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UNITED STATES ATOMIC ENERGY COMMISSION

**FLOW METER FOR MEASURING AIR-FLOW
THROUGH SPECIAL HOODS**

Final Report

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INTRODUCTION

At a flow rate of 30 c.f.m., the approximate rate required to provide an air change per minute in a four-foot hood, the pressure drop across a new filter is 1.0 inch of water. As the filter loads or clogs, in order to maintain the same rate of flow, the pressure drop across the filter increases. It can increase to approximately 3.0 inches of water at which point the capacity of the blowers is reached. At that point the pressure drop remains constant and the flow rate falls off. This flow rate will continue to decrease until the hoods are no longer properly ventilated and the filters should be changed. The rate at which the filters clog varies from hood to hood and therefore, the periods at which the filters should be changed also varies from hood to hood. In order to know the flow rate and thereby when to change filters, a flow meter is necessary.

The specifications for such a meter are: low cost
an accuracy of approximately plus or minus 10 per cent, compactness, corrosion resistance, ease of installation, and adaptability to the present ventilation scheme.

Instrument suppliers were contacted on the problem, but their prices were excessive. Some showed skepticism as to whether the problem could be solved or not. However, it was decided to attempt to measure the flow rate by means of an impact tube and a differential manometer.

SUMMARY AND CONCLUSIONS

The differential manometer in conjunction with the *Spelling* pitot or impact tube idea was found to meet all the specifications. A workable model was developed after several attempts using different designs, materials of construction, and liquids.

The pitot tube (see Figure 1) was made of copper tubing bent at an angle of 90° and installed in the Saran supply duct with the bent leg facing upstream. A second piece of copper tubing was attached to the Saran duct opposite the open end of the bent tube. The location of these tubes in the duct is critical. The pressure drop between these tubes is given by the following formula:

→ **FIGURE NO. 1** ←

PRINCIPLE OF OPERATION: IN THE ABOVE SET-UP WITH THE PRESSURE OPENING FACING SQUARELY UPSTREAM, AND THE SECOND TUBE MOUNTED IN THE DUCT PERPENDICULAR TO THE DUCT, THE PRESSURE DROP DEVELOPED WILL BE ONLY THE VELOCITY HEAD (NOT STATIC HEAD) AND IS DIRECTLY PROPORTIONAL TO THE VELOCITY OF THE AIR FLOWING. HOWEVER, WITH THE IMPACT TUBE LOCATED EXACTLY IN THE CENTER OF THE TUBE, THE VELOCITY MEASURED IS NOT THE AVERAGE VELOCITY AS THE VELOCITY VARIES ACROSS THE CROSS SECTIONAL AREA OF THE DUCT. THE REYNOLD'S NUMBER CHARACTERISTIC OF THE FLOW CONDITIONS VARIES FROM 9000 TO 27000. WITHIN THIS RANGE THE AVERAGE VELOCITY OF THE AIR FLOWING WILL BE 0.79 TO 0.81 TIMES THE VELOCITY INDICATED BY THE PITOT TUBE OR AN AVERAGE OF 0.80 THIS SHOULD BE TAKEN INTO ACCOUNT WHEN CALIBRATING AND CHECKING THE APPARATUS.

$$V = 1059.6 \sqrt{dP/d} \quad (\text{see Chart 1}) \quad (1)$$

where:

V = Velocity of air in duct at pitot (ft./min.)
dP = Pressure drop between tubes (inches of water)
d = Density of air flowing (lbs./cu. ft.)

The velocity of the air flowing is related to the quantity flowing by the following:

$$C = VA \quad (\text{see Chart 2}) \quad (2)$$

where:

C = Quantity of air flowing (cu. ft./min.)
V = Velocity of air flowing (ft./min.)
A = Cross sectional area of duct (sq. ft.)

The pressure drop across these tubes is transmitted to the differential manometer by means of copper tubing and is multiplied by this manometer to such a degree that it is readable.

The differential manometer (see Figure 2) was made entirely of Polystyrene. The principle of its operation is described under Figure 2. The multiplication obtainable with this type of manometer can be calculated by the use of the following formula:

$$\Delta P = \frac{R}{dW} (dL - dT + \frac{A_1}{A_2} dT) \quad (\text{see Chart 3}) \quad (3)$$

where:

ΔP = Pressure drop at pitot (inches of water)
R = Difference between levels of menisci (inches)
dW = Density of water (lbs./cu. ft.)
dL = Density of lower liquid (lbs./cu. ft.)
dT = Density of top liquid (lbs./cu. ft.)
 A_1 = Cross sectional area of leg (sq. in.)
 A_2 = Cross sectional area of reservoir (sq. in.)

From the above, it can be seen that greater magnification can be attained by: using liquids with low densities, using liquids with as nearly the same densities as possible, and making the ratio of the cross sectional area of the reservoir to the leg as great as possible. Mineral oil with a specific gravity of

CHART NO. 1

$$V_p = 1059.6 \sqrt{\frac{\Delta P}{\rho}} \text{ WHERE:}$$

V_p = AIR VELOCITY (FT. PER MIN.) (AT PITOT)

ΔP = PRESSURE DROP (INCH. OF H₂O)

ρ = DENSITY OF AIR (0.08 LBS./CU. FT.)

V_A = AIR VELOCITY (FT. PER MIN.) (AVERAGE)

$$V_p = \frac{V_A}{0.80}$$

CHART NO. 2

$C = VA$ Where:

C = QUANTITY OF AIR (CU. FT./MIN.)

V = VELOCITY OF AIR (FT./MIN.)

A = CROSS SECTION AIR DUCT (SQ. FT.)

- ① = AIR CHANGE/MIN. IN 3 FOOT HOOD
- ② = AIR CHANGE/2MIN. IN 3 FOOT HOOD
- ③ = AIR CHANGE/MIN. IN 4 FOOT HOOD
- ④ = AIR CHANGE/2MIN. IN 4 FOOT HOOD
- ⑤ = AIR CHANGE/MIN. IN 5 FOOT HOOD
- ⑥ = AIR CHANGE/2MIN. IN 5 FOOT HOOD

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— **FIGURE NO. 2** —

PRINCIPLE OF OPERATION: THE PRESSURE DIFFERENTIAL DEVELOPED BY THE PITOT TUBE IS TRANSMITTED TO THE ABOVE MANOMETER BY COPPER TUBING. THIS PRESSURE DIFFERENTIAL IS REFLECTED IN THE LIQUID LEVELS OF THE TOP LIQUID (A). THE DIFFERENCES IN LEVELS IS DIRECTLY PROPORTIONAL TO PRESSURE DROP. IN ORDER FOR THE DIFFERENCES IN LEVELS TO OCCUR THE LIQUIDS IN THE LEGS MUST MOVE, ONE UP, THE OTHER DOWN. DUE TO THE SMALLER CROSS SECTIONAL AREA OF THE LEGS, THE LIQUIDS WILL MOVE FARTHER IN THE LEGS THAN IN THE RESERVOIRS THUS MULTIPLYING THE READING. THIS MULTIPLYING EFFECT IS PROPORTIONAL TO THE RATIO OF CROSS SECTIONAL AREAS. THE AMOUNT OF MOVEMENT IS ALSO RELATED TO THE DENSITIES OF THE TWO LIQUIDS, THE MORE EQUAL THE DENSITIES, THE GREATER THE MAGNIFICATION. TWO LIQUIDS ARE USED TO CAUSE A MENISCUS. THE IDEAL TYPE IS THAT IN WHICH THE TWO DENSITIES ARE EQUAL AND MULTIPLICATION IS DIRECTLY PROPORTIONAL TO THE RATIO OF AREAS.

CHART NO. 3

$$\Delta P = \frac{R}{d_w} \left(d_L - d_T + \frac{A_L}{A_L} d_T \right) \text{ WHERE:}$$

ΔP = PRESSURE DROP (INCHES OF WATER)

R = READING (INCHES)

d_w = DENSITY OF H₂O (62.517 ^{lb}/CU. FT.)

d_L = DENSITY OF LOWER LIQ. (0.65 X 62.517 ^{lb}/CU. FT.)

d_T = DENSITY OF TOP LIQ. (0.65 X 62.517 ^{lb}/CU. FT.)

A_L = CROSS SECTION OF LEG (0.895 SQ. INCH)

A_L = CROSS SECTION OF RESERVOIR (0.895 SQ. INCH)

$$R = 21.4 \Delta P$$

ΔP = PRESSURE DROP (VEL. AT PITOT)

AVE. VELOCITY (FT. PER MIN.)

AVE. VEL. (DUCT) (FT./MIN.)	VEL. AT PITOT (FT./MIN.)	ΔP (INCHES)	CALC. RO (INCHES)	OBS. RO (INCHES)
100	225	0.001	0.02	
250	540	0.007	0.15	
400	800	0.018	0.39	0.40
550	1060	0.031	0.66	0.70
700	1340	0.050	1.07	
850	1600	0.071	1.52	1.55
950	1760	0.084	1.80	1.80
1050	1920	0.105	2.25	2.70
1200	2100	0.150	3.21	3.55
1350	2250	0.189	4.05	4.00
1400	1750	0.218	4.67	4.80
1500	1800	0.250	5.35	5.50
1600	2000	0.288	6.10	
1700	2130	0.320	6.85	7.00
1800	2250	0.349	7.70	
1900	2380	0.400	8.55	
2000	2500	0.450	9.50	

DIFFERENTIAL MANOMETER READING (INCHES)

5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0

0.85 was used for the upper liquid. Redistilled water mixed with the proper proportion of ethyl alcohol to yield a specific gravity of 0.85 plus a coloring agent (phenol red) and a wetting agent (liquid soap) was used for the lower liquid. The ratio of the cross sectional areas of the legs and reservoir were then used to give the multiplication desired for the range in pressure drops obtainable. 2

Due to differences in the sizes of hoods and the sizes of supply ducts, 2 designs for the differential manometer are necessary. One manometer to multiply by 15 is required in the 5-foot hoods with 3-inch Saran ducts and another to multiply 10 times for use in the 2 1/2 and 3-foot hoods with 2-inch Saran ducts and a similar one for use in the 4-foot hoods with 2 1/2-inch Saran ducts. A recapitulation of the data for these different manometers under maximum and minimum flow conditions is shown in Table I.

Table I
DATA FOR DIFFERENT MANOMETERS

Conditions of Flow	Duct Dia. (Inches)	Duct Area (Sq. Ft.)	Av. Vel. in Duct (Ft./min.)	ΔP (Pitot) (In. of H ₂ O)	Ratio A_1/A_2	Mult. Factor	Reading (Mano.) (Inches)
Max.	2	0.0205	1460	0.236	1/8.5	10	2.36
Min.	2	0.0205	480	0.026	1/8.5	10	0.26
Max.	2 1/2	0.0280	1070	0.127	1/8.5	10	1.27
Min.	2 1/2	0.0280	460	0.024	1/8.5	10	0.24
Max.	3	0.0440	680	0.051	1/12.8	15	0.77
Min.	3	0.0440	380	0.016	1/12.8	15	0.24

Note: Each manometer at minimum flow conditions will have identical readings (0.25 inches).

In order for the above described manometers with the pitot tube attachment to operate with a minimum of error, certain precautions should be taken in the installation which are:

1. The bent end of the pitot tube should be located in the exact center of straight pipe, at least 50 diameters from a restriction or bend on the upstream

side and 10 diameters on the downstream side, with the open end at a 90° angle to the air-flow. The second tube should be located opposite to the open end of the first tube, perpendicular to the duct, and flush with the inside surface of the duct.

2. The machining of the legs and reservoirs of the manometer should be to as close a tolerance as possible, especially the legs where a small discrepancy in diameter is multiplied tremendously.

3. The densities of the two liquids should be ascertained at the temperature at which the manometer will be used.

4. Before density measurements are taken, each liquid should be shaken with the other so as to saturate each with the other.

5. Sensitive hydrometers should be used to measure densities to insure nearly equal densities.

6. Each manometer after installation should be checked against an accurate anemometer or velometer to insure its accuracy.

With the above precautions taken allowing a variation in room temperature of plus or minus 5°C. and a machining tolerance of plus or minus 0.005 inches, an overall error in accuracy of plus or minus 5 per cent can be attained.

EXPERIMENTAL WORK

Glass was first used as the material of construction of the differential manometer. However, due to its fragility and the difficulty of mounting it, cleaning it, and making connection to it, the glass was discarded almost immediately. Lucite was used and seemed satisfactory. The manometer used in making tests of the different liquids tried was made of Lucite (see Figure 2). However, it was found that the two liquids finally selected as ideal for the purpose caused swelling at the Lucite, and therefore, the same manometer was made of Polystyrene which was satisfactory. Figure 3 shows the test setup.

The specification for the liquids to be used are: non-inflammable, low densities, adjustability of the density of one in order to make its density equal to that of the other, low surface tension, low viscosity, low solubility of one liquid in the other, and the ability of both liquids to form menisci at the interfaces. Quite a few different liquids were tried, some of which did not meet the specifications setup for the liquids. Their properties are listed in Table II.

— **FIGURE NO. 3** —

TEST PROCEDURES: AIR WAS PASSED THROUGH THE ANEMOMETER, THROUGH THE DUCT, PASSED THE PITOT TUBE, THROUGH THE HOSE CONNECTOR, PASSED THE CONTROL VALVE, AND INTO THE BLOWER. THE ANEMOMETER WAS USED TO ACCURATELY MEASURE AIR FLOW AND THE VALVE TO CONTROL THE AIR FLOW. THE ARMS OF THE PITOT TUBE WERE CONNECTED TO VARIOUS TYPES OF DIFFERENTIAL MANOMETERS USING DIFFERENT LIQUIDS. READINGS WERE CHECKED AGAINST VALUES CALCULATED BY MEANS OF FORMULA 3 USING DATA COLLECTED BY HYDROMETERS, THE ANEMOMETER, AND CALIPERS. A COMPARISON OF THE ACTUAL TEST DATA AND CALCULATED VALUES USING FORMULA 3 FOR THE MANOMETER DESCRIBED AS THE MOST SATISFACTORY UNDER SECTION "B" IS SHOWN ON CHART #3.

Table II
PROPERTIES OF LIQUIDS

<u>No.</u>	<u>Liquid</u>	<u>Specific Gravity</u>	<u>Remarks</u>
1	Redistilled H ₂ O	1.000	Surface Tension too High
2	Red H ₂ O + Liquid Soap	1.000	Satisfactory
3	Toluene	0.866	Inflammable
4	CCl ₄	1.595	Density too High
5	Decalin	0.896	Surface Tension too High
6	Dibutyl Phthalate	1.046	Surface Tension and Viscosity too High
7	Indene	1.006	Viscosity too High
8	Ethyl Alcohol	0.789	Ideal when Mixed with (2)
9	Mineral Oil	0.850	Ideal for Upper Liquid (Low V.P.)
10	Light Machine Oil	0.880	Viscosity too High

Redistilled water plus soap was used in nearly all tests as one of the liquids. Mixtures of others above which are immiscible with water were used for the other. Most of these were satisfactory mainly because the surface tension or viscosity was so high that the menisci would not return to zero at the end of the run. However, when mineral oil was used as the upper liquid and redistilled water plus soap added to ethyl alcohol to yield the same density as the mineral oil was used as the lower liquid, the results were satisfactory.

Chart 3 shows a comparison of the experimental data versus calculated data (Formula 3) for a differential manometer of a similar design as those recommended to be tried in several hoods at Unit V.

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