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Beneficiation of Indian Coals: Process Intensification by Power Ultrasound

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Abstract:

Coal is the largest source of fuel for generation of electricity throughout the world. The effective usage of coal is limited by the presence of high levels of unwanted or unburnt ash. During coal burning, the mineral matter transforms into ash, and the generation of ash is enormous in quantity that it is tedious exercise to store and utilize effective manner. Mineral matter in coal induces several drawbacks, including: unnecessary cost for transportation, handling difficulties during coal processing, leaching of toxic elements during ash disposal, ash deposition during coal combustion leading to the deterioration of boilers and accessories. Power ultrasound can also be used as a remedy for dirty Indian coals. In this study, state-of-the-art a 20 kHz ultrasonic probe will be used. To study the effect of sonication on de-ashing, the sonicated sample was separated into three levels by decantation. Top level was expected to be rich in lighter impurities, middle level was expected to be mostly clean coal; and bottom level was expected to be ash-rich coal. From the experimental results it has been observed that the top and the middle level coal contains low ash and high fixed carbon than the bottom level decanted sample. The pH, bulk temperature of the mixture during sonication and the coal recovery after the sono-treatment is also discussed.

Keywords: Power Ultrasound, Cavitation, Deashing and Coal Recovery

I. INTRODUCTION

India's energy consumption is set to grow 4.2% a year by 2035, faster than that of all major economies in the world, according to BP Energy Outlook. India, will overtake Asia's second-biggest energy consumer China in terms of energy in volume by 2030. The use of coal is increasing every year, in 2006 the world consumed over 6×10^{12} kilograms of coal. Globally, energy demand will increase by about 30% by 2035 [1]. Indian Lignite: Lignite coal, aka brown coal, is the lowest grade coal with the least concentration of carbon. Lignite contains only around 40 to 60% of fixed carbon. Coal being a conventional source of energy production is being employed due to its abundance. The grand utilization of coal is limited due to the presence of mineral matter in it. This necessitates there is a need for coal treatment. The existing conventional coal wash has several disadvantages: , interior part of the coals are uncleaned and it offers only surface cleaning, economically not viable (time, solvent consumption is high and also neutralizing the coal sample after the reagent treatment is tedious etc.).

II. LITERATURE REVIEW

Various methods of coal cleaning have been proposed in the following literature for the removal of mineral matter using conventional method of solvent based deashing and desulfurization. Mukherjee and Borthakur [2] revealed from the investigation is that, compared to alkali and acid treatment individually, successive treatments with alkali and acid resulted in substantial cleaning of the coal. Alam et al. [3] have investigated the effect of process parameters on desulfurization of Mezino coal by using the solvents HNO_3/HCl. The data analysis showed that the acid concentration plays a major role in coal cleaning. Ali et al. [4] investigated the effect of H_2O_2, NH_4OH, $K_2Cr_2O_7$ on coal cleaning. From the experiments it has been observed that the sulfur and mineral matter removal was 50% - 90% and 50%-55% depending on the concentration and solvent used. This suggesting that researchers still looking to identify the suitable technology for coal washing. An attempt has been made by few researchers using power ultrasound to clean the coal. Ultrasound ($\geq$ 20 kHz) is cyclic sound pressure with a frequency greater than the upper limit of human hearing. Ultrasound is a novel technology which is in widespread use in various scientific and medical fields [14, 15].

Farmer et al. [5], Mason et al. [6] and Newman et al. [7] suggest a ultrasonic methodology for the remediation of soils contaminated with inorganic pollutants. Kruger et al. [8] investigated the effect of ultrasound on degradation of highly volatile chlorinated compounds present in groundwater. Then the application has been extended towards cleaning of coal by Zaidi [9], Ze et al. [10]. In recent years numerous research works has been attempted on ultrasonic coal-wash for deashing and desulfurization of Indian high ash and high sulfur coal by Ambedkar et al. [11,12 and 13]. The experimental results revealed that Ultrasonic coal-wash is a promising technique to effectively remove ash and sulfur from coal prior to combustion. In addition, it is easy to scale-up as a continuous process. Due to this reason, ultrasonic coal washing is a prime technique for cleaning from surface and interior part of the coal matrix. But this method involves numerous influencing factors and several complex, interdependent mechanisms. These are not well understood by the researchers. This study deals with effectiveness of power ultrasound in coal cleaning, pH, bulk temperature of the coal slurry mixture during sonication and coal recovery after the sono-treatment.

III. EXPERIMENTAL PROCEDURE

The lignite coal to be used in this study was received from Neyveli Lignite Corporation, Tamilnadu, India. The procured coal sample was grounded and sieved using sieve shaker to a particle size of <212 microns. Then the sample is air dried and stored in a air tight container. As received coal sample was subjected to proximate analysis for it's moisture, volatile matter, ash, fixed carbon content as per IS 1350 standard procedure. The proximate analysis of as received coal is shown in Table 1.

Table 1 Proximate Analysis of as Received Lignite Coal

Moisture	Volatile Matter	Ash	Fixed Carbon
13.1	31.29	20.22	35.39

The coal-water slurry (1:10) was prepared and taken into a beaker. The mixture is subjected to sonication for about 30 min at 20 kHz frequency, 487 Watts power (65% of Total Power 750W) and 10 sec ON-OFF cycle. The photographic view of probe type sonicator is shown in Figure 1.

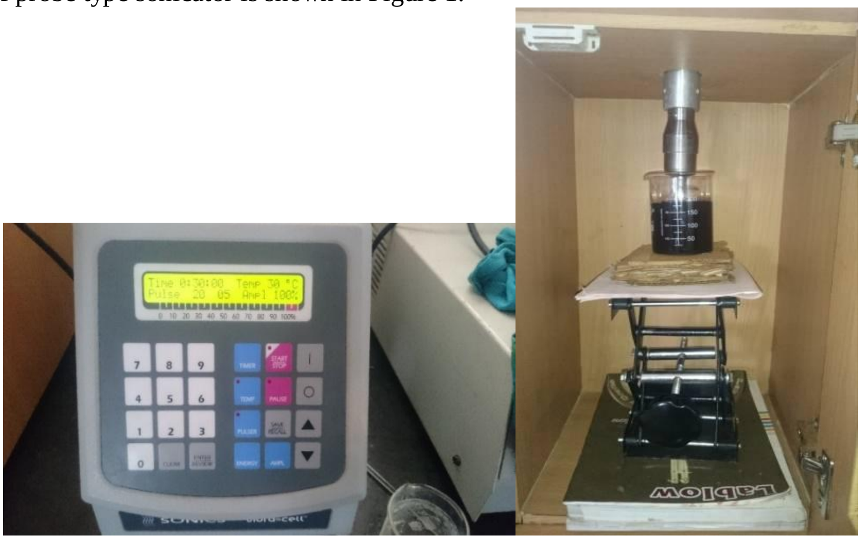

Fig. 1 Probe Type Ultrasonicator

During sonication the mixture pH and temperature was noted. Then, the treated coal sample mixture was transferred into decanting column for density based three level separation. Then, the separated three levels of treated coal samples were filtered, washed with water and dried for about 5 hours in an oven at 100 ^{o}C and then subjected to proximate analysis. Furthermore, the coal recovery after the sono-treatment was determined.

IV. RESULTS AND DISCUSSIONS

4.1 Size Distribution Analysis of Coal

As received coal lumps were size reduced using Jaw crusher followed by Ball milling. Then, the size reduced coal samples were subjected to sieve analysis to analyze the size distribution of the sample. The data's were used to do the differential and cumulative analysis and are shown in Figure 2 and 3.

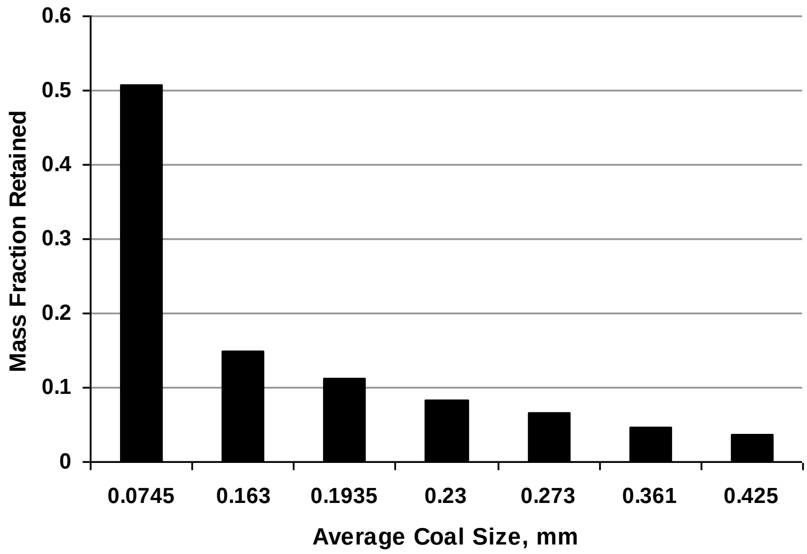

Fig. 2 Differential Analysis of Lignite Coal

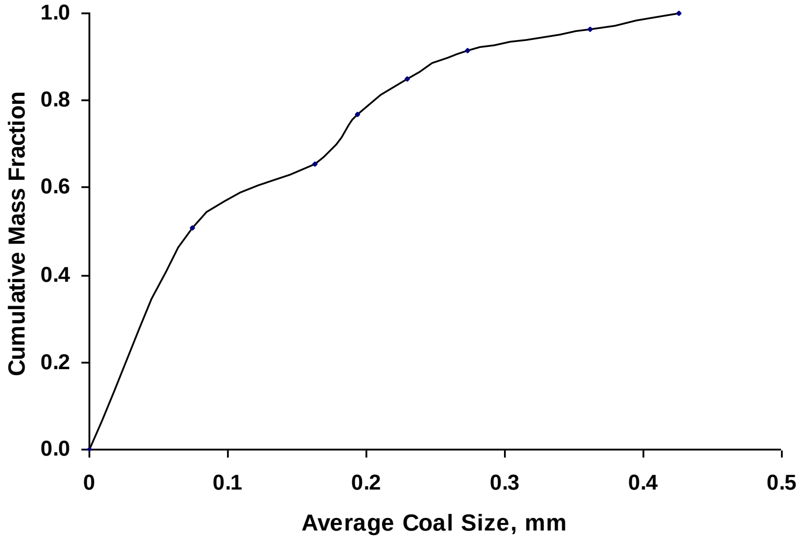

Fig. 3 Cumulative Analysis of Lignite Coal

From the figure it has been observed that more than 50% of the coal particle falls below 74 micron sizes and another 25% of the particles are in 163 to 230 micron size range. The above size ranges of coal particles were used for this experimental investigation reaming 25% of the coal particles and their corresponding sizes were excluded for the study.

4.2 Bulk Temperature Rise during Sonication

When ultrasound is applied to a medium such as water, two basic physical phenomena involved in producing changes were observed. i. Acoustic cavitation and ii. Streaming. Cavitation is the dominant mechanism in ultrasonic fields in the <100 kHz frequency. In this study cavitation dominant frequency (25 kHz) was used. Transient cavitation, encountered in our system, bubbles grow, coalesce and collapse. Cavitational collapse results in extreme conditions producing light emission, shock waves, and localized high temperatures (up to approx. 5000 K) and pressures (up to 100 atm). These shock waves are responsible for the rupturing of neighbouring solids (coal particle), leading to the generation of shear forces and eddies which, in turn, lead to an increase in turbulent energy dissipation in the form of bulk temperature rise in the reaction mixture. The bulk temperature rise during sonication of coal-water mixture is shown in Figure 4.

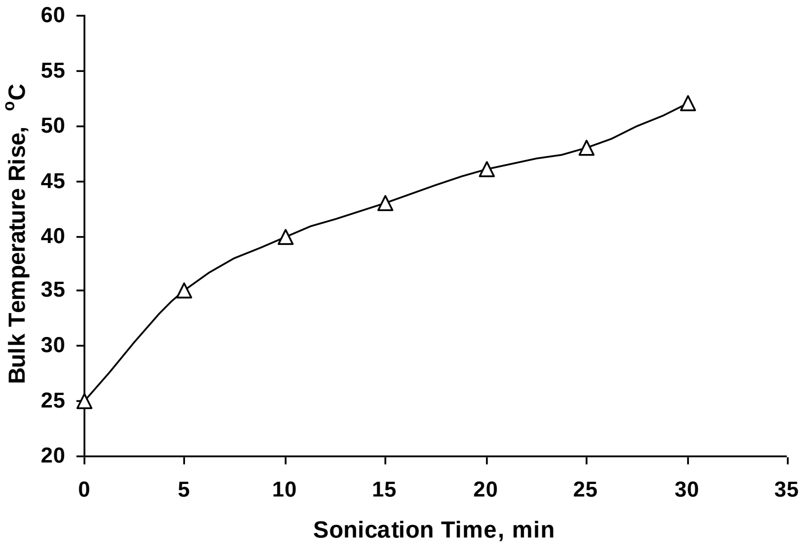

Fig. 4 Coal Water Slurry Mixture Bulk Temperature Rise during Sonication

The observed initial slope is high reason being, at low temperature facilitate vigorously cavitation that are leading to the linear temperature rise during first 5 minutes of sonication. And the remaining 25 minutes of sonication leads to the total approx. 20 ^{o}C bulk temperature rise due to lowest cavitation threshold that makes an ease of cavitation.

4.3 pH Change during Sonication

The initial pH of the coal-water slurry is 7.5 pH slightly alkaline in nature. But during sonication the mineral mater dissolves in water that make the mixture more acidic. Most interestingly, first five minutes of sonication furnishes the drastic pH changes from 7.5 to 3.3 pH and are shown in Figure 5. These changes are confirmed from the linear trend observed in bulk temperature rise during short span of initial sonication. (Figure 4)

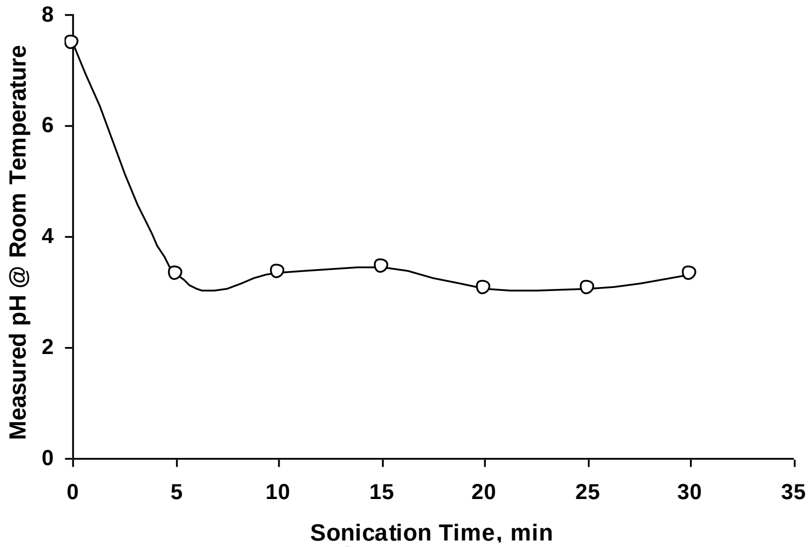

Fig. 5 Measured pH at Room Temperature

4.4 Proximate Analysis of Sono-Processed Coal

Table 2 shows proximate analysis of sono-treated followed by decanting coal samples. Top level was expected to be rich in lighter impurities, middle level was expected to be mostly clean coal; and bottom level was expected to be ash-rich coal (heavier impurities). From Table 2, it can be confirmed that the ash content of the top and middle level is lower than that of the bottom level and as received coal. Sono-fragmentation of coal leads to the detachment of ash impurities from coal and separation by decantation process using density difference as a driving force. The bottom level requires further treatment for de-ashing.

Table 2: Proximate Analysis of Treated Coal Samples

	% Moisture	**% Volatile matters**	**% Ash**	**% Fixed carbon**
Top	13.1	23.09	**7.81**	**56.0**
Middle	13.2	19.41	**9.88**	**57.51**
Bottom	13.1	26.25	18.96	41.69

4.5 Coal Recovery after Sono-Treatment

In these experiments, 39.2% of coal samples were recovered from top and middle level, remaining are settled in the bottom at a given settling time and are tabulated in Table 3. Further sonication on the bottom level coal sample followed by decantation would render the increased coal recovery.

Table 3 Coal Recovery after Sono-Treatment

Levels	**Weight Retained (gm)**
Top	9.2
Middle	10.4
Bottom	29.1
Total	**48.7**

V. CONCLUSION AND RECOMMENDATIONS

The present study uses power ultrasound to clean the coal. From the lab scale experimental investigation sono treatment produces approximately 40% of low ash coal in the top and middle level of decanting column cumulatively. The bulk temperature rise during sonication shows linear trend in short span (5 minutes) of initial treatment due to high cavitation threshold. Similar trend was observed in the pH (7.5 to 3.3 pH) during first 5 minutes of sonication due to dissolution of mineral matter that makes the mixture more acidic. Hence, the results suggesting that the ultrasonic coal wash method has a potential to replace the conventional method. Reagents based ultrasonic coal wash can be used to intensify this process. In addition, tank type sonicator are recommended for the large scale treatment of the samples which is known for uniform cavitational intensity throughout the tank.

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