CRITICAL FLOW RESTRICTING ORIFICES

D-Zero Engineering Note: 3740.510-EN-173

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INTRODUCTION

The installation of flow restricting orifices in both the nitrogen gas and instrument air supply lines in the D-Zero Building limits the flow available to the various users. These orifices are strategically positioned along the lines such that no one user can monopolize the gas supply and deprive others of their flow required to operate.

ORIFICE PLATE SIZING

The following formula, taken from Marks' Standard Handbook for Mechanical Engineers, Ninth Edition, 1987, was used to size the openings for the orifice plates according to their given flow conditions.

$$m=(0.53*C*p_1*A_2)/(T_1^{1/2})$$

Where: m=mass of fluid flowing past a given section per s, lb (here m=pq, p=density, lb/ft^3, q=volume of fluid flowing past section, cfm)

C=empirically determined coefficient of discharge (according to Marks': C=0.61 for a sharp edged orifice, and C=0.80 for a short tube)

p_1=pressure of fluid at inlet section, lb/ft^2 abs

A_2=area of orifice, ft^2 ($A_2=\pi/4*D_2^2$, D_2=diameter of the orifice, ft)

T_1=inlet temperature, °R

Upon using this formula, the following assumptions were made:

- fluid was air, an ideal gas
- reversible adiabatic expansion through the orifice
- inlet velocity<<velocity through the orifice and thus negligible
- ideal gas constant, R=53.3
- $k=C_p/C_v=1.3937$
- critical flow pressure, $p_m=0.53*p_1$

When the downstream pressure is less than the critical flow pressure, the flow rate becomes independent of the downstream pressure. This fact is later proven by the flow tests performed on the two different sample plates.

The required flow parameters are:

	A	B	C
fluid	nitrogen	air	air
line size, in (D_2<line i.d.)	0.25	0.25	0.50
p, lb/ft^3	0.075	0.075	0.075
q, scfm	2	2	10
T_1, °F	60	70	70
p_1, psia	45	115	115

Table 1

The plates used for the testing had diameters of 0.099" (sharp edged orifice) and 0.0867" (short tube orifice).

FLOW TESTS

Two sample plates were fabricated, sized for an expected flow rate of 10 scfm at 100 psig inlet pressure. Plate "A" was a sharp edged orifice plate and plate "B" was a short tube orifice plate. The tests were done with the help of D. Ostrowski using the set-up shown in Figure 1.

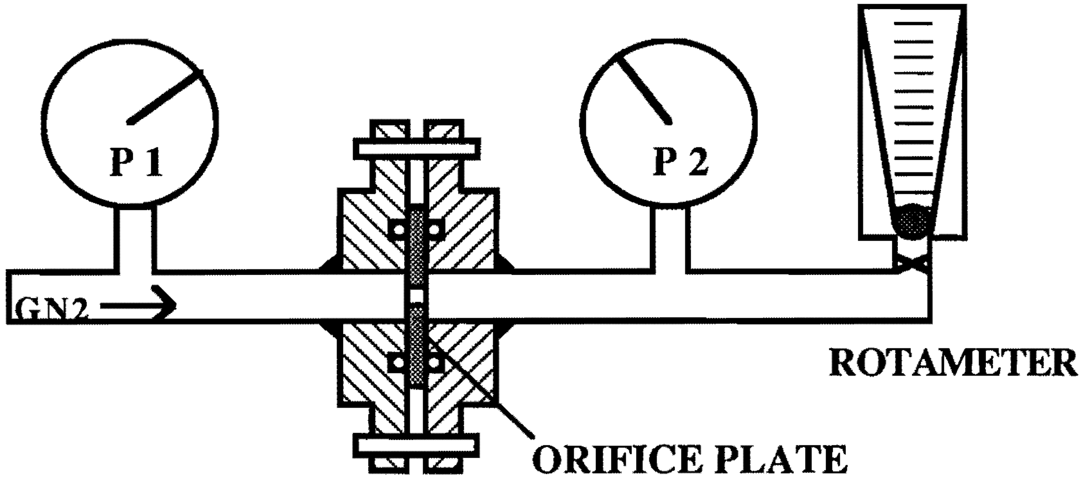

Figure 1

With the valve on the rotameter fully opened, the inlet pressure was gradually increased and the corresponding flow rates were recorded. This demonstrated that higher pressures result in higher flow rates. An inlet pressure of 100 psig produced a flow rate of 1000 scfh (16.67 scfm) for plate "A" and a flow rate of 760 scfh (12.67 scfm) for plate "B". Both of the observed flow rates were higher than the 10 scfm value for which the orifices were sized. While a part of this difference in the values can be attributed to experimental error, e.g. rotameter and pressure gauge precision, the difference between the calculated and observed flow rates for plate "A" could be due to a geometry variance between the proposed design and the final machined piece. The discharge coefficient for a sharp edged orifice is 0.61 and that of a rounded edge orifice is 0.98. Upon close examination of the orifice plate, the edge appears to have more of a rounded than a sharp edge quality. Inserting the higher discharge coefficient value of 0.98 into the previously used sizing equation yields a flow rate value of 16.17 scfm, which is in better accordance with the empirically obtained value.

The downstream pressure was varied by 5 psig increments by the valve on the rotameter to keep the inlet pressure constant, and the corresponding flow rates were recorded. The results for plates "A" and "B" are shown in Figures 2 and 3, respectively. When the downstream pressure was less than the critical flow pressure ($p_2 < p_m = 0.53 * p_1$), the flow rate of the nitrogen gas did not change. This phenomenon was demonstrated for three different inlet pressures with each prototype plate.

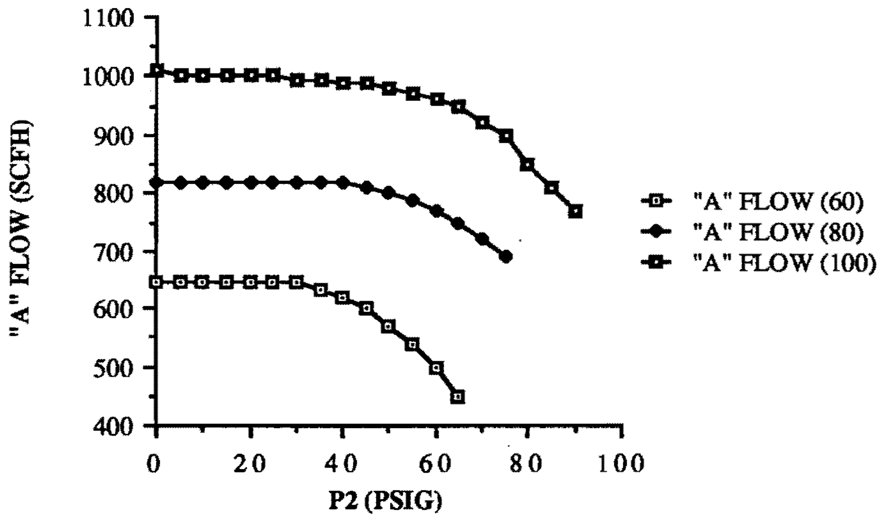

Figure 2

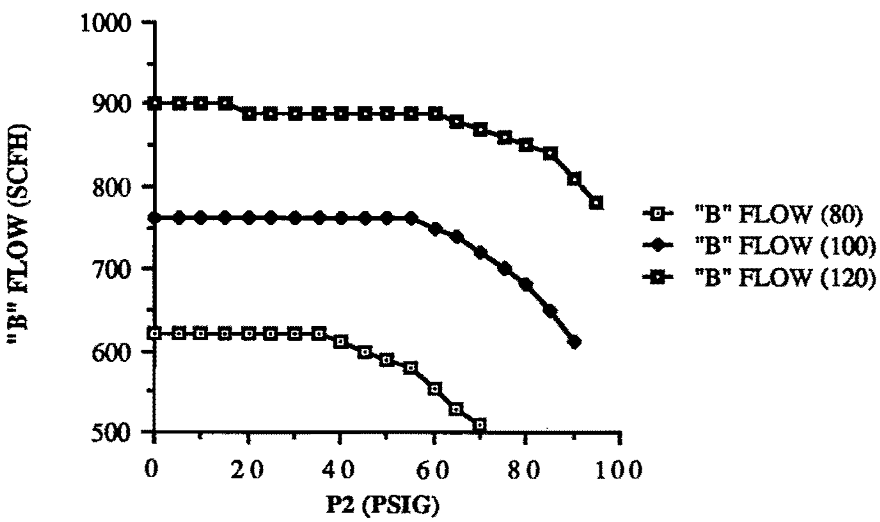

Figure 3

CONCLUSION

Provided that the necessary orifice plates are machined in a manner similar to that of the prototypes, the orifices for the various lines were sized using the discharge coefficient for the round edge orifice because the calculated values were in good agreement with the empirically obtained values for this case. The final calculated orifice diameters for the round edge, sharp edge, and short tube cases are listed in Table 2.

	A*	B	C
round edge			
diameter	0.0554"	0.0349"	0.0783"
drill size	54	65	47
sharp edge			
diameter	0.0703"	0.0442"	0.0993"
drill size	50	56	39
short tube			
diameter	0.0614"	0.0386"	0.0867"
drill size	53	62	44

Table 2

* Note: A, B, and C refer to the three different flow cases presented in Table 1.