LASER VERSUS WHITE LIGHT MEASUREMENT OF OPTICAL DENSITY OF PVC SMOKE

Smoke no doubt is a major cause of deaths in the case of fires and it also greatly hinders fire fighting and rescue operations. Correct measurement of somoke that is caused by various material while burning is important. In this paper M.P. Singh and Sunil K. Sharma, Scientists, Fire Research, Central Building Research Institute, Roorkee, have, based on some experiments carried out by them, compared the laser and white light measurements of optical density of smoke produced by burning of PVC cables.

Editor

ABSTRACT

Based on principle of 'obscuration of light' optical density of smoke from samples of PVC cables was measured with two different wavelengths using a flow system. Samples of different lengths were cut from a 3 core general purpose low capacity PVC cable. Optical density profiles were recorded using a He Ne laser (monochromatic light source) and an incandescent bulb (white light source) in the measurement system. Observations were taken to ascertain the difference in optical density measurements caused by the two sources. Factors responsible for the variations have been investigated.

INTRODUCTION

Smoke along with the toxic gases is the main factor responsible not only for deaths/incapacitation during a fire emergency but also for hindering fire fighting and rescue operations. Its early detection and control are crucial for ensuring adequate fire safety at any premises. Importance of correct smoke measurements in the field of fire safety activities has phenomenally increased these days. An increasing number of scientists and other investigators concerned with smoke detection, smoke suppression, smoke control and evaluation of ever expanding class of newer building materials/products are attempting to make precise smoke assessments. But because of its complex intrinsic nature, precise measurement of smoke or of its various physical properties remains a daunting task before technologists. For better understanding it is desirable to characterize smoke in terms of its intrinsic properties like number, concentration of particles, mass concentration or optical constants. But such properties are difficult to assess particularly for aging smokes encountered in fire situations and for which detection and control devices are designed.

In fire research, smoke concentration measurement is basedon the principle of 'attenuation of light intensity by smoke aerosols'. This is mathematically expressed by Lambert Beer law as:

$I_x = I_o \, EXP \, (-KCX)$

where I_o = initial intensity of collimated beam of light

X = distance traversed by the beam through smoke

IX = beam intensity after a distance X

C = concentration of smoke particles, and

K = extinction coefficient

As attenuation of beam intensity is primarily caused by twin phenomena of scattering and absorption by smoke particles, K has two components:

$K = K_{sca} + K_{abs}$

For highly absorbing smoke such as from PVC, K_{abs} dominates over K_{sca}. In grey smoke K_{sca} exceeds K_{abs} and the principal phenomena responsible for attenuation is scattering. Ratio I_o/I_x is taken as a measure of smoke concentration. A term 'Optical Density (OD)' derived from Lambert-Beer law, denoted by D and defined as:

$D + 10 \log \{I_o/I_x\} \, d\beta = 10 \log \{100/T\} \, d\beta$ [3]

(where $T = 100 \, (I_x/I_0)$ denotes the percentage transmittance of light)

is the most widely used parameter for indicating smoke quantity or concentration. When smoke concentration changes with time, I_x changes accordingly and hence D becomes a function of time written as D (t). A plot of D(t.) against time is called smoke or OD profile. Sometimes OD is assessed in absolute terms i.e. independent of the path length (X) and expressed in units of decible per meter using the equation:

$D(t) = 10/X \log \{I_o/I_x\} = 10 X \log \{100/T\} \, d\beta/m$ {4}

Any measuring system for optical desnity (D values) would obviously require a well collimated light beam. The light may be monochromatic in nature as in case of He-Ne laser soruce or polychromatic in nature as in case of incandescent bulb source. It is the later source that is most frequently being used in investigations concerning fire research. However of late He-Ne laser is also finding increasing use[1,2] Laser light is not only monochromatic (0.63 micron wavelength) but also inherently collimated. White light in contrast has the seven colours of visible spectrum. It would be interesting to compare and contrast the laser and the white light measurements of optical density of smoke and this comparison forms the subject matter of this paper. Apart from implications arising due to wavelength difference it is important to remember that Lambert-Beer law is strictly valid for monochromatic light only[3].

METHODOLOGY

Objective of these experiments was to simultaneously measure smoke profile by two OD meters operated with different light sources and to compare the recorded data. A general purpose, 3 core, PVC cable of low capacity (5 ampere rating and 8 mm dia.) was taken as the source material for smoke. Cable samples of 80 mm to 165 mm length were cut and burned inside a chimney under highly controlled conditions such that the length of the cable burnt in different experiments varied betwen 65 and 150 mm. The resulting smoke was directed to flow through a L-shaped duct where the flow rate was controlled at 0.5 m/s with the help of a regulated suction fan as shown in FIG. 1. Laser and white light beams were projected across the duct through small ports provided with glass filters for collection of soot, if any. The concentration of smoke flowing through the duct was measured by two OD meters-one using He-Ne laser and the other using white light as the light source. OD profiles recorded by the two meteres were compared to highlight the difference (if any) in the measurements and the factors responsible for the variations. The peak values of OD and the smoke yield (area under the profile) were measured in all the experiments.

THEORY AND EXPERIMENTAL SET-UP

As mentioned earlier smoke attenuates light and the extinction is caused primarily by two phenomena - scattering and absorption by particulates. Both these phenomena depend not only on the intrinsic aerosol properties (such as size, composition, refractive index) but also on wavelength (λ) of the light being attenuated. If optical density (OD) of a given smoke is being measured by two OD meters operating on different wavelengths, variations in OD measurements are expected theoritically as the extent of scattering as well as of absorption would be different for the two wavelengths [4]. PVC smoke is highly absorbing in nature. In the present study it is K_{abs} which dominates the attenuation process and the wavelength dependence of K_{abs} would cause variations in OD profiles of the two meters. The experiments were designed to observe these variations and ascertain the extent of difference in OD measurements when laser and white light are used.

Stanton Redcroft Flammability Test Apparatus (FTA); the Oxygen Index Apparatus; was used to burn the samples under controlled conditions of oxygen concentration and flow rates. Smoke from burning smaples was directed through 104 mmdia. duct. Laser and white light sources and detectors were mounted in the vertical section of the duct to avoid any effect of settling.

Samples of the sizes and weight given in Table-1 were placed inside the chimney of the FTA and ignited by a propane torch. Out puts from both the meters were fed to a strip chart recorder to contineously monitor the OD profiles.

SMOKE YIELD

an index or measure of the total particulate production ie smoke yield from the sample. But estimate of total smoke will also depend on the volumetric flow rate (V) of purging air/gas and must be accounted for in the time integral. Therefore smoke index or smoke yield (S) is given by:

$$S = O^{T}\int_{0} V\,D(t)\,dt$$

where T is the time for which the smaple burns.

As V is constant in all the experiments, comparison of smoke yield obtained with two OD profiles D_l and D_w can be readily done by the equation:

$$\frac{S_l}{S_w} = \frac{\int D_l\,dt}{\int D_w\,dt} \quad [6]$$

where subscript 1 and w stand for laser and white light respectively.

Integrals on the right hand side can be evaluated by measuring the area under th OD profile with the help of a planimeter.

OBSERVATIONS AND DISCUSSIONS

First of all the out put of the two meters was recorded for about five minutes to check the stability of both the measuring systems. Figure-2 shows the out put records of the two meters. Laser meter shows a sinuosidal variation in its out put with a periodicity of about 12 seconds and an amplitude of about 5% of the maximum (full scale). This stability problem limits the sensitivity of laser meter as smoke concen-tration producing less than 5% variation in the light transmittance shall not be recorded reliably on long term basis. White light meter on the other hand is quite stable and therefore has better signal to noise ratio. A trial run record of the out put of both the meters reveals; as shown in figure-3; existance of high frequency fluctuations which need to be smoothened to evaluate the integrals (area under the profiles) of equation 5. Output of both the meters were therefore smoothened using a RC network having a time constant of about 1 second.

After these initial observations and adjustments PVC sample were burnt and four sets of experiments were conducted using sizes given in Table-1. OD profiles were recorded in terms of percentage light transmittance(T). Figures-4 to 7 show the profiles obtained by laser and white light meters. Table-2 summarises the minimum transmittance percentage (T%), the peak optical density and the smoke yield (or smoke index) obtained with the two meters of different quantities of PVC burnt.

In all the experiments the two meters registered significantly different values for minimum T%, peak OD and smoke yield (S). It is observed that difference in the peak OD values is more pronounced for smaller samples/lesser quantities burnt with laser meter rgistering quite higher values. Similarly higher values of smoke yields are registered by laser meter compared with white light meter. As mentioned earlier the wavelength is one of the apparent factor responsible for difference. However, factors such as forward scattering, multiple scattering etc. may also be greatly dominating for these differences and need to be investigated. Also whether similar trend exist for other materials is also to be seen. Such questions are planned to be addressed in future experiments. Factors responsible for more pronounced difference in peak OD vlaues for smaller samples may be higher smoke concentration at the duct axis caused by greater flow rate in the centre. For larger samples this effect is not significant.

CONCLUSIONS

Optical density is an important parameter in the assessment of smoke hazard and smoke propensity of different materials. Equally important are the methods of measurement and design factors of the OD meter such as wavelength, presence of forward scattering and multiple scattering. For PVC samples burnt under specific conditions, laser OD meter was found to register higher values of optical density. The role of forward and multiple scattering remains to be assessed. Also, other materials need to be tried. In terms of stability white light OD meter seems to be more suitable.

ACKNOWLEDGEMENT

The authors are thankful to the Director Central Building Research Institute, Roorkee for granting permission to publish this paper.

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Table-1 Cable Specimens - Burning Data

Sl. No.	Lenght of cable (mm)	Weight (gms)		Quantity of PVC Burnt (gms)	Duration of Burning (Sec)
		Initial	Final (gms)		
1	65	7.7	4.2	2.9	180
2	90	10.1	5.2	4.9	210
3	120	12.9	6.6	6.3	240
4	150	15.8	8.5	7.3	270

Table-2 Data related to the Smoke measurment as Registered by Two Meters

Sl. no.	Quantity of PVC Burnt (gms)	Minimum T%			Peak OD			Smoke Yield		
		Laser	White	Difference	Laser	White	Difference	Laser	White	Difference
1	2.9	44.5	67.0	-22.5	0.352	0.174	0.178	71.0	23.0	48.0
2	4.9	24.0	65.5	-41.5	0.620	0.184	0.436	61.6	31.2	30.4
3	6.3	9.7	8.5	1.2	1.013	1.070	-0.570	136.0	124.6	11.4
4	7.3	11.2	11.0	0.2	0.951	0.959	-0.008	142.6	122.4	20.2

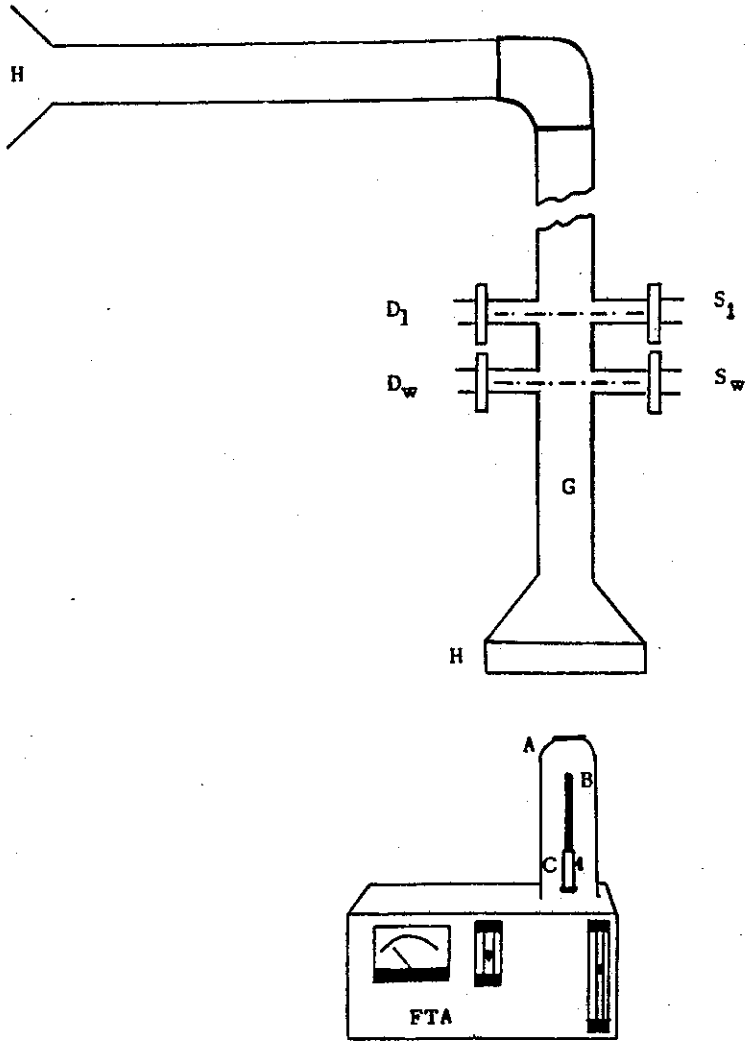

FIGURE 1 SCHEMATIC DRAWING OF FTA AND OD MEASURING SYSTEM (FTA-Flammability test apparatus, A-chimney, B-cable, C-clamp, H-hood, G-duct, D_w-detector white light, S_w- source white light D_1 -detector laser, S_1 -source laser, H-exhaust)

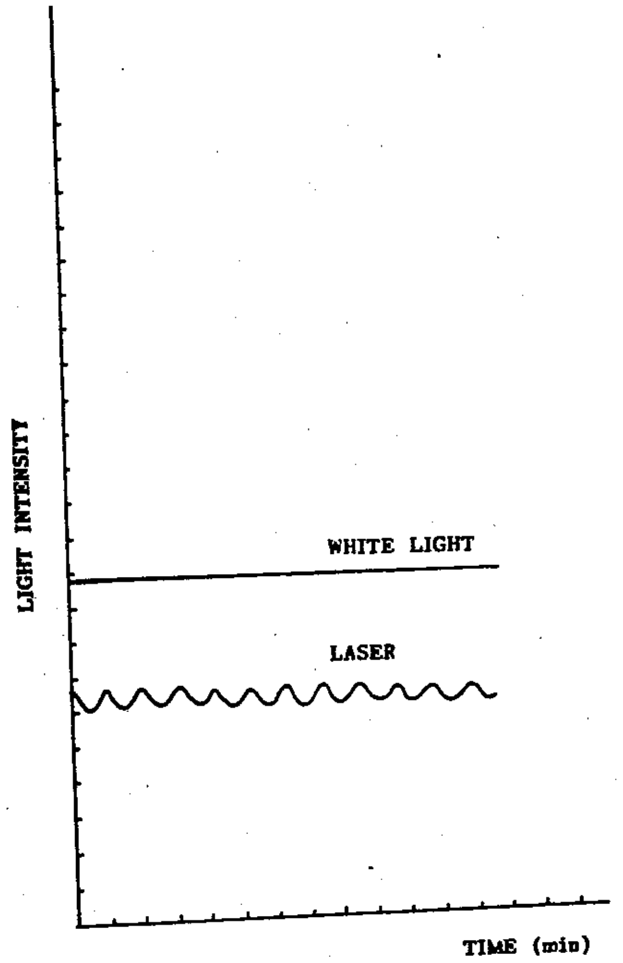

FIGURE 2 STABILITY OF SOURCE INTENSITY

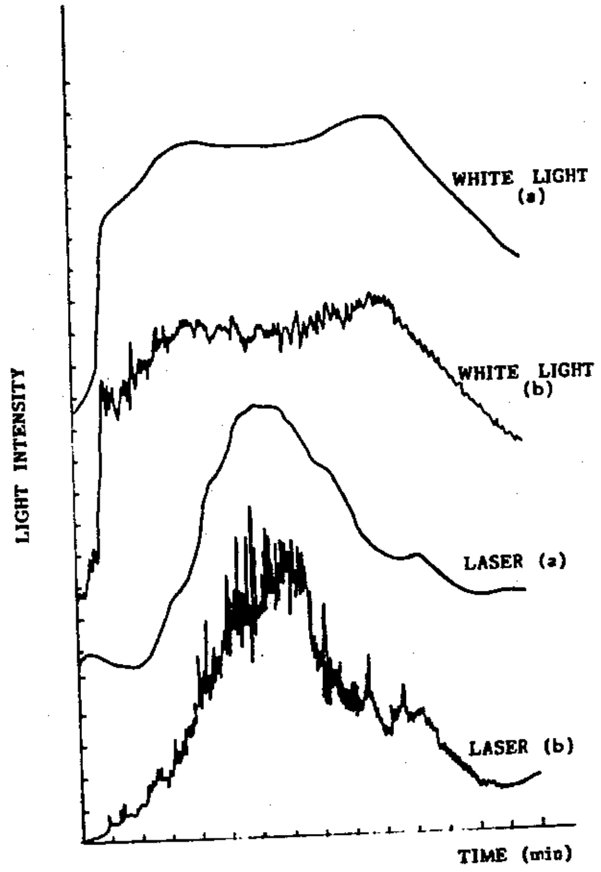

FIGURE 3 HIGH FREQUENCY FLUCTUATIONS IN THE OUT PUT(s)

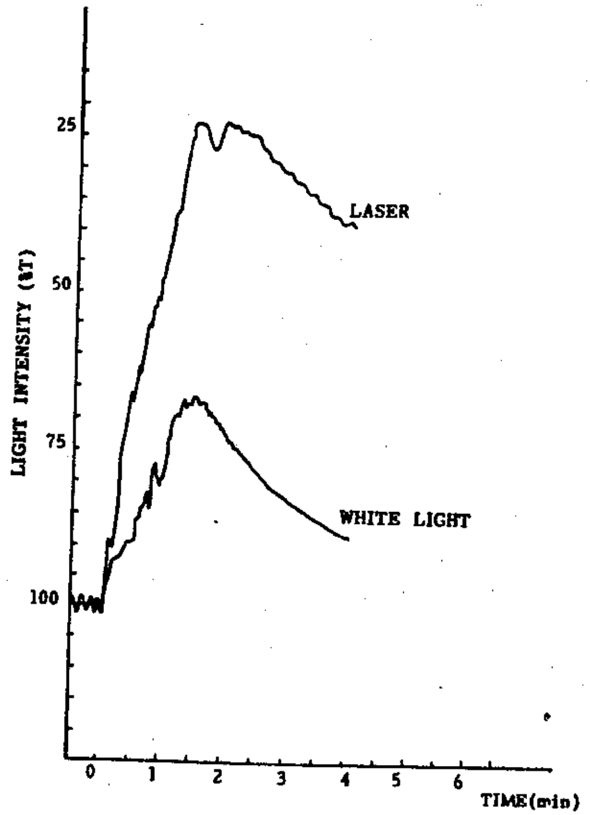

FIGURE 4 SMOKE PROFILE (6.2 gms)

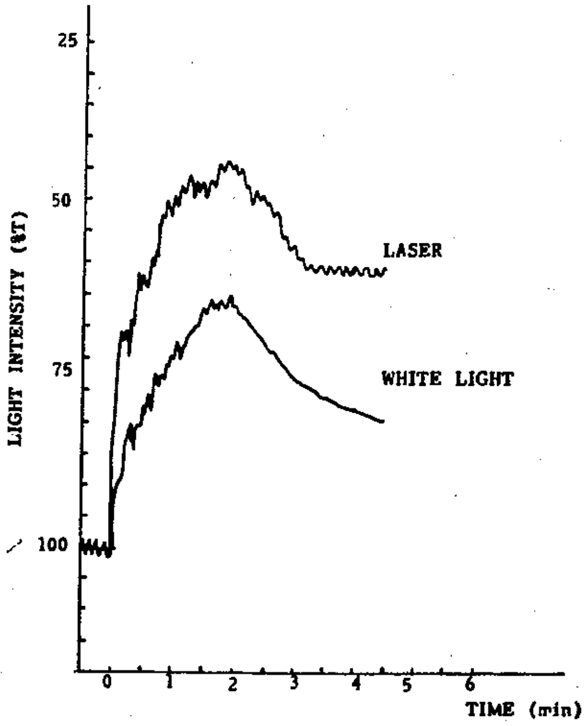

FIGURE 5 SMOKE PROFILE (8.6 gms)

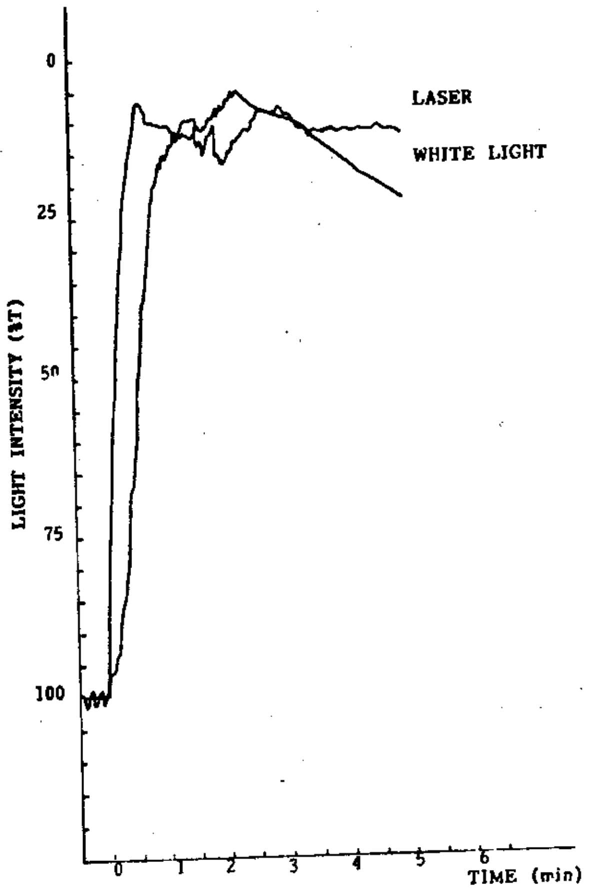

FIGURE 6 SMOKE PROFILE (11.5 gms)

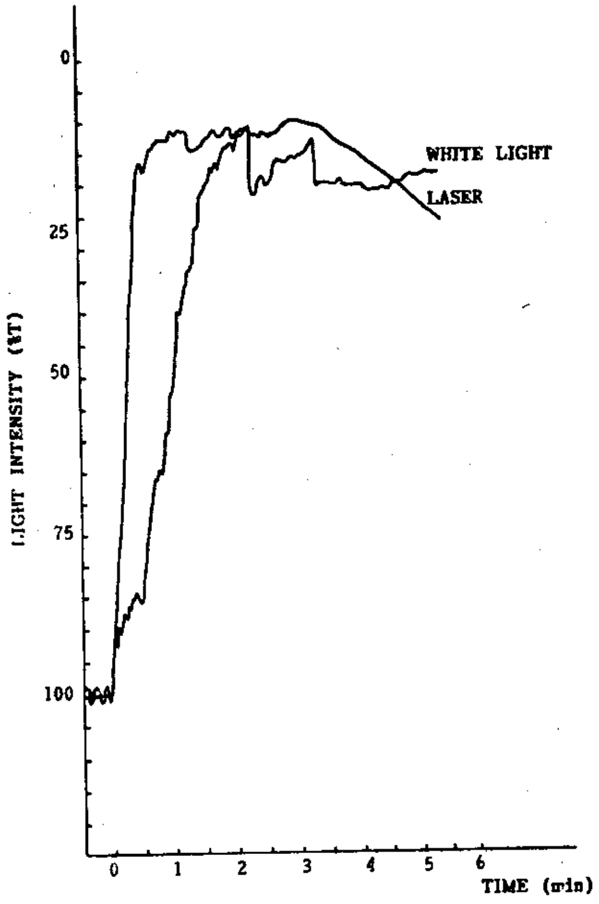

FIGURE 7 SMOKE PROFILE (14.4 gms)