Metering Orifice Flow Test

Overview

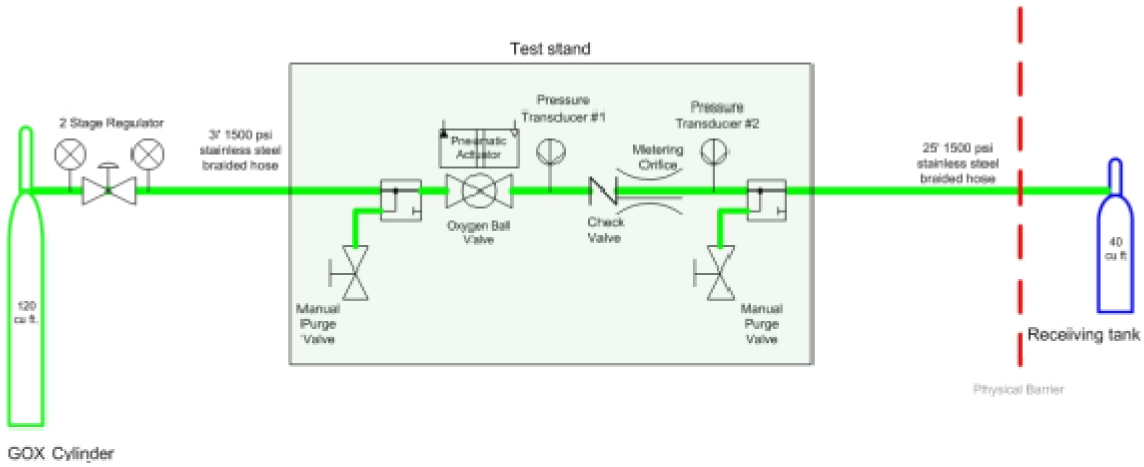
In this test we will attempt to measure the actual mass flow rate from our flat plate metering orifice and compare this with the calculate value of mass flow rate.

We will attempt to do this by sensing only two variables, namely, receiving tank pressure and temperature. This will we used with two other known values; 1) receiving tank volume. 2) test duration. From this we should be able to calculate the mass flow rate of gaseous oxygen given at standard atmospheric conditions.

This value will then be compared to the calculated value of mass flow rate for a choked flat plate orifice of given diameter and given upstream pressure.

For this test certain assumptions have been made, which may or may not be true:

Assumptions : 1) Isentropic and adiabatic flow
2) Choked flow is maintained during the entire duration of the test.
3) Final receiving tank temperature is same as ambient temperature



Experimental Setup

One 120 cubic foot tank of oxygen at 2200 psi will be regulated down to a constant 1000 psi using a Tescom regulator. The 1000 psi oxygen will then connect to a manifold via a high pressure braided stainless steel hose. The manifold has a manual purge valve to drain the oxygen from the high pressure line and also an outlet that runs to a pneumatically controlled ball valve.

The pneumatically controlled ball valve will initiate and terminate the flow of oxygen to the metering orifice via a rigid pipe and check valve. the pneumatically operated ball valve is controlled from a computer controlled Flextek microcontroller and can be open for precise intervals.

The 1000 psi oxygen stream will then enter the metering orifice and exit to a lower pressure region on the other side of the orifice. The pressure drop will be no less than 500 psi to insure choked flow.

After leaving the metering orifice the oxygen will pass through another identical manifold/manual purge valve assemble and then down a 20 foot section of high pressure braided stainless steel line and into a 40 cubic foot receiving tank.

There will be two pressure transducers in the system. One upstream of the metering orifice to measure the inlet pressure and one transducer downstream of the metering orifice to measure receiving tank pressure.

Feasibility

The test will be conducted by using the current Gox/Paraffin test stand to do automated switching and sensing of the oxygen and pressure respectively. The goal is to use a pressurized 120 cu ft oxygen bottle to fill a smaller 40 cu ft empty bottle through our flat plate metering orifice.

In order for this to work we must assure that we maintain choked flow in the metering orifice during the test by not exceeding the .0528 down stream to up stream pressure ration (PR) This can be estimated by; 1) knowing the upstream pressure (read from regulator gauge and pressure transducer) and 2) calculating what we think the final receiving tank pressure will be. This assumes the calculations are a true reflection of reality which they may not be for a wide variety of reasons, but we will be able to check this pressure assumption at the end of the test to see if we were right or wrong and make corrections based on these finding.
The ideal gas law states:

$$PV = nRT$$

Where :

P = pressure
V = Volume
n = number of moles of gas
R = Gas constant (for O_2 is 260 J/kg*K)

For a fixed mass of a particular gas in a scenario where the temperature remains constant we can say:

P * V (state 1) = P * V (state 2)

or

$$P_1 \cdot V_1 := P_2 \cdot V_2$$

Given an initial state pressure and volume (in our case the outlet volume of the metering orifice given at standard atmospheric condition) we can solve for an unknown pressure (the receiving tank pressure) given a known final state volume (the physical volume of the receiving tank). Therefore :

$$P_2 := \frac{P_1 \cdot V_1}{V_2}$$

Where :

P_1 = ambient pressure (14.7 psi)
P_2 = receiving tank pressure
V_1 = metering orifice outlet volume
V_2 = receiving tank volume

Before we can solve for target receiving tank pressure (P_2) for a given metering orifice test we must find out what the expected outlet volume (V_1in scf) of the metering orifice will be for the indicated upstream pressure for any given test.

Calculate transferred O2 volumetric flow rate

Find the oxygen flow rate through a specific diameter metering orifice at a given upstream pressure.

Given :

$C_d := .84$	Flat plate metering orifice
$P_{atm} := 14.7 psi$	
$P_{atm} = 1.014 \times 10^5 \, Pa$	Atmospheric pressure
$P_{inlet} := 1000 psi$	
$P_{inlet} = 6.895 \times 10^6 \, Pa$	Upstream pressure
$A_1 := \frac{\pi \cdot (.0565 in)^2}{4}$	
$A_1 = 1.618 \times 10^{-6} \, m^2$	Metering orifice area using a #54 drill bit
$R := 260 \frac{J}{kg \cdot K}$	Gas constant for oxygen
$\gamma := 1.4$	ratio of specific heats for oxygen
$T_1 := 293.15 K$	Gas temperature

$$q := C_d \cdot A_1 \cdot P_{inlet} \cdot \sqrt{\frac{\gamma}{R \cdot T_1}} \cdot \left(\frac{2}{1+\gamma}\right)^{\frac{\gamma+1}{2\gamma-2}}$$

$q = 0.023 \frac{kg}{s}$ Equation 15 ref [1]

$$V_{dot} := \frac{q \cdot R \cdot T_1}{P_{atm}}$$

$V_{dot} = 0.017 \frac{m^3}{s}$ $V_{dot} = 37.023 \frac{ft^3}{min}$

Calculate receiving tank pressures

Given (assume) :

$V_{recievingtank} := .209 ft^3$	Just an educated guess - NEED TO BE MEASURED
$P_{atm} := 14.7 psi$	Orifice No. 1 (#54 drill bit)

	Upstream Pressure	Duration	Target transfer volume (O_2)
Trial #1	$P_{u1} := 1000 psi$	$t_1 := 8s$	$V_{t1} := V_{dot} \cdot t_1$
Trial #2	$P_{u2} := 1000 psi$	$t_2 := 10s$	$V_{t2} := V_{dot} \cdot t_2$
Trial #3	$P_{u3} := 1000 psi$	$t_3 := 12s$	$V_{t3} := V_{dot} \cdot t_3$

Receiving tank pressure

Pressure Ratio
(must be <= .0528)

Trial #1

$$P_{rt1} := \frac{P_{atm} \cdot V_{t1}}{V_{recievingtank}} \qquad P_{rt1} = 347.2psi \qquad PR_1 := \frac{P_{rt1}}{P_{u1}} \qquad PR_1 = 0.347$$

Trial #2

$$P_{rt2} := \frac{P_{atm} \cdot V_{t2}}{V_{recievingtank}} \qquad P_{rt2} = 434psi \qquad PR_2 := \frac{P_{rt2}}{P_{u2}} \qquad PR_2 = 0.434$$

Trial #3

$$P_{rt3} := \frac{P_{atm} \cdot V_{t3}}{V_{recievingtank}} \qquad P_{rt3} = 520.8psi \qquad PR_3 := \frac{P_{rt3}}{P_{u3}} \qquad PR_3 = 0.521$$

It can be seen that for an metering orifice inlet pressure of 1000 psi and test durations of 8,10,12 seconds that choked flow should be maintained throughout the trials.

Procedure

1) Make sure experiment and operators are in safest and maximum protection configuration.

2) Open receiving tank valve.

3) Make sure Flextek board is operational.

4) Precharge inverter and cycle ball valve once.

5) Make sure ball valve is closed.

6) Close manual purge valves.

7) Make sure DAQ system is ready to trigger and log.

8) Open oxygen tank valve.

9) Set second stage of regulator to 1000 psi.

10) Start countdown sequence.

11) Take cover.

12) Let test terminate and ball valve close.

13) Close oxygen tank valve.

14) Open upstream manual purge valve.

15) Insure data logging was successful and file stored.

16) Monitor (do not log) downstream pressure transducer till output is steady state.

17) Log steady state pressure and ambient temperature at test site.

18) Log test duration (ball valve open time)

19) Drain receiving tank and HP line by opening downstream manual purge valve.

Cautions

1) High Pressure System - only one person should be near equipment when oxygen tank valve is opened to the time the test is complete and receiving tank is drained.

2) Barricade or bury receiving tank in the event of tank failure.

3) Secure high pressure lines in case of failure.

Reference:

[1] Design of a Flow Metering Orifice for First Wax Hybrid test.
http://psas.pdx.edu/WaxPlumbing/2003test-orifice.pdf