TESTING SMALL ORIFICES

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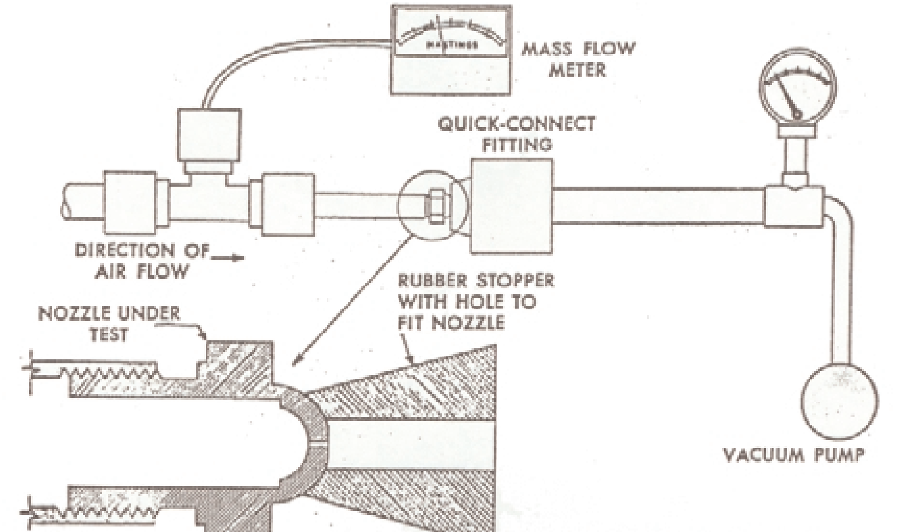

FIG. I. ARRANGEMENT for testing small nozzles and orifices.

A mass flaw meter can be used for rapid check of orifice diameter of small nozzles in production. Use of critical flow makes test independent of pressure downstream of orifice.

Small orifices and nozzles of the types used in gas burners, oil burners, spray guns and expansion throttles of refrigeration machines are manufactured to tolerances that may be difficult to hold in routine production unless sample units are regularly inspected for accuracy of the drilled holes. Probably the most satisfactory method of inspecting these orifices is to establish a flow through the hole under a given set of conditions that are accurately known, and to measure the resulting flow. The method described here makes use of a sensitive flowmeter comprising a compensated thermopile to measure the critical flow* of air through the nozzle. The air flow through the orifice can readily be established at the velocity of sound; this condition is easily reproduced with simple equipment that is well suited to routine testing. The method and equipment have proven particularly well adapted to the measurement of orifices having diameters ranging from 0.002" to 0.010", but are not limited to that range.

CRITICAL FLOW

When gas flows through a nozzle or orifice, the flow depends on the pressure differential across the orifice only up to a certain point. If the upstream pressure is held constant and the pressure at the discharge end is decreased, the flow of gas will increase up to a critical value. Beyond this point further decrease in the downstream pressure causes no further increase in flow. This is the critical flow condition. (It is related in a simple way to the velocity of sound in the gas, which in turn depends on the molecular weight and ratio of specific heats of the gas, as well as the temperature.)

When air flows through a nozzle, the critical condition is obtained if the upstream pressure is approximately two or more times the downstream pressure.' The equation for critical flow through a nozzle is:
where q is mass rate of flow of the

$$q = CApK\sqrt{MU/T} \qquad (1)$$

gas; C is discharge coefficient; A is cross-sectional area of the nozzle throat; p is upstream static pressure of the gas; K is dimensional coefficient involving the gas constant; M is molecular weight of the gas; T is absolute temperature of the gas upstream; and U is a constant that is characteristic of the gas equal to: k $[2/(k+1)]^8$, in which k is the ratio of specific heats (C_p/C_v) and s = (k+1)/(k—1).

For air flow, this equation becomes:

$$q = 0.53\ CpA/\sqrt{T} \qquad (2)$$

where q is flow rate (lb/sec), C is discharge coefficient, p is pressure (psia), T is absolute temp (°R), and A is nozzle area (sq in).

A vacuum pump can be connected to the discharge end while the up. stream end of the orifice is open to the atmosphere. The upstream pressure, p, is then barometric pressure; T is the absolute temperature of the atmospheric air entering the nozzle.

If the barometric pressure and the ambient temperature are constant, the flow (q) then depends only on C and A. Although much experimental data have been published for orifices having diameters of the order of 1" and more, data for commonly used small orifices having diameters of the order of a few thousandths of an inch are more limited. However, some tests on several small orifices assembled from commercially available sapphire-cap bearing jewels ranging from 0.0024" to 0.044" diameter have been described.[2] On those tests the discharge was measured at a pressure ratio of approximately 3 to 1, assuring critical flow. Variations of 10% in the downstream pressure resulted in no measurable change in discharge. Variations in the upstream had a linear effect on the discharge, in accordance with theory. Although the cap bearing jewel is not designed as a nozzle, the contour of the orifice does resemble that of a nozzle, and would be expected to have somewhat similar discharge characteristics.

Several "standard" sets of atmospheric conditions are in use. One standard, which has the advantage of being near the conditions usually found in a shop environment, specifies a temperature of 75°F (534.9°R) and a barometric pressure of 29.99" Hg (14.73 psia). At these standard conditions, and for

*Critical flow is flow that is dependent fo downstream pressure.

a nozzle coefficient of unity, the computed mass flow rate of air is 20.2 pounds per minute per square inch of nozzle area.

For actual nozzles made according to ASME standards, coefficients of between 0.92 and 0.97 are common. The coefficient for thin-edged orifices may be as low as 0.6.

Equation (2) can be rewritten as a function of the orifice diameter. The volume flow in cubic centimeters per minute of air at standard temperature and pressure becomes:

$$V = 6.0\ a^2$$

where a is the diameter in mils (0.001”).

Table 1 lists numerical values used in estimating the range of flowmeter suitable for testing various sizes of nozzles.

TABLE 1-EXPECTED VELOCITY FOR VARIOUS NOZZLE SIZES

a (Mils)	V(cc/min)
1	6
2	24
4	96
8	384
16	1536
20	2400

Equipment and Procedure

A convenient arrangement for testing nozzles is shown in Fig. 1. The vacuum pump may be of several types. A water aspirator is satisfactory and inexpensive. Some models of diaphragm vibrator pumps, such as used for paint sprays, also are satisfactory. A mechanical pump may be preferred for routine testing. The pump should have adequate pumping speed at the desired pressure of from 0.2 to 0.4 atmosphere. The smaller models of 1-stage or 2-stage vacuum pumps with 1/4- to 1/3-hp motors are also satisfactory.

The suction line is provided with a quick connect coupling at the point where the test nozzle is to be inserted. A compression-type seal, perhaps using a rubber O-ring, can be provided on the downstream side of the nozzle. This is the point at which leaks are most likely to be troublesome. The flow tube can be connected to the upstream side of the nozzle by another O-ring coupling, by a rubber tube, or by grommet. As there is no appreciable pressure drop across the flow tube, leaks are not likely to be troublesome on the upstream side of the nozzle. Note that leaks on the downstream side of the orifice are unimportant if they do not exceed the reserve capacity of the vacuum pump. This can be assured easily by observing the Bourdon-type vacuum gauge in the suction line.

On the upstream side of the flow tube, a simple air filter will insure against fine particles being drawn into the nozzle to cause clogging. The filter tip of a cigarette is convenient and suitable for this purpose.

When testing a large number of units it is advisable to have one nozzle with the desired characteristics. Others representing the high and low limits also may be desirable. Another sample having the same dimensions, but without a hole in it also should be available. The standard nozzle can be tested occasionally as a check on the overall performance of the setup. The dummy can be inserted in the line as a check to insure against errors from leaks at the coupling.

SENSITIVITY

The sensitivity of the method can be computed from the known sensitivity of the flowmeter and the theoretical formula for flow through a nozzle. Consider a nozzle having a throat diameter of 0.005". The critical flow will be approximately 150 cc/minute. A change of 3 cc per minute corresponds to a change of approximately 0.000 1" diameter of the orifice, or 3%. This can be read easily on a 0-500 cc per min-ute meter scale; a 150-1000 cc per minute scale also is available for tests of larger nozzles.

RESULTS

In a series of tests a number of commercially available nozzles was tested to see if they exhibited a definite value of critical flow which remained constant as the downstream pressure varied. A series of small orifices used in hand torches that burn propane gas was included. The flow through one sample having a bore of approximately 0.006" was measured for several different pressures on the suction side. The flow was found to be 132 standard cc per minute, constant within ± 1% for all pressures from 1/2 to 1/10th atmosphere, the lowest pressure included in. the tests. The theoretical flow through a nozzle having a throat diameter of 0.006" is 216 cc per minute. The nozzle coefficient in this case is 132/216, or 0.61. The small nozzles used in these tests were more like a thick-plate orifice than a stand-ard ASME nozzle.[3]

No attempt was made to examine the theory in detail for any particular shape of orifice or nozzle. It is sufficient for the present purpose that the results showed general agreement with theory.

A number of nozzles, all of the same production run, showed variations that were measured readily. Differences in flow among the various samples revealed variations in nozzle characteristics that correlated with variations in dimensions of the openings as measured with a micrometer microscope.

This flowmeter test method is fast and has the advantage of requiring a minimum of skill and concentration of the operator. The method also is adaptable to automatic controls when used with meter relays or recorders to measure flow. An additional advantage over optical inspection is that the flowmeter test measures the nozzle discharge directly, rather than inferring it from a dimension that is difficult to determine, especially if the orifice is out-of-round.

Reference

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