ONLINE FLUE GAS EMISSION MONITORING FOR INDUSTRIAL BOILERS

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Abstract:

Online monitoring of pollutants such as SO_x, NO_x particulates etc.released into the atmosphere by burning of Fossil fuels in Industrial Boilers has come to be the order of the day. The increasing awareness in protecting the natural environment has resulted in the Government bringing about stringent Pollution Control Acts and Rules. To comply with these regulations, Industrial Boiler Customers procure these analysers as part of the overall boiler package. This paper aims at providing adequate guidance for Engineers dealing with these Analysers.

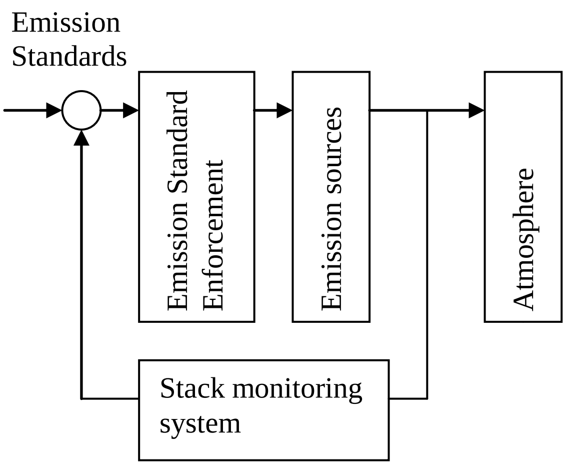
Combustion of Fossil fuels in Industrial Boilers produce particulate matter, Oxides of nitrogen, Oxides of Sulphur, Carbon monoxide and unburnt carbon which pollute the atmosphere. The possibility of emission of carbon monoxide and unburnt carbon in current boilers have been almost eliminated by ensuring complete combustion through implementation of sophisticated combustion control system in the microprocessor based Distributed Control System in all recent Projects.

The stringent Pollution Control Acts, Rules and Notifications issued by Central Pollution Control Board has necessitated online monitoring of -

a) Oxides of Sulphur (SO_2, SO_3)
b) Oxides of Nitrogen (NO & NO_2)
c) Particulates (Smoke and Dust)

Many state-of-an-art online analysers employing latest microprocessor based technology are available in the market today. All Boiler Customers/Consultants now insist for inclusion of these analysers in the Boiler Package. The above mentioned parameters are continuously monitored and are documented. When the parameters exceed acceptable levels, steps must be taken by the Operator to take corrective measures. The figure below depicts the real time air pollution control system.

Real Time Air Pollution Control System:



Indian Coals fortunately contains less amount of Sulphur. Sulphur in coal leads to formation of harmful oxides of Sulphur (SO_2, SO_3). This emission if excessive would result in acid rain leading to widespread destruction of vegetation. Sulphur can be captured in the boiler combustion chamber by limestone injection. The limestone reacts with the oxides of Sulphur emanating from coal/lignite resulting in the formation of calcium sulphate, which can be drained along with ash. Such systems are employed in Environment Friendly Circulating Fluidised Bed Combustion Boilers.

The oxides of Nitrogen namely Nitric Oxide (NO) and Nitrogen-di-oxide (NO_2) are the most important nitrogen oxide air pollutants. They are frequently grouped together under the designation NO_x, although analytical techniques can distinguish clearly between them. Of the two, NO_2 is more toxic and irritating gas.

The Oxidation of N_2 by the O_2 in combustion air occurs primarily through two reactions -

$$N_2 + O \longrightarrow NO + N$$

$$N + O_2 \longrightarrow NO + O$$

Known as the Zeldovich mechanism.

The first reaction above has a relatively high activation energy, due to the need to break the strong N_2 bond. This is highly temperature sensitive. Nitric Oxide formed by this method is called Thermal NO_x.

The second mechanism for NO formation in combustion is by the Oxidation of organically bound nitrogen in the fuel. Nitric Oxide formed in this manner is referred to as Fuel NO_x.

Ensuring combustion at lower temperatures and limiting excess air can effectively control the formation of nitrogen oxides.

Properties of Major Air Pollutants:

Physical properties	Concentra-tion level	Sources
SO_2 Colourless gas with irritating pungent odour, highly soluble in water.	Global background concentration levels in the range of 0.04 to 6 ppb	- Combustion - Atmospheric oxidation of organic sulphides.
NO Colourless, odourless gas; non-flammable and slightly soluble in water; toxic	Global background level from 10 to 100 ppt	- Combustion - Bacterial action - Lightning
NO_2 Reddish - Orange brown gas with sharp, pungent odour; toxic and highly corrosive	Global background level from 10 to 500 ppt	Combustion

Particulate matter refers to everything emitted in the form of a condensed (liquid or solid) phase. In utility and industrial use, coal and to a lesser extent, oil combustion contributes most of the particulate emissions. Coal is a slow burning fuel with a relatively high ash content. Coal combustion particles consist primarily of carbon, silica, Alumina and iron oxide. Oil is a fast burning, low ash fuel. The low ash content results in formation of less particulate matter and the sizes of particles formed are also much smaller. Oil combustion particulate matter contains cadmium, cobalt, copper, nickel and vanadium.

In our country where there is high ash content in coal, the problem is significant. The particulate emission into the atmosphere is contained using Flue gas cleaning techniques such as Electrostatic Precipitators, bag filters etc. The conditions of these devices have to be maintained in top class condition to ensure that the emission levels are within limits.

Bharat Heavy Electricals Limited, Tiruchirappalli is a pioneer in the manufacture of various types of Industrial Boilers such as -

a) Bubbling Fluidised Bed Combustion Boilers;
b) Circulating Fluidised Bed Combustion Boilers; and
c) Heat Recovery Steam Generators.

BHEL is an environment friendly Company in its activities, products and services. It strictly complies with applicable environmental legislation/regulations. It strives for continual improvement in Environmental Management System to protect our natural environment and control pollution by using Pollution Prevention Techniques/technologies. The Company has been recently accredited with **ISO 14001 Certification** for its efforts in the area of Environmental Management System.

BHEL has got vast experience in various types of Flue Gas Analysers for its various Industrial Boiler Contracts.

Technologies prevalent are as follows:

A SO$_2$ ANALYSER

1.0 Techniques employed:
- a) Full Extractive sampling technique.
- b) Dilution Sampling Technique.

2.0 Measurement Principle:
- a) Ultraviolet fluorescence
- b) Non dispersive infrared absorption.

B NO$_x$ ANALYSER

1.0 Techniques employed:
- a) Full extractive sampling technique.
- b) Dilution sampling Technique.

2.0 Measurement Principle:
- a) Chemiluminescent
- b) Non dispersive infrared absorption.

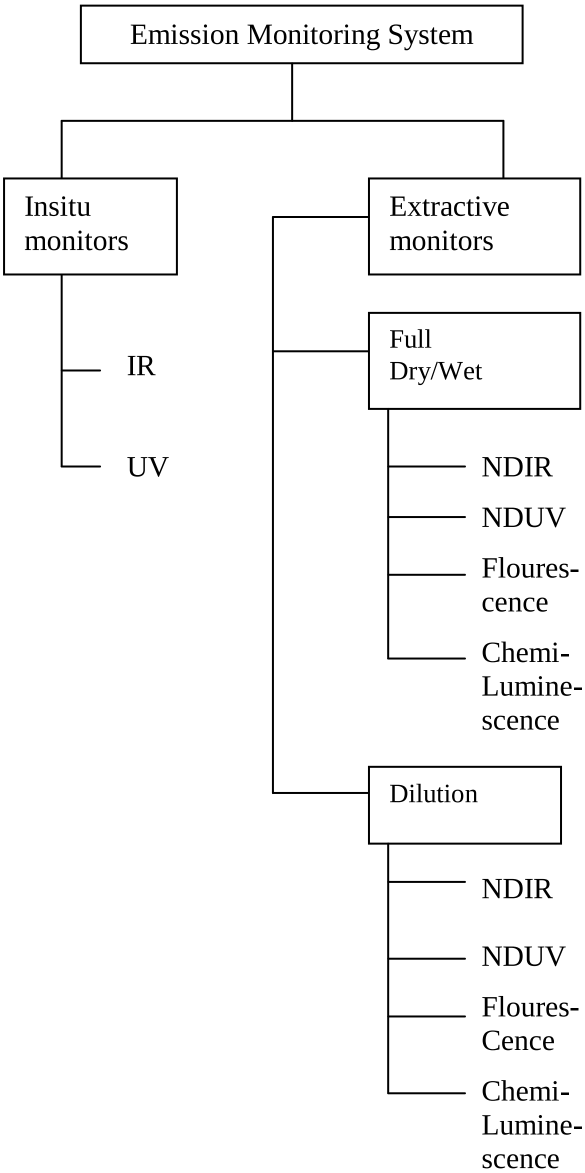
C PARTICULATE ANALYSER (Smoke & Dust)

1.0 Techniques employed:
- a) Cross Duct

2.0 Measurement Principle:
- a) Attenuation of visible light.

Online flue gas emission monitoring system can be described as all equipment required to determine a gas concentration or emission rate. This system encompasses sub systems that acquire, transport and condition the sample, determine the concentration of the pollutant and acquire and record the result.

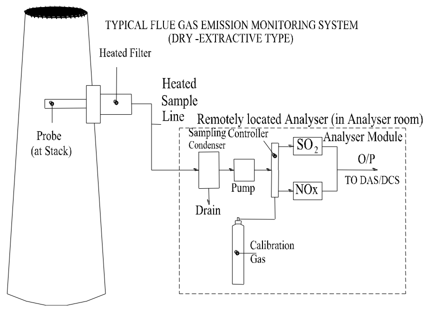
All systems fall into one of the two categories; insitu or extractive. Extractive units can be further classified into full extractive or dilution extractive systems.



An insitu system measures the concentration of a particular gas as it passes by the analyser in the stack. The measurement chamber is placed directly into the sample flow system to measure the gas. Many gases including SO_2 and NO have been measured insitu with light absorption instrumentation, such as UV and IR spectrometers. This technique is very popular till date for measurement of Oxygen in flue gas. However, it is not popular for other gases such as SO_2, NO, CO etc. since gas calibration using standard gas cylinders are not possible.

Dry – extractive system

A standard dry extractive system extracts a gas sample from the stack and delivers it to an analyser cabinet through sample lines as shown below.



. This system removes moisture through a combination of refrigeration, condensation and permeation tube dryers that pass the sample through water excluding membranes. This system helps keep the gas analyser dry and removes any interferences caused by water. Calculation of moisture removed adds complexity to the system. Operating an extractive system is complicated by the daily calibration, zero and span checks of the analysers and the need to back purge the sample handling system to clear the probe and filters. A controller sequences the operation of all valves and controls gas flow.

The major advantage of extractive systems is their ability to spread the analyser cost over several measurement points.

Wet-extraction system

Wet extraction systems are similar to dry extraction ones except that the sample is maintained hot, and moisture in the flue gas is retained throughout. Heat tracing is the critical component of a wet extractive system. Sample temperatures must be maintained around 250^{o}C to prevent acid gases from condensing within the sampling lines and analysers. Wet extractive systems are more expensive than dry extractive ones.

Dilution – Extractive system

In this system, the sample is diluted with clean dry instrument air. Particulates are filtered out at the sample point. A precisely metered quantity of flue gas is extracted through a critical orifice mounted inside the probe. Dilution system dilutes the sample at a preset dilution ratio and delivers the sample under pressure to the gas analysers. This ensures that the system is protected against any uncontrolled dilution from a leak in the sample line or system.

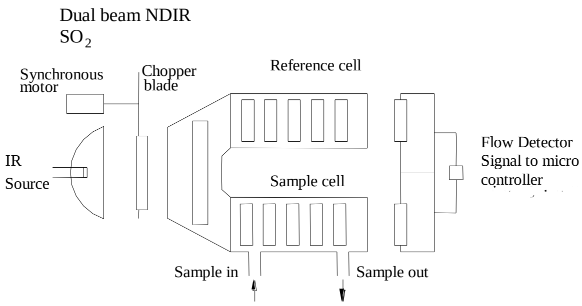
The engineer must consider the lowest pollutant concentration that can be detected by the monitoring device while deciding upon the dilution ratio.

PRINCIPLE OF OPERATION:

SO_2 Analyser – Non dispersive infrared type:

This analyser utilises the infra red absorption characteristics of gaseous species to measure concentration.

An infra read source generates broad band radiation, which is modulated by a mechanical chopper designed to produce two parallel synchronous beams as shown below:



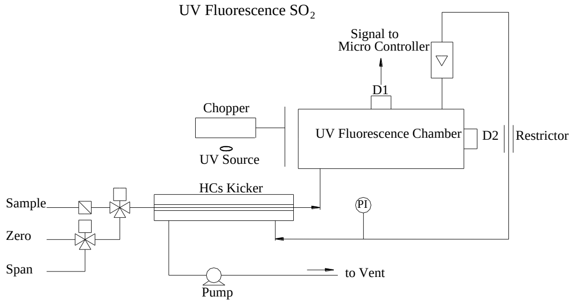
These are transmitted through two parallel cells, viz. a sealed reference cell and a sample cell containing flowing gas sample. Energy transmitted through the two cells reaches the detector – this is a mass flow type, with two parallel chambers filled with the gaseous species to be measured. Infra red energy reaching the detector chamber heats the gas causing expansion due to specific infra red absorption. A small flowpath between the two chambers contains a microflow sensor. If there is no measured species in the sample gas, the energy reaching both sides of the mass flow detector is identical. Therefore, no flow develops between the two chambers.

When the sample contains the measured species, the specific absorption of the species causes reduction in the energy transmitted through the sample cell, hence reducing the expansion in the sample side of the detector. This produces an oscillating flow between the chambers, which is related in frequency to the chopper speed and in amplitude to the concentration of the species in the cell. The signal from the flow sensor is fed into the microcontroller.

SO_2 analyser – UV fluorescence type:

The analyser employs the UV fluorescence method.

Sample gas is drawn into a fluorescence chamber where it is exposed to UV light as shown below:



The UV light is chopped, filtered and focused into the fluorescence chamber where it excites the SO_2 molecules into a higher energy state. As this energy decays the excited SO_2 modules emit a characteristic radiation. A second filter allows only radiation at the characteristic wavelength to reach the photomultiplier tube (D1), which converts the radiation into electrical impulses. These impulses are filtered, amplified and scaled by analyser electronics to provide a signal to a microcontroller.

A photodetector (D2) at the end of the chamber automatically provides compensation for fluctuations in lamp output.

Sample gas is drawn into the module by the diaphragm pump. It passes through a particulate filter and hydrocarbon "kicker". This latter device removes aromatic hydrocarbons from the sample to prevent interference of the SO_2 measurement. It operates on a selective permeation principle, allowing only hydrocarbon molecules to pass through the inner tube wall across which there is a differential pressure. A vacuum pressure indicator is used to monitor the differential pressure of the kicker, which is held at approximately 250 mm Hg.

Calibration:

The analyser is provided with two solenoid valves. These permit zero and span gases to be introduced into the analyser for calibration.

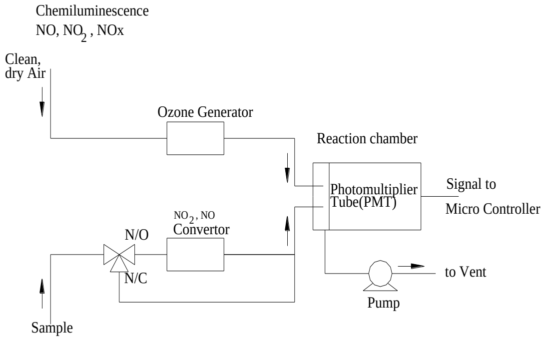
NO_x Analyser – Chemiluminescence type:

The analyser is based on the Chemiluminescence reaction between nitric oxide (NO) and ozone as shown below:

$$NO + O_3 \longrightarrow NO_2{}^* + O_2$$

$$NO_2{}^* \longrightarrow NO_2 + hv$$

The NO_2* produced in the reaction is in an electronically excited state which quickly decays giving a light output hv proportional to NO concentration. This is detected using a photomultiplier tube as shown in the drawing.



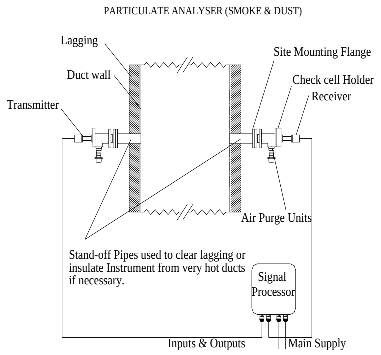
Measurement of NO_x is accomplished by means of a catalytic convertor, which converts NO_2 to NO prior to reaction with ozone. The ozone required for the reaction is generated internally within the instrument.

The Chemiluminescence signal from the reaction chamber is detected and amplified by a photomultiplier tube and fed into the microcontroller.

The analyser is operated with a pump on the reaction chamber exhaust reducing chamber pressure to less than –20 inches of HG.

Particulate Analyser:

Optical transmissometers is an accepted technique for measurement of particulates. These instruments operate on the principle that the intensity of a beam of light, transmitted through the gas, will be reduced by the particulate matter as shown below.



The amount by which it is reduced being a function of the particulate loading of the gas. These instruments use a motor and notched blade to physically “chop” the light beam. The light source can be modulated electronically. The detector and detection circuitry are designed to be sensitive only to light with the precise frequency and phase.

The selection of the analyser is mostly influenced by the requirements spelt out by Customers/Consultants.

All requirements in the form of detailed ordering data has to be clearly communicated to the analyser vendor. This would ensure that the execution is smooth.

The ordering data should cover major aspects such as –

- Scope
- Measurement principle
- Analysers Panel Constructional features
- Calibration
- Commissioning requirements
- Documentation

- Inspection and testing
- Packing
- Proper storage of the hardware before installation
- Proper timing of receipt of calibration gas cylinders at Site.

Steps for Preventing Field Problems:

- Analyser packing when received at site must be kept in covered storage area. The storage and preservation procedure recommended by the Vendor should be meticulously followed. Since most of the components are fragile in nature, extreme care must be taken while handling these packages.
- Customer inspectors should look for any material damage, pilferage etc., immediately on receipt at site and should promptly take up with the Vendor/Insurance Agency in case any discrepancy is noticed.
- Erection should be done as per the engineering drawings provided by Vendor.
- Customer should identify one or two of their Engineers to get fully involved during actual erection and commissioning of these analysers.
- Since analysers are maintenance intensive instruments, detailed maintenance schedule has to be made and religiously followed.

CONCLUSION:

This paper has touched upon the important pollutants (namely SO_2, NO_x and particulates) released by Industrial Boilers. The characteristics of the pollutants, its toxicity and impact on the environment has been discussed. The principle of operation of various analysers has been elaborated. Steps to be taken for preventing field problems have also been highlighted. It is felt that this paper would provide sufficient guidance for engineers dealing with these analysers.

REFERENCES

1. Richard C.Flagan and John H.Seinfeld, 1988, Fundamentals of Air Pollution Engineering, Prentice Hall, Englewood Cliffs, New Jersey.
2. Bela G.Liptak and David H.F.Lik, 1996, Environmental Engineers' Handbook, Lewis Publishers, New York.
3. Technical Catalog of various analysers published by Rotork Analysis Limited, Regal Way, Faringdon, UK.
4. Technical literature on Monitoring Particulate emissions published by Combustion Developments Ltd., Station Building, Station Road, Bakewell, Derbyshire, U.K.