THE MEASUREMENT OF VENTILATION RATES USING A RADIOACTIVE TRACER*

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Synopsis.

The qualities desirable in a tracer gas for the measurement of ventilation rates in buildings are reviewed. The use of a radioactive tracer has certain advantages for some applications, and the paper reports experiments in which radioactive argon was used to measure the ventilation rate in a room. The results obtained agreed with simultaneous measurements using hydrogen as tracer. It is suggested that the method may be particularly useful for measuring ventilation rates in large buildings.

Introduction.

THE tracer-gas method of measurement of ventilation rates in rooms and buildings is a well-established technique which has been used by many investigators during the past century. A suitable tracer gas is introduced and the subsequent rate of decay of its concentration is measured. From this the number of air changes per hour is directly obtained.

A tracer used to measure air-change rate must have some physical or chemical property which is easily and accurately measurable to provide an estimate of its concentration. For use in occupied rooms it must be non-toxic in the concentrations used and preferably be undetectable by the human senses. Also it should not be absorbed by or react chemically with walls or furnishings. And the density should be similar to that of the air so that it will have a similar rate of migration.

Development of the Tracer Method.

Early estimates of the air-change rate in an occupied room were based on the measurement of the concentration of the carbon dioxide exhaled by the occupants when this had reached a steady value.[1] Subsequently, measurements were made by introducing carbon dioxide into the room from a cylinder, and thus obtaining a higher concentration and improved accuracy of measurement.[2] The standard method for determining the carbon dioxide concentration was a chemical one, using the Haldane apparatus.

Other substances used as tracers include water vapour,[3] which suffers from the disadvantage of absorption by walls and furnishings, and tertiary butyl hypochlorite estimated chemically,[4] which did not, however, appear to give consistent results.[5]

Hydrogen, estimated by a katharometer or thermal conductivity meter, has been found by several workers to give reliable and consistent results.[6, 7] For occupied houses helium has been used as a safer alternative to hydrogen.[8] Carbon dioxide has also been used with the katharometer, but the sensitivity is much less than with hydrogen.

Limitations of the Katharometer Method.

To obtain a reliable result from the katharometer method using hydrogen it is necessary to have a tracer concentration of not less than 0·3 per cent. Whilst there is no difficulty in attaining this concentration in a domestic dwelling, in a hospital ward, measuring, say, 100 ft × 20 ft × 10 ft, 60 cu ft of hydrogen would be required, which is half the contents of a normal cylinder. Apart from inconvenience in handling the bulk, difficulty would be experienced in releasing the gas sufficiently rapidly through the valve to build up the concentration, and in ensuring that it was completely mixed with the air in the ward. In the case of helium or carbon dioxide the output produced by the katharometer is less than that obtained using hydrogen, and the amounts of tracer required are respectively 1·6 and 8·0 times as great.

The light gases also diffuse more rapidly than air. This has not given rise to any significant inaccuracy when used in brick-built structures with walls plastered internally, but these gases might prove unsatisfactory in a building with a more porous construction, where the increased rate of diffusion of the tracer gas could increase the apparent air-change rate. The presence of a light tracer causes a diminution of the density of the room air, but the effect is negligible with the concentrations used.

Other effects which could possibly cause difficulties include absorption by the building materials. Carbon dioxide might be expected to have some chemical action on plaster in the presence of water vapour, but this does not occur rapidly enough to affect the measured ventilation rate. Where its use is not impracticable, due to the size of the room, carbon dioxide has the advantage of having a density more nearly equal to that of air.

The Use of a Radioactive Tracer.

Radioactive materials are now becoming available and appear to offer great advantages for measuring ventilation rates in large buildings. The rate at which disintegrations occur can be used as a measure of the concentration, and with a sensitive detector (usually a Geiger counter and ratemeter which record the counting rate directly and continuously) only minute amounts of tracer are required. One microcurie of tracer will produce 37 000 disintegrations per second. The choice of radioactive tracer is, however, somewhat limited. In addition to meeting the requirements already discussed it must have a suitable half life,* and produce no harmful radioactive decay products. It is also desirable that the activity used should be low enough for people to be in the room or building while the experiment is in progress. The most suitable tracers to satisfy these conditions are the inert gases argon and krypton. Both of these can be obtained in a radioactive form, and in each case the concentration required for a ventilation rate measurement is below the tolerance dose for continuous exposure, so that there is no danger to health from short-term investigations.

In France, radioactive xenon (Xe^{133}) has been used successfully by counting with an ionisation chamber the ions produced by the passage of the beta particles.[9] Our experience with argon as a tracer is described below.

Experimental Verification of the Method.

Tests were undertaken in one of the experimental houses of the Building

 Manuscript received February 8th, 1955.

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* The period of time taken for radioactivity of a substance to decay to half its original

Research Station to demonstrate the suitability of the method, using normal katharometry with a hydrogen tracer as a check. A preliminary test was made with radioactive ethylene dibromide as this was readily available. It was found, however, to be retained in the room by absorption into walls and furnishings, and hence gave a false reading.

For the next test a small quantity of the radioactive argon isotope A^{41} was released into the living-room of the experimental house in which was installed a Geiger counter and ratemeter, and a katharometer. Hydrogen was injected at the same time, and simultaneous measurements made of the rate of decay of the two tracers.

From the decay curves obtained from these readings the ventilation rate of the room was deduced by the two methods. With the radioactive tracer allowance was made for the natural rate of decay of activity. The comparative values obtained were 1·1 and 1·2 air changes per hour with the windows closed and 2·8 and 3·0 air changes per hour with one top hung light vent open, the figure for the radioactive tracer being given first in each case. There was no evidence of any absorption on the walls or furnishings, and after opening all the windows the counting rate quickly fell to very little above the normal background.

Characteristics of Radioactive Tracers and Their Use.

The argon isotope A^{41} emits energetic beta particles, and also gamma rays. Half of the beta particles are absorbed in two feet of air, and thus, if a Geiger counter which is sensitive to beta particles is used, it will be principally sensitive to the air in a sphere around the counter, two feet in radius. The gamma rays, however, have a very much longer range and they will be received from all points in the room which are not shielded by heavy material such as machinery or brick walls. If a higher concentration of activity were used it would be possible to count the gamma rays only, by using a counter insensitive to beta particles, and thus local variations in the activity in the immediate vicinity of the counter would not affect the reading, and a smoother decay curve would be obtained.

The main disadvantage of the use of radioactive argon as a tracer is that its activity decays by a factor of two every 110 minutes, which restricts its use to short investigations near the source of supply. However, it may therefore be used safely in places where the rate of leakage is small since the activity will have decayed almost to the background level within a day.

A possible alternative, krypton (Kr^{85}) has a more useful half-life of 9·4 years and emits beta particles with a small percentage of gamma rays. The beta particles are not so energetic as those of argon and the major contribution to the counting rate would come from a sphere of about 10 inches radius round the counter. Both argon and krypton have a rate of diffusion which is much closer to that of air than either hydrogen or helium, and from this point of view either of them can be used with advantage.

There are two sources of inaccuracy in determining the concentration of activity in the air. One is due to the background counting rate in the detector, originating from cosmic radiation, and from stray radiation from the earth and the building. Its value may be determined quite accurately before the experiment commences, and it is necessary to use a tracer activity that is always much greater than the background counting rate.

The other possible source of inaccuracy derives from the fact that radiations from a source of activity take place as a series of random events and are subject to the laws of statistics. If a count of magnitude N is recorded, the standard error in this is $\pm\sqrt{N}$. Hence for a total count of 10 000 there is a standard error of $\pm$ 100 or 1 per cent., and a total count of 100 gives a standard error of 10 per cent. In determining ventilation rates, a series of short readings is taken and these are plotted against time. A standard error of $\pm$ 5 per cent. on a single reading of half a minute duration would be acceptable for most investigations, and this would require a counting rate of about 1000 per minute. This counting rate is found by experiment to be obtained by the use of radioactive argon (A^{41}) with a concentration of about 0·025 microcuries/cu ft or radioactive krypton (Kr^{85}) with a concentration of 0·1 microcuries cu ft. A commercially produced beta particle detector 24 cm long would be used. This has a natural background of about 90 counts per minute. Thus in a space of 20 000 cu ft, an activity of about 500 microcuries of argon or 2000 microcuries of krypton would be required. These activities could be obtained in 2 cubic centimetres of argon, and in considerably less volume for the krypton. When using these small quantities of gas the addition of, say, 100 cubic centimetres of inactive argon or krypton carrier may be advisable to reduce any small absorption losses.

In a space of this size, of course, it would be necessary to ensure complete mixing by fans or otherwise before measurements were commenced.

Precautions.

Very stringent handling precautions are not necessary with these amounts of activity. The active gas will normally be contained in a small glass ampoule and this should be stored in a lead container until required. The ampoule should be extracted with handling tongs and broken in front of a fan placed so that the more concentrated active gas is blown away from the operator.

Conclusion.

Tests described with the argon isotope (A^{41}) show that radioactive tracer gases appear to offer a practicable and effective method of measuring air-change rates in buildings in which the normal technique of using katharometers and hydrogen or carbon dioxide is unsuitable owing to the large volume or the presence of porous materials in the construction. High price and difficulty in obtaining supplies of the tracers that have proved successful on account of a suitable half life and acceptable physical and chemical properties may at present restrict general use of this method for routine air-change measurements in dwellings. It is anticipated, however, that suitable tracers may become more freely available in the future, and the advantages of small bulk and similar rates of diffusion to air may encourage the more widespread use of the method.

Acknowledgments.

The authors wish to express their appreciation of the help and guidance afforded by Mr. J. B. Dick, of the Building Research Station, and Mr. L. O. Brown, of the Atomic Energy Research Establishment, in the design and execution of the experiment.

The work described was part of the ventilation research programme of the Building Research Board of the Department of Scientific and Industrial

Research and was done with the co-operation of the Atomic Energy Research Establishment. This paper is published by permission of the Director of Building Research.

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