High Ratio Fabric Filters With 12 m Long Bags for Large Coal Fired Power Plants

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ABSTRACT

For many years, electrostatic precipitators (ESPs) have been used to collect particulate emissions from coal fired boilers. Today, with the need to produce the lowest cost electricity with the lowest possible emissions, coal fired boilers need to have flexibility to burn a wide variety of coals and at the same time achieve very low emissions. In this case the size, cost and arrangement of the ESP becomes very large and plants are now considering the use of high ratio fabric filters (HRFFs) to meet these requirements. While HRFFs have been used to collect particulate emissions from coal fired boilers for many years, designing the filters to meet the required emissions from large 800 to 1100 MWe boiler systems is a more challenging task than for smaller boilers (100 to 600 MWe).

The most effective means to reduce the steel weight and footprint of HRFFs is to increase the bag length, while maintaining, or even reducing, the bag-to-bag pitch. Alstom has more than 20 years experience of 8 m long bags, on-line cleaned, and more than 5 years successful experience of 10 m long on-line cleaned bags in coal fired boiler applications. Alstom Power has now developed a HRFF design with 12 m long bags, and reduced bag-to-bag pitch, for large coal fired boilers, as a continuation of the HRFF design with 10 m long bags successfully launched in 2008.

This paper presents information on key issues that need to be considered when designing and evaluating a HRFF with 12 m long bags for a large coal fired boiler installation. Aspects of gas/dust flow distribution to the individual compartments of the filter as well as the concerns regarding large flow/loading into the bag nest in each compartment will be discussed. A very efficient, newly developed, cleaning system has been incorporated in the filter to clean the bags properly without increasing dust emissions, and allowing the system pressure drop to be kept as low as possible.

Included is also information on several HRFF reference installations in the 800 – 1000 MWe boiler range, as well as data on coal fired boiler reference installations in Australia and South Africa with successful long-term operation on abrasive fly ash at inlet loads similar to those from firing domestic Indian coals.

The reduction in HRFF first cost with 12 m as compared to 10 m long bags, and tighter bag row pitch, is estimated at around 10 %.

Keywords
Fabric filter, power plant, dust emission, pressure drop, flow modelling, pulse cleaning.

INTRODUCTION

HRFFs are gaining market share over ESPs for solid fuel fired power plant applications, for a number of reasons, e.g;

A major advantage of the HRFF is its ability to cope with most fly ashes, with practically no change in the outlet emission. This allows the user to burn a wider range of fuels than would be possible with an ESP. The particulate collection in a fabric filter is not effected by the electrical properties of the ash. The tolerance for variations in boiler operation is larger for a HRFF than with an ESP, provided the gas temperature entering the filter stays above the flue gas acid dew point and at or below the maximum design level. A fabric filter efficiently collects the very finest particles, and may also be designed in such a way that a PM10 or PM 2.5 emission limit can be obtained [1].

Fabric filters offer a distinct advantage for scrubbing with dry sorbents in its capability of further enhancing, as compared with ESPs, the absorbtion process, due to the forced contact with the absorbent on the surface of the bags [2, 3].

Alstom has delivered in-house designed fabric filter systems for power plants on more than 25,000 MWe installed capacity world-wide since 1978. Utilizing the experience of successfully supplying HRFFs with 8 m long bags for more than two decades [4] and longer bags in recent years, the design concepts have been standardized and a number of projects in the 800 – 1000 MWe boiler size range using the recent design standards are now under construction, see further information later in this paper.

The most effective means to reduce the steel weight and footprint of HRFFs is to increase the bag length, while maintaining, or even reducing, the bag-to-bag pitch.

Alstom is currently completing an extensive effort of further increasing the amount of filter area that can be installed in each compartment of a HRFF, by further increasing the bag length to 12 m and, at the same time, reducing the bag-to-bag pitch.

The new HRFF design with 12 m long bags, which is a continuation of the current design standard with 10 m long bags, aims to further reduce the capital cost - as well as offer a smaller footprint due to its more compact design - with no degradation in performance with regard to outlet emission, pressure drop and bag life. The major technical challenges are to achieve low velocities close to the bags (avoiding bag erosion), the same or lower pressure losses, and to ensure that the pulse cleaning system has sufficient cleaning capability for the 12 m long bags and increased bag area per pulse valve. At the same time, the design should be robust enough to withstand normal variation in filter operating conditions, as well as capable of handling extreme conditions.

This paper presents the key aspects of the required HRFF design to address gas and dust distribution and pressure drop issues, as well as the pulse cleaning system design and capacity with 12 m long bags.

Included is also information on several HRFF reference installations in the 800 – 1000 MWe boiler range, as well as data on coal fired boiler reference installations in Australia and South Africa with successful long-term operation on abrasive fly ash at inlet loads similar to those from firing domestic Indian coals.

CLEANING SYSTEM

The performance of the bag cleaning system is an essential part of successful HRFF operation. The quality of the cleaning system has a great influence on:

- bag life
- gaseous and particulate emission
- pressure drop across filter bags
- total energy consumption

The most important design criteria for the cleaning system is to quickly produce a high pressure inside the filter element, by rapidly injecting a large volume flow of pressurizing air against the resistance offered by the filter fabric [6]. A very high rate of volume flow rapidly injected into the filter element is essential to achieve the large cleaning forces required for efficient on-line cleaning of long bags. In the Alstom pulse system design, these requirements are met by using components with low pressure loss, large flow cross section areas, and an optimum geometry, see figure 1. The system is designed to work with a pressure in the pulse tank between 2.5 - 3.5 bar.

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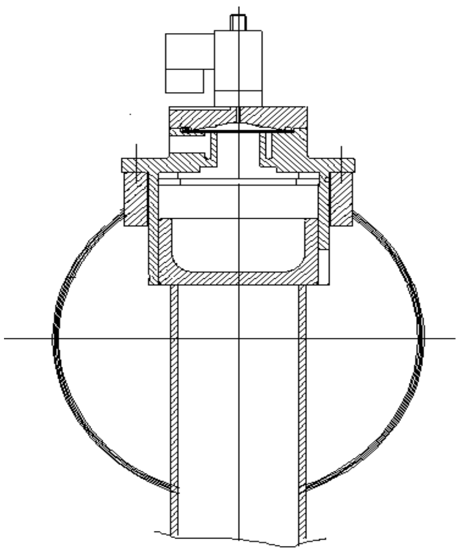

Figure 1. Pulse cleaning system with valve, tank and pulse pipe.

The pulse cleaning system has been developed and continuously improved during the last 30 years, utilizing e.g. a full-scale pulse test rig, where the static pressure inside the filter bag during pulsing is measured using pressure sensors. The test rig is further described in [9].

The cleaning system produces a large flow rate of cleaning air. Peak pressure in the bag is reached in about 10 ms. The high cleaning energy can be utilized in several ways, for example:

- cleaning very long bags and many bags at same time
- on-line cleaning is no problem
- cleaning flexibility as required for process changes

The fast action of the pulse air delivery system results in a minor stretch of the fabric when it is expanded to the circular form. At the same time no bending of the fabric or friction against the cage occurs in this expanded circular form. Hence, the fast, efficient cleaning will have no negative effect on the bag life. On the contrary, it prolongs the bag life by keeping the fabric clean and in full operation throughout the life of the bag. When the pulse pressure across the filter bag decreases to a value less than the differential pressure across the filter bag, the return of the bag towards the bag cage starts. The return force is of the same magnitude as the previous cleaning force if the pulse is cut off in a fast manner (short pulse), and will result in an aggressive landing of the bag on the cage, with abrasion and increased local stress in the bending zones, as well as significant emission peaks due to seepage and straight through PM penetration. Seepage is normally dominating [10].

The negative landing effects of the bag on the cage can be very much reduced by decreasing the pulse pressure gradually in a controlled way to achieve a soft landing of the filter bag on the cage.

Alstom has developed and implemented as standard for more than 10 years the Modulated Pulse Cleaning (MPC) system, to reduce PM emissions and bag wear in connection with pulse cleaning of bags. The MPC cleaning system can be described as a 3 step operation, with a rapid acceleration during the pulse, followed by flushing with a large quantity of air, and finally a slow decrease of pulse pressure to reduce the impact when the bag returns to the cage, see figure 2.

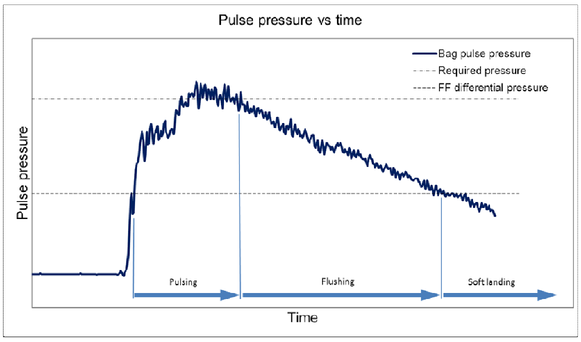

Figure 2. Typical pulse pressure profile vs time, MPC cleaning system.

The MPC system fulfils the important factors for long bag life by a very effective and even cleaning of all of the bags in each row. This is achieved with very low stress on the bag during the whole cleaning action, expansion and return of the bags to the cages.

To enable the new HRFF design with 12 m long bags and increased total bag area per pulse valve as compared to the existing design with 10 m long bags [5], an enhancement of the pulse system performance was a prerequisite.

Prior to initiation of the development work, benchmark design criteria with regard to minimum and maximum bag pressure, as well as the pressure distribution along the nozzle tube were set, based on Alstom Power´s experience. The cleaning pulse must reach all the way to the bottom of the bag, without either excessive pulse overpressure in the top of the filter bag, or insufficient pulse pressure in the bottom portion of the bags in the row.

A systematic investigation of the potential to improve the currently used pulse cleaning system was performed, utilizing flow modelling work with CFD (Computational Fluid Dynamics) transient compressible model simulations, and test rig measurements, as well as dynamic Finite Element Analysis (FEA) for fatigue resistance. Each system component, from pressure vessel to filter bag inlet, was studied to a varying degree, focusing on minimized pressure loss.

A new nozzle pipe design, denoted Radius Nozzle pulse pipe, was developed. The revised nozzle pipe design uses the dynamic part of the pressure to a high extent. The usage of the dynamic pressure decreases the pressure loss between the tank and the bags. The nozzle also provides a homogeneous shape of the jet, which gives a uniform cleaning pressure along the bags also for 12 m long bags, see figure 4.

Pulse system performance measurements, to verify sufficient cleaning power for the increased total bag area per valve for the new FF design with 12 m long bags, were performed, see figure 3 and figure 4.

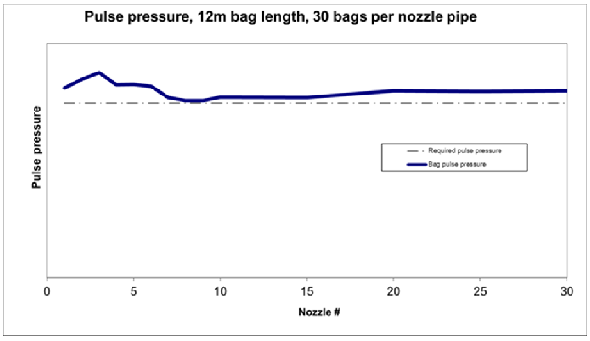

Figure 3. Pulse pressure along nozzle tube with 12 m long bags. Radius Nozzle pulse pipe.

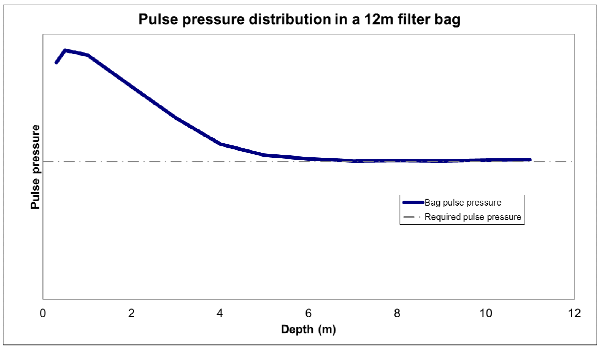

Figure 4. Pulse pressure along the depth of a 12 m long bag. Radius Nozzle pulse pipe.

The results from these tests confirm that the benchmark design criteria have been met, and that approximately 20 % more bag area per pulse valve can be efficiently cleaned.

GAS DISTRIBUTION DESIGN

Proper gas distribution into each bag nest in each compartment of the filter system is essential in order to facilitate on-line cleaning of long bags, and to achieve long bag life. In the Alstom Power HRFF design the raw gas enters the filter compartments from the inlet distribution plenum via inlets equipped with guide vanes to direct the gas towards the upper section of the filter bags. This arrangement creates a downward gravimetric gas flow along the filter bags, assisting ash transport into the hopper at cleaning of the bags. The optimized gas distribution system further ensures that local high approach velocities of the gas/ash mixture are avoided at the filter bags, which is very important to avoid erosion damages on bags and to achieve long bag life.

The new HRFF design was targeted to use 12 m long bags, and in addition, a reduction in the bag row pitch of around 10 %. This required the development of a revised gas flow design, as a continuation of the current HRFF design [5].

Benchmark design criteria with regard to velocities in the inlet plenum and dampers, and velocities close to the filter bags were set, based on experience. Likewise, design criteria for the mechanical pressure drop were established, based on experience and contract requirements.

Extensive flow modelling work with CFD and physical modelling, was performed to develop the gas flow design.

The aim of the model testing was the following:

1. Verify and tune the design of the inlet distribution plenum, dimensions, inlet dampers and the design of guide vanes, taking into account the risk of dust accumulations.
2. Verify and tune the maximum gas velocities, approaching the bag nest, at the bag face and in-between the filter bags, not to exceed certain criteria.
3. Minimize the mechanical pressure drop from the common inlet duct to the filter bag plane.
4. Verify the design of the outlet gas flow path, including pulse tubes.
5. Minimize the mechanical pressure drop, from the bag plane to the common outlet plenum, including the restriction of the pulse tubes and the outlet dampers.
6. Verify that the design is robust with regard to varying velocity profiles throughout the system.

The flow modelling was performed at a typical gas-to-cloth (G/C)-ratio for power plant applications, 75 m/h (4.1 fpm).

In order to optimize the flow modelling work, physical scale model testing and CFD analysis were planned and performed to complement each other, utilizing e.g. the large experience base gained from the development work for the previous HRFF design [5].

CFD was the main design tool, and was utilized for modelling and optimizing of the ducting arrangement, as well as modelling of a single FF compartment with detail studies of the flow arrangement inside the compartment. Physical scale model testing was then performed to confirm and fine-tune the design derived from the initial CFD modelling.

Finally, a final round of CFD modelling utilizing the results from the physical scale model testing was performed to arrive at the final, recommended design.

CFD modelling, using ANSYS CFX software, was done on a single FF compartment model, see figure 5 , on an inlet plenum consisting of inlet duct and inlets to 3 compartments. One compartment including filter bags was fully modelled, and the other two compartments were represented with an outlet and a fixed flue gas flow. The CFD model, and the physical flow model, reflects a FF design with 2 rows of compartments, each row with 3 compartments, i.e. in total 6 compartments, with 1200 bags in each compartment.

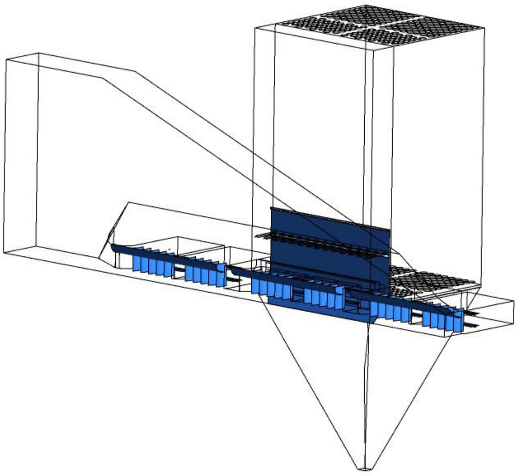

Figure 5. One chamber CFD-model.

Figures 6, 7 and 8 illustrate the flow pattern and velocities for the recommended design from first round of CFD analysis. Among the newly developed gas distribution devices was a progressive bar grid to improve the velocity profile in side inlet duct.

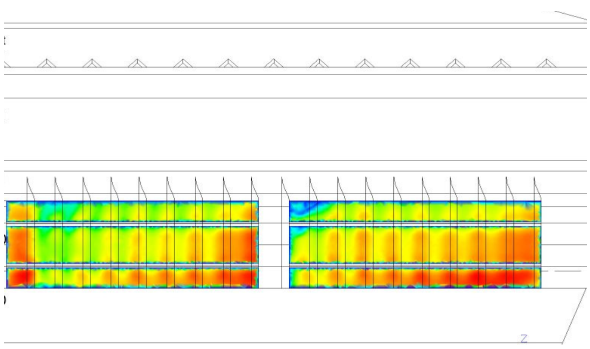

Figure 6. Flow pattern in inlet plenum. First round CFD design.

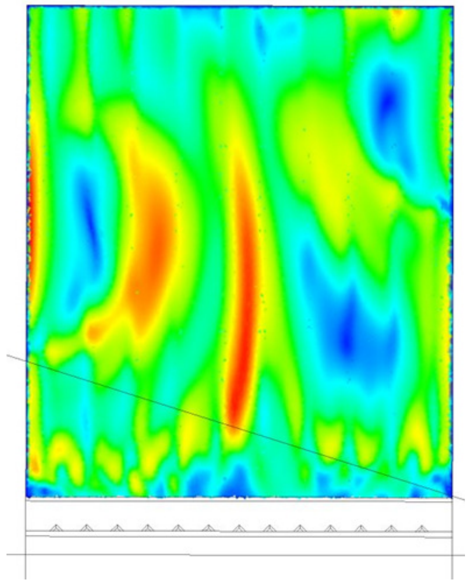

Figure 7. Velocities close to the bag nest. First round CFD design.

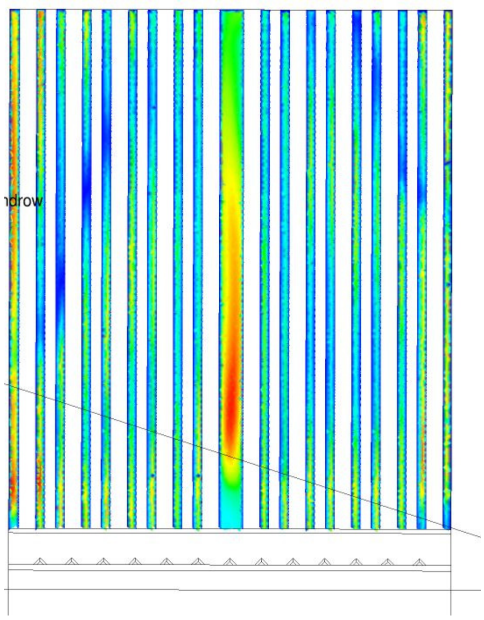

Figure 8. Velocities between first and second bag row . First round CFD design.

The physical model, see figure 9 and figure 10,   was built in scale 1:8.44, with perforated plastic tubes used to simulate the filter bags. One compartment of the FF is modelled. In full scale, there are 1200 bags per compartment. All required internals such as guide vanes, dampers and structures have been represented in the model. The model chamber and the chamber bypass duct are connected to a permanent flow exhaust system by separate calibrated venturi meters for flow control. The bypass duct is adjusted to have the same pressure drop as the filter chamber, and simulates the flow to the two chambers downstream of the tested chamber.

Figures 11, 12 and 13 illustrate flow patterns and velocities from the physical flow model testing.

Figure 9. Physical flow model, Växjö, Sweden.

Figure 10. Physical flow model with perforated plastic tubes.

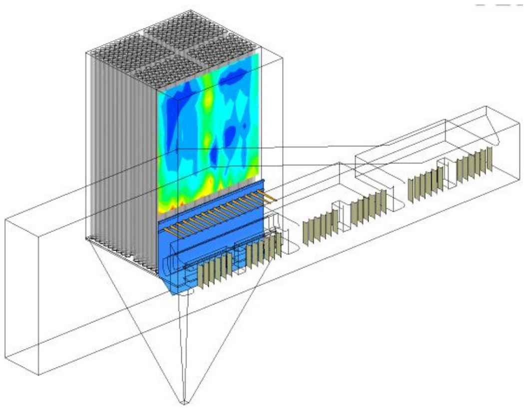

Figure 11. Velocities close to the bag nest. Physical flow model.

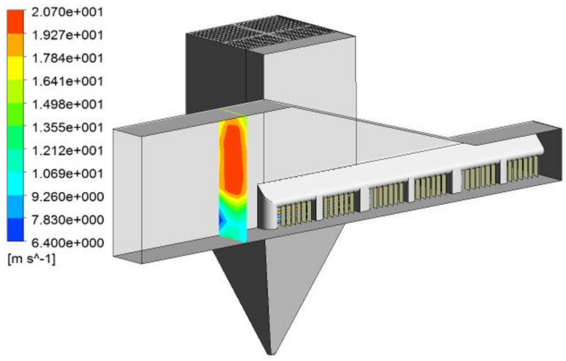

Figure 12. Skewed inlet velocity profile, robustness test. Physical flow model.

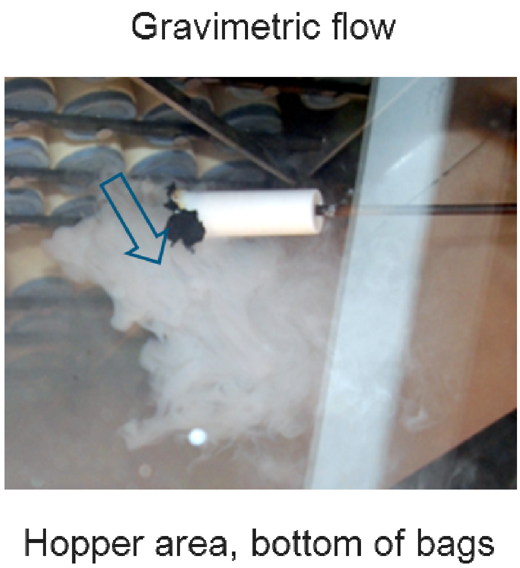

Figure 13. Smoke test photo to verify gravimetric direction of flow in the bag nest. The arrow indicates the observed smoke flow direction from the bottom part of the bags down into the hopper area. Physical flow model.

Figure 14 and figure 15 illustrate the flow pattern and velocities for the final, optimized FF design with 12 m long bags and a reduction in the bag row pitch of around 10 % as compared to previous design [5].

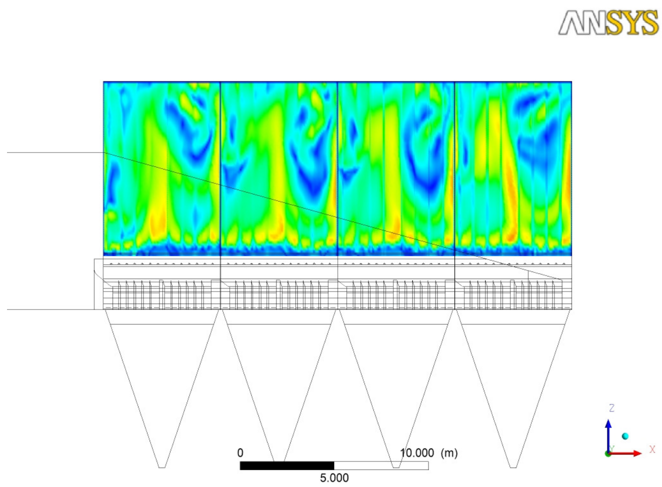

Figure 14. Velocities close to the bag nests. Final FF design.

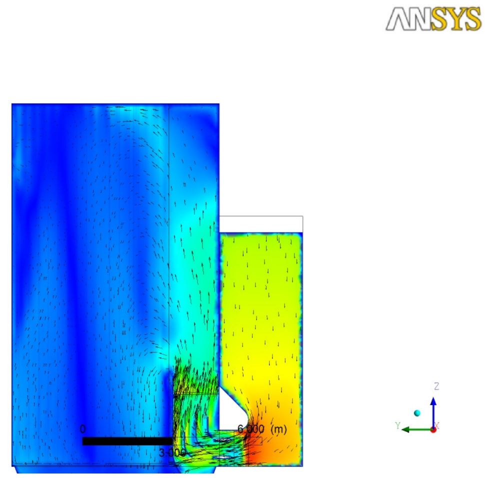

Figure 15. Gravimetric flow in bag nest. Final FF design.

A gravimetric flow pattern in the bag nest is achieved, and all other benchmark design criteria have been met.

NEW HRFF DESIGN

Catia dimensional parametric design was used to develop design drawings, see figure 16.

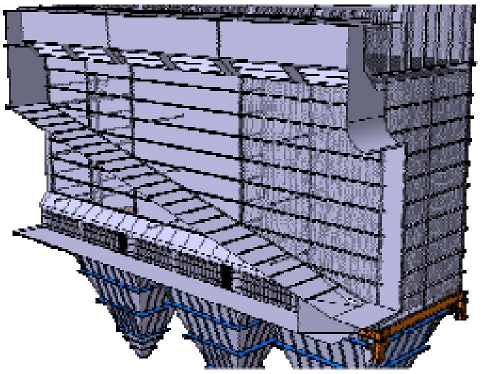

Figure 16. New HRFF design with 12 m long bags and tighter bag row pitch.

The preferred and recommended clean gas plenum design is of walk-in-plenum type, see figure 17. A top door design is however also available.

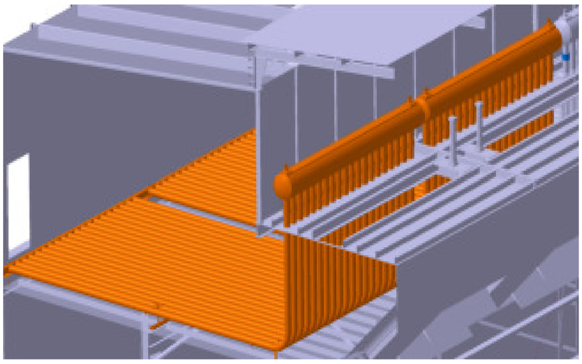

Figure 17. Clean gas plenum type walk-in-plenum, with upgraded pulse cleaning system.

The estimated reduction in HRFF first cost with 12 m as compared to 10 m long bags, and tighter bag row pitch, is significant, around 10 %.

REFERENCE PLANTS

The present HRFF design [5] has enjoyed considerable market success on large coal fired boiler plants. There are a number of reference installations in the 800 – 1000 MWe boiler range with 10 m long bags. These plants include;

- Linkou, Taiwan – 3 x 800 MWe
- Talin, Taiwan – 2 x 800 MWe
- Sandy Creek, USA – 1 x 900 MWe
- Tanjung Bin, Malaysia – 1 x 1000 MWe
- Manjung, Malaysia – 1 x 1000 MWe

The Sandy Creek plant in Riesel, Texas, has been successfully commissioned. The other plants are under construction.

Manjung will be South East Asia's first 1000 MWe supercritical coal fired power plant. The unit will produce enough electricity to power nearly 2 million households in Malaysia.

The 1000 MWe Tanjung Bin power plant is Alstom Power's second turn-key contract for a supercritical coal fired unit in Malaysia, following the order to build the 1000 MWe Manjung power plant.

The Linkou and Talin power plant renewal projects are developed by Taiwan Power Company.

The HRFFs for Linkou, Talin, Manjung and Tanjung Bin are all positioned downstream the air preheater, to effectively remove fly ash before the flue gas enters the Sea Water Flue Gas Desulphurisation (SWFGD) wet FGD systems. The HRFF particulate matter emission guarantees are down to 7 mg/Nm^3 dry gas.

Domestic Indian coals are characterized by low sulphur content (< 0.5 %) and high ash content (~ 45 %), which leads to high inlet dust loads, typically in the range of 45 – 50 g/Nm^3 wet gas at the FF inlet.

Alstom has, for more than 20 years, successfully been supplying greenfield and brownfield HRFF plants to utility customers in Australia and South Africa on abrasive fly ash from low sulphur, high ash coals, at inlet loads very similar to those from firing domestic Indian coals and boiler sizes up to 750 MWe [4, 7]. Bag life in excess of 40 000 operating hours has been achieved with high performance bag materials on several plants, as detailed below.

Kogan Creek is a 750 MWe supercritical base load duty boiler in Australia, figure 18. The boiler was delivered by Babcock

Hitachi Kure, Japan, and was commissioned in May, 2007. Local high ash, low sulphur coal is fired. The design FF inlet dust load is 39 g/Nm^3 wet gas for the guarantee coal and 48 g/Nm^3 wet gas for the worst coal. The bag material is (PI + PPS)/PPS needlefelt, areal weight 600 g/m^2. The original set of bags achieved a bag life of > 40 000 operating hours with a low accumulated bag failure rate. The HRFF at Kogan Creek comprises around 16 500 filter bags.

Figure 18. Kogan Creek HRFF, 750 MWe, Australia.

Arnot Power Station is a 6 x 350 MWe boiler plant in South Africa with base load duty, figure 19. Local high ash, low sulphur coal is fired. The FF inlet dust load is in the range of 45 – 50 g/Nm^3 wet gas.

Figure 19. Arnot Power Station, 6 x 350 MWe, South Africa. HRFFs on Unit 1 – 3. ESP to HRFF retrofit.

Units 1 – 3 were converted from ESPs to HRFFs in 2004 – 2005. The total number of bags is around 41 000 pcs.

The bag material is (PI + PPS)/PPS needlefelt, areal weight 600 g/m^2, of the same quality as installed at Kogan Creek in Australia. It is to be noted that the bag supplier supported a bag life warranty of 40 000 operating hours/5 calendar years from start-up.

This warranty was met. Actual bag life for Unit 1 was 44 000 hours, for Unit 2 > 45 000 hours, while the bags were preventatively changed at 39 000 hours for Unit 3. The accumulated bag failure rate was very low, << 1 %, for all 3 units.

The successful HRFF operating experience, with very long achieved bag life, from South Africa and Australia, has made stand-alone HRFFs the preferred future choice for Eskom when upgrading the APC equipment for the existing fleet of coal fired boilers in South Africa. The bag quality installed at Arnot is also installed at following HRFFs on coal fired boiler plants in South Africa [7, 8]:

- Camden Power Station (8 x 200 MWe)
- Grootvlei Power Station (3 x 200 MWe)
- Hendrina Power Station (2 x 300 MWe)
- Duvha Power Station (3 x 600 MWe)

CONCLUSION

Due to the increasing market demands for HRFFs for power plant applications, suppliers need to provide properly designed, efficient, cost effective HRFF designs. The major technical challenges with more compact and cost effective designs are to achieve low velocities close to the filter bags - to avoid bag erosion - the same or lower mechanical pressure losses, very low emissions, and to ensure that the pulse cleaning system has sufficient cleaning capability for the longer bags and increased bag area per pulse valve.

Alstom has developed a new HRFF design, with 12 m long bags, and reduced pitch between bag rows, meeting these technical challenges and fulfilling all benchmark design criteria.

Comparisons with the current standard HRFF design indicate a reduction in first cost of around 10 %.

The present HRFF design has enjoyed considerable market success on large coal fired boiler plants. There are a number of reference installations in the 800 – 1000 MWe boiler range with 10 m long bags.

Alstom has, for more than 20 years, successfully been supplying stand-alone HRFF plants to utility customers in Australia and South Africa on abrasive fly ash from low sulphur, high ash coals, at inlet loads very similar to those from firing domestic Indian coals and boiler sizes up to 750 MWe. Bag life in excess of 40 000 operating hours has been achieved with high performance bag materials on several plants.

Alstom is actively promoting the new design with 12 m long bags for large coal fired boiler applications.

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