A simple technique to measure soot production

Anil K. Rajvanshi, Etienne Gayet*, Kavita Jagtap and Megha Patil
Nimbkar Agricultural Research Institute (NARI)
P.O. Box 44, **PHALTAN-415523**, Maharashtra, India
E-mail: nariphaltan@gmail.com

Introduction

Soot from cook stoves and inefficient kerosene lanterns in rural households kills 2 million people worldwide.[1] Besides it is an important contributor to global warming.[2] Various programs for improving cook stoves have been underway all over the world.[3,4] These devices run on biomass and their developers claim high efficiency and low soot production from them in labs.[4] However in real life situation their performance deteriorates with time and they start emanating substantial amounts of soot. It is therefore necessary to measure soot production in users' huts to ascertain their contribution to poor health and global warming. Besides a simple soot measurement technique can also help to rapidly compare the performance of different household stoves.

Measurement of soot in user huts has been done by researchers using sophisticated equipment.[4, 5] This includes collecting air samples from huts by costly air sampling devices. This soot-laden sample is then taken to a lab and passed through either IR or laser particulate counters for measuring the total soot quantity and also the particle size of the soot. The procedure is tedious, costly and can neither be performed easily nor for a large number of households.

Thus a simple method of measuring soot using a smart phone has been developed and is described below.

The basic idea is to collect the soot on a metal plate and then measure the reflection of light from it using a smart phone and correlate the reflection with amount of soot collected. Fig. 1 shows the schematic of the device while Fig. 1(a) shows the configuration. It is a very simple device which can be made in any small workshop.

* Intern at NARI from Claude Bernard University, Lyon, France.

It should also be pointed out that the total soot entrapment and its measurement is a very good indicator of the indoor air pollution and is much simpler and cheaper option than measurements of PM_2 or PM_{10} particle sizes.

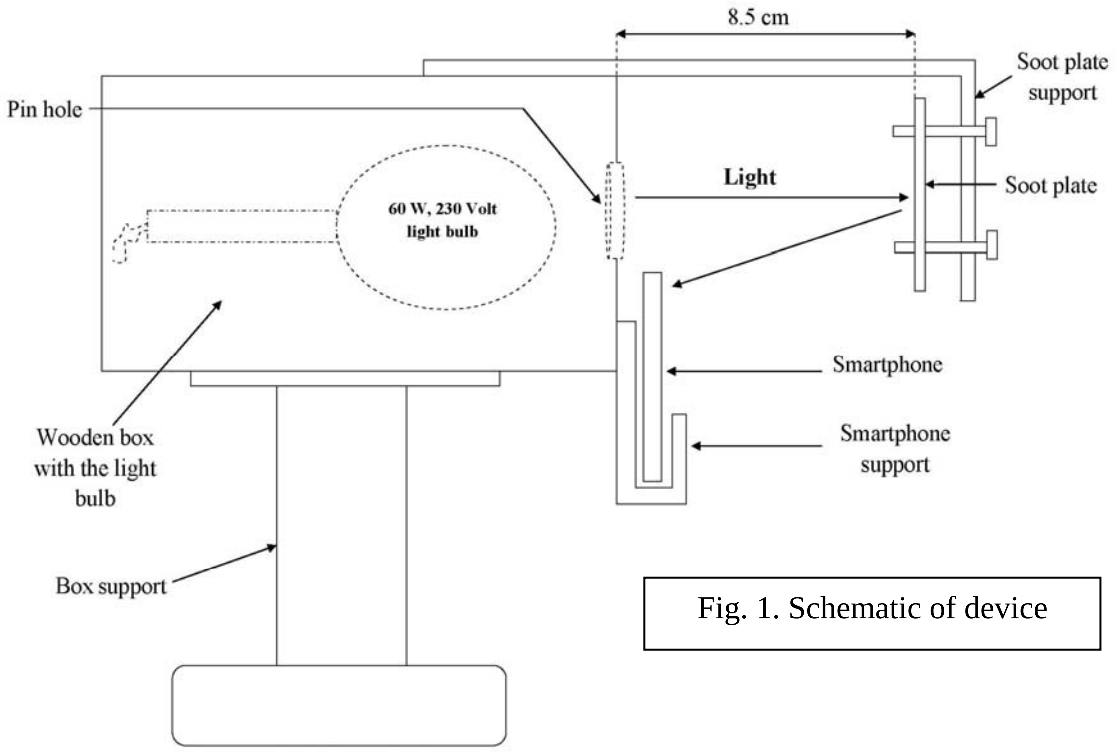

Fig. 1. Schematic of device

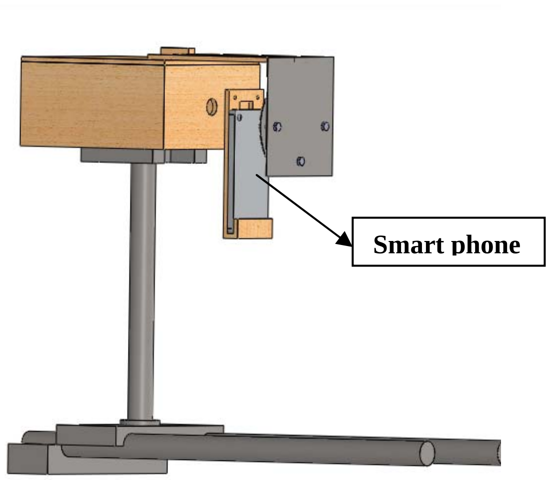

Fig.1 (a) Configuration of device

Materials and Methods

A 10 cm diameter galvanized iron (GI) sheet of 0.5 mm thickness was used as a soot harvesting plate. It was thoroughly cleaned with fine emery paper and washed with soap and water at the start of each experiment. The rough surface of GI sheet made it suitable for soot entrapment. The choice of GI sheet was made since it is easily available at very low cost.

Since soot reflection is a surface phenomenon it should be independent of the material characteristics. To test this hypothesis a stainless steel (SS) plate of 10 cm diameter and 1.0 mm thickness was also used in the study.

An ordinary hurricane lantern which produces high amounts of soot was used to coat the GI and SS sheets with soot. The plates were exposed to the lantern for varying times and the weight of the soot was measured using precision Ohaus PAG 214C electronic balance (0.1 mg accuracy). The soot-coated plates were then put in the device shown in Fig. 1 and the light reflected from the plates was measured by an Android Samsung (Model GI-I-9082) phone. To convert this phone into a light flux meter a suitable application from the internet was downloaded.[9] Though this smart phone had an 8 mega pixel camera, any smart phone with a camera of more than 5 mega pixel would work satisfactorily.

The calibration curve for soot production vs. the light reflected was developed and is shown in Fig. 2.

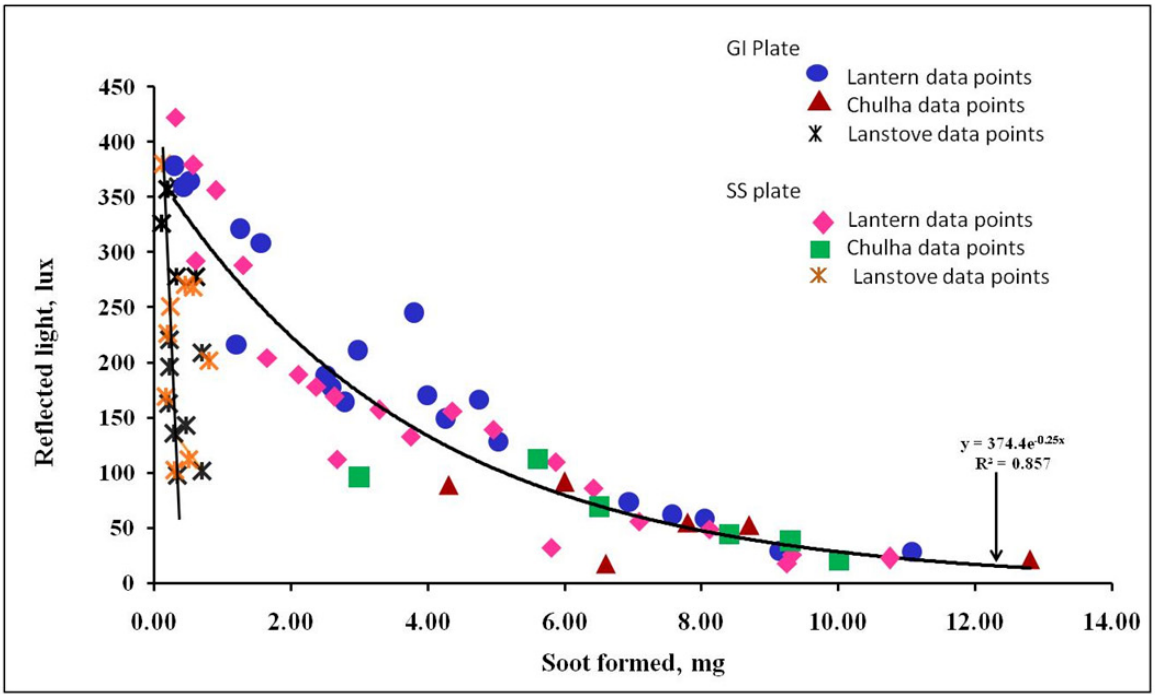

Fig. 2. Relationship between soot production and reflected light

In order to test the reliability of this method and device the actual test data of smoke, during cooking, from chulhas (woodstove) used in a hut was measured. The plates were mounted close to the chulha (distance varying from 10-25 cm from its end) during the cooking operations which lasted for 1.5-2.0 hours. Six test runs on different days were conducted. The plates were then brought back to the lab and their weight and reflections were measured. The data is also plotted in Fig. 2.

The choice of keeping the plates at 10-25 cm distance from the chulha was dictated by the fact that women generally sit at these distances while cooking and hence particulates emission at this distance is a more useful indicator of the inhalation of smoke and pollutants.

The data from these tests also show that the total particulate emissions from the chulhas used in this study were in the range of 0.1 to 0.4 g/kg of wood used. This is much less than the values of 3-5 g/kg as reported in the literature.[10] These higher values of particulates reported resulted since all the soot produced by chulhas is captured in fancy collection devices and measured.

Nevertheless the good fit of all the data from chulhas and different material of the plates attests to the efficacy of this simple method of soot measurement.

Nimbkar Agricultural Research Institute has developed an extremely efficient lanstove for rural huts.[6] This lanstove is an excellent combustion device which provides about 3000 lumens light and in the heat of the light cooks a complete meal for a family of five. Since this is an excellent combustion device, it was thought prudent to measure the soot formation from it and show its efficacy as a non-polluting cooking and lighting source.

Thus the same GI and SS plates (used earlier) were used with the lanstove. A suitable hood over the lanstove was made on which these plates were mounted so as to collect the soot. Since the soot production is very small hence the plates were kept over the hood for 3 to 4 hours to collect sufficient amount. The data from this experiment is also plotted in Fig.2.

It is clear from this figure that the amount of soot production from lanstove is very small. The actual soot production was 1.8-2.5 mg/kg of fuel used which translates to 15-20 μg/m^3. The average hut volume used in our work is 25 m^3 and using the norm of one air exchange in two hours for such buildings (with one door and a small window), the amount of soot per volume of air was calculated.[7] This volumetric particulate emission is equal to or lower than that measured in the air of some of the cleanest cities of the world[8], thus confirming the non-polluting nature of lanstove.

It is also evident from Fig.2 that the soot reflection line for lanstove does not coincide with that from the chulhas and hurricane lantern. One of the reasons is that some tar mixed with small amount of soot gets deposited on the plate. Since the flue gases from lanstove are in the range of 350-400^0 C, there are very good possibilities of tar and soot condensing on collection plates. This oily coating reflected and broke the incident light into beam of different colors which gave fluctuating readings on the Samsung phone. Hence this method of soot measurement is mostly suitable when heavy soot production, which coats the plates evenly, takes place.

We have not patented this device or the method and feel that it should be freely available so that soot production map of various cook stoves used in different regions of the world can be developed.

Though we have shown the efficacy of this method, it should however be pointed out that there is a need to develop a universal curve or set of curves for soot production versus reflection based on various materials of collection plate, various cook stoves and for different smart phones. Once these graphs are developed then it will be easy for researchers to simply measure the light reflected and calculate the amount of soot production under different conditions. This paper may help in this endeavor.

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