Thermal Analysis & Operation Performance of Fluidized Ash cooler

S.V. Thite, S.B. Ingole

Abstract— **Fluidization technique is used frequently in various operating plants. The ash generated in FBB is carrying heat during drain operation. To save this heat energy, as well as to make it safe to handle this ash, Fluidized Bed Ash Cooler (FBAC) is proposed in this paper. In CFBC technology the bed temperature is around 800-900 ºC. To maintain constant, boiler bed height it is necessary to drain the bed once it reaches to the desired limit. Transportation of this drained hot ash is difficult and unsafe unless it is cooled. It is proposed to cool hot ash by the air tapped from the primary air ducting to a temperature at which it can be transported easily and safely by conventional technology. The proposed bed ash cooler can take drained boiler bottom ash at a high temperature from Fluidized bed or Circulating fluidized bed boilers continuously and controllably. Consequently the heat is recovered from the hot ash by air and is fed back to the boiler as secondary combustion air above the fluidized bed in order to avail it for further combustion in the furnace. In this paper, FBAC is manufactured based upon the calculations done taking the actual inputs of ash generation CFBC. Testing of the same is done on site. Results obtained from the field data and the data developed by the distributed control station (DCS) are verified for the desired results.**

Index Terms— **Fluidization, Ash cooler.**

I. INTRODUCTION

The paper relates to the circulating fluidized bed combustor apparatus and particularly to the apparatus for the cooling the ash of the fluidized bed. Circulating fluidized bed apparatus is being increasingly utilized for the wide variety of applications. The use of circulating fluidized bed is particularly advantageous because of technological developments which have resulted in significant advances in both operating and fuel flexibility. While the present invention has primary application to a combustion process in steam generation system, it will be understood that the present invention may also bed used in wide variety of the fluidized bed apparatus. The term fluidized bed refers to the condition in which solid materials are given free flowing fluid like behavior. As a gas is passed upward through the bed of solid particles, the flow of gas produces forces which tend to separate the particles from one another. At low gas flows, the particles remain in contact with each other solids and tend to resist movement. This condition referred to as a fixed bed. As the gas flow is increased, a point is reached at which the forces on the particles are just sufficient to cause separation. The bed is then deemed to fluidization.

The gas caution between the solids allows the particles to move freely, giving the bed a liquid-like characteristic Fluidized bed combustion makes possible the burning of fuels having such a high concentration of ash, sulphur and nitrogen that they would ordinarily be deemed unsuitable. The fluidizing gas is generally combustion air or the gaseous products of combustion. Two main types of fluidized bed combustion systems are (1) bubbling fluid bed (BFB) in which the air in excess of that required to fluidize the bed passes through the bed in the form of bubbles. The bubbling fluid bed is further characterized by modest bed solids mixing rate and relatively low solids entrainment in the flue gas and (2) circulating fluid bed (CFB) which is characterized by higher velocities and finer bed particle sizes. In such systems the fluid bed surface becomes diffused as solids entrainment increases, such that there is no longer a defined bed height. Circulating fluid bed systems have a high rate of material circulating from the combustor to the particle recycle system and back to the combustor. The present invention has application to any fluidized bed apparatus, however, it has particular application to circulating fluid bed boilers operating with a fuel that produces more than the usual amount of ash. Such fuels may be referred to as high ash fuels. A high ash fuel is a fuel having an ash that weighs 35% or more of the weight of the fuel. (Low ash fuels typically do not require a fluid bed ash cooler although some may be cooled with cooling apparatus such as a screw cooler. Screw coolers have a jacketed sleeve around a helix that it is rotated to move solid matter axially within the sleeve). The ash produced in the fluid bed includes both the back pass ash and the bottom ash. It is essential that the temperature of the ash leaving the combustor be cooled so that the ash does not damage or destroy the conveying equipment.

The bottom ash should be cooled from combustor temperature to below 200 degrees C before entering the bottom ash conveying system. When a high ash fuel is used, the heat in the bottom ash stream may represent a significant percentage of boiler heat input. Consequently, it can be desirable to recover this heat. Fluidized bed ash coolers are generally used for this purpose. Cooled ash from the ash cooler passes to the bottom ash handling system for transport to storage. This is usually a mechanical system consisting of flight conveyor's, although a pressured pneumatic system can

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also be used. Alternately, a mechanical system can be used to transport bottom ash to an intermediate hopper, from which a pneumatic system conveys the material to storage.

Circulating fluidized bed (CFB) boiler bottom ash contains large amounts of physical heat. While the boiler combusts the low-calorie fuel, the ash content is normally more than 40% and the physical heat loss is approximately 3% if the bottom ash is discharged without cooling. In addition, the red-hot bottom ash is bad for mechanized handling and transportation, as the upper limit temperature of the ash handling machinery is 200 °C. Therefore, a bottom ash cooler (BAC) is often used to treat the high temperature bottom ash to reclaim heat, and to have the ash easily handled and transported [1, 2]. As a key auxiliary device of CFB boilers, the BAC has a direct influence on the secure and economic operation of the boiler. There are many kinds of BACs equipped for large-scale CFB boilers with the continuous development and improvement of the CFB boiler, such as water cooled ash cooling screw [2], rolling-cylinder ash cooler (RAC) [2–3],fluidized bed ash cooler (FBAC) [4–5]. The RAC and FBAC have a large capacity, and have been commonly and reasonably applied.

Figure 1.1 show typical ash flow diagrams for CFBC Boiler. In CFBC Boiler total ash generated during combustion is extracted through four (4) extraction points namely, Bed ash (BA), Cyclone ash (CA), Airpreheater ash (APH) and ESP ash. Out of the total ash generated 90% of ash is fly ash and remaining 10% is collected as bed ash.

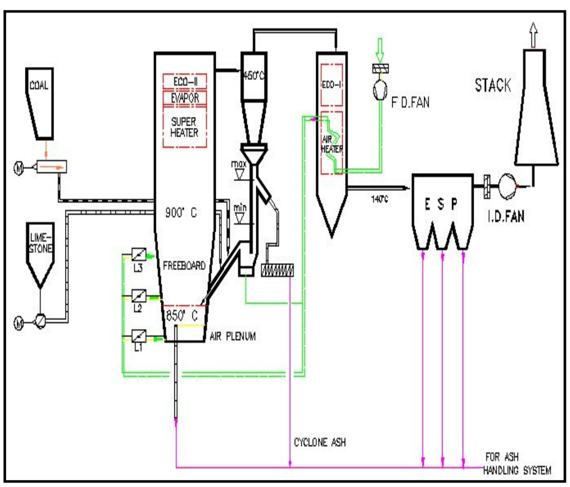

Fig 1 Typical flow diagram of CFBC Boiler

This bed ash starts accumulating gradually in the boiler bed during the boiler operation. This accumulation of bed ash in the boiler bed increases the boiler bed height which in turn increase the static head of primary air required for fluidizing the bed. Therefore extra accumulated bed ash should be drained from the bed so as to maintain sufficient bed height (~1000mm) for proper fluidization and combustion.

II. COOLER CONSTRUCTIONS AND EXPERMENTATION TEST SET UP

Figure 2 shows the general arrangement of fluidized bed ash cooler. To facilitate the draining of this accumulated bed ash from the bed two bed ash drain pipes of 200 NB are provided. Each ash drain pipe is connected to Fluidized air bed ash cooler. In FBAC bed ash at 8500C is cooled to temperature of 2000C with help of air at 40oC which is tapped from PA fan discharge duct. Hot air at FBAC outlet after absorbing the heat from the ash is connected to the SA nozzles and fed to the furnace.

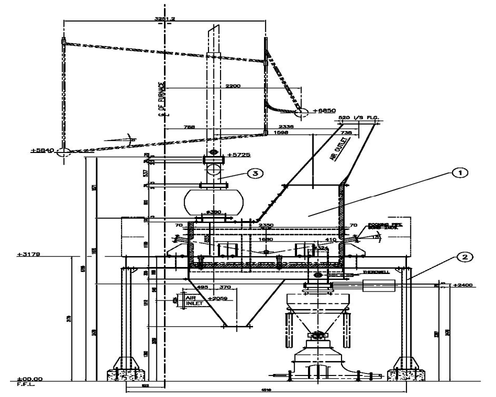

Fig 2 General arrangement of fluidized ash cooler.

The distribution plate is provided just above the air inlet chamber. The distribution plate having perforated hole is kept inclined towards the ash discharge side. This inclination is provided to flow of ash towards the discharge side. Due to this inclination there will not be ash hip inside cooler. Above this distribution plate fluidization occur which subjected to high erosion of plate due to fluidization and high abrasiveness of ash. To avoid the erosion the 70 mm thickness low cement castable refractory is provided. The refractory is hold to distribution plate by means of refractory anchor. The distribution plate is subjected to temperature from 8500C to 200 0C. Hence the material selected for distribution plate and anchor is stainless steel (ASTM A240 SS 304).

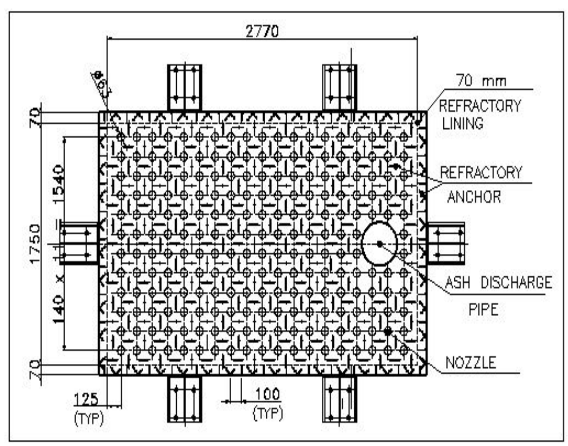

Fig 3 Plan view of distribution plate with nozzle, refractory and anchor

Typical plan view of distribution plate is shown in fig. 3. The nozzle spacing, refractory lining, refractory anchor is shown in the plan view. The nozzle and refractory anchor welding details is shown in fig.4. The pitch considered for anchor plate and arrangement is shown in below figure 4. This anchor holds the refractory and gives strength to refractory lining. The material selected for refractory anchor is of stainless steel.

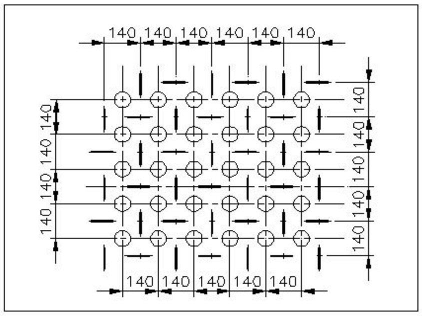

Fig 4 Anchor welding details on Distribution plate.

There are different types of nozzle available, the selected nozzle arrangement is shown figure 5. The nozzle is welded to nozzle distribution plate; the desired slot is made on nozzle pipe at a desired angle. The angle is made at equispaced distance on circumference of nozzle pipe. This will evenly distribute the air in the fluidizing chamber.

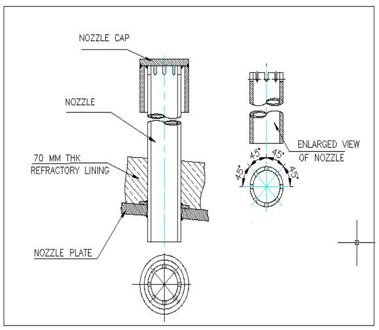

Fig 5 Typical Nozzle details

To avoid the direct entry of ash particle in the nozzle the top cap is welded to nozzle. So air enters in the nozzle from bottom and takes 90 degree turn and goes to fluidized area. As this nozzle is directly contact with hot ash particle, hence material selected for all part is stainless steel. As nozzle/distribution plate is kept at an angle so that ash will move to words the ash outlet gate. To take of this inclination all nozzle row height is made different such that top & bottom level of all nozzles is kept constant. The hot air coming out of fluidizing chamber is connected to boiler furnace. The outlet pipe is provided with metallic expansion joint to cater the boiler furnace expansion

The process and instrumentation diagram for ash cooler is shown in fig 6. Ash discharge pipe which is connected to boiler bed conveys the hot ash to cooler. The temperature element (thermocouple) is provided on ash discharge pipe to measure the temperature of ash coming in the cooler. The pneumatic slide gate is provided on the ash inlet pipe to cooler, the manual side gate is provided to isolate the inlet pipe. The manual slide gate will be closed for maintenance of pneumatic slide gate. The emergency discharge pipe with manual slide gate is connected to ash inlet pipe. If due to some reason if cooler is not working then ash will be get drained to ground through the emergency discharge pipe.

As shown in the figure the two temperature measuring thermocouple is provided on the cooler which measure the temperature of ash in the cooler. On discharge pipe from cooler is provided with temperature measuring element(thermocouple) and pneumatic slide gate. Cold air inlet piping to cooler is provided with annubar for air flow measurement, motorized butterfly valve for flow regulation, manual butterfly valve, and pressure transmitter for inlet pressure measurement.

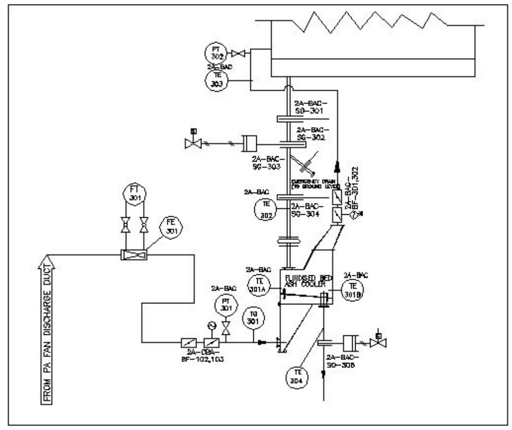

Fig 6 Experimental set up diagrams

Hot air piping from cooler outlet to boiler is provided with temperature measuring element (thermocouple), pressure transmitter, motorized butterfly valve and manual butterfly valve.

Once construction & erection of boiler & cooler is completed, then the bed material such as sand is filled inside the cooler from the manhole provided on cooler. Sand is filled up to top of nozzle approximately 150 mm height above distribution plate. These sand acts as bed for fluidization. The ash inlet and outlet slide gate are closed so that there will not be any material coming inside the cooler and leaving from cooler. With this the hot air outlet butterfly valve is opened and cold air inlet motorized valve is start opening slowly from 0% opening. As cold air start coming inside the cooler, whether fluidization starts or not is checked manually through the manhole.

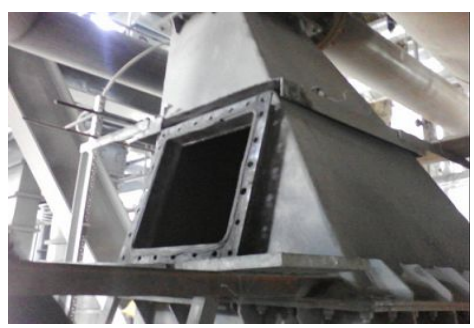

Photo 1 – Manhole details in bed ash cooler

With certain % of inlet motorized butterfly opening the fluidization of bed material is seen in the cooler. The % opening inlet butterfly valve is noted which is around 40%. In addition the pressure transmitter reading on air inlet pipe is noted which is 450 mmWC. The cold air inlet & hot air outlet valve is closed, and then the manhole cover is closed such that there is no any open area in the cooler.

Photo2 – Motorized & Manual valves in cold air entry to ash cooler

The above step is performed the cooler is ready for take hot ash batch from furnace bed. The hot air outlet valve is open. Inlet air valve is continuously open to 35% during entire operation of cooler and outlet ash slide gate is closed, in this condition the ash inlet to cooler pneumatic slide is opened for certain time interval. This will drain certain mm of boiler bed height to cooler. The opening time interval of inlet slide gate is decided based on ash generation rate in boiler bed and height of bed ash drained from furnace bed. For our case the opening time of inlet ash slide gate is 40 seconds and during this time boiler bed height is reduced by 30 to 35 mm.

Photo 3 – Pneumatic slide gate in hot ash entry to ash cooler

The air inlet motorized valve is in open condition. The pressure of inlet air start increasing which is reached to 650 mmWC till the inlet slide get closed, this is due to increase in the resistance across fluidizing bed. This air will exchange the heat with ash particle and hot air is leaving cooler and feed to boiler furnace. This process heat exchange will continue till the final temperature ash particle is reached to below 200^0C. During this process the ash temperature and outlet air temperature is noted for every 1 minute.

After the ash temperature is reached to below 200^0C, the air inlet motorized butterfly valve open; the ash inlet pneumatic slide gate is closed. The ash outlet slide gate is opened to discharge ash to the ash conveying system. As air inlet valve is open due to churning of ash particle inside cooler will discharge the ash to ash conveying system. This process will continue till pressure transmitter reading on air inlet line will show 450 mmWC. Once the pressure is reached to 450mmWC, the ash outlet slide gate is closed. The remaining height of ash column will act as bed material for next batch of ash cooler operation.

When ash outlet slide gate is closed the cooler is ready for taking another batch of ash in to cooler. The above steps are repeated till the final desired ash temperature is achieved. While doing the all operation all the valves are opened through DCS by giving the manual signal by operator with coordination with site engineer who is present near the cooler. To feed to the logic to DCS and predict the behavior of cooler the above procedure is repeated 40 to 50 times. And during each batch the drop in furnace bed height, time required for cooling ash are noted.

After doing 40 to 50 batches manually the field operator & DCS operator gets the idea about the performance of ash cooler. Then the logic is feed to DCS. After this there will not be any manual intervention on operation of cooler. The DCS continuously monitor the above parameter and report for any abnormality observed during operation.

In addition to above for the cooled ash sample is taken from cooler and given to laboratory for meaning the sieve analysis and density of ash particle.

Once initial trial is completed on the cooler as explained above, the logic of instruments such as opening time of pneumatic slide gate, motorized valve opening is directly feed to DCS. So that there will not be any manual intervention in process of ash cooling. The operator sitting in control room will check the operation of system. If found any abnormality then only he change the valve setting through DCS. The logic feed to DCS and some interlock feed to start the process are as below.

To built the logic in DCS the cooling of ash inside the cooler is completed in three steps

Step- 1 – Opening of inlet motorized valve

During the trail we got the information that inlet valve will be opened to 40% to have fluidization inside cooler. This valve will remain open during entire cycle of cooling. In any case valve should not open beyond 40%.

Step-2 Hot Ash Entry to Ash Cooler

This step will be carried out by operating the pneumatic gate in the bed ash drain pipe. This pneumatic slide gate will be open for time interval of 40 sec. when the gate is opened ash from the boiler bed at 850^0C will fall inside the bed ash cooler above the bed material inside. During this 40 sec the certain bed height will be drained in to cooler.

Open Permissive required for the pneumatic ash slide gate hot ash drain line is

Boiler Bed Height is > 980 mm

Bed ash cooler temperature is < 200^0C

Ash cooler hot air outlet motorized and manual valves are in open condition.

Inlet air motorized valve opening must be greater that 30 %.

The cold air inlet pressure shall be 450 +/-25 mmWC.

Step-3:- Opening Of Cooler Ash Outlet slide gate

After the step-3 is over the bed ash cooler will be ready for draining the ash to bed ash handling system. Considering the ash handling system design below the ash cooler outlet ash slide gate will be opened four time for 20 sec at interval of 90 sec between each opening of slide gate.

The pneumatic ash slide gate at bed ash cooler outlet will open only when following conditions are healthy. Open permissive required for opening the valve are as follows.

Ash cooler temp. < 200^0C

Hot ash inlet slide gate shall be in closed position.

Inlet cold air pressure shall be greater than 450 mmWC & less than 650 mmWC.

During this process the ash will be drained to the point the pressure transmitter reading on the air inlet line reaches to the 450 mmWC. Once this is reached immediately the outlet ash slide gate is closed.

III. RESULT & DISCUSSION

A. Minimum Fluidization Velocity.

The boiler ash contains the ash from varying particle diameter from 0.5 mm to 10 mm. Fig. 4 present the minimum fluidization velocity required for varying particle diameter. The exact particle size of ash in cooler is difficult to predict because it depends on coal sizes used in the boiler.

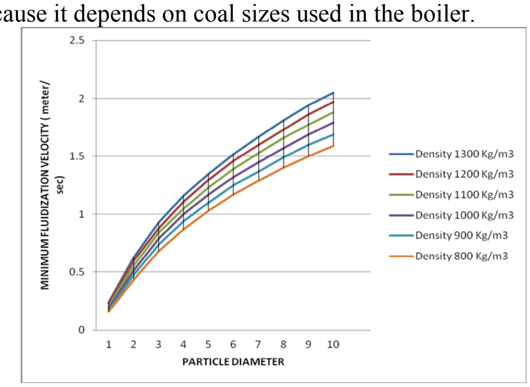

Fig 7 Minimum fluidizing velocity for different particle diameter

B. Pressure Drop Aacross Fluidized Bed

Before starting the operation of cooler, the bed material need to be filled the cooler for proper fluidization. The pressure drop across the cooler be is noted. As hot ash is drained to cooler the pressure drop across the various height of cooler bed is noted. Figure 8 present the pressure drop across the cooler bed with different bed height. This pressure drop readings are used to decide the opening of hot ash inlet & closing of cold ash outlet slide gate.

Fig.8 Pressure drop across bed with different bed height of ash in the cooler.

C. Experimentation Result.

The experimentation/performance is carried out on cooler at site as per procedure stated above. The data recorded during the operation of cooler are bed height drained, time required for ash cooling, pressure before and after ash cooling. The performance data is tabulated in table I.

Table I – Performance data of fluidized bed ash cooler.

SL.NO	BED HEIGHT DOWN	TEMP RAISING IN BAC AFTER DRAINING	TIME TAKEN FOR TEMP RAISING	TIME TAKEN FOR TEMP DECREACING UPTO 200'C	CYCLE TIME
	Mm	Deg C	minutes	minute	minute
1	45	624	4.22	11.58	17
2	41	648	4.16	11.26	16.2
3	43	662	4.26	11.37	16.4
4	33	652	4.16	11.31	16.3
5	19	682	4.18	11.12	16.1
6	26	662	4.32	11.22	16.3
7	23	689	4.12	11.24	16.2
8	34	682	4.16	11.31	16.3
9	40	658	4.32	11.12	16.3
10	26	605	4.5	18.3	24
11	32	693	4.1	13.3	18.2
12	25	687	4.07	16	20.5
13	36	684	4.3	16.3	21.4
14	27	678	4.41	16.05	21.3
15	22	715	5.1	16.1	22
16	27	668	4.3	13	18.1
17	25	654	5.1	13.2	19.1

In addition to above the drops in ash temperatures at every minute is noted for four to five batches and are presented in table 6.8. The ash temperature with time during the cooling the ash in cooler is shown in fig 9. from the figure we can see that cooler bed temperature rises during initial time and reached to equilibrium, after this ash temperature falls with time. The certain height of bed material about 200^0C is present in the cooler before draining the ash. Once 850^0 C ash is drained to the cooler, and during mixing of this two temperature material the cooler bed temperature stats increasing for initial period. But it will never reach to 850^0 C.

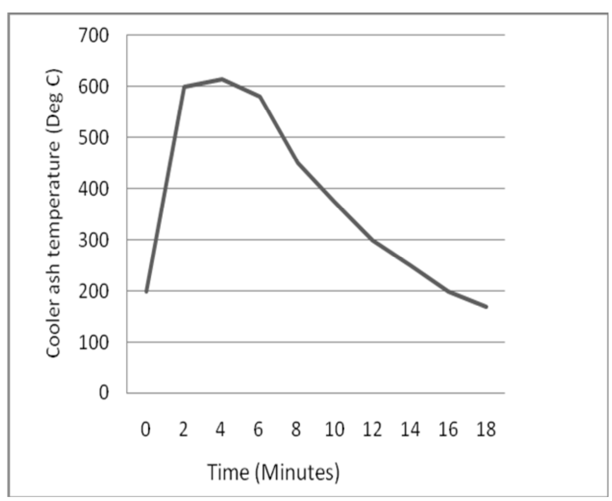

Fig. 9 Temperature profile of ash with time observed during experimentation.

CONCLUSION

Fluidized ash cooler is proposed in this paper, an experiment is conducted on the cooler of 7 TPH ash. Primary conclusions are summarized below.

The experimental result shows approximately 20 minutes are required to cool the one batch of ash from 850^0C to 200^0 C. It also shows that cooler bed temp increase and attains maximum values for initial 3 to 4 minutes and after this the ash temperate starts decreasing with time.

As the air used for cooling the bed ash in cooler is tapped from the PA fan discharge so no separate prime mover or motor is required to generate cooling air. Where as in water cooler bed ash cooler separate motors with gear box are required to run the cooler. Hence the power consumption observed by using air cooled bed ash cooler is reduced by 40KW.

Maintenance required for the fluidized ash cooler is easier as there is no moving parts in fluidized ash cooler as if in screw type water cooled bed ash coolers.

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he industrial application revealed that the operation of fluidized ash cooler was found to be satisfactory. This cooler has good cooling effect and had better energy conservation than water cooled ash cooler.

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REFERENCES

[1] K.F. Cen, M.J. Ni, Z.Y. Luo, J.H. Yan, Y. Chi, M.X. Fang, et al., “Theoretical Design and Operation of Circulating Fluidized Bed Boiler”, China Electric Power Press, Beijing, 1998, pp. 647–663.

[2] X.F. Lu, “Equipments and Operation of Large-scale Circulating Fluidized Bed Boiler”, China Electric Power Press, Beijing, 2006, pp. 125–133.

[3] W. Wang, X.D. Si, H.R. Yang, H. Zhang, J.F. Lu, “Heat-transfer model of the rotary ash cooler used in circulating fluidized-bed boilers” , Energy Fuels 24 (2010) 2570–2575.

[4] M.L. Shu, J.H. Chen, X.F. Lu, H.Z. Liu, “Investigation on fluidized bed bottom ash coolers in large-scale CFB boilers”, Power Syst. Eng. 23 (2) (2007) 29–31.

[5] P. Xiao, T. Guo, Z.Q. Xu, J.Z. Jiang, H.S. Lu, Q. Li, et al., “Large capacity fluidized bottom ash cooler and its operation performance”, Proceedings of the CSEE, 29, 2009, pp. 113–117, (S).

[6] D. Xie, B.D. Bowen, J. R. Grace, C. J. Lim (2003). “Two dimensional model of heat transfer in circulating fluidized beds. Part-I –Model development and validation”, International journal of heat and mass transfer.