Realtime Weight Densitometer for Glass Wool Using Solar Cell for Industrial Use

Masahiro UEDA, Jing CHEN, Keiji TANIGUCHI*, and Katsuhiko ASADA*
Faculty of Education, Fukui University, 3-9-1 Bunkyo, Fukui 910-0017
*Department of Information Science, Faculty of Engineering, Fukui University, 3-9-1 Bunkyo, Fukui 910-0017

(Received January 10, 1998)

An optical method has been developed for measuring the mean weight density of raw glass wool in manufacturing plant. The method is based on the light attenuation theory. The system consists of several white lights as a light source, several solar cells as a light sensitive receiver, amplifiers, a personal computer with A/D converter for data acquisition and a monitor for display of processed data. Mean error of the system was about 10%, which was enough accuracy to be used in the practical plant. The system may further be applied for the quality control of manufacturing raw glass wool.

Key Words: Weight densitometer, Glass wool, Solar cell, Industrial use

1. Introduction

The glass has recently been used more and more, in particular owing to the advancement of manufacturing technique of high purity and glass fiber. An optical fiber in a communication service is the representative example. The other examples are processed goods of glass wool such as a dust proof paper, separator to insulate electric current in a battery and heat-resistant and sound-resistant mat used mainly in a car and a building. An efficiency of the finished goods, i.e., homogeneity in particular, depends on a manufacturing process, mainly on a weight density of raw glass wool.

The weight density may be measured by an attenuation of a sound wave and electromagnetic waves such as microwave and light wave through the raw glass wool. A source of the microwave will, however, be rather expensive for an industrial use. The sound wave will have a troublesome problem of noise when it is used in the factory. That is, a signal obtained by the sound wave of proper frequency for the measurement will include rather large noise produced in the factory. The noise will usually include all over the frequency range and we can not distinguish between signal and noise. On the contrary, we can, easily screen the noise light from the signal light.

We have previously reported a new method to monitor the thickness of a semitransparent foam sheet in realtime using a laser light.1-3) The principle of the method is based on the light attenuation through the foam sheet. The method can also be applied to glass wool weight density since the thickness is directly proportional to the weight density if the foam sheet is homogeneous. It was very simple and was found to be effectively applied for industrial use. It has, however, a drawback to scan the laser beam to examine all the area because an intensity of the laser is rather small. The raw glass wool usually produced is rather thick and then light attenuation and divergence through it become rather large. It, therefore, requires a focusing lens for a transmitted laser light due to a divergence through the glass wool.

This prevents use of laser light as a light source and photodiode as a light receiver.

In this paper, we propose a practical method to overcome these drawbacks, that is, high intensity white light is used as a light source and a large scale solar cell as a light receiver.

2. Method and System

The fundamental principle of the method is based on the light attenuation theory.1-3) But the method in this paper is different from the previous one in two points from a practical point of view. One is to use a white light with high intensity instead of laser light. This enables us to use solar cell as a light sensor and the method to be effectively applicable for high attenuation object. The other is to use a solar cell as a light sensitive sensor instead of photodiode. The solar cell, in itself, is not a light sensitive sensor but a converter from a light power to an electric power. The solar cell has a large dimension as compared to the photodiode. It makes, therefore, a spatial averaging over the cell dimension without scanning the area. It can, further, measure a rather diverged light through the thick semitransparent object such as glass wool without focusing lens. The solar cell has, however, such disadvantages as a low sensitivity to the light and an incomplete characteristics in each cell. The low sensitivity can be solved by using an intense light source and a large scale cell. The incomplete characteristics can be compensated by using an amplifier to each solar cell independently as in Fig.1.

Fig.1 shows a whole system used in a manufacturing plant. Four high intensity white light sources with each output of 500 W were used. These were placed at a distance about 800 mm from a top of the glass wool to illuminate it uniformly as possible as we can. Sixteen solar cells of each dimension 90 mm x 230 mm were used as the light receivers. These were placed at about 30 mm from the bottom of the glass wool to receive the transmitted light directly and at the same time to avoid an attachment of the glass wool to the cells.
The outputs of each solar cell are amplified independently to compensate the output characteristics of each solar cell and the lack of uniformity of irradiated light intensity on the glass wool. That is, all the outputs of each solar cell are adjusted by each amplifier to show the same value under the same weight density. These amplified signals are then digitized by an A/D converter, averaged by a computer and displayed on the monitor as shown in Fig.1. Sampling time of data acquisition is about \( t_s = 0.1 \text{s} \) and a processed data is obtained at an interval \( T_d = 1 \text{s} \) in this case. That is, one data is obtained as a 10 times averaging \( n = T_d/t_s \), \( n \) times for averaging). The data can, however, be obtained at an arbitrary time interval by the computer control. The production speed \( v \) of the glass wool is about \( v = 250 \text{ mm/s} \) and then the processed data on the monitor is a mean value for an area of 90 mm \( \times \) 250 mm (= 25 mm \( \times \) 10). Strictly speaking, the averaging area is not so as discussed in the chapter 3. Lamber's law, \(^4\) which gives a relation between input \( I_i \) and output \( I_o \) light intensity, can be expressed as follows.

\[
\frac{I_o}{I_i} = \exp(-kD), \text{ or } \ln\left(\frac{I_o}{I_i}\right) = -kD,
\]

where \( D \) shows the glass wool weight density of the corresponding area and \( k \) an absorption coefficient which depends on a property of the material. Thus, a natural logarithms of the light intensity ratio is in direct proportion to the weight density. The weight density of a practical product has nearly a constant value, \( D = D_c \), as shown in Fig.1. In this case, a small increment in density, \( \Delta D_c \), may causes a small decrease in output light intensity, \( \Delta I_o \), using a first approximation as follows.

\[
\frac{\Delta I_o}{I_o} = -k(\Delta D_c)
\]

This shows that a small increment in the weight density from about a constant density \( D_c \) is in direct proportion to a small decrease in the output light intensity \( I_o \). The error of this approximation is only 2 % for \( \Delta D_c \leq 0.2 \), since \( e^{0.2} \cdot (1 + 0.2) = 0.021 \). We use Eq. (2) in a practical application of this system.

### 3. Result and Discussion

The system has successfully been used in a manufacturing plant of Japan Inorganic Chemistry Co. Ltd. at Yuki Factory, Ibaraki. Each datum obtained by averaging 10 sampling data is displayed at an interval 1s and is used for control inspection of raw glass wool. That is, a pilot lump signal turns on and off and, at the same time, a position signals on both directions, i.e., width direction and production direction, are stored on the computer when the weight density change exceeds \( \pm 25 \% \).

Fig.2 shows an example of the light intensity for one channel (by optical method) and the measured weight density of the corresponding area (by direct method). Thus, the tendency between both values by optical and direct methods with time flight is found to be coincide perfectly with each other. All the data for 16 channels have similar tendency.

Fig.3 shows both change rates by optical and direct methods in Fig.2 to discuss the validity of this method. The optical change rate is different about 10 % from the direct one. This may be considered as an error of this optical method. It is not, however, necessarily so since a cutting the raw glass wool into pieces is very difficult and then the measured value itself includes some errors. The set point of this weight density is 500 g/m\(^2\) in manufacturing plant. The averaged values, however, is 547 g/m\(^2\) which is larger about 10 % than that of the set point. This is indispensable to assure the finished good's efficiency, i.e., adiabatic and sound-proofing effectiveness. It was further found that the change rate of optical value is always smaller than that of measured value. This is unavoidable to this method which uses large scale photoreceiver for measuring a light intensity through a moving object.

Fig.4 shows this principle. A piece of raw glass wool used for both measuring methods has a dimension 9 cm \( \times \) 25 cm. The solar cell having a dimension of 9 cm \( \times \) 23 cm receives transmitted light corresponding that area on the glass wool. The glass wool moves 25 mm between each data sampling and 25 cm between each processed data since it is obtained by a ten-time averaging of the sampling data. In the central region of the piece,
Fig. 3 Change rate of the weight density by both direct and optical methods. Optical values are reversed.

Fig. 4 Principle of the received light intensity on the large scale solar cell from the measuring area of the raw glass wool. 

Fig. 3 Change rate of the weight density by both direct and optical methods. Optical values are reversed.

Direct measured area

Solar cell

Sampling time for averaging

Glass wool

Move

Transmitted light incident upon solar cell

Measuring area of I_j

i.e., regions 5 and 6 of sampling time for averaging, the solar cell receives 9/10 of the transmitted light from the measuring piece. But it receives only 5/10 from the measuring piece and a remaining part from the adjacent piece as shown in this figure. The optical value, therefore, shows the results obtained from wider region than that of measuring piece. This is a reason for the difference between measured and optical change rates. The difference may be reduced slightly by taking a weighted mean in place of an arithmetic mean used in this experiment. The method of a weighted mean can not, however, settle the problem radically because the measured region for both methods of optical and direct measurement is essentially different.

Errors within plus or minus 10 % or so exist in our optical system as seen in Fig. 3. It can be, however, decreased in accordance with 1/(N)^1/2 from the theory of error3, where N is an averaging times. To do this effectively, a smaller size photoreceiver than that used in this system must be used for the same measuring area and the sampling time of data acquisition must be reduced considerably. This can effectively make N large without the essential problem caused by using large photoreceiver. However, this inversely leaves a strong point of using large scale solar cell described in chapter 1. In conclusion, we must find out a meeting point between them.

The optical method in this study can only measure a relative value of the weight density. The correction is required to obtain an absolute value from the optical value. For this purpose, the absorption coefficient k in equation (1) has to be determined from some light outputs for some known weight densities, for examples, 400, 500 and 600 g/m².

4. Conclusion

The optical method using a white light and a solar cell as a light source and light receiver has been developed for the weight density measurement of raw glass wool in real time. The mean error of the method is about 10 %. The system has now been successfully used in a manufacturing plant to find out inferior goods of more or less than 25 % weight density. It can further be applied for production process.

Acknowledgement

All the experiments have been done with Japan Inorganic Chemistry Co. Ltd. at Yuki Factory Ibaraki, Japan and technical support was provided by Mr T. Inaki of Fukui University.

References