Date of Issue: October 19, 1953

Report Number: ~~(KLI-2616)~~

K-5002

AECU-3242

AECU-3242

THE RESPONSE TIME OF SMALL PITOT TUBES

H. L. Weissberg

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

Watkins, R. D.
Carpenter, F. R.
Weissberg, H. L.

CARBIDE AND CARBON CHEMICALS COMPANY
UNION CARBIDE AND CARBON CORPORATION
K-25 Plant
Oak Ridge, Tennessee

Photostat Price \$ 1.80

Microfilm Price \$ 1.80

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

1 2468

707-1

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

A B S T R A C T

An equation is derived from which one can determine for a given pitot tube and manometer, the time necessary for the pressure in the manometer to become sufficiently close to the pressure at the mouth of the pitot tube. The equation can be used to determine a lower limit for the radius of pitot tubes in order to obtain manometer readings in a reasonable length of time.

THE RESPONSE TIME OF SMALL PITOT TUBESIntroduction

In using pitot tubes to measure gas velocities in flow channels, it is desirable to use as small a tube as possible in order to minimize disturbances of the velocity or concentration distributions in the gas stream. However, since gas must flow through the tube into some kind of manometer to produce a "reading", any resistance to flow can produce a troublesome time lag for equalization of the pressures inside the manometer and at the mouth of the tube. It is therefore helpful to be able to predict the manometer response time when designing pitot tubes small enough that their resistance to flow becomes appreciable.

In the following, it will be shown that the difference between the pressure at the mouth of the pitot tube and that in the manometer decreases exponentially with time and an expression for the appropriate time constant will be derived. The results will be applied to illustrative examples.

Derivation of the Time Constant

Consider a pitot tube of length, L , and radius, r , connected to a manometer of internal volume, V . It is assumed that the resistances to flow of the connecting line and of the static pressure tap are negligibly small compared to that of the tube. The volume of the line is included in V . It is also assumed that Poiseuille's law for viscous flow in an infinitely long tube is applicable to the flow through the pitot tube; i.e., end effects are neglected.

Let the constant P be the pressure at the mouth of the pitot tube while the function of time $p(t)$ is the pressure in the manometer. $p(t)$ is taken to have the value p_0 at the start of the observation, say at $t = 0$. We have then, from Poiseuille's law, that

$$\frac{d(pV)}{dt} = \frac{\pi r^4}{8\mu L} \frac{P^2 - p^2}{2}, \quad (1)$$

where μ is the viscosity of the flowing gas. We are thus treating the pitot tube as a long tube in which viscous flow occurs in response to the pressure drop across it, $P - p(t)$.

Note that, in general, V as well as p varies with time as, for example, when the liquid level changes in a U-tube or inclined tube type of manometer. Thus, a pertinent manometer characteristic, in addition to the volume, V , is the rate of change of the volume with pressure, dV/dp . We assume this to be a constant, say m . Then

$$\frac{d(pV)}{dt} = V \frac{dp}{dt} + pm \frac{dp}{dt}$$

so that the flow equation, (1), can be written as

$$\frac{V + mp}{P^2 - p^2} dp = \frac{\pi r^4}{16\mu L} dt.$$

Integrating gives

$$\frac{V}{2P} \ln \frac{P+p}{P-p} - \frac{m}{2} \ln (P^2 - p^2) = \frac{\pi r^4}{16\mu L} t + C.$$

The constant of integration, C, is evaluated from the initial condition $p = p_0$ at $t = 0$:

$$C = \frac{V}{2P} \ln \frac{P+p_0}{P-p_0} - \frac{m}{2} \ln (P^2 - p_0^2).$$

Then, making the approximation (valid for $P - p_0 \ll P$)

$$\frac{P+p}{P+p_0} = 1,$$

we have

$$\ln \left(\frac{P-p}{P-p_0} \right)^{V/P} + \ln \left(\frac{P-p}{P-p_0} \right)^m = \frac{\pi r^4}{8\mu L} t,$$

$$\ln \frac{P-p}{P-p_0} = - \frac{P}{Pm + V} \frac{\pi r^4}{8\mu L} t,$$

$$P - p = (P - p_0) e^{-t/K} \quad (2)$$

where

$$K = \frac{8\mu L}{\pi r^4 P} (V + mP). \quad (3)$$

It is thus seen that $P - p$ drops exponentially with time, being decreased by the factor $1/e$ after a time interval, K .

The time constant, K , is the sum of two terms, the first depending on V/P and the second on the manometer characteristic, m . Both terms are proportional to the viscosity of the gas and the length of the pitot tube and inversely proportional to the fourth power of the tube radius.

Examples

1. Consider a pitot tube with a diameter of 0.01 cm. (I.D. = 4 mils), one centimeter long, connected to a manometer such that the volume of the manometer and connecting line is 100 cc. Let the flowing stream be air at room temperature and atmospheric pressure. Then

$$\mu = 1.83 \times 10^{-4} \text{ poise}$$

$$P = 760 \text{ mm. Hg} = 760 \times 1332 \text{ dynes/cm.}^2$$

$$L = 1 \text{ cm.}$$

$$r = 0.005 \text{ cm.}$$

$$V = 100 \text{ cc.}$$

Let us suppose that we have an ideal manometer such that the volume does not change when the pressure changes. Then $m = 0$. In this case,

$$\frac{8\mu}{\pi P} = 4.6 \times 10^{-10}$$

and

$$\frac{LV}{r^4} = 1.60 \times 10^{11}$$

Then equation (3) with $m = 0$ gives

$$K = 74 \text{ seconds.}$$

Since it would take several times K for the manometer reading to become virtually constant at $p = P$, one would probably have to allow about five minutes for a manometer reading in this case.

2. Consider the same condition as in the preceding example, but now we do not take $m = 0$. Suppose we have an inclined tube manometer such that a one centimeter change in the position of the liquid surface corresponds to a pressure change of 100 dynes/cm.² If the cross section area of the tube is 0.5 cm.², then

$$m = \frac{dV}{dp} = \frac{0.5}{100} = 0.005 \frac{\text{cc.}}{\text{dyne/cm.}^2}$$

In this case, from equation (3) the K value computed for the preceding example is increased by the amount

$$\frac{8\mu}{\pi} \times \frac{L}{r^4} \times m = (4.66 \times 10^{-4}) \times \frac{1}{(5 \times 10^{-3})^4} \times 0.005$$

$$= 3,750 \text{ sec.} = 1.04 \text{ hours,}$$

a prohibitively long time.

Summary and Conclusions

When a small pitot tube is placed in a gas stream, the manometer to which the tube is connected does not immediately give the pressure at the mouth of the tube. A measure of the rapidity of response is furnished by the time constant, K, in the equation

$$P - p = (P - p_0) e^{-t/K}$$

where P and p are, respectively, the pitot and manometer pressures, t is the time, and p₀ is the manometer pressure at t = 0. The time constant is given by

$$K = \frac{8\mu L}{\pi r^4 P} (V + mP)$$

where

μ = viscosity of the gas

L = length of the pitot tube

r = radius of the pitot tube

V = internal volume of the manometer

m = dV/dp, change in manometer volume with pressure.

Evaluation of K for reasonable choices of values for the various quantities that appear in the equations shows that careful consideration of manometer design as well as pitot tube size is necessary to avoid prohibitively slow approach to equilibrium manometer readings.

H. L. Weissberg
H. L. Weissberg

Flow Research Laboratory
Barrier Research Department
Laboratory Division

HLW/gma

707-6

1-6

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK