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DYNAMIC SMOKE MEASUREMENT FOR STACK EMISSION USING He-Ne LASER

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ABSTRACT: Stack emission is a major cause of air pollution. It comprises of dust, smoke and gaseous products. Continuous monitoring of this emission is desirable from pollution control and public health point of views. A new technique for continuous monitoring of optical density of smoke and smoke yield using a He-Ne laser is proposed in the present communication.

INTRODUCTION

Stack emission from the industries, which is a major cause of air pollution, is mainly the by-product of external combustion and comprise aerosols and gaseous products. Aerosols are found either in the form of dust or as smoke. On account of their particle size (TABLE 1) dust and fly ash settle under the influence of gravity. Smoke produced by incomplete combustion consists of finely divided particles and thus remains suspended for relatively longer period of time.

TABLE 1

AEROSOL	SIZE (Microns)
Dust	20 - 80
Fly ash	3 - 80
Smoke	0.01 - 1

From air pollution point of view aerosols in the range of 0.01 μ to 100 μ are important. Particles below 1 μ are due to smoke from various sources, fumes from chemical and metallurigical industries, carbon black and sulphuric acid mist. Since majority of the pollutants fall in the range that causes loss of visibility, they are capable of curtailing activities (such as scheduled airline flights) which depend on clear line of vision. The problem is further agrivated when the aerosols are hygroscopic in nature as they lead to the formation of fog.

Though pollution is a common by-product of industries, smoke emission is associated mainly with the industries that use coal e.g. thermal power plants, steel industries etc. Indian coal contains upto 40 % ash and 3-5% sulphur. The huge quantities of ash and unburnt carbon particles released as flue gases necessitates continuous monitoring and control of stack emission. Smoke is measured by different methods i.e. Mechanical, Electrical and Optical. However, optical methods are the ones most frequently used. ASTM Task Group (E_5O_2)[1] has given a concise report on smoke test methods exclusively pertaining to the building fire safety. More recently a crisp account of the prevailing trends in smoke measurement including applications and limitations of various methods has been given by Sharma[2]. Broadly these methods can be classified as 'Static' and 'Dynamic'.

CONTROL EQUIPMENTS FOR STACK EMISSION

The stack discharge to the atmosphere has long been the most common industrial method of disposing waste gases. Although tall stacks may be affective in lowering the ground level concentration of pollutants they do not in themself reduce the amount of pollutants released into the atmosphere. However, in certain situations their use can be the most practicable and economical way of dealing with air pollution problems. The acceptable ground level concentration, topography of the area, meteorological conditions and the composition of the waste gases with their physical and chemical properties are used for design of stack. Acceptable criterion for SPM and SO_2 (TABLE 2) are often obliviated posing air pollution hazards.

Suspended particulate matter (SPM) is separated from the flue gases by using a combination of settling chambers, bag filters,

TABLE 2

AMBIENT AIR *			STACK EMISSION **		
Region	SO_2	SPM	Area	SO_2	SPM
A	60 av 200 max	200 400 max	Senestive	20	100
B	60 av 200 max	300 av 600 max	Residential	50	200
C	60 av 200 max	500 av 1000 max	Industrial	100	500

* IS 10193,
** Central Pollution Control Board
Sulphur dioxide in ppm and SPM in $\mu g/m^3$

cyclone separators, scrubbers, electrostatic precipitators depending upon the contaminant, the particle size and the dust load present. TABLE 3 gives the particle size of the aerosols in relation to the desirable air pollution control equipments.

TABLE 3

Pollution Control Equipment	Particle Size
Sonic Agglomerator	0.06 - 80 μ
Bag House Filter	0.06 - 80 μ
Special Gas Washers	0.01 - 100 μ
Electrostatic Precipitator	0.01 - 10 μ
Centrifugal Dust Separator	> 0.6 μ
Gas Washer	> 30 μ
Settling Chamber	> 90 μ

SPM is controlled by use of mechanical collectors, electrostatic precipitators (ESP) and a combination of the two, in thermal power plants. Liquid scrubbers, spray chambers, towers packed with materials such as 'Berl Scaddles', orifice scrubber and venturi scrubbers are used for removal of soluble gases and particulate contaminants in a gas stream.

SMOKE MEASUREMENT

Basically there are two sites for air pollution (dust/smoke emission) measurements:

- measurement at the outlets, and
- ambient air quality measurements

The former measurements are taken at the ESP outlets. Based on dispersion studies adequate number of monitoring stations are set up to measure ambient air quality. It takes into account any contribution of the pollutants by other factors, to the overall loading.

The central board for prevention and control of pollution has carried out a comprehensive study of different industries and brought out a document fixing emission from chimneys as 150 mg/m^3. To achieve this standard continuous smoke density measurements are essential. Generally, these measurements are carried out by manual sampling two or four times every month depending on the size of the plant. Efforts are being made to establish methods for continuous measurement of smoke by using optical density which correlates well with the SPM loading (mg/m^3). This reveals the SPM level present at a given instant or over a period of time. The principle of such measurements is 'attenuation of light intensity by aerosols' which is mathematically expressed by Lambert- Beer Law as:

$$F(x) = F_o e^{-\sigma x} \quad \ldots.(1)$$

Where F = The light flux attenuated by the smoke layer

F_o = The light flux at source

σ = The attenuation coefficient

x = The path length through the smoke

or $$\log_{10} \frac{F_o}{F(x)} = \frac{x}{2.303} \quad \ldots\ldots\ldots(2)$$

DYNAMIC MEASUREMENT OF SMOKE

In a dynamic system, smoke is made to flow through the duct. Optical density (D) of smoke at any instant 't' i.e. D(t) is continuously measured across the duct as smoke flows through it. Peak value as well as instantaneous values of OD can be read from the OD profile. One of the method based on optical density measurement in a dynamic system [3] uses a sealed light source projecting a parallel beam of energy through smoke travelling upwards in the stack. The photocell reciever detects energy radiated from the light source and produces a minute electric signal proportional to the energy detected. The signal is suitablly amplified and recorded. This method combines continuous monitoring with instant indication -fast response to excessive emission and maintaining air pollution to minimum. In this method white light (polychromatic) is used. Lambert-Beer Law is strictly valid for monochromatic and collimated beam[4]. Laser is not only monochromatic but also inherently collimated. Errors would result with the use of polychromatic light that would further agrivate if collimation is not proper. In fact errors as high as 25% have been reported when non-monochromatic light is used[5]. In view of these He-Ne laser is finding increasing use in smoke measurements[5,6].

An experimental study was carried by the authors to continuously monitor smoke generation using He-Ne laser. The set-up used in this study is shown in FIGURE 1 and 2 . The main components of the set include: specimen ignition system, smoke collection device and optical density meter. A 2 mW randomly polarised He-Ne laser (Aerotech) was used in the study. Its beam was passed through the duct at about 300 mm from the top of the hood. The laser beam intensity was monitored by the matching Radiometer (Silicon diode photo-detector) - Aerotech Model 71. The laser power was displayed on a digital panel meter. The radiometer also had an analogue output for recording and integrating the output. The output of the radiometer decreased with the increase in smoke concentration inside the duct.

PROBLEMS ENCOUNTERED WITH LASER SYSTEM

Some of the problems encountered with the use of the He-Ne laser for measurement of optical density of smoke were:

- Laser beam alignment was difficult to be preserved as the beam diameter is small and the viewing angle of the photo-sensor is narrow. A rigid fixing may reduce the problem.

- High frequency fluctuations present in OD profile (FIGURE 3 profile a) caused the main difficulty in evaluation of the integrals of OD. The origin of these high frequency fluctuations can be attributed to eddies in air flow, inherent instability of smoke and inhomogeneity in its concentration through out the cross section of the duct. Unless such fluctuations are smoothened out, OD integrals can not be evaluated.

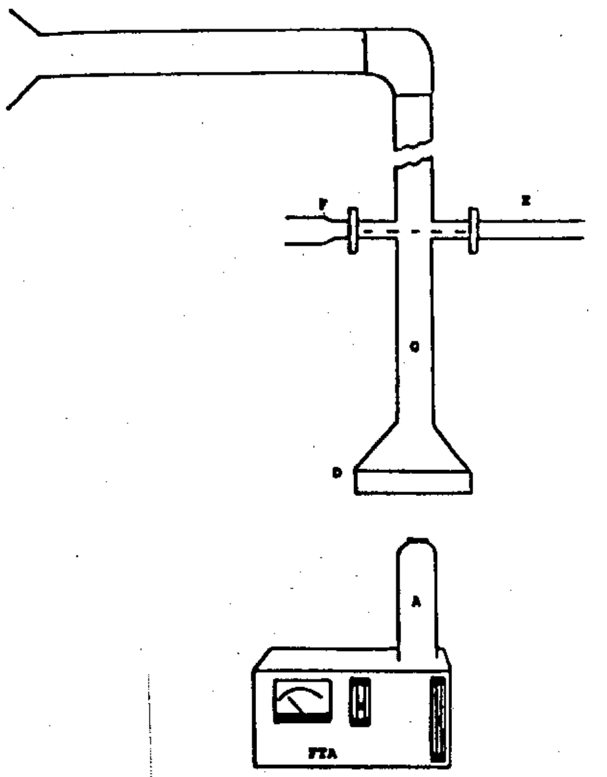

Figure 1 Schematic diagram of the apparatus for smoke generation and its measurement by the flow method. FTA—flammability test apparatus, A—chimney, D—hood, E—He-Ne laser source, F—laser radiometer, G—duct, H—exhaust fan.

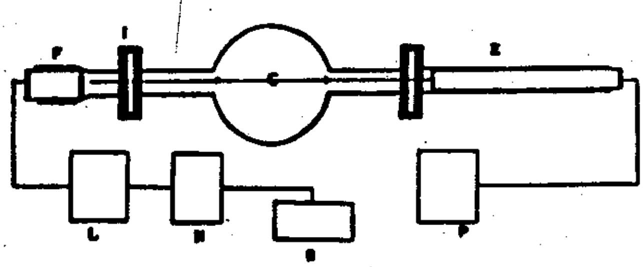

Figure 2 Smoke monitoring using He-Ne laser. F—radiometer, I—optical filter, G—duct, E—laser source, L—radiometer readout, N—integrator, P—power supply, R—recorder.

Instead of using single three-point moving average routine for smoothening of data as reported by Clarke[5], an integrator formed by resistor R and capacitor C was connected to analogue output of the photodetector (Radiometer Model 71) to suppress the high frequency

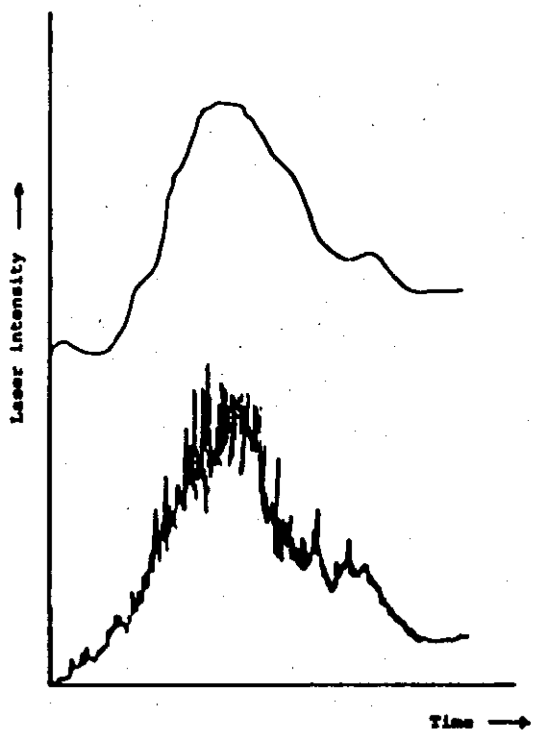

Figure 3. Suppression of high-frequency variations

variations (FIGURE 3 profile b). An active electronic filter to filter out high frequency variations may also be employed to avoid any loss of amplitude.

ADVANTAGES OF THE PROPOSED SYSTEM

In majority of problems concering stack emission and smoke measurements, the measurements centre around 'optical density' which correlates well with smoke concentration (mg/m^3). The other related parameter of interest is 'smoke yield' which measures the amount of smoke released in a certain time interval and is derived from the time integral of the optical density. The proposed use of He-Ne laser system can directly be used in case of stack emission studies. It not only has an edge over the normal practice of 'grab sampling' but also over the optical smoke density indicators[3] using white light. An instantaneous value as required under the norms of the central pollution control board can be obtained at the press of a button. Also, the overall efficency of the pollution control systems can be adjudged continuously without any extra efforts. The system can be designed to sound an alarm whenever there is a change in the emission pattern or the smoke concentration in the flue gases exceed the recommended or predetermined level. The use of this system will therefore give a continuous indication of the emission levels with greater reliability and accuracy. A system comprising of two or more laser sources can thus be used for ambient air quality monitoring along with the stack emission. This would enable to know the

- ambient SPM loading as well as
- stack emission loading from a plant

to give an overall hazard assessmet. As laser is a standard source of light with respect to wavelength and collimation, problem of comparability would be reduced. From optical density profile, an assessment of smoke yield can also be made whenever desired.

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REFERENCE

1 ASTM E_5O_2 (1976) Task Group on Smoke Test Methods, ASTM Standarization News, 18.

2 Sharma Sunil K. (1995) ' Measurement of Smoke From Fires : The Present Trends' , J.Sci. & Ind. Res. Vol 54, pp 98-107

3. Institution of Engineers (India) Bulletin (Oct 1991) Vol. 41 Page 15.

4 Chow W.K. and Lai K.F. (1992), 'Optical Measurement of Smoke ', Fire and Materials, vol 16, pp 135-139

5. F.R.S. Clarke,(1985)' Assessment of Smoke Density with a Helium-Neon Laser', Fire and Materials vol 9, pp 30-35

6 Sharma Sunil K. , Singh M.P., Saxena N.K. and Srivastava S.K.,(1993) Assessment of Effectiveness of Smoke Suppressants- Using a He-Ne Laser in a Flow System', Fire and Materials, Vol 17, pp 271-277