Consideration of Frequent Low Loads Operation for Electrostatic Precipitator Installation

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Abstract. For the design of an installation for particulate removal from flue gases containing an Electrostatic Precipitator (ESP), associated flue gas ducts and dust handling system, there are a number of factors affecting the optimal configuration. Nowadays there are required installations with ESPs for ultra-low emissions and to be able to operate with greater variation in gas flows, chemical composition, operating temperatures and dust quality.

The detailed design of the installation must consider the technological and structural aspects.

Technological aspects comprise of operating parameters as flue gas volume flow in actual conditions, flue gas and particulate analyses, changes of temperatures, pressure and other process fluctuations to determine particle properties and risks of condensing gaseous compounds into liquid or solid state and its related effects as corrosion, sticky dust and final particulate emission.

The structural design must consider a combination of a number of forces generated by wind, snow and collected dust loads, under or over pressure in the installation and must include risks for exceptional conditions of temperature, pressure and earthquakes. Design features should be included to minimise any potential detrimental effects in order to ensure operational ability and safety. Typical models for the ESP and flue gas ducts designs accurately predict performance for balanced conditions for a relatively narrow operating window, but for enlarged ranges of operation loads - in the case that the volume flow of gases at maximum load may be 3 times higher than flows frequently achieved at low loads – there are more challenging tasks.

Keyword: Sticky dust· Flue gas ducts· Process fluctuations· Low loads

Introduction.

Electrostatic fields created in ESPs are used in different industrial processes for the efficient removal of solid particles from aerosols. Depending on the composition of the gaseous mixture and the collected solid particle layer properties, which are different in each process, the applied ESPs have different mechanical and electrical configurations to meet the required outlet emission [1- 3].

Some ESP suppliers have developed rules for design, erection and successful operation of the ESP for a given process application.
There are a number of recommendations with consideration to specific conditions and collected dust properties at operating temperatures.
Important parameters are:

- Flue gas temperature.
- Required range of gas flow in actual conditions.
- Moisture content in flue gas.
- Sulphur dioxide (SO_2) and sulphur trioxide (SO_3) concentration (SO_2/SO_3 conversion rate).
- Temperature of Acid Dew Point (T_{ADP}).
- Presence of Ammonia, Ammonia Bisulphate.
- Inlet dust concentration.
- Collected dust properties:
  a) chemical composition,
  b) dust size distribution,
  c) bulk density of dust,
  d) pack density,
  e) hygroscopic properties,
  f) dust absorptivity,
  g) hardness,
  h) stickiness,
  i) flowability,
  j) abrasiveness,
  k) corrosiveness.

More detailed information about dust parameters and their test methods are well described in publications: [4-8].
The dust properties dictate what inlet gas ducts configuration and which ESP bottom arrangement should be used:

- a pyramid bottom hopper with required inclination angle of walls (valley angle),

- a through bottom hopper with a screw or with a chain conveyor,
- a flat bottom with a scrapper.

Also, the collected dust evacuation from the bottom of the ESP must be adequate.

Moisture in combustion gases.

Moisture content in dusty flue gases have a strong influence for the quality of separation of dust particles in the electrostatic field. At very low moisture contents in the gas mixture, the collected dust layer shows high resistivity and the process of electrostatic precipitation is more difficult. At high moisture contents, the collected dust layer absorbs moisture decreasing resistivity and depending on the temperature there is a risk of water vapor condensation. In case of the gas mixture containing of gaseous SO_3 there is a risk of acid condensation in amounts depending on concentration of moisture, SO_3 and temperature.
Concentration of water vapor and gaseous SO_3 in dust free gas mixture determine the T_{ADP} [9].

In the dust free wet gas mixture at saturation point, nucleation of water can be initiated by the presence of electric charges [10].

In an ESP there are high amounts of electric charges and solid particles acting as vapor nucleation centres effectively increasing T_{ADP}.

Water vapor can very easily penetrate the whole volume of the dust collector – also in places with no intensive gas flow. In places of an ESP, where there is no intensive flow of hot gases, steel elements might have a lower temperature. If locally the temperature is close to T_{ADP} there is a risk of moisture condensation on the surface of those elements.

In some places a small amount of water might condense that is fully absorbed by collected dust and it is not causing problems (e.g. dust layer stays as a semi dry - loose material and it can be easily dislodged from the ESP).

If in some places the condensed water amount is higher than the dust layer absorbed, it can become wet and create structures which are more sticky or create lumps.

In the case that the amount of condensed water is higher than the amount of collected dust able to absorb water, then liquid water on the surface of steel elements can cause corrosion (if the element is not stainless steel). Presence of SO_3, HF and HCl in combustion gases creates a higher risk of acid condensation that intensify the corrosion process.

ESP operation at temperatures of flue gases at the inlet close to T_{ADP} in some conditions allow to improve dust collection efficiency [11-13], however, it is only successful at full boiler loads.

A higher moisture in combustion gases from biomass and presence of more hygroscopic components in the fly ash make the conditions for moisture condensation easier [14-16].

Gas and temperature distribution inside the ESP.

Temperature distribution inside the dust collector strongly depends on the distribution of hot gases inside the dry ESP. Influence of gas distribution quality for ESP performance has been discussed extensively in the literature [17-26].

To eliminate the risk of moisture condensation and the risk of getting wet dust layers it is recommended to have higher temperature than T_{ADP} in the entire volume inside the ESP.

For many years some ESP suppliers used different configurations of gas distribution elements to get a non-uniform flow of hot gases inside the ESP. Based on numerical modelling, the collecting efficiency for non-uniform flow was expected to improve [27-32]. An achieved skewed flow in the ESP many times was good enough but only when the boiler operated at full load, e.g. close to 100% of Maximum Continuous Rate (MCR).

To find out an optimal configuration of the ESP and related flue gas ducts, computer simulations were used with a number of assumptions and simplifications for a set of dominating phenomena to get results in a reasonable time. Results from numerical modelling were often verified on laboratory models built for conditions in relation to the expected operation of installation at high loads.

Frequent low loads of the installation.

A number of boilers are rebuilt and modernized so that they are able to operate in greater variations of loads – the new minimum load is drastically decreased.

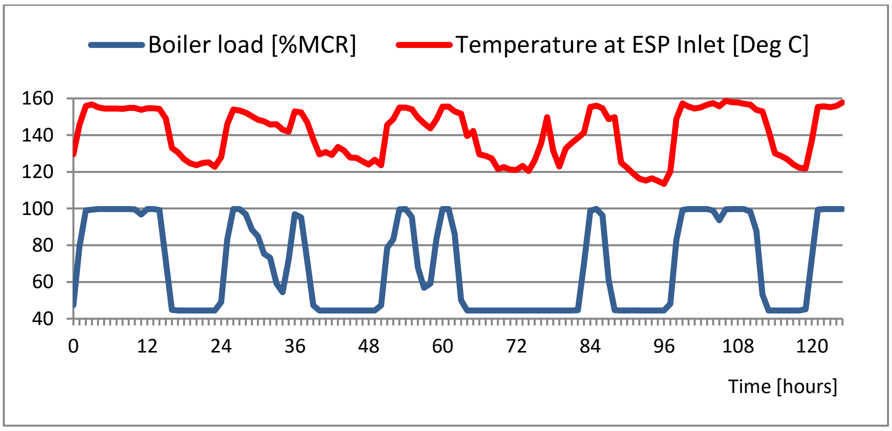

Fig . 1. Example trends of coal fired boiler load and flue gas temperature at the ESP inlet.

A prolonged operation at boiler loads lower than 45% MCR is not unusual. In some power plants in Europe, where there are no systems for energy storage, operation at minimum boiler load occurs every day for 8 - 12 hours. Operation trends as in Fig. 1. are observed almost on every power boiler capacity 200-240 MW; 360 MW; 500 MW; 900-1000 MW in Poland. In the moment of minimum boiler load the volume flow of combustion gases is much lower and usually their temperature at the ESP inlet is lower.

If for example the ESP is originally designed for conditions with the maximum boiler load and the average gas velocity inside the ESP achieved on level 0.80 m/s then at minimum load (45% MCR) in the ESP the gas velocity will be lower than 0.27 m/s in actual conditions. In this situation the gas distribution quality inside the dry ESP will not be as required – with a risk of getting large dead zones (e.g. zones with hot dusty gases with flow velocity close to 0,0 m/s but with water vapor transfer by diffusion). Therefore, in the dead zone there is a process of moisture condensation on the surface of locally colder collecting plates and no dust which can dry electrodes and cause intensive corrosion as observed in Fig. 2.

Fig 2. Corroded electrodes in second fields of ESP's with skewed flow model and frequent low boiler loads.

Often operation for a prolonged time at minimum boiler load drastically decreases the ESP lifetime, previously from decades to only a few years.

In coal fired boilers, coals containing different compositions of mineral parts and sulphur are used. The present combustible sulphur in the fuel produces sulphur dioxide (SO_2). Sulphur dioxide in combustion gases is partly converted into sulphur trioxide (SO_3) on the surface of the solid ash particles [33]. The rate of conversion of SO_2 into SO_3 depends on the composition of the mineral part of the fuel especially the concentration of Iron (Fe), Vanadium (V) and other elements which acts as a conversion catalyst. For an increased amount of coal fired boilers there are installations of Selective Catalytic Reactors (SCR) for nitric oxides (NO_x) removal. There is ammonia (NH_3) injected into the combustion gases in a little higher than stoichiometric quantities - which gives ammonia slip. The side effect of typically used catalysators is additional conversion of SO_2 into SO_3 with rate 1.0-1.5% (the catalysator becomes older, the effective conversion rate of SO_2 into SO_3 increases). The higher the concentration of SO_3 in combustion gases, the higher the T_{ADP}.

In operation of the ESP where all the following conditions are met:

a) low boiler load,
b) low gas temperature at inlet of the ESP,
c) biomass fired with high sulphur coals,
d) SCR installation,

the fly ash becomes easier to collect in the electrostatic precipitator. In addition, the SCR gives the effect of dual flue gas conditioning processes (ammonia slip and increased SO_3 concentration) [34]. When the collected dust becomes wet it is more problematic for the typical ESP configuration and its critical elements lifetime is shortened. The typical lifetime of moving elements like rotating shafts with rapping hammers and shaft bearings is shortened from 2-5 years to a few months for operation in conditions with moisture condensation. In some cases, using bearings and shafts made from more wear resistant materials helps slightly but often there is still more maintenance required and replacement of wearing parts.

During the last decade new boilers have been built with the ability to operate with loads in the range 40 - 100% MCR. They were equipped with horizontal flue gas ducts before the ESP, which was believed to be the most economic configuration. Moreover, in flue gas ducts sized for an average gas flow velocity 13 – 16 m/s at maximum boiler load, operating at conditions of minimum loads will be achieved at a velocity lower than 7 m/s. This makes the system much more sensitive to drop out coarse dust particles from the gas stream in the horizontal part of the gas duct. Generally, it is recommended to keep gas flow velocities in the gas duct before the ESP not lower than the minimum established for the given process application. The minimum velocity depends on particle size distribution, dust properties and flowability. For different process applications there are recommended different minimum velocities at inlet, from 8.0 m/s up to 11.0 m/s.

Fig 3. Example of horizontal inlet gas duct before the ESP of coal fired boiler.

There is shown in Fig. 3. an example of a flue gas duct configuration with horizontal ducts before the large ESP of a coal fired boiler, which should be able to operate with loads in range 40 - 100% MCR. This boiler operates often at minimum load and needs frequent shut down (every 6 - 8 weeks) for manual removal of accumulated dust from those horizontal ducts (Fig. 4.).

Fig 4. Manual evacuation of large dust deposits from horizontal gas duct shown in Fig. 3.

At low boiler loads there is a higher risk for excessive moisture condensation inside the ESP creating wet and sticky dust.

Additional phenomena start to dominate in flue gas ducts and in the ESP in conditions at minimum boiler loads:

- A lower quality of gas distribution in the gas duct and in the ESP (at very low average gas velocity, gas distribution elements do not work as well as required),
- Changes of temperature distribution inside of the ESP,
- Moisture condensation,
- Getting wet dust layers,
- Creation of sticky dust layers on gas distribution screens and on electrodes,
- Creation of wet dust on rotating insulator,
- Collected dust from electrodes becomes more difficult to remove,

- Necessity of using rapping system for inlet gas distribution screens due to wet dust sticking onto screen panels,
- Uneven distribution of current density in the ESP volume,
- Getting clogging dust,
- Creating dust accumulation on horizontal surface of gas guides inside gas ducts,
- Creating dust lumps,
- Dust bridging in bottom hoppers,
- Faster wear of internal moving elements,
- Large displacement of shaft with rapping hammers because of fast wearing of the shaft and its bearing,
- Faster wear and often falling damaged rapping hammers of Discharge Electrodes causing short circuits, deforming electrodes and blocking bottom hopper or dust valves,
- Faster wear of dust valves,
- Blocking of the dust handling system,
- Corrosion,
- Dust build-ups in the ESP on internal elements:
    a) lumps on Discharge Electrode Frames at top – causing short circuits,
    b) lumps on Discharge Electrode Frames at bottom – causing short circuits,
    c) lumps on internal horizontal stiffeners of the ESP casing,
    d) on bottom hopper ridges under electrodes creating high dust columns causing short circuits,
    e) dust layer blocking the bottom part of inlet funnel,
    f) solid lumps blocking outlet of bottom hopper,
    g) high level of dust in the bottom of the ESP and switching off a high voltage power supply resulting in some fields out of operation leading to a higher outlet dust emission.

These phenomena can cause the need for more frequent additional maintenance and emergency actions:

- Often necessary to temporarily shutdown the boiler,
- Necessity of manual evacuation of accumulated dust and lumps from horizontal flue gas ducts,
- Necessity of manual evacuation of accumulated dust and lumps from the bottom of the ESP, (needs special equipment),
- Often manual washing of the ESP electrodes needed,
- Installation of additional valves on bottom hoppers for slurry evacuation during ESP washing is necessary,
- Needed external equipment for slurry handling during ESP washing.

A number of mentioned problems could be avoided when the ESP and its flue gas ducts are correctly designed and built for enlarged ranges of operation loads.

Fig. 5. shows an example of inclined flue gas ducts before the ESPs – this configuration eliminates the risk of dust build-ups inside gas ducts and ensures a good gas distribution quality.

Fig 5. Example of inclined inlet flue gas ducts before the ESPs.

There are special designs for ESPs dedicated for extreme clogging dust. In those applications the collected dust might be very reactive, and, in some conditions, dust components create a eutectic mixture which smelts at slightly higher operation temperatures than the T_{ADP}. In this process, collected dust is loose when fresh and it is possible to remove it by normal rapping, but when it is exposed for too long to reactive process gases it creates hard build-ups which are difficult to remove. In those conditions, a simple rapping system with typical control strategies effective for dry or semi-dry dust is not enough for long time successful operation.

ESPs for more difficult conditions.

There are configurations of ESPs dedicated for collecting hygroscopic, extremely clogging and high concentration of dust at the inlet (up to 200 g/Nm^3) and achieving dust removal efficiency 99,99%. For those cases there are more advanced ESP mechanical designs successfully operating for more than 20 years, without the necessity of often manual dust removal or ESP washing. The more advanced ESP consisting of:

- Multipoint rapping of each frame of discharge electrodes,
- Multipoint rapping of each curtain of collecting electrodes,
- Equipment for eliminating dust columns on bottom hopper ridges,
- Additional rapping for bottom hoppers walls,
- Equipment for eliminating dust layers collected on the bottom baffles,
- Additional rapping system for inlet gas distribution screens,
- Additional rapping system for outlet gas distribution screens,
- No permanent internal walkways to support dust deposits in the ESP,
- Additional rapping system for walls of the ESP inlet funnel,
- Vertical ESP inlet funnel (gas inlets from top or bottom),
- Additional rapping system for walls of vertical or inclined inlet gas ducts,
- Gas tight evacuation of collected dust (e.g., no cold air leakage into the ESP from dust handling system),
- Hot gas ventilation for insulators,
- Used high availability dust handling system from the bottom of the ESP (to avoid storage of dust in the bottom of the ESP),
- Bigger size of chute and dust valve (not promoting the creation of dust bridges over the valve or chute),
- Used good thermal insulation on the ESP and equipment for compensation of heat loss of the bottom of the ESP,
- Gas distribution elements ensuring even gas and temperature distribution inside the ESP in all fields,
- Operating with flue gas at temperatures relatively higher than temperature of T_{ADP},
- Optimized control of periodic rapping operation of all mentioned rappers.

Conclusions.

Electrostatic Precipitators are successfully used for the efficient removal of particulates from a flue gas stream for different process applications under a general condition: that they are correctly designed and assembled for the given process conditions.

Scientific and technological progress in different activities has allowed us to apply new solutions for ESPs, however, today there are more complex conditions for the sizing of gas cleaning installation when:

- There is frequent operation on low load when a gas flow in actual conditions is 3 times lower than at maximum load,
- Various types of blended fuels are used,

- Dust properties are changing in the ESP during operation in prolonged low load periods.

Experience from previous ESP installations applied for specific industrial processes helps to improve an ESP in more common applications for upgrading existing installations or building new ones.

The ESP flue gas ducts configuration and dust handling system must be taken into consideration for successful operation of the ESP with required particulate removal efficiencies. In order to avoid excessive dust fall-out before the dust collector, the gas duct design must consider the characteristics of the gas, the fly ash properties and gas velocity for the extended operating range. With today's competitiveness, reduced technical margins are used with the help of computer simulations.

Computer simulations are used with a number of assumptions and simplifications for a set of the most important dominating phenomena. Results from numerical modelling must be verified and checked against laboratory models built for conditions in relation to the extended operation of installation at high and low loads.

For the extended operating range there is more differentiation between dominating phenomena at low load compared to high load. The designer still has to have full knowledge and understanding of the wide and varied range of the process conditions for which the ESP with related gas ducts configuration can be applied.

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