Note to Members:

Enclosed in this mailing is a new bulletin in the Foundation's Preventive Engineering Series -- "Air Flow Measurement by the Dilution Method." This is one of several reports which will be issued as a result of ventilation studies which the Foundation is supporting at the University of Pennsylvania. Tests indicate that the technique outlined in the bulletin offers a practical approach to determining basic exhaust ventilation requirements in certain industrial processes.

Industrial Hygiene Foundation
4400 Fifth Avenue
Pittsburgh, Pa.

July, 1942

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Air Flow Measurement by the Dilution Method

PITTSBURGH, PENNSYLVANIA
JUNE, 1942

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FOREWORD

Upon recommendation of its Preventive Engineering Committee, Industrial Hygiene Foundation authorized a comprehensive study of exhaust ventilation. A grant was made to the University of Pennsylvania, where work is now being carried on under supervision of Professor Theodore Hatch, ably assisted by Robert H. Walpole, Jr.

Reports will be issued from time to time, so that members of the Foundation may benefit while the study is in progress. The reports will be in the form of bulletins in the Preventive Engineering Series; the first is on AIR FLOW MEASUREMENTS.

The fundamental factor which determines the rate of exhaust ventilation for certain industrial processes is the rate of air displacement produced by the process itself. As a starting point, therefore, in the development of a basic approach to the design of exhaust systems, it is desirable to measure the rate of air displacement produced by the process which is to be ventilated.

In general, the air displacement occurring in a given process takes place in such a way that the ordinary air flow meters are not applicable. It becomes necessary, therefore, to utilize a different method of measuring air flow.

The method described in this bulletin was developed to meet these needs, and is capable of measuring the rate of air flow in a complex system which has multiple air inlets and outlets. A major advantage of the method is that it is not necessary to measure the amount of air escaping from every opening.

Practical field tests have indicated that the technique offers a useful and practical approach to the determination of basic exhaust ventilation requirements for those industrial processes which by their operation cause air displacement.

H. B. MELLER,
Managing Director.

4400 Fifth Avenue,
Pittsburgh, Pa.
June 1, 1942.

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AIR FLOW MEASUREMENT BY THE DILUTION METHOD

By

THEODORE HATCH*

and

ROBERT H. WALPOLE, JR.*

Problems in air flow measurement are encountered in which it is not possible to confine the air stream entirely and force it through a meter or past a definite velocity-measuring station. Under these conditions, the rate of air flow may be determined by the dilution method wherein a test gas is fed into the air stream at a known rate and, after uniform mixing is established, its concentration is determined in a unit volume of air. The rate of feed of the gas divided by its resulting concentration equals the rate of air flow.

The test gas must be one that is not absorbed either chemically or physically in the system and, for general use, it must not be toxic or explosive. It should lend itself to collection and measurement by means of simple sampling apparatus and analysis. Carbon dioxide meets these requirements. It is readily available in pressure cylinders and may be fed at a constant rate through a standard pressure-reducing valve and flow-meter. It is easily absorbed in an alkaline solution and is quickly determined by simple titration with as high an accuracy as may be desired. For approximate tests, a portable CO_2 analysis apparatus of the volumetric type may be employed. It is, of course, necessary to subtract from the total amount of CO_2 in the sample that amount which is normally present in the air in order to determine the concentrations of the added gas.

The basic apparatus required for air flow measurement by the dilution method is shown in Figure 1 and the various parts are enumerated below:

1. Cylinder of CO_2.
2. Constant pressure valve.
3. Flow-meter, calibrated in grams of CO_2 per minute at 760 mm. Hg and 0° C. Correction values for other pressures and temperatures are arranged in a convenient table.
4. Gas-feeding tube, arranged to insure uniform mixing of the test gas with the air stream.
5. Sampling tube.
6. Dust filter (when required).
7. Sampling apparatus, including absorption flask and flow-meter.
8. Source of suction.

Many combinations of feeding and sampling equipment will suggest themselves. The apparatus should be simple, rugged, and positive in opera-

* Department of Public Health and Preventive Medicine, School of Medicine, University of Pennsylvania.

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tion. The flow-meter for feeding the CO_2, for example, may be built into the pressure-regulating valve while a hand-operated, constant-flow pump may be employed with the sampling apparatus.

Accuracy

The accuracy of the dilution method, using CO_2 as the test gas, depends upon the following:

1. Uniformity of mixing of the CO_2 with the air stream.
2. Accuracy of flow-meter in the feeding apparatus.
3. Accuracy of the analytical procedure employed for determining the CO_2 concentration in the air stream.
4. Ratio of the concentration of added CO_2 to the normal atmospheric content of this gas.

Complete mixing of the test gas with the air stream is obviously essential. It is readily obtained in a simple air stream in which the air enters through a single inlet and the sampling point can be located a considerable distance downstream. In a complex flow system, however, with numerous inlet and discharge openings and with opportunities for short-circuiting of the test gas, considerable care must be exercised to insure thorough mixing. In certain cases we have found it necessary to introduce the CO_2 into two or more of the secondary air streams before they join to form the main stream. Proof of uniform mixing is demonstrated when the concentration of the CO_2 is found to be the same at the several points of discharge.

The accuracy of rate of feed of the test gas depends upon the design and calibration of the flow-meter, the corrections that are applied for the effects of temperature and pressure and the constancy of flow during the test. These are subject to direct control and the error may be fixed to meet the demands of the problem. This is also largely true with respect to the analytical procedure employed to determine the CO_2 concentration. A number of methods for measuring this gas are described in standard textbooks on gas analysis. The volumetric method, in which the change in volume of the sample resulting from absorption of the CO_2 is measured directly, is perhaps the simplest. It requires no separate sampling device nor is chemical titration involved. The standard instrument, however, does not measure the concentration more closely than to 1 part in 10,000 and, since the amount of gas added may not exceed 6 to 8 parts in 10,000, the accuracy of the air flow measurement will be ±15 to 20 percent. More accurate methods depend upon the absorption of the CO_2 in an alkaline solution of known strength and determination of the amount collected by acid titration. This requires an accurate flow-meter, an efficient absorption device, protection of the absorption liquid from contamination with CO_2 from the air before and after sampling, and careful chemical analysis. It is capable, however, of measuring the CO_2 concentration with a high degree of accuracy. With simple apparatus and analytical procedures which are adaptable to field conditions an accuracy of ±5% is readily obtained.*

The ratio of the concentration of added gas to the normal atmospheric content is, next to uniformity of mixing, the most important factor in deter-

* Conductivity methods are also available.

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mining the accuracy of air flow measurement by the dilution method. The error in air flow measurement increases as the ratio of added to normal CO_2 decreases, as indicated by the following equation:

$$1 \pm \frac{E_Q}{100} = \frac{R}{\left[\left(1 \mp \frac{Eco_2}{100}\right)(R+1)\right] - 1}$$

Where E_Q = Percent error in air flow measurement.
Eco_2 = Percent error in CO_2 concentration.
R = Ratio of added to normal CO_2 concentration.

The relation between E_Q and R is plotted for three values of Eco_2 in Figure 2. These curves exhibit sharp breaks at certain values of R below which the accuracy of air flow measurement decreases rapidly. For an error of ±5% in the CO_2 determination, the critical ratio is approximately 1.5 and this value has been selected for practical field work, thus giving an accuracy of air flow measurement of ±10%. This requires a rate of CO_2 feed of at least 36 grams per 1,000 cu. ft. of air, at sea level. The feeding apparatus should be provided with several interchangeable flow-meters to cover the range of air flow rates to be measured and in a particular problem it is necessary to select the proper rate of CO_2 feed from an initial estimate of the air flow and subsequent trial.*

Application

The dilution method has been found particularly useful in studies of the exhaust ventilation requirements for certain industrial processes in which the principal factor controlling the ventilation needs is the rate of air displacement established by the process itself. As an example, the discharge of crushed rock through a chute onto a belt sets up a flow of air with the falling material and the air escaping from the point of feed onto the belt disperses dust into the surrounding atmosphere. The rate of exhaust ventilation at this point must be in excess of the rate of air displacement. The latter can be measured by the dilution method, thus providing a basis for the design of the exhaust hood. The convenience of this method of measuring air flow rates is well illustrated by the example shown in Figure 3. As indicated in the sketch, crushed ore was fed into the boot of an elevator through two chutes, one from primary screens and the other from a crusher. The material discharged from the elevator into a closed bin from which it was fed to screens, the oversize from which dropped through a bin and chute to the crusher. The problem was to determine the rate of air displacement in the elevator. Smoke tests revealed that air was entering the boot of the elevator with the ore discharging from the primary screens and from the crusher as well. Above the elevator boot the housing was found to be under pressure with air escaping at the elevator head and at intermediate openings. Four air flow measurements were made at the locations shown in Figure 3. By means of tests 1 and 2 the rates of air flow induced by the

* High rates of CO_2 feed (75 gms. per minute and more) through the pressure-reducing valve cause freezing in the valve. The use of a heating element near the reducing valve helps.

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discharge of ore from the primary screens and the crusher respectively into the elevator were determined whereas tests 3 and 4 were designed to measure the total rate of air displacement in the elevator. Since the major air inflow occurred in the screen and crusher discharge chutes, it was expected that the sum of the rates of air flow determined in tests 1 and 2 would approximately equal that obtained in test 3. The results from tests 3 and 4 would be in substantial agreement provided there was no leakage in the elevator housing below the point of CO_2 feed in the latter test. The rates of air flow were found to be as follows:

Test	Rate of air flow, cfm.
1	1810
2	2750
1 + 2	4560
3	5000
4	4600

In view of the fact that the rate of flow of ore was not constant during these tests, the agreement among the results is excellent.

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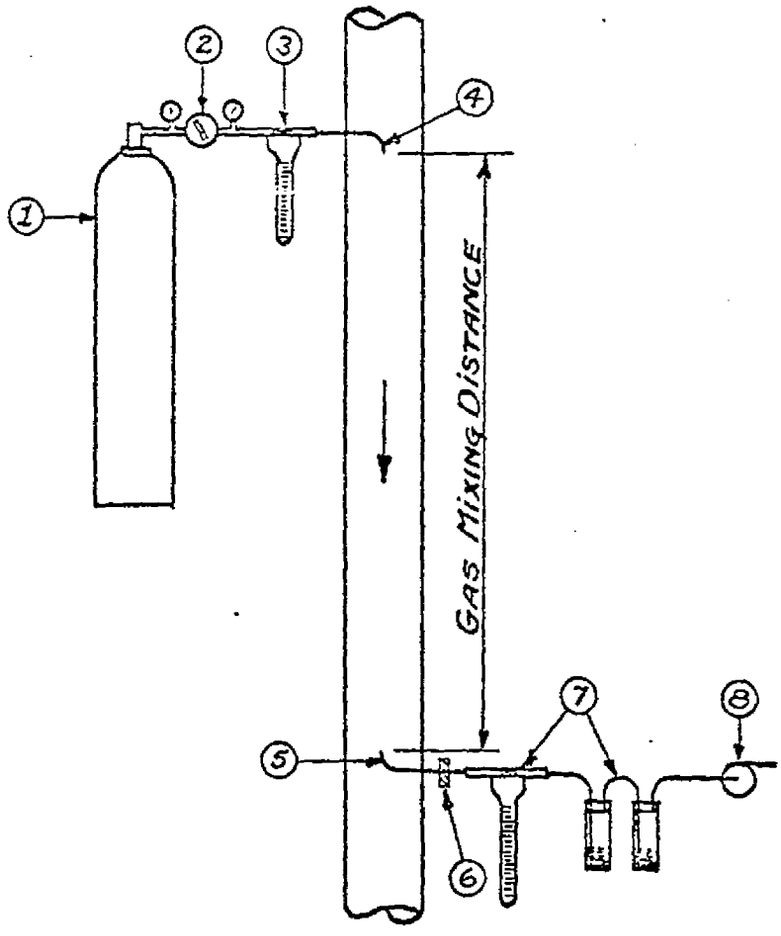

Figure 1.
Diagrammatic layout of apparatus employed for air flow measurement by the dilution method.

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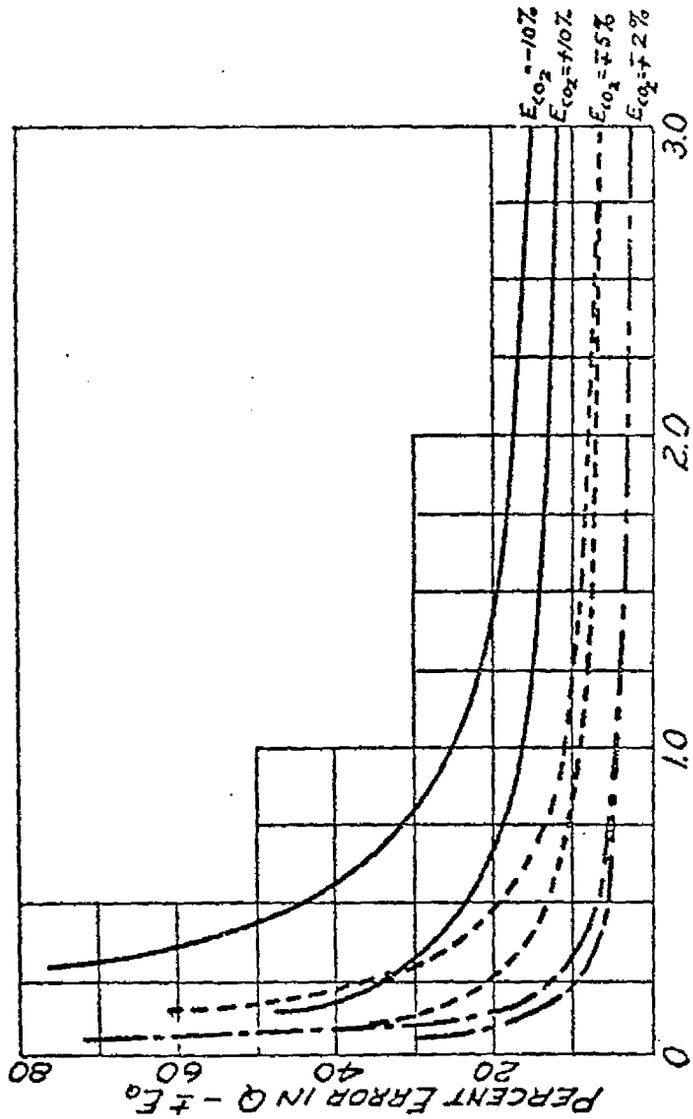

Figure 2.
Error in air flow measurement in relation to the ratio of added to normal CO_2 concentration in the air.

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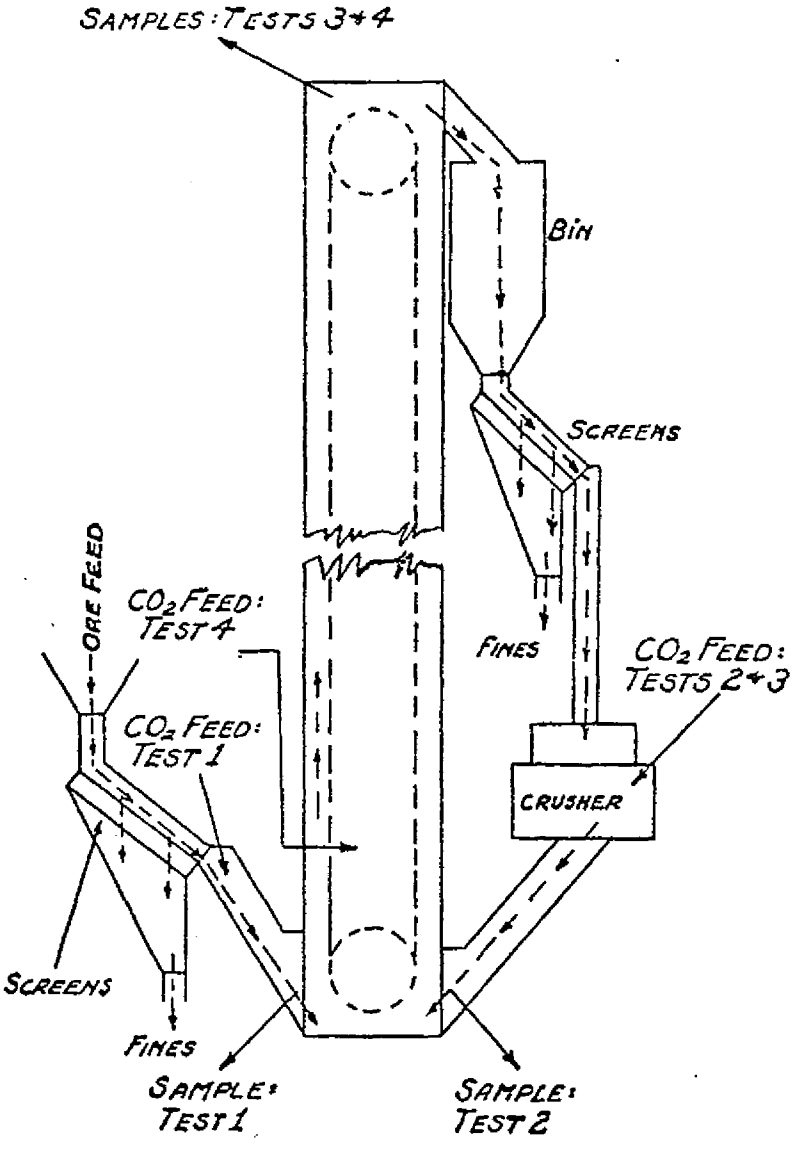

Figure 3.
Measurement of air flow in an elevator by the dilution method.

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