Bo Nitrogen Injection Analysis Primer

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December 3, 2012

1 Injection System

We will make injections of nitrogen gas from a 30CC cylinder mounted above Bo, pictured in figure 1. The cylinder has valves above and below. We will charge it to a known pressure, readable in PSI from the pressure gauge, by opening the top valve which connects to a bottle of pre mix. The bottle has a pressure regulator so that we can fill the cylinder at a reasonable rate. Once we are at the desired pressure, we will close this valve, leaving a fully charged cylinder.

Then, when the lower valve is opened, this cylinder of gas is injected into the bottom of the liquid volume. The nitrogen will bubble quickly to the surface, remaining mostly as gas, and circulate in the condenser system a few times, gradually coming to equilibrium with the liquid argon. Below we calculate the amount of nitrogen injected for a p% pre-mix.

Bo operates at a pressure of between 5 and 15 psi above atm (14.7 psi). The injection cylinder can be charged up to around 30 psi above atmospheric pressure.

The density of argon gas at 0C and 14.7psi is $\rho^0_{Ar} = 1.74g/L$. The density of nitrogen gas at 0C and 14.7psi is $\rho^0_N = 1.25g/L$. The density of a p% premix by mass at STP is

$$\rho^0_{mix} = p\rho^0_N + (1-p)\rho^0_{Ar} \tag{1}$$

We assume both to be ideal gasses, and therefore the densities scale as

$$\rho = \frac{N}{V} = \rho^0 \frac{P}{P_0}\frac{T_0}{T} \tag{2}$$

In a 30cc volume at pressure P_{inj} and temperature T_{inj}, the masses of nitrogen and argon in the injection cylinder are

$$m^N_{cyl} = \rho_N V_{inj} = p\rho^0_N \frac{P_{inj}}{P_0}\frac{T_0}{T_{inj}} V_{cyl} \tag{3}$$

$$m^{AR}_{cyl} = \rho_{Ar} V_{inj} = (1-p)\rho^0_{Ar} \frac{P_{inj}}{P_0}\frac{T_0}{T_{inj}} V_{cyl} \tag{4}$$

After opening the lower valve, the pressures between the Bo volume and the cylinder will come to equilibrium. We assume that the cylinder is small enough that the injection does not alter the overall pressure in Bo. We shut the injection valve directly after injection to prevent gradual diffusion of the remaining gas into the volume through the capillary, as this will be a very slow process which we cannot control well. The remaining gas in the cylinder after injection will be

$$m^N_{rem} = \rho_N V_{inj} = p\rho^0_N \frac{P_{Bo}}{P_0}\frac{T_0}{T_{inj}} V_{cyl} \tag{5}$$

$$m^{AR}_{rem} = \rho_{Ar} V_{inj} = (1-p)\rho^0_{Ar} \frac{P_{Bo}}{P_0}\frac{T_0}{T_{inj}} V_{cyl} \tag{6}$$

The dimensions of Bo are 22" diameter and 40" height. However, the fill level L will be somewhere between 25 and 36". The density of liquid argon is approximately constant in this temperature and pressure range, and is $\rho_{LAr} = 1.4g/cm^3$. Therefore, the total mass of argon in Bo filled to level L is

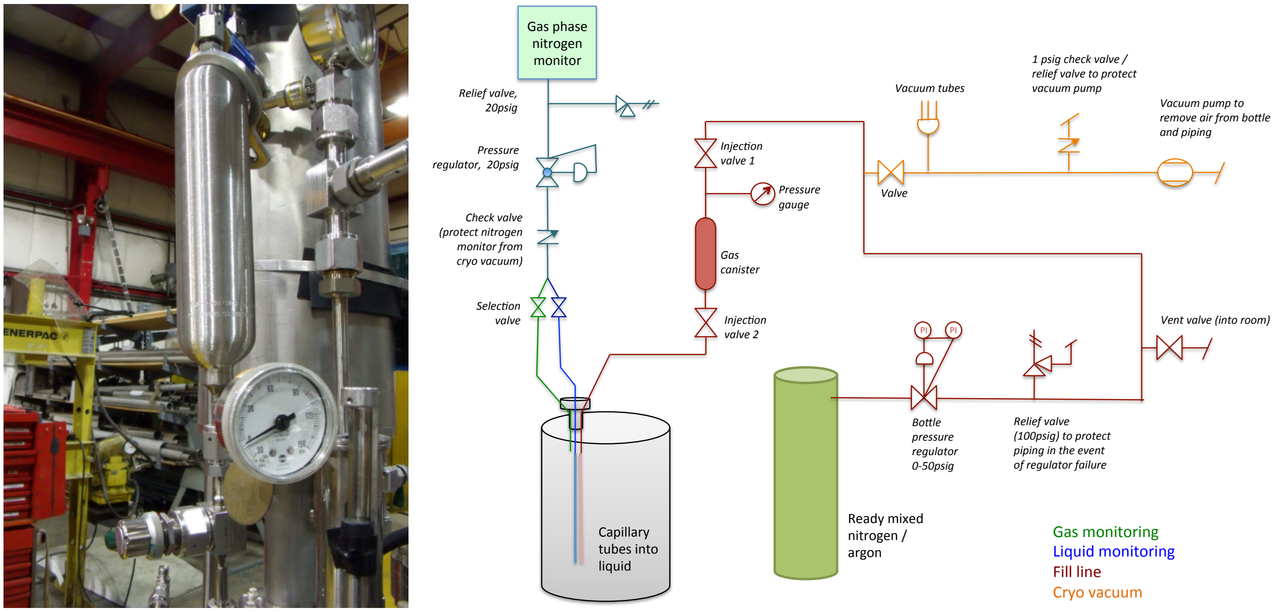

Figure 1: Bo nitrogen injection system

$$m_{Bo}^{LAr} = \rho_{LAr} \pi r^2 L \tag{7}$$

So assuming the injected gas comes to perfect equilibrium in the liquid volume (keeping in mind that we will need to apply thermodynamical corrections from the two phase equilibrium condition), the fraction of nitrogen injected by mass from a p% pre-mix will be

$$f_N = \frac{m_{cyl}^{N} - m_{rem}^{N}}{m_{Bo}^{LAr} + \left(m_{cyl}^{Ar} - m_{rem}^{Ar}\right)} \tag{8}$$

The amount of argon injected is tiny compared to the Bo volume, so we can drop the term in brackets in the denominator. Therefore, the fraction of nitrogen injected is

$$f_N = p \rho_N^0 \frac{T_0}{P_0} \frac{1}{T_{inj}} \frac{\left(P_{inj} - P_{Bo}\right) V_{cyl}}{\rho_{LAr} \pi r^2 L} \tag{9}$$

Taking some reasonable values, we assume

$$\begin{aligned} T_{inj} &= T_0 = 273K \\ P_{inj} &= P_0 + 30psi \\ P_{Bo} &= P_0 + 15psi \\ L &= 30\text{''} \end{aligned} \tag{10}$$

Then we have

$$f_N = p * 1.5 \times 10^{-7} \tag{11}$$

So a 1 ppm injection is 7 full cylinders of 100% N2 gas. We are interested in probing the 10-20ppm range where quenching effects become visible. This suggests that we do not want to order pre-mix at all, but run with pure LN2 injections. We also have the option of replacing the 30CC cylinder with a 100CC cylinder, which means we will not need to make so many injections to get each ppm. This may be an a good idea.