ICESP XIII, September 2013, Bangalore, India

Top Electromagnetic Impact Rapping ESP Applied in 660MW Units of a Power Plant in India

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Abstract: This paper takes the mating top electromagnetic impact rapping ESPs for the 7 × 660MW supercritical boilers of some Indian power plant as an example to analyze the coal and ash characteristics and explain the ESP sizing consideration. The paper introduces the technical features of top electromagnetic impact rapping for collecting electrode (referred as CE hereinafter) & discharge electrode (referred as DE hereinafter), describes design problems of supersize ESP, such as CE & DE match model, thermal expansion problem, air flow uniform distribution and special design for hopper safety, energy conservation design, guarantee for low air leakage rate, etc. These give a conclusion of the design methods of supersize ESP for Indian coal-fired power plant and make a good reference for ESP design of other Indian coal fired power plants.

Keyword: ESP, Top electromagnetic impact rapping, Technical proposal and ESP sizing, Air flow uniform distribution, Energy conservation design

1. Foreword

As a country of the world 3rd largest coal output and the 2nd largest coal consumption, half of Indian energy need is satisfied by coal. As Indian economy developed in recent years, the electric power demand gap was increasingly big. Subsequently, power plants emerged in each state. Therefore, the importance of ESP as environmental protection equipment of removing the particle dust in the waste gas from the coal-fired boiler, restraining environmental pollution and improving air quality rises. Nowadays, in most Indian thermal power plants, ESPs with side winding hammer rapping are used. While project cases with ESP of top electromagnetic impact rapping are barely seen in India. The following takes the mating top electromagnetic impact rapping ESPs for the 7 × 660MW supercritical boilers of some Indian power plant as an example to introduce the 1st top electromagnetic impact rapping ESP in Indian dust removal market of power industry.

2. Equipment profile

2.1 Project survey

2.1.1 Boiler type: supercritical parameter direct current furnace, corner tangential firing, single reheat, balanced draft, outdoor arrangement, dry bottom ash extraction, all steel structure, all hanging structure of Π shaped arrangement.

2.1.2 Analysis of components and characteristics of coal and ash

Table 1 Coal analysisParameter	Design coal	Best coal	Worst coal
Moisture (%)	10	12	11.90
Ash content (%)	37	28.45	41.5
Fixed carbon (%)	25.4	28.05	23.6
Volatiles (%)	27.6	31.5	23.5
Carbon (%)	41.6	47.8	35.60
Hydrogen (%)	2.6	2.95	2.23
Sulfur (%)	0.25	0.3	0.45
Nitrogen (%)	1.025	1.20	1.22
Oxygen (%)	7.2	7.3	7.6
Moisture (%)	10	12	11.9
Ash content (%)	37	28.45	41
higher heating value (kcal/kg)	3927	4527	3331
Hardgrove grindability index	50	53	50

Table 2 ash analysis

Parameter	Design coal	Best coal	Worst coal
Silica (%)	54.16	51.008	55.72
Aluminum oxide (%)	27.62	25.852	26.48
Iron sesquioxide (%)	8.04	8.08	7.37
Titanium dioxide (%)	1.7	1.82	1.80
Phosphorus oxide (%)	0.16	0.356	0.26
Calcium oxide (%)	3.4	4.176	3.45
Magnesium oxide (%)	2.34	2.756	2.25
Sulfur trioxide (%)	1.28	2.764	1.35
Deformation temperature	1140 ℃	1136 ℃	1180 ℃
Hemispherical temperature	1340 ℃	1240 ℃	1300 ℃
Flow temperature	1400 ℃	1350 ℃	1400 ℃

2.1.3 Analysis of ESP sizing

a. Sulfur content: when $S_{ar}>3\%$, the coal is classified as high sulfur coal, $Sar=1\sim2\%$ as medium sulfur coal, $S_{ar}<1\%$ as low sulfur coal. The sulfur content has a big influence on fly ash resistivity. The sulfur in coal turns into SO_2 while burning. Usually, 0.5% to 1% of SO_2 is oxidized into SO_3, which is able to enhance the surface conduction of the fly ash and reduce the fly ash resistivity. Low sulfur coal with $S_{ar}<1\%$ is of little SO_3, therefore the fly ash resistivity is high and back corona happens easily. The sulfur content of the coal in this project is between 0.25% and 0.45% and is low sulfur coal, of which the fly ash resistivity is high and is hard to be charged. And subsequently back corona is easy to happen and the fly ash is different to collect.

b. Ash content: the design coal ash content is 37%; the best coal ash content is 28.45%; the worst coal ash content is 41%, which is median to high level. The ash content level of the coal will directly influence the inlet dust concentration of the ESP. under the same outlet emission requirement, the higher the inlet dust concentration is, the higher the dust removal efficiency is required to be. In this particular project, the inlet dust concentration is 70 g/Nm^3. In this case, much attention must be paid to avoid corona obstruction. We adopted power off control technology and 2 DE wires matching 1 CE plate type of discharging capacity, which is able to effectively prevent corona obstruction from happening .

c. Moisture: moisture is favorable for fly ash to reduce dust surface resistivity ($SO_3+H_2O=H_2SO_4$). Besides, the moisture is able to capture electron and form heavy ion, make electron migration velocity rapidly decrease and to raise gap breakdown voltage. Furthermore, high moisture make charging easy and consequently make space charge of bigger function. In short, high moisture will bring high breakdown voltage, decreasing dust resistivity, rising dust removal efficiency. In this project, the water vapor volume content is 8.8% to 10%, which is median moisture level.

d. Ash content analysis: the higher the SiO_2 and Al_2O_3 content in ash is, the higher the ash fusion point is. Otherwise, when ash contains oxidant with low fusion point such as CaO, MgO, Fe_2O_3, Na_2O, K_2O, the ash fusion point will be comparatively low. Generally speaking, the higher the ash fusion point is, the higher the dust resistivity is. In this case the content of $SiO_2+Al_2O_2$ is 82.2%; therefore the fly ash resistivity will be comparatively high.

From the above analysis, the conclusion is achieved that the coal for this project is of poor quality, high ash content and high resistivity, of which the ash is hard to collect. Besides, the owner of this project requires the Specific Collecting

Area (SCA) to be bigger than 260 $m^2/(m^3.s^{-1})$ when one electric field is shut down, which is far bigger than ordinary design seen in China. Therefore, we gave a full consideration of the above factors during design and maintained some design margin to make sure the reliable performance of the equipment.

On the basis of the above coal parameter and fly ash analysis, we determined the mating ESPs for this project to be two ESPs each of two chambers, which is of the total effective sectional area of 720m^2, 10 electric fields, 30 flue gas passage, passage width (CE space) of 400mm and effective CE plate length of 15m. In the ESPS, the 1st to the 9th electric fields are all consist of two separately energized zones. Each energized zone is equipped with 5 CE plates along the electric field length direction. The 10th electric fields is also consist of two separately energized zones. Each energized zone is equipped with 4 CE plates along the electric field length direction. The effective width of each CE plate is 475mm. The SCA reaches 296$m^2/(m^3.s\text{-}1)$ and is 266$m^2/(m^3.s^{-1})$ with one electric field out. (refer to Figure 1)

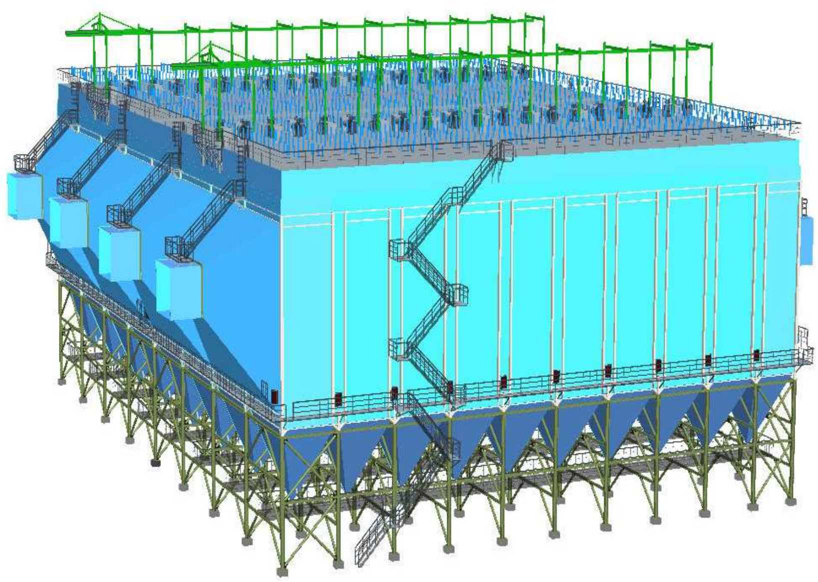

Figure 1 ESP profile

Because the mating ESPs for this project are top electromagnetic impact rapping ESPs of four chambers and ten electric fields. The ESPs are of 60 m at longitudinal direction, 100 m at transverse direction and 40 m at height direction, which could be considered the biggest, the most advanced technology and the most comprehensively equipped large-scale top electromagnetic impact rapping ESPs in the world by now. During the design, besides the top electromagnetic impact rapping for CE and DE, we also had special designs for its CE &DE match type, heat expansion displacement problem, flow gas distribution, hopper safety problems etc. To ensure the air leakage requirement of less than 1%, we have taken some solutions during manufacture and erection.

2.2 Top electromagnetic impact rapping

Top electromagnetic impact rapping ESP is a mechatronic product combined with ESP body, mating high voltage rectifying equipment and low voltage control system. The unique outside-dust top electromagnetic impact rapping technology is of the following features:

a The rapping devices are located on the top of the ESP, which raises the space utility rate and is especially favorable when site space is limited.

b The rapping devices are on the top of the ESP and outside the flue gas, which is able to realize convenient on-line maintenance of rapping devices and raise the normal operation rate.

c As the accumulated ash on the collecting plates is of fine particles and thin layer on the upper part of the collecting plate, and is of coarse particles and thick layer on the lower part of the plate, it requires the rapping force to be bigger at top and smaller at the bottom. Exactly, the rapping force of top rapping devices is transferred from top to bottom and is bigger at top and smaller at the bottom and perfectly fits the requirement.

Top rapping: the acceleration distribution accord with the CE & DE ash removal requirement.

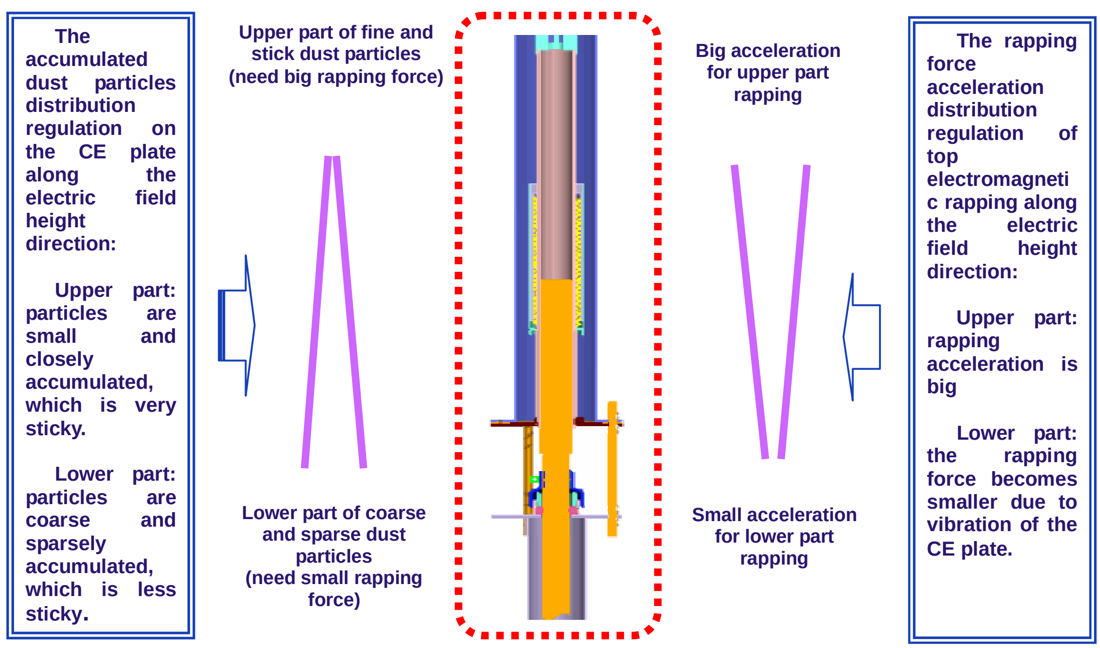

Figure 2 relation between top rapping force and ash removal d Because of adapting topping rapping and suffering no shear force, the collecting plate only need vertical rigidness which can be guaranteed by anti-wind hook. For horizontal rigid ness is unnecessary, no stiffener is required during rolling the collecting plate. Therefore, during rapping, the collecting plates will tremble and make an easy falling off for the dust on the collecting plates and obtain good dust removal efficiency.

e Adapting top rapping, small rapping unit is available. Reasonable control of the small rapping unit is able to gain effective dust removal as well as to restrain reentrainment.

f The discharge electrode system adopts the structure of separating hanging beam and anvil beam, which reduces the impact suffered by supporting insulator and therefore guarantee the its life span.

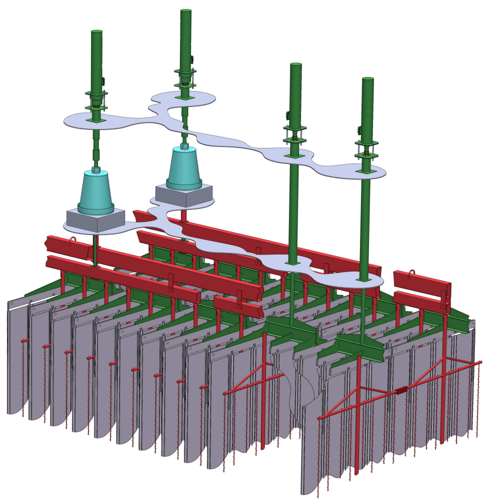

Figure 3 rapper arrangements for CE & DE

3. Special designs of ESP

3.1 DE wire choice

In ESPs, requirements for corona wires are high electric field density, evenly distributed corona current density, low corona inception voltage, high flashover voltage, and wide operation range between corona inception voltage and flashover voltage. In this project with ESPs of 4 chamber and 10 fields, we adopted different type of DE wires according to different dust concentration and its specific need for discharge. The dust concentration of the ESP inlet of this project has reached 71.3g/Nm^3. Therefore back corona would happen easily in the front fields. For Field 1 and 2, the dust concentration is high and the dust particle is of large size. And our target is to charge the dust as much as possible. Therefore, we adopted CS20A wire with strong discharge character. Long discharge needle of this type of DE wire would to the biggest content avoid DE wires being covered by accumulated ash and avoid discharge obstacle. For Field 3~7, the dust concentration and particle size reduce. To avoid back corona, CS10A AND CS10B were chosen with decreasing discharge capacity. For the last fields (Field 8~10), we chose CW09A type wave shaped wire for the dust here was hard to collect because of fine particle and high specific resistivity.

Figure 4 needle wire

Figure 5 wave shaped wire

3.2 Heat expansion problem of ESP

The ESP is of four chambers and ten electric fields structure, which is of 60 m at longitudinal direction, 100 m at transverse direction and 40 m at height direction. During operation the flue gas temperature is 146℃. And there is bound to be heat expansion problem due to temperature difference between components in touch with flue gas such as casing and components not in touch with flue gas such as steel support. For such huge structure, the influence of heat expansion will be bigger, for which we made some special improvement.

We reserve some space for heat expansion. The distance between two neighboring columns of steel support is 5mm bigger than the distance between the correspondent two neighboring columns of the casing. Also, the top plate of the steel support is enlarged to ensure that the casing column is still near the center of the steel support despite the displacement during operation.

The top big thermal insulation box was divided into several small thermal insulation boxes. As the rappers of top electromagnetic impact rapping ESP are set on the top of the ESP and are outside the flue gas, it will be able to realize convenient on-line maintenance of the rapping facilities. However, there will be certain thermal displacement between the rapping rod and the thermal insulation box due to the temperature difference inside and outside the ESP. Usually to deal with this problem, we would make the inner diameter of the rapper bracing tube bigger than the diameter of the rapping rod and leave some margin to accommodate the thermal displacement. Whereas, for this supersize top electromagnetic impact rapping ESP, the diagonal distance between two adjacent rappers is nearly 70 m. obviously simply enlarging the rapper bracing tube will not function as well as usual. Therefore, we innovatively divided the huge thermal insulation box of 49740mm×51990mm into 9 regular sized thermal insulation boxes. Between each insulation box, thermal insulation material was filled and rainproof measures were taken. After the division, the thermal displacement between the rapping rod and the thermal insulation box was reduced significantly, and the conventional solution of rapper bracing tube was able to meet the requirements.

3.3 Air flow uniform distribution design

The flow distribution and uniformity degree of the flue gas in the flue duct and ESP electric fields will directly influence the dust removal efficiency of the ESP. As for this project, we first adopted CFD analysis to calculate the flow field distribution of the whole ESP (including inlet and outlet flue duct) and to provide a primary baffle arrangement plan. And then, we modify the data through physical model test and get the final design plan.

3.3.1 CFD test

The simulation range is from the outlet of the air preheater to the inlet of the induced draft fan, including the ESP body and inlet & outlet flue ducts. The model is built in the scale of 1:1 with the real ESP. For a convenient simulation, we simplified the ESP structure to some extent, such as neglecting the internal tube brace, support column, DE frame, neglecting the rotation direction of the air preheater and assuming the inlet flow is even etc. CFD test result showed that when there was no guide baffle inside the flue ducts, the flow distribution simulation result for the flue ducts is as Figure 6 showed. From the simulation result, it was easily seen that when there was a flow deviation more than 5% among each chamber which is not able to meet the design requirements. Besides, the flow of inlet flue duct 2 and 3 is distinctly increased and the flow distribution of the inlet flue duct 1 and 4 is far from uniform.

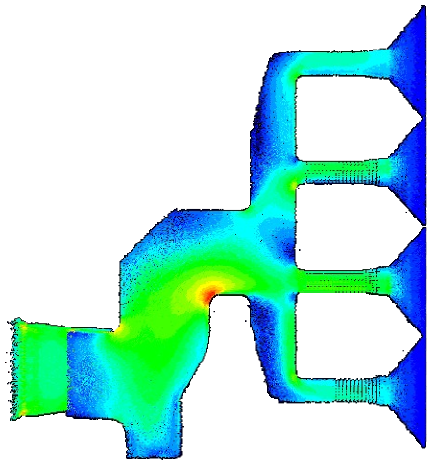

Figure 6 Air flow vector diagram on the center section at the height direction

Based on the primary simulation result, guide baffles were equipped in the main inlet flue duct to adjust the flow distribution of each chamber. Guide baffles were equipped at the elbow to improve flow distribution uniformity at the flue duct cross section and to reduce elbow resistance. The position and angle of the guide baffle is repeated adjusted to finally manage to assure the flue gas flow distribution to meet the requirements. The guide baffle configuration is as Figure 7 shows.

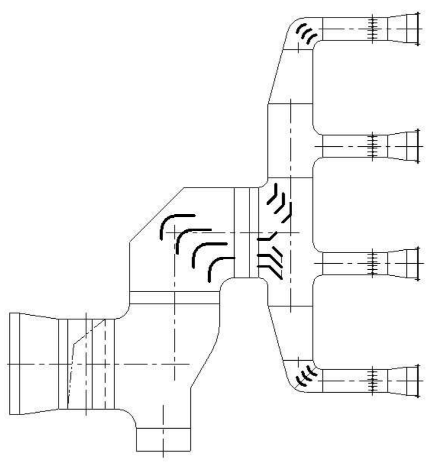

Figure 7 Flue duct guide baffle configuration drawing after CFD

3.3.2 Physical model test

ESP air flow distribution model test is undertaken with good sealing and cold state air. The model should be similar with the prototype in geometric, kinematic, dynamic ways and in boundary conditions. Among these, the most important is to meet geometric similitude and to make air flow status enter the 2nd self- modeling zone.

Through repeated test, the original CFD test guide baffle plan was slight adjust to make sure the inlet relative flow distribution of the Chamber 1 to 4 is respectively -0.3.84%、-0.53%、+4.47%、-0.10%. And the outlet relative flow distribution of the

Chamber 1 to 4 is respectively -1.50%、-0.87%、+2.71%、-0.34%. The flow distribution of both inlet and outlet flue duct both meet the requirement of being less than ±5.0% and of almost identical flow distribution regulation. The air flow uniform distribution device of the inlet flue duct is as Figure 8 shows.

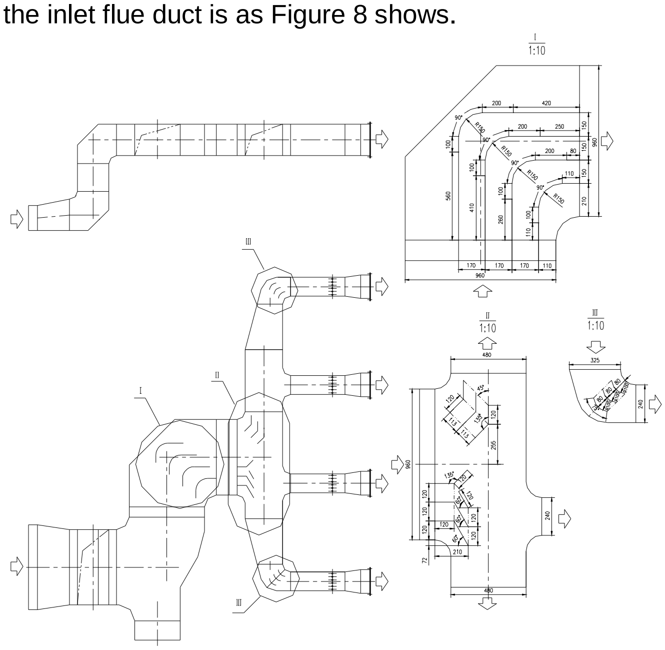

Figure 8 Flue duct guide baffle arrangement after adjustment

3.4 Hopper safety problem

The dust collected by ESP is discharged by hopper and ash discharge and conveying devices, which is an important part of ESP stable operation. In fact, poor ash discharge happened now and then during system operation and prevented the ESP from normal operation. Therefore, this part should be paid enough attention. In this project, the ESP inlet dust concentration reaches 71.3g/Nm^3. The normal treated flue gas volume is 4072752m^3/h according to the technical agreement. Assumed the 1st electric field works with the efficiency of 80% (including free settling), then the ash volume for Field 1 would be as high as150t/h. Therefore, beside regular electrical heat, ash poke hole, manual rapping anvil, high & low level probe, we equipped the system with additional emergency ash conveying device. We equipped every hopper of Field 1 with 2 emergency ash discharge devices at both lower and upper part of the hopper. We also equipped every hopper of Field 2 to 10 with 1 emergency ash discharge device. This device is composed by manual knife valve and ash discharge tube. When ash conveying system fails or function poorly, emergent ash discharge could be done by open the knife valve to ensure the safe operation of the ESP.

3.5 Energy reservation control design

For such a huge ESP, its power consumption will be an extremely important consideration. In order to remove the dust, control emission as well as reduce power consumption, we adopted a series of solutions.

3.5.1 Thermostatic control is adopted for insulators and hopper electric heating by reasonably control and setting the thermostatic control parameters.

3.5.2 The heating power of the hoppers is adjusted according to the ash deposit status from Field 1 to 10 to ensure the hopper heating as well as the power consumption of the whole ESP.

3.5.3 CS10B needle wire and CW09A wave shaped wire with gentle discharge ability were used in Field 5 to 10, which reduced the field current density while guaranteed the performance.

3.5.4 Intermittent impulse power supply with power-off rapping technology was adopted. Back corona automatic tracing and control technology was used to choose best impulse duty factor for intermittent power supply. Power-off rapping was realized through the interaction of high voltage and low voltage devices. By these, back corona is effectively restrained; the CE plate dust removal efficiency is raised, and the power consumption is reduced.

3.6 Guarantee measures of air leakage rate

Air leakage rate is one of the main factors influencing the performance of the ESP. Because the ESP is of big size and heavy weight, it is usually delivered from the workshop in parts and components and is assembled and erected at site. Therefore, how to ensure the air tightness and low air leakage rat during design, manufacture and erection is especially important for EMP to meet the requirements of low emission. Particularly for this supersize ESP, we take some measure from the angles of design, manufacture and erection.

3.6.1 Measures taken during design

As for manhole door design, we adopted bilayer manhole. And he seal of manhole door adopted seal strip made of good quality silicon rubber which won't aging for a long time under the high temperature of 350℃to ensure long-term sealing capability. The stuffing box of the rapper foundation adopts anti-high temperature and aging silicon rubber to effectively reduce the possibility of air leakage.

3.6.2 Measures taken in manufacture and installation

For the hoppers, casing wall plates, inlet and outlet nozzles which need to be assembled on site, assembly on the ground and hoisting in a whole was the most favorable method. Ground assembly is able to proceed welding and test well to assure sealing weld quality. Butt welds of hopper and inlet & outlet nozzle were required to undertake kerosene penetration test. For the rest weld, visual test is required. The found weld failure was polished and welded again. The hoisting weld joint was required to be cleaned and examined by the welder himself immediately after the weld was finished. If failure is found, it needs to be repaired. And all the hoisting weld joints were visually examined by the supplier supervisor one by one.

After the ESP installation completed, “foam method” was used to inspect the overall weld joint. I.e. seal the inlet and outlet nozzles, shut down all the hopper gate valves, manhole doors and inspection doors, open the fan of the ESP to make the ESP internal part a positive pressure, and brush liquid suds booster on all the weld joint weld at site, such as manhole door, rapper foundation to perform inspection and then correspondent treatment till the joint met the requirements.

3.6.3 Overall air leakage rate acceptance before putting into operation

Before the whole ESP is installed and is ready to be put into operation, the ESP preceded acceptance test by “U type pitot tube detection method”. As the “foam method”, “U type pitot tube detection method” needs to seal the inlet and outlet nozzles, shut down all the hopper gate valve, manhole door and inspection door make the sealed ESP reach different level of positive pressure. And then repeatedly read from the Venturi meter and U type pitot tube. Once the calculated ESP air leakage rate based on the date obtain as above said maintain less than 1%, the air leakage test was done.

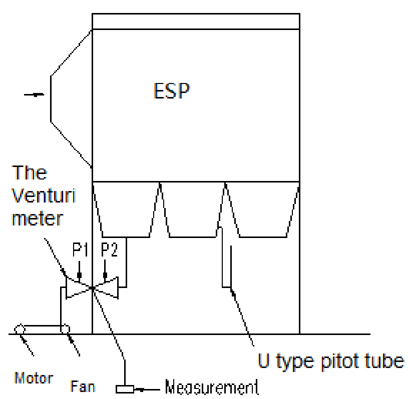

Figure 9 Air leakage rate test arrangement

4. Conclusion

The mating ESPs for Unit 1 & 2 finished installation respectively at August and December of 2012 and have respectively passed 336 hr. full-load trial operation on 12th, Oct., 2012 and 25th, March, 2013. At 6th, April, Boiler 2# was put into use and the boiler operates normally at present. Under the condition of burning Indian local coal of high ash content, the two ESPs operated reliably with good efficiency with all the operating parameters are better than the design values and the turbidity is less than 1%.

The successful operation of ESPs of Boiler 1# and 2# of this project shows that the top electromagnetic impact rapping ESP is able to adapt to the flue gas treatment under the conditions of Indian local coal and ash. This gives the potential Indian owners a good choice except side rapping ESP. And we also obtain a successful typical case for supersize top electromagnetic impact rapping ESP application.

Figure 10 The stack view after Boiler 1# being put into normal operation

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