THE MOST PERFORMING EXISTING FILTER ON COAL-FIRED POWER PLANTS, TORREVALDALIGA NORD (ITALY)
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Generality
In the frame of the conversion to coal of the existing Torrevaldaliga Nord power plant (ENEL), 3 new hyper-supercritical boilers have been installed and started-up from 2008 to 2010.

In 2005 Termokimik received the order for the FF; this technology was selected for particulate removal due to the very low limit of 10 mg/Nm$^3$ and to the requirement to use several types of coals and strong limitations in the available plan. During the execution of the contract, the requirement became significantly more stringent due to modifications in local permits and a new target of 6 mg/Nm$^3$ was fixed, thus leading to significant modifications in the design of the filters including the use of more advanced fabrics. In the following the final configuration of the filter is analysed in detail.

Technical characteristics of Torrevaldaliga FF
Each boiler is equipped with a bag filter with a twin-body, each with a central duct for gas inlet/outlet. Each body has 8 independent bag compartments, each equipped with isolation dampers to allow maintenance activities to take place even during boiler’s operation.

Each FF is therefore composed of 16 compartments and 13,824 bags, with a diameter of 144 mm and a length of 8,015 mm, for a total filtering surface of more than 50,000 m$^2$. The efficiency in terms of filtration for such large units can be guaranteed only by means of an accurate fluid dynamic study of the internals, in order to achieve an even distribution of flue gas to all compartments and the correct collection of removed particles inside the hoppers of each sub-unit, thus avoiding undesirable turbulence and re-entrainment phenomenon.
Plant’s short description

Each boiler unit has its own flue gas line, divided into two semi-sections each located downstream a dedicated air preheater. Therefore, two separate gas ducts and two separate filter’s bodies, working in parallel, have been foreseen. Moreover, along the inlet ducts, an equilibrium duct equipped with a regulating damper has been installed. Each body is composed by 8 independent compartments, fed by a central raw gas duct and feeding a clean gas discharge duct, as shown by the following pictures. Each compartment can be isolated by means of dedicated flag inlet dampers (two) and dedicated outlet poppet dampers (three), always having the possibility to carry out maintenance activities and/or substitution of damaged bags without stopping the plant or decreasing boiler load. As a matter of fact, the plant has been designed to operate at full load even if one compartment is out of service.

As in Fusina, bags cleaning system is a high pressure, low volume, pulse jet type (PJ HP/LV), in which the air is fed through a nozzle positioned on bag axis. The concentrated jet of pressurized air, from the top to the bottom of the bag, provokes ash fall inside the hopper, both due to sudden fabric expansion and to air counter-flow from inside to outside, i.e. in the opposite direction of flue gas flow. Cleaning system is “on-line” and therefore bags cleaning is carried out while the bags themselves are in operation. Three poppet valves for dilution air inlet have been installed on the inlet duct of each semi-section to protect filtering bags from very high temperatures in case of boiler and/or air heaters failure; moreover, four poppet dampers have been installed on the oblique wall separating raw flue gas from clean flue gas, in order to allow a complete by-pass of the filter body.
Design criteria

In this project, binding design requirements are constituted by the area available at site to install the filter and by the maximum allowable pressure drop between Ljungstroem outlet and fabric filter outlet, equal to 2.4 kPa. The flue gas filtration mechanism that foresees the passage of flue gas through a fabric is rather simple, but when the emission target becomes so ambitious, each small detail becomes critical. Particularly, both filtering material and bag construction technology have a great influence on filter’s performance, so as cleaning pressure, opening time and sequence, flue gas flow distribution, temperature distribution, coal characteristics, etc.

Referring to the bags, in the past the most utilized material for coal fired power plants was PPS (polyphenilensulphide), the same used in Fusina. For Torrevaldaliga the performances of standard PPS bags were not acceptable and new generation bags were required. It is important to consider that bags performances in terms of filtration are related to the fabric type but also to how the fabric itself is produced and namely:

• Specific weight
• Diameter of the fibres
• Surface Treatments
• Coatings

Recent technological innovations allow obtaining a PPS having a finer diameter (trilobal PPS), thus ensuring lower emissions. Additionally, the most up-to-date technology foresees a mix between PPS and P84 that, other than further improving the emissions, enables also an easier cake removal.

Therefore, on the basis of the above described evolution of bag fabric, Torrevaldaliga Nord bags are made of PPS trilobal / Polyimide microfiber blend needle felt, with PPS supporting tissue and PTFE finish surface treatment.

Once filter structure, filtering surface and suitable bag type have been selected, TKC has driven its design efforts on system fluid dynamic study.

The target of 2.4 kPa as maximum allowable pressure drop was established for the whole filtering system (from APH to FF outlet flange); since filtration efficiency increases with $\Delta P$ on the bags, one of the main goals of TKC’s fluid dynamic study was to limit global pressure drop on the whole system in favour of a higher $\Delta P$ on the bags.

It is important to highlight the fact that operating a filter having a high $\Delta P$ allows also to diminish bags’ cleaning operations frequency; this means less stress on bags’ fabric itself, so that they are able to maintain their filtering performances for a longer period of time.

The correct dimensioning of filtering surface and the use of the best available technology concerning bag material are essential aspects, but they alone are not enough to guarantee plant performances and reliability; in fact, almost 2 million Nm$^3$/h of coal combustion gas will have to be evenly distributed among filter compartments and, inside each compartment, said gas should have a behaviour that smooths the ash deposit on the hoppers.

For this reason, flow distribution inside the FF has been deeply analysed and optimised with the aid of computerised fluid dynamic simulation (CFD).

| Nominal weight | 630 g/m$^2$ |
| Surface layer | P84 / PPS trilobal composite |
| Next layer | PPS |
| Scrim | PPS |
| Inner batt | PPS |

The felt construction details
Thermal profile at filter’s inlet
As gas at fabric filter body inlet comes from the correspondent Ljungstroem, a non-uniform gas temperature at interface section has been envisaged. Said uneven distribution has to be levelled out before filter body inlet so that a flue gas having the same temperature could be evenly driven into the various compartments.
Termokimik’s fluid dynamic model has enabled to point out the ideal configuration for a low pressure drop static mixer, an effective solution in terms of thermal profile rectification at filter inlet.
The result obtained is +/- 7.5 °C with reference to the average value, against a thermal stratification on gas delivery section equal to +/- 35°C.
Moreover, inlet duct fluid dynamic optimization allows using internal profiles as well as internal baffles apt to even out flue gas velocity profile and to avoid areas of undesired ash deposit.

Fluid dynamic study
CFD has been used to:
• Level out thermal profile of combustion gas coming from Ljungstroem;
• Equally distribute flow rate among 8 compartments;
The plant at Padua thus represents the state-of-the-art in the field of recovery of energy from waste, with significantly lower emissions if compared to almost all similar existing facilities and therefore represents a step toward the alignment of the Italian waste management system with the best European standards.
• Give to the gas inside the compartment a motion suitable to ash separation through cleaning;
• Minimize pressure drops during change of directions and shrinkages;
• Evaluate influences of duct structures downstream the filter on fluid dynamic behaviour of the filter itself.
Equal distribution of gas flow rate inside compartments

Duct structure inside filter body as well as the related openings (2 for each compartment) at compartment inlet have been optimized so that it is possible to equally distribute treated flue gas on each compartment. The selected architecture allows an even bag “average fouling” on the different compartments.

Flue gas fluid dynamic behaviour inside the compartment

Flue gas coming from inlet duct inside body filter enters the compartment through 2 flag valves (completely open). One special screen is positioned at flue gas inlet so that the flue gas does not run directly over the side of those bags which are nearer to flue gas inlet. In this case, screen structure has been thoroughly investigated, in order to come up with a configuration that allows deviating 95% of inlet flow rate towards the top of the bag. This solution is aimed at obtaining a downflow stream, making ash deposit on bottom hopper during in-line clearing operation easier and thus limiting the re-entrainment of fine ash as observed in Fusina. Moreover, screen structure foresees a minimum opening towards the hopper, allowing to a 5 % residual flow rate to maintain the hopper side clean and to discharge gross particulate, without bringing it inside the compartment.

Pressure drop

As already stated, reduction of pressure drop of the whole system (filter + ducts) allows a better use of the bags both in terms of bag performances and of bag life. The model applied has enabled to select and to position suitable baffles in correspondence of sudden direction changes (inlet duct, gas inlet compartment section) to minimize turbulences and therefore limiting pressure drops; moreover, also passage sections of inlet/outlet duct inside the filter have been studied and clean gas plenum has been increased by 200 mm in height compared with traditional design.
Ducts influence downstream filter
Given the strategic importance that the FF has on the whole coal reconversion project of Torrevialdiga Nord power plant, Termokimik has simulated fluid dynamic behaviour of clean flue gas ducts downstream filter. Said simulation was aimed at evaluating influences on plant technical solutions applied downstream the filter itself, if any. Said study does not highlight any significant modifications on fluid dynamic behaviour already evaluated on filter system out without considering downstream plant configuration.

Components
It goes without saying that bags, cleaning system, isolation and by-pass dampers have to be of the highest quality and they must ensure both the best performance and the most reliable operation. In this regard, the attention was focused on dampers, because for each FF, 32 flag dampers and 48 poppet dampers have been installed. As said components are rather numerous and as they play a very important role on plant reliability, Termokimik has directly designed and constructed those dampers after testing their prototypes thoroughly tested.

Functional tests on prototypes have been carried out in order to ascertain if said dampers are able to intercept gas at design temperatures and for a number of cycles adequate to the service to be carried out. After dimensional and flatness checks have been carried out on prototypes, tests’ configurations of both flag and poppet damper have been prepared according to the following representation.

Basically, after having been heated up to 180°C through to an air heater (recirculated on the prototype itself) and to gas torches, the prototype has been tested for 1,000 open/close cycles, controlling that operating time would not slow down or that the working gear operates correctly. After hot functioning test, the prototype has been subjected to subsequent cooling and heating cycles, in order to simulate effective plant working conditions in case of thermal-electric group firing-up and shut-down.

Once cooling/heating cycles ended, the damper has been tested once again, in order to ascertain problems on mechanical handling devices (if any) because of deformations on the damper due to temperature variations. In the end, the prototype has been heated once again up to 180 °C, pressurized at 90 mbar on test cell side and the time necessary to reduce by half the pressure has been measured in order to evaluate the effective damper leak-tightness degree. Therefore, thanks to prototypes tests, it has been possible to modify and to adjust several constructional details such as opening leverage structure, contact surface body/blade, etc. so as to obtain an efficient and reliable standard, that has then been series-manufactured to satisfy the requirements of such an important project.
Operating Experience
Although still limited in time, the filters in Torrevaldaliga Nord have been now in operation for more than twenty thousand hours and the results are excellent both in terms of emissions and of all the other guarantee parameters (temperature distribution, electrical consumption, equipment and components reliability, etc). Analyses of the main operating parameters are still running, as in the Fusina case, to check the behavior and the evolution of such parameters and to verify possibilities of further technological improvements.

Conclusion
In the last years significant reductions in the emissions limits for coal-fired power plants have occurred all over the world and particularly in the EEC countries. As far as particulate emissions are concerned, the possibilities to improve emission abatement are basically limited to upgrading the existing ESPs or to convert them into FFs. At the end of nineties, specific site constraints have created a favorable ground for the conversion of existing ESPs into FFs in Italy (first Fusina and then Genova). The positive operating experience created the basis for the decision to install FF on 3 new boilers (Torrevaldaliga Nord) and for another important ESP conversion in 2010-2011 (Brindisi Sud - 2x660 MW). The FF allows the power plants to use a wider range of coals and provides the possibility to treat other pollutants such as mercury if and when such treatment becomes an issue. The reasons that lead to the choice to use FF instead of ESP, both for new plants and for upgrading, can also be present in countries other than Italy and South Africa, where FF are now massively used. For instance, Termokimik was awarded in 2009 the contract for a new FF on an 800 MW coal fired boiler in Mainz-Wiesbaden (Germany). Even if the project is on hold, the choice to use FF in a country traditionally ESP-oriented is considered an important signal which is encouraging TKC efforts to further invest in the development of this technology which is nowadays a consolidated and serious alternative to the traditional ways for particulate collection.