Technical characteristics of this system

This mobile cooling plant is required to supply up to 5g/s of liquid C_3F_8 sub-cooled to temperatures as low as -30°C in order to remove a heat load of up to 500W by full evaporation the flow.

The following pressure-enthalpy diagram depicts the thermodynamic cycle envisaged for this unit.

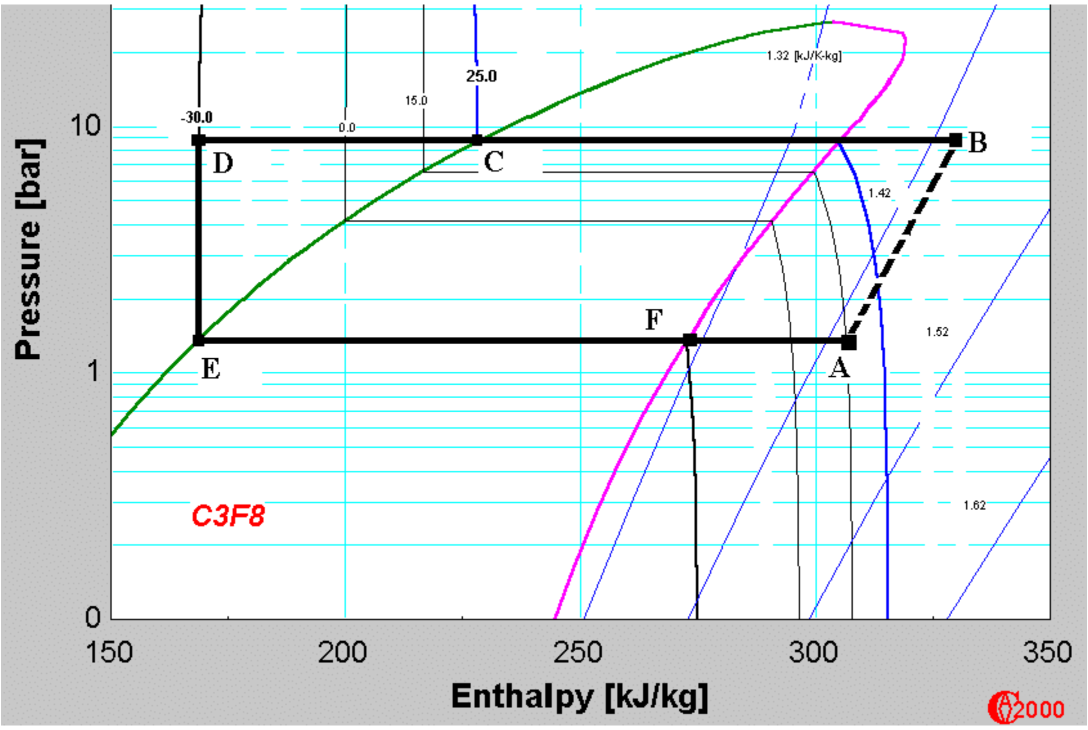

Fig.1

The pressure corresponding to evaporation at -30°C is 1350mbar(a). The compressor was tested with this inlet pressure and the mass flow was measured. As shown in Fig.2, the mass flow satisfies the user requirements of 5g/s.

The compressor speed is adjusted by a PID controller in order to maintain a constant buffer tank pressure.

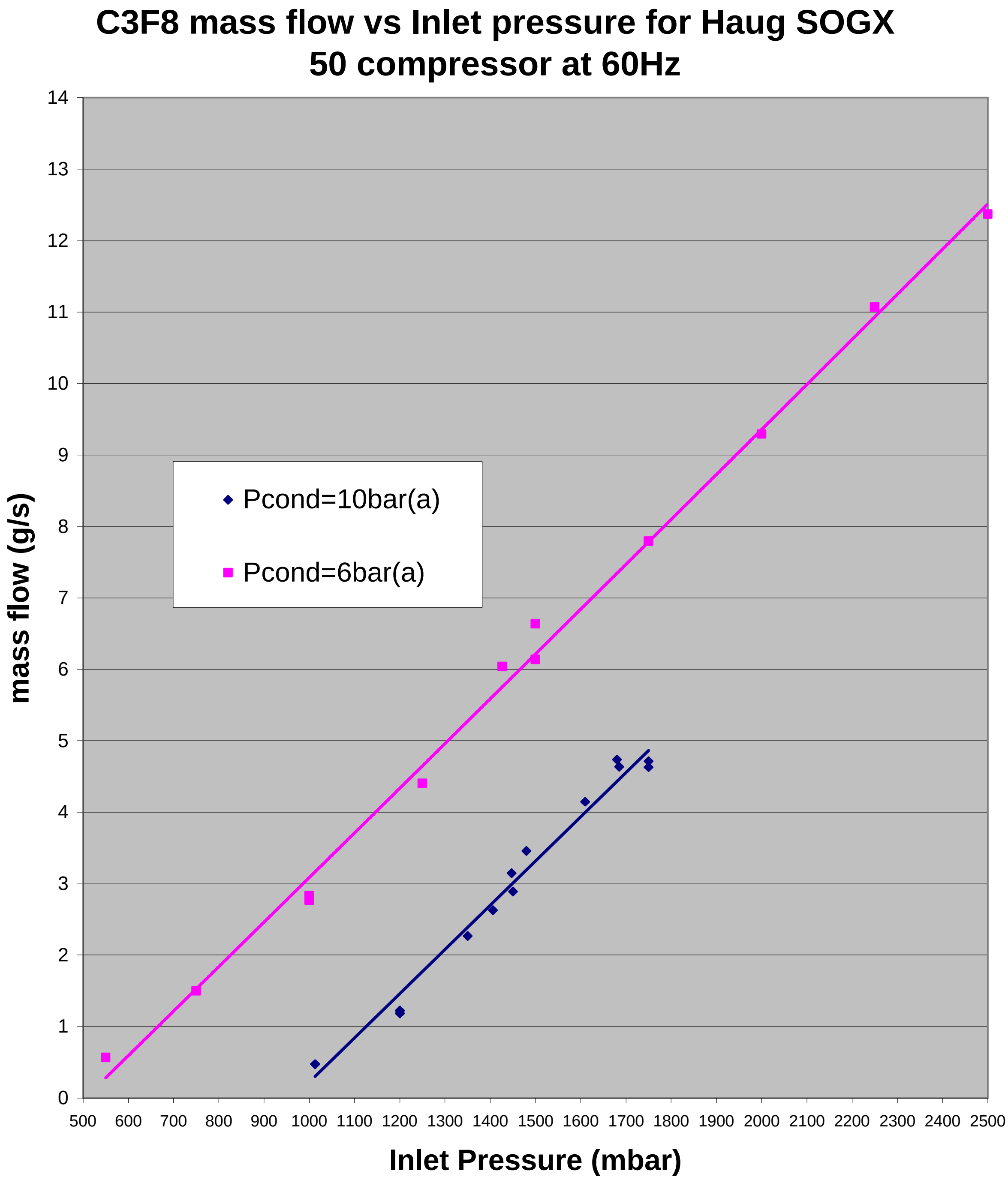

Fig.2

Comments:

It can be seen that the mass flow is a function of both inlet and outlet pressures:

$\dot{m} = f(P_{in}, P_{out})$

And also that it depends more on P_{in} than on P_{out},

$$\frac{\partial \dot{m}}{\partial P_{OUT}} \approx \frac{5-2}{10-6} = 0.75 gs^{-1}/bar$$

$$\frac{\partial \dot{m}}{\partial P_{IN}} \approx \frac{4-2}{1.6-1.3} = 6.7 gs^{-1}/bar$$

Theoretical background

Let ***p*** be the percent clearance of the compressor,

$$p = \frac{Vc}{V_{MAX} - Vc} \times 100 \qquad \textbf{(a)}$$

Where:

- $\boldsymbol{V_{MAX}}$ is the maximum volume in the cylinder, which occurs when the piston is at one end of its stroke.
- ***Vc*** is the minimum volume, or clearance volume, which occurs at the other end of the piston stroke

The ***clearance volumetric efficiency*** is

$$h_{VC} = \frac{Volume\_of\_vapour\_drawn\_in}{swept\_volume} = \frac{V_{MAX} - V_{OPEN}}{V_{MAX} - V_C} \times 100 \qquad \textbf{(b)}$$

Where $\boldsymbol{V_{OPEN}}$ is the volume in the cylinder at which the pressure is low enough for the suction valve to open. **($\boldsymbol{V_{MAX}}$ -$\boldsymbol{V_{OPEN}}$) is the volume of gas drawn into the cylinder and ($\boldsymbol{V_{MAX}}$ -$\boldsymbol{V_C}$) is the total volume swept by the cylinder.**

(a) and (b) can be combined to give:

$$h_{VC} = 100 - p\left(\frac{V_{OPEN}}{V_C} - 1\right) \qquad \textbf{(c)}$$

If an ***isentropic expansion*** is assumed for the gas trapped in the clearance volume, i.e. between ***Vc*** and $\boldsymbol{V_{OPEN}}$,

$$\frac{V_{OPEN}}{V_C} = \frac{r_{OUT}}{r_{IN}} = \left(\frac{P_{OUT}}{P_{IN}}\right)^{1/K} \qquad \textbf{(d)}$$

Where r_{IN} is the density at the compressor inlet and r_{OUT} at its outlet and ***k*** is the coefficient of isentropic expansion
Thus,

$$h_{VC} = 100 - p\left(\frac{r_{OUT}}{r_{IN}} - 1\right) = 100 - p\left(\left(\frac{P_{OUT}}{P_{IN}}\right)^{1/k} - 1\right) \qquad \textbf{(e)}$$

The volumetric flow is:

$$\dot{V} = N \times V_{SWEPT} \qquad \textbf{(f)}$$

Where, as seen above $\mathbf{V_{SWEPT} = V_{MAX} - V_C}$ and **N** is the number of cycles per second

The mass flow is

$$\dot{m} = \dot{V} \times h_{VC} \times r_{IN} = N \times V_{SWEPT} \times \left[100 - p\left(\left(\frac{P_{OUT}}{P_{IN}}\right)^{1/k} - 1\right)\right] \times r_{IN} \qquad \textbf{(g)}$$

ρ_{IN} is of course, a function of P_{IN}.