

Hydrodynamic Characteristics of Dry Beneficiation of Iron Ore and Coal in a Fast Fluidized Bed

M. Das, R. K. Saha and B. C. Meikap

Abstract—Iron ore and coal are the two major important raw materials being used in Iron making industries. Usually ore fines containing around 5% Alumina are rejected due to higher proportion of alumina. Therefore, a technology or process which may reduce the alumina content by 2% by beneficiation process will be highly attractive. In addition fine coals with ash content is used nearly 12% is directly injected in blast furnace. Fast fluidization is a technology by using dry beneficiation of coal and iron ore can be done. During the fluidization process the iron ore and coal is fluidized at high velocity in the riser of a fast fluidized bed, the heavier and coarse particles are generally settled at the bottom in a dense zone of the riser while the finer and lighter particles are entrained to the top dilute zone and then via a cyclone is fed back to the bottom of the riser column. Most of the alumina and low ash fine size coals being lighter are expected to move up to the riser and by a natural beneficiation of ores is expected to take place in the riser. Therefore in this study an attempt has been made for dry beneficiation of iron ore and coal in a fluidized bed and its hydrodynamic characterization.

Keywords—beneficiation, fluidization, gas-solid fluidization, riser.

I. INTRODUCTION

MAJOR quantities of Indian coal are high ash (more than 30% by weight) and generally used in thermal power plants. As most of the coal produced from Indian coal mines will be thermal grade and utilized for power generation, it will not be necessary to clean the coal at low partition densities or to achieve the low ash levels necessary for coking coal. Dry cleaning of coal would enable production of fuel with quite high specific energy; particularly mineral content of coal will be low and CFB may be used for enhancing the separation process[1-2].

The effect of fluidizing the bed is to allow settling of the high-density material to the bottom, while the low-density coal stratified at the top. The rejects are discharged via an adjustable toothed roller while the clean coal leaves via a lip and chute at the end of travel. More efficient fluidized bed separation has been developed, particularly in research institutions of Canada and China, using dense medium. The medium is an air/solids suspension adjusted to a relative density in a similar manner to magnetite medium in a wet plant. The suspension

B. C. Meikap is a Professor of Chemical Engineering, University of Kwazulu-Natal, Durban, South Africa (phone +27 31260 3802, fax: +27 31 260 118; e-mail: meikap@ukzn.ac.za).

M. Das was associated with Indian Institute of Technology, Kharagpur, India as PhD scholar and received doctorate in 2009. (e-mail: mitalidas@gmail.com).

R. K. Saha is a Professor of Chemical Engineering, with Indian Institute of Technology, Kharagpur, India (e-mail: rks@che.iitkgp.ernet.in).

has a stable and uniform density, the high-density material sinks readily and the low-density coal floats, providing quite an efficient separation[3-5].

Most of the power plants in India are not operating effectively due to supply of high ash feed coal than the designed level. The power factors are very low and breakdown is very high due to high ash content. The performance can be improved if coal at designed level can be fed continuously. The other major advantage of low ash coals is reduction of fly ash generation and fly ash handling equipment. It is desirable to reduce ash in run-of-mine (ROM) coal to the desired level before feeding to the power plants. Dry beneficiation of coal is a cost-effective method to reduce ash from coal. Various dry beneficiation techniques like differential crushing and classification, air classification, magnetic separation, electrostatic separation are there. Air classification has given better results where ash is reduced by 5-6% with appreciable yields.

Experiments were carried out in a CFB system having riser dimensions of (0.1x 5.62 m). The system was fitted with pressure taps to measure the static pressures at different locations along the CFB loop. Besides solid samples were withdrawn non-isokinetically using a probe and a vacuum pump at different positions along the riser column. From the solid composition analysis with respect to Iron powder and ash analysis from the withdrawn coal one can evaluate the extent of separation feasible in the given system. It is revealed in the present case that iron content in the solid samples decreases from 62 percent to 48 percent while there is corresponding rise in silica and alumina content from 4.68 to 5.82 and 2.69 to 3.94 respectively in the riser. Similarly, the ash percentage of coal decreases from 43% to 34% i.e. 7-8% beneficiation of ash is feasible in the present system for the operating conditions for which the experiments were carried out. It is obvious from the initial experiments carried out that both iron ore and coal can be dry beneficiated in the riser of a CFB Column. Using multiple risers in series and using the fines as the feed in the second riser it could further improve upon the extent of separation.

II. EXPERIMENTAL SET-UP AND TECHNIQUE

Fig. 1 shows the schematic diagram of the experimental set-up. It consists of a blower (A), airlines provided with orifice meters (D), a fast bed column (G), a cyclone separator (J) with a bag filter (K), a downcomer along with a butterfly valve (L), a slow bed column (H) and a solids control valve (L) fitted in solids transfer line. For visual observation, the set up was made up of Perspex. Solid sampling probes are installed at heights (h=0.67 m, 1.20 m, 1.79 m, 3.66 m, 4.3 m, 4.77 m and 5.09 m) above the distributor and detailed characteristics presented in Table 1. Solids are generally withdrawn by suction through a vacuum pump and a calibrated rotameter and collected in a sampling vessel for subsequent off-line detailed analysis.

TABLE I
PHYSICO-CHEMICAL PROPERTIES OF COAL AND IRON ORE

Bed Material	Particle size distribution	Mean particle size	Solid density, Kg/m ³	CFB Inventory, kg	ϵ_{mf}	U_{mf} , m/s	Ash %	Moisture %	V.M., %	Calorific Value (kcal/kg)
Coal	10+16=5.5% 16+22=9.2% 22+30=20% 30+44=9.2% 44+52=7.4% 52+72=9.9% 72+100=5.5% 100+150=27.6%	215	1150	21	0.57	0.995	43	0.5	19	4627.3
Iron ore	300+240=9.63% 240+200=12.36% 200+150=3.01% 150+120=13% 120+100=62%	141	5192	20	0.44	1.78	--	--	--	--

All experiments were carried out at steady state conditions. The mixing process was monitored by continuous sampling of solids at a given location of $h=0.67$ m above the distributor plate at one radial position of $r/R=0$, i.e. on the axis of the riser. It was found that the local solid compositions remain constant after 20 minutes of operation of the apparatus. In case of ash analysis samples were weighed and put in furnace, which was maintained initially at a temperature of 450°C for one and half hours. The temperature is then increased to 800°C and kept for three hours. By heating at such a high temperature all the volatile matter, fixed carbon get burned and only ash left.

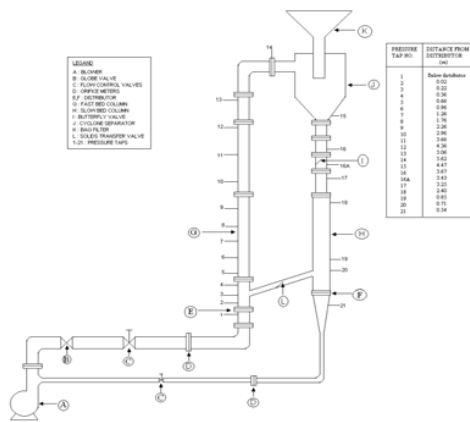


Fig. 1 Schematic diagram of the experimental set-up

III. RESULTS AND DISCUSSIONS

Fig. 2 shows the loop pressure profile curves for coal-air and iron powder-air system. The study of this profile is essential to understand the process of smooth flow and transfer of solid materials from the slow bed to the fast bed that make the system continuous. This is all the more important for an industrial system where the solids flow in the system is not visible from outside and one has to study the loop pressure profile so as to be able to determine the various regimes in different part of the CFB system. From the point 2 to point 12 there is drop in pressure, which show how in the riser there is pressure drop as the solids-gas suspension moves upward. Between point 12 and 13 there is pressure drop due to the flow of the suspensions in the

bend. Between 13 and 14 there is the cyclone and there is an overall pressure increase. In the cyclone, there is on one hand pressure drop and at the same time there is pressure increase as well as the solids gas suspensions move downwards. In the present cases there is a net pressure increase in the cyclone. Depending on the system and the nature of suspensions in some cases there may be net pressure drop between 12 and 13 also. From 14 to point 19 there is pressure increase in the system facilitating smooth flow of the solids suspension from the slow bed to the fast bed via the transfer line. This is shown between 17 and 2/3. The pressure drop from 17 and 2/3 is due to valves employed between them to control the solids flow rate independently.

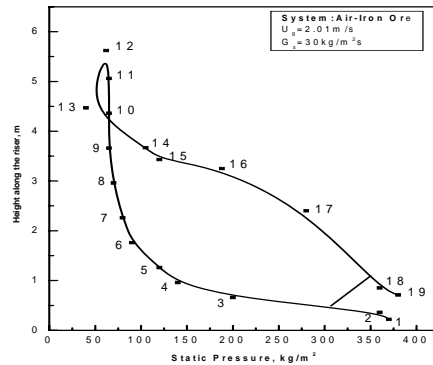


Fig. 2 Loop pressure profile various regimes in different part of the CFB system

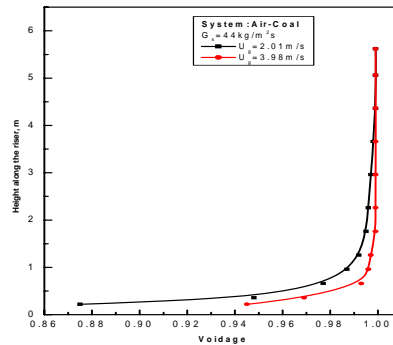


Fig. 3 Voidage along the riser

Fig. 3 shows the typical voidage profiles for coal-air and Iron-air system respectively. It is evident the curve that for the coal air system the voidage shows a decreasing trend as the superficial gas velocity rises from 2.01 to 4.02m/s. Fig. 4 shows the static pressure profiles along the riser length both for coal-air and Iron-air system. It is observed from the graph that for having the same solids circulation rate of 41.7 and 23kg/m²s the static pressure all along the riser shows a decreasing trend. This is possibly due to large carryover of the particles at higher velocity[6-7]. For the same solids circulation rate and gas velocity the run was repeated several times to test its repeatability. It is evident from the table that there is considerable beneficiation along the riser. The iron ore content at the bottom of the riser ranges between 63-64% at the bottom and goes down to the range 53.5 -55%. At the top. At the same time there is corresponding rise in the silica percentage from 4.68 percent at the bottom to 5.82 % at the top and for alumina it is 2.61% at the bottom and 3.54 % at the top. Iron powder comprises a mixture of iron oxide, silica,

alumina and others impurities of different densities but may be of the same sizes. Due to differences in their densities heavy iron powder settles preferentially at the bottom while comparatively less heavier and lighter silica and alumina goes to the top and elutriated out of the riser. As a result there is beneficiation in the riser of the column with iron powder having higher concentration settles at the riser bottom and its concentration goes down at the top of the system. Correspondingly there are increases in silica and alumina concentrations at the top of the riser. The feed concentration of iron oxide is 59.95 percentages, i.e. even during its passage from the slow bed to the riser bottom there has been segregation and there is corresponding beneficiation at the extreme bottom part with iron oxide percentage increases to 63-64 % [8].

Fig. 5 shows the beneficiation curves for coal. At three different gas velocities and solids circulation rates the solids samples were collected at different position along the riser length and were analyzed. The results as percentage ash in coal are plotted against riser length in the figures. Fig. 5. shows the percent change in ash composition of the given coal sample along the riser length: $U_g=4.02\text{m/s}$. and solids circulation rate between 9.7 and 11.3 $\text{kg/m}^2\cdot\text{s}$. It has been found that percent change in ash composition of the given coal sample along the riser length: $U_g=3.55\text{m/s}$ at a gas velocity of 3.55m/s and solids circulation rates of 6.87 to 10.11 $\text{kg/m}^2\cdot\text{s}$. And the effect of height of the CFB on coal ash for a gas velocity of 2.82m/s and solids circulation rate between was found as 4.45-6.06 $\text{kg/m}^2\cdot\text{s}$. The initial ash percentage in coal was 42 %. It has been found that ash percentage at the bottom depending on gas velocity and solids circulation rate decreases from 41-45 % at the bottom to a lower level of 33-35% at the top. That is there can be 7-8 % beneficiation or ash reduction in the dry beneficiation process. When the gas velocity and solids circulation rate increase there is more mixing and less segregation of material depending on their densities resulting in less beneficiation of coal.

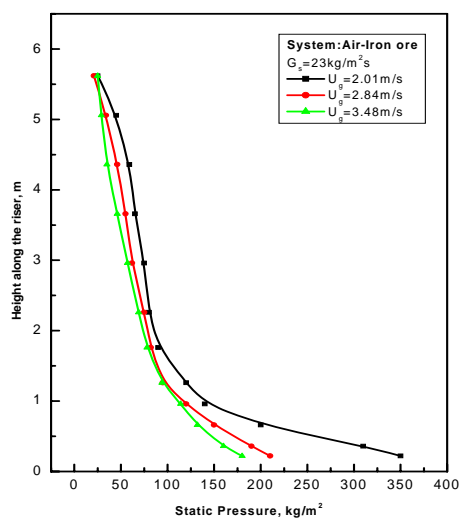


Fig. 4. Static Pressure profile along the CFB loop for Air-Iron system

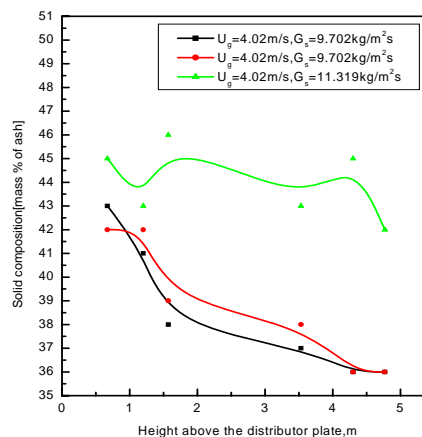


Fig. 5 Percent change in ash composition of the given coal sample along the riser length: $U_g=4.02\text{m/s}$.

IV CONCLUSIONS

It is revealed that there is considerable amount of beneficiation both for iron powder as well as for coal. Industrial CFB system is expected to be much larger in diameter and with higher riser length. While larger diameter will increase the throughput, the increased riser length is expected to have further improvement in iron powder and ash beneficiation. Moreover multiple risers in series may be tried in dense FFB mode to further improve the beneficiation efficiency as well as capacity.

REFERENCES

- [1] Q. Chen, L. Wei, "Coal dry beneficiation technology in China: The start-of-the-art" *China Particology*, vol. 1, pp. 52-56, 2003.
- [2] M. Das., B. C. Meikap, R. K. Saha, "Dry beneficiation of iron ore and coal in a fast fluidized bed-a case study" *Int. J. of Chem. Sci.*, vol. 5, pp. 1691-1700, 2007.
- [3] N. C. Lockhart, "Dry beneficiation of Coal". *Powder Technology*, vol. 40, pp. 17-42, 1984.
- [4] Z. Luo, Q. Chen, "Dry beneficiation technology of coal with an air dense medium fluidized bed", *Int. J. of Min. Processing*, vol. 63, pp.167-175, 2001.
- [5] L. Zhenfu, J. Zhu, M. Fan, X. T. Zhao, "Low density dry coal beneficiation using an Air dense medium fluidized bed" *J. of China University of Mining & Technology*, vol. 17, pp. 306-309, 2007.
- [6] M. Das., B. C. Meikap, R. K. Saha, "Characteristics of axial and radial segregation of single and mixed particle system based on terminal settling velocity in the riser of a circulating fluidized bed" *Chem. Eng. J. Journal*, vol.145, pp. 32-43, 2008.
- [7] M. Das., A. Bondopadhyay, R. K. Saha, "Axial voidage profiles and identification of flow regimes in the riser of a circulating fluidized bed" *Chemical Engineering Journal*, vol. 145, pp. 249-258, 2008.
- [8] M. Das., B. C. Meikap, R. K. Saha "Voidage and pressure profile characteristics of sand- iron ore-coal-FCC single particle systems in the riser of a pilot plant circulating fluidized bed" *Ind. & Eng. Chem. Res.*, vol. 147 pp. 4018-4024, 2008.

M. Das received her doctorate degree in Chemical Engineering from IIT Kharagpur. She worked as post-doctoral project scientist at IISc Bangalore. Her specialization is Circulating fluidized bed. She has published a good number of publications in International journals. Dr. Das is also member of professional societies including Indian Institute of Chemical Engineers.

R. K. Saha is an emeritus Professor, Department of Chemical Engineering and has long experience in the area of fluidization and circulating fluidization. Dr. Saha guided a large number of PhD scholars and handled various projects of Government and Industrial sectors as Principal Investigator. Prof. Saha is member of many professional societies including IChE and he was also Editor of Indian Chemical Engineer journal. Prof. Saha was Council Member of IChE and took the leadership as Head of the Department of Chemical Engineering during 2003-2006.

B. C. Meikap is a Professor of Chemical Engineering, University of Kwazulu-Natal, South Africa. Dr. Meikap is teaching Environmental Engineering and Industrial Pollution Control to B. Tech. and M. Tech. Students for more than 17 years. He is the recipient of Dr. A. V. Rama Rao Foundations Best Ph. D. Thesis and Research Award-2002; Innovation Potential Project Award- 2002 of Indian National Academy of Engineering, INSA Visiting Fellowship-2004, Artemis Biotech Best Masters Thesis and Research Award for 2004 by the Indian Institute of Chemical Engineers. He was visiting faculty at Asian Institute of Technology (AIT), Bangkok in the School of Environment Resource Development in 2004 seconded by Govt. of India and he has published over 17 papers in peer reviewed International/National journal. He is a life member of IChE, IPHE, IE(I), IIM, CSI, ICS and ISTE. Dr. Meikap is actively engaged in teaching, research and consultancy projects related to industrial pollution Control and more than 50 journal publications.