i.e., when the ratio of the pressure in either side of the orifice is .53, we have the condition of maximum discharge.

Equation (2) may be used to determine the theoretical velocity

$$V = \sqrt{2g \frac{\gamma}{\gamma - 1} P V_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \right]}$$

$$PV = RT$$

$$\therefore V = \sqrt{2g \frac{\gamma}{\gamma - 1} R T_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \right]}$$

This reduces to

$$V = 109{\cdot}1 \sqrt{T_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \right]} \qquad (4)$$

V = Velocity in feet per sec.
g = 32·2
γ = gamma = $\frac{CP}{Cv}$ = 1·404 for air.
P = Pressure in lbs per square foot.
A = Area in square feet.
R = Gas Const. = 53·2 foot lbs per lb of air.
T = Absolute Temp. Fah.
v = Volume of air in cubic feet per pound.
k = Kinetic Energy.

Discussion.

Mr. A. W. Tournay-Hinde said that it gave him pleasure to propose a vote of thanks to the author of the extremely interesting paper that had been presented to them that evening.

The paper was particularly lucid as to the methods used by the author for calibrating a sharp-edged orifice, when used for determining the flow of air. It interested the speaker very much, and he also felt sure that those present could not fail to be impressed with the simplicity and with the accuracy of the methods employed by Mr. Swain. The paper was not one that permitted of much discussion, as it was a statement of actual results achieved, and it only permitted one to express their commendations to the author for the great care taken in carrying out the experiment, and also their appreciation of his generosity in placing the data of the experiment so fully at the disposal of the Association. The speaker had had considerable experience in measuring the flow of air through both large and small pipes at varying pressures, and appreciated fully the difficulties associated with work of this character, and a knowledge of the difficulties enabled him to appreciate fully the work done by Mr. Swain.

MR. POOLE: In supporting the vote of thanks, said that he was greatly interested in what had been said that evening, because the measurement of gas, air or steam was a much more difficult problem than, for example, such a material as water. It has been found that the variation in co-efficients of flow of air through orifices differs from, but is very similar to, that of water under like conditions. A scheme has been installed on the Rand* to supply the various mines with compressed air from a central plant, instead of each mine generating its own. Some idea of the magnitude of the undertaking can be gauged from the fact that air meters have been installed to the capacity of over 300 million horse-power-hours per annum. Under the terms of the agreement between the Power Company and the consumers, it was stipulated that the air meters should be obtained which would register accurately to within ± 3 per cent. This necessitated very careful calibration of orifices, and then of various types of meters. Meters, both of the "Venturi" and "Gate" type, are used for regulating consumption. It was found that the accuracy of "Venturi" meters was about ± 1 per cent.

* See Hodgson: "Commercial Metering of Air, Gas and Steam." Proc. Inst. Civil Engr. vol. cciv.

Weighted vane indicators were in 1901 placed in the supply pipe to each of the blast furnaces at the Port Pirie Works. Though these were not meters, they gave a good idea of the comparative distribution from a common bustle pipe. An orifice in a thin partition or plate has been used for many years in mines with mechanical draught for measuring the air supply, resistance of the mine, or varying efficiency of the fan plant. The method adopted is to provide a rectangular orifice which is adjustable in size of opening, and it is known as the "equivalent orifice" of the mine. The orifice is calibrated by measuring for various sizes of opening the flow of air under a constant gauge pressure, e.g., 3 inches of water. The resistance of a mine with the various extensions of air courses may be thus gauged. The equivalent orifice is also used to compare the efficiency of one plant with another.

The smoke test referred to by Mr. Tournay-Hinde is used in metal mines, e.g., the deep shafts at Charters Towers—1000 to 2500 feet deep to the first air offtake. An open pan of black gem powder is fired just below the mouth of the shaft, and at the same time an electrical signal sent to the observation station below. It is found that the first and the last of the smoke puff is fairly distinct, so that a good average time and velocity may be determined. It is found that the average velocity multiplied by the cross section of the shaft give a reliable estimate of the volume of air passing into the mine.

He had much pleasure in seconding the vote of thanks to the author.

Mr. Barr: The method put forward by the author was certainly very ingenious. He had never heard of the idea of making a mixture of gas and air to determine the flow, and thought the practice was open to certain objections. The percentage of gas, 4 cubic feet in 35.5 secs., as compared with 181 cubic feet of air, is only 2 per cent., or if 7 cubic feet per min. would be present in 181 cubic feet, it would be equal to about 4 per cent. An analysis of the mixture might not give a true percentage of the contents.

The figures given by the author indicated that an error did not appear, but he (the speaker) was doubtful. Theoretically, the value .53 for maximum discharge of air compared well with the figure .58 attained by Professor Rateau, who delivered a paper about 12 years ago dealing with 400 experiments made with steam through pipes of various sections. The maximum flow was intended to be .58, with an entire pressure of 100lbs. per inch, outlet 80lbs. per inch.

At that time no other paper was available, but later it was shown that with thin, sharp-edged orifices, a coefficient of discharge equal to .2 to .4 was obtained.

With converging nozzles and a maximum discharge of .6 to .8 as against .53 given here, it would appear that there is something not yet known as to the behaviour of steam and air through nozzles. If the expression (4) is theoretically correct, and the maximum discharge obtained is .8, it would appear that the coefficient used by the author would require revision.

Sharp-edged nozzles appear to be subject to variation in pressure more than converging nozzles. Professor Rateau has designed a nozzle whose co-efficient of discharge is unity when discharging through pumps.

Converging nozzles are not so susceptible to changes as sharp-edged orifices—possibly due to pulsations set up.

MR. CALMAN: I have read Mr. Swain's paper with a great deal of interest, and I very much regret that I am prevented from attending the meeting this evening. The very evident care and thoroughness with which the author has carried out his experiments and placed the results before members will, I feel sure, lead to a more than usually hearty vote of thanks being accorded him, and I wish strongly to support it. Mr. Swain's "gas shunt" method is particularly interesting, and the ingenious manner in which he explains how it occurred to him in no way detracts from the merit of developing the idea. Whilst the paper does not seem to hold out the method as other than a laboratory one for primary calibration work, it appears as though it would be useful in the direct measurement of almost any constant flow gas system. In the case of gauging the output of large smoke-blowers, the supply of sufficient gas suitable for admixture might be a source of difficulty, but not beyond the limits of practicability. The resulting accuracy would probably be higher than that secured with pitot tubes, as are commonly employed.

I note that no allowance is made by Mr. Swain for the initial CO_2 content of the air, and assume therefore that he was using air of negligible CO_2 impurity. In some situations it would be necessary to make an allowance on this account, especially if working with a small proportion of inserted CO_2.

In conclusion, I should like to urge that if there could be carried out in the Universities and Technical Colleges more original work of the nature of that which Mr. Swain has had the energy to undertake, it would be extremely beneficial to the country, both on account of the information that would be made available, and because we should have at hand the facilities for carrying out with our own resources any special investigations, the need for which might seem urgent from time to time.

The President, Mr. Harricks, said that one small matter had occurred to him, and that was the position with regard to the sampling pipe which was inserted to extend across the full width of the six-inch pipe, but as the CO_2 would be heavier than the other gases, a better average would be obtained by placing the sampling tube vertically. The frequent reference to the "Pitot" tube had reminded him of a modified "Pitot" for which is claimed a high degree of accuracy. As it will doubtless interest members, an extract from the "Engineering Record" is given below:—

The Pitot tube has long been used as a device for measuring the flow of liquids and gases, but only when used with the utmost care have the results proved uniform. Many experimenters have worked with modified forms in the endeavour to reduce the variation in results, but it is evident not only that the data obtained are variable in the hands of different men, but that the same tube may have different coefficients.

In order to correct this latter defect, Prof. H. A. Thomas has devised what may be termed the "Hydraulic Shunt-Flow Tube," which is described in the March issue of the "Rose Technic," p. 176. This device is a tube so arranged that it may be introduced into the stream with the tip directed against the flow, and yet maintain at the tip the same pressure that existed before the introduction of the tube. The water flows into this tube, and may be shunted into a small container, and weighed, leaving the velocity undisturbed from the normal.

The velocity of flow at the tip of the tube will be equal to the quantity of water collected in the measuring tank in a measured time, divided by the area of the tip—all quantities being measured in the usual units. It is possible to demonstrate mathematically that turbulent flow should not affect the coefficient of the tip. Theoretically, of course, the tip coefficient should be unity under all conditions, but a series of experiments undertaken with this in view show that it varies less than 1 per cent.—the Pitot coefficient under like conditions varying more than 4 per cent.

Mr. Swain's Reply.

MR. SWAIN thanked the meeting for the way in which his paper had been received. The information gleaned by the discussion was very valuable.

Re Mr. Barr's remarks, the author agreed with the speaker as to discrepancy that may occur, and also agreed that quite wide results might be obtained. The readings taken were from approximately 100 experiments.

Re the question concerning the value of pressure ratio, the value .53 as given is for an adiabatic condition, with freedom from eddies and disturbances of any kind. Such eddies, etc., may exist and not be noticed, and these may have accounted for Mr. Barr's different reading.

The shape of orifices also has a bearing on the readings. The author would like to see the type of apparatus referred to by Mr. Barr.

He very much appreciated the President's remarks, and the point raised as to the position of gas tube he thought might have some bearing on the readings.