, 2006. Characterization and evaluation of thur coal for different mineral contents. J. Chem. Soc. Pakistan, 28(3): 207-210.

Slaczka, A. and A. Wasilczyk, 2012. The effect of chemicals on the rheology of highly loaded coal water slurries (CWS). Physicochem. Probl. Mi., 48(1): 141-148.

Wang, C., L. Jianzhong, Y. Yujie, L. Lulin, C. Jun, Z. Junhu and C. Kefa, 2010. Slurryability of coal water slurry prepared by Inner Mongolia brown coal. Proc. Chin. Soc. Electr. Eng., 30(Suppl.): 85-90.