Cryocooler Contamination Study: Temperature Dependence of Outgassing

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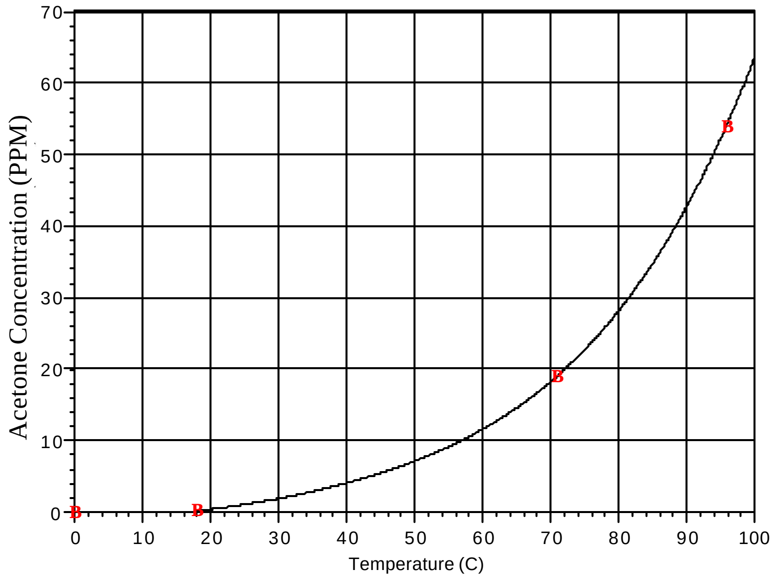
ABSTRACT

With the advance in technology, the life of the tactical cryocooler has extended way beyond the conventional 4,000 hours milestone[1]. And with the life extension, the contamination control of the manufacturing process has to be revisited, or cooler life may fall short of expectation, because outgassing is a function of time. This means that cooler components need to be baked out at a higher temperature or for a longer period of time. This in turn requires the knowledge of outgassing rate as a function of temperature. Contamination study of foreign gases and liquids in a cryocooler was discussed elsewhere[2]. Outgassing curves of water, alcohol, and acetone at 71°C were presented in the above study. This is a follow-up study emphasizing the temperature dependence of outgassing.

INTRODUCTION

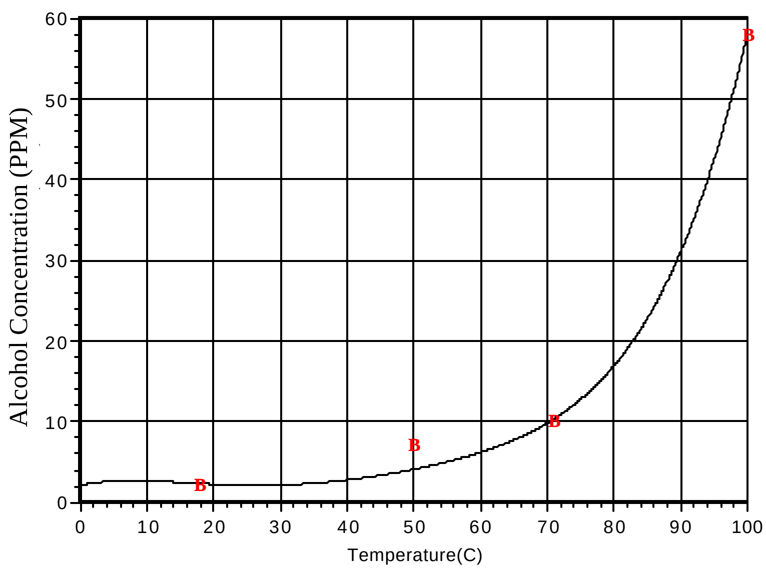
As the mean time to failure (MTTF) of cryocoolers approaches and surpasses 10,000 hours, contamination becomes a crucial factor that impacts cooler's life. Cooler manufacturers are faced with the task of further reducing the beginning-of-life contaminant levels so that the end-of-life levels will still lead to performance that meet the specification. This translates to longer bake-out time at elevated temperatures. To shorten the process time, bake-out at a higher temperature is called for. This requires knowledge of outgassing as a function of temperature.

Outgassing properties of various gaseous and liquid contaminants in cryocoolers have been investigated in Reference 2. Due to the lack of outgassing data as a function of temperature, a linear function was adopted, assuming desorption of gases from a monolayer[3]. Further testings conducted at BAE Systems indicated that the temperature dependence of outgassing is nonlinear. The test setup and procedure are described in Reference 2, except that the test chamber temperature was varied between 23°C and 100°C. Figures 1 to 3 show the concentration of acetone, alcohol and water as a function of temperature respectively. As one can see the data show an exponential dependence of concentration as a function of temperature, with much higher outgassing rates at elevated ambient temperatures.



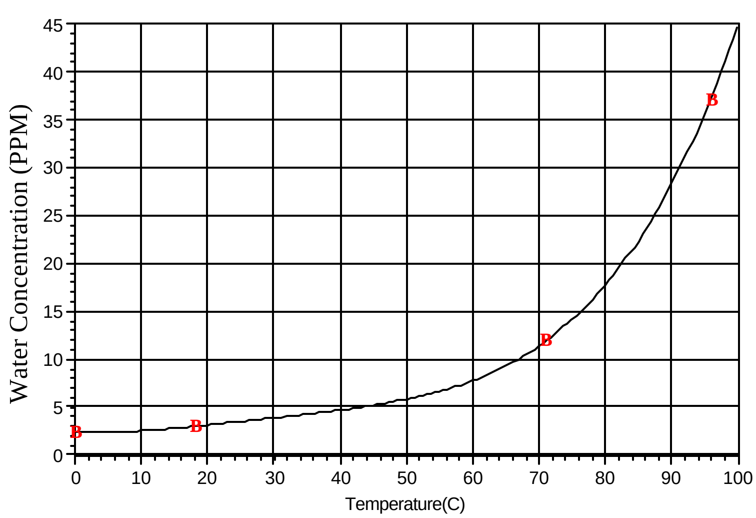
Temperature (°C)

Figure 1. Concentration of acetone vs. temperature.



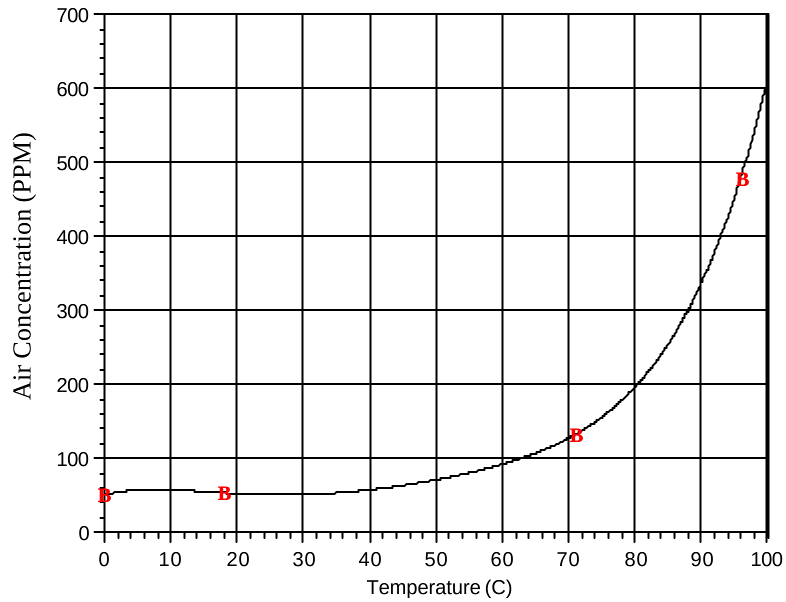
Temperature (°C)

Figure 2. Concentration of alcohol vs. temperature.



Temperature (°C)

Figure 3. Concentration of water vs. temperature.



Temperature (°C)

Figure 4. Concentration of air vs. temperature.

The high outgassing rate at elevated temperature was first attributed to the possibility of phase transition. As the boiling points of the liquids are exceeded, vaporization of the liquids may have resulted in the high contents of concentrations being measured. Further testing on the outgassing property of air shows that it exhibits similar exponential behavior. This confirms that the exponential outgassing property as a function of temperature is intrinsic to all gases and liquid tested.

Using a least squares curve approach, the above data can be fitted with the following equation.

$$m = K_1 \exp^{(BT)} + K_2 \qquad \text{Eq. (1)}$$

Where m is the concentration, T is the ambient temperature, B, K_1, and K_2 are constants.

Knowing the temperature dependence of the outgassing property, one can then combine with the time dependence function reported in Reference 1 to arrive at the following equation.

$$m = m_o \exp^{(BT)} [1-\exp^{(-t/A)}] \qquad \text{Eq. (2)}$$

Where m_o is a function of the initial contaminant level in the system (i.e., the larger the value of m_o the higher the contamination level), B is the temperature dependence constant found in Equation (1), and A is the time dependent constant found in Reference 2. The values of these constants are listed in Table 1.

Table 1- Outgass parameters of acetone, alcohol and water.

	m_o (PPM)	B (dimensionless)	A (dimensionless)
Acetone	22.69	0.0384	100
Alcohol	0.111	0.0666	36.4
Water	0.607	0.0512	45.0

Equation (2) is plotted in Figures 5, 6, and 7 for acetone, alcohol and water respectively at three temperatures, 100°C, 71°C, and 23°C. Experimental data at 71°C are also included.

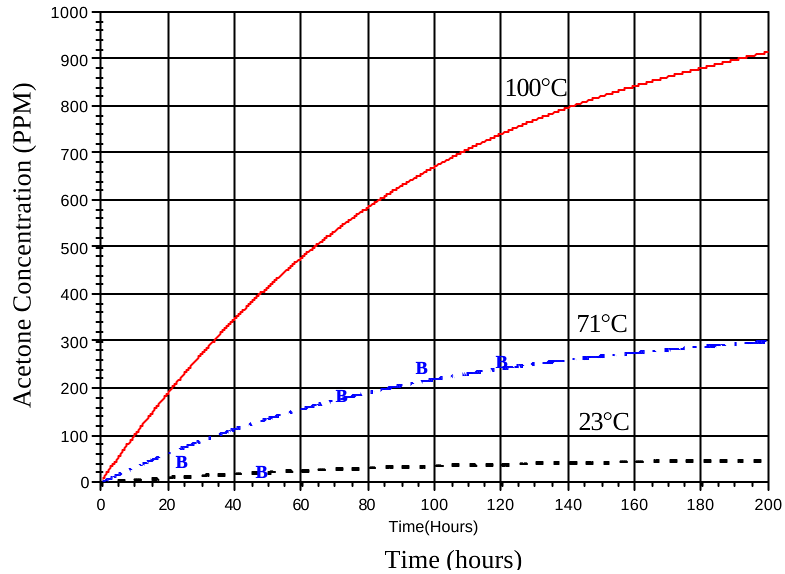


Figure 5. Acetone concentration as a function of time.

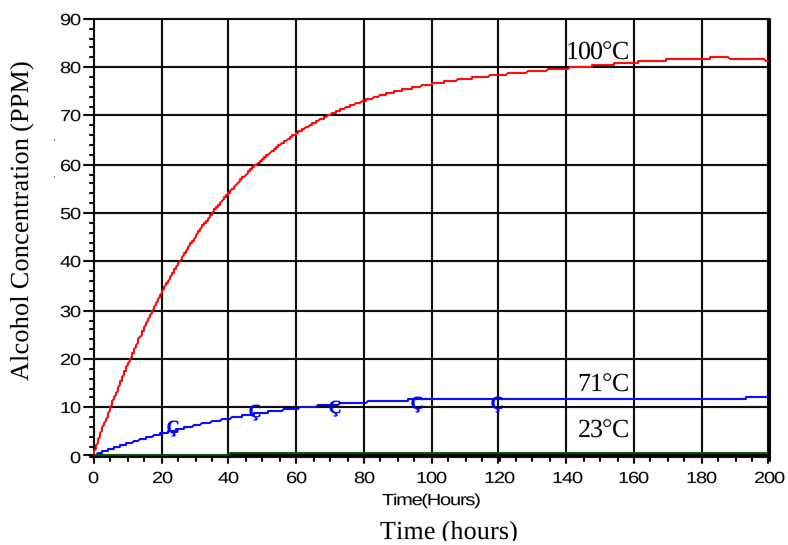
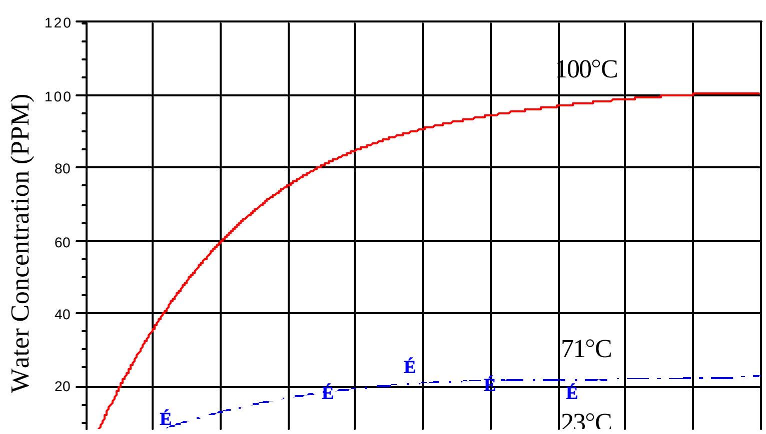


Figure 6. Alcohol concentration as a function of time.



Time (hours)

Figure 7. Water concentration as a function of time.

Figures 5, 6, and 7 are extremely useful in devising the bake-out process. The same level of bake-out can be achieved with a much shorter time at an elevated temperature. For example, to reach the same concentration level, the bake-out time for alcohol and water at 100°C is only one tenth that of 71°C. As for acetone, the bake-out time at 100°C is only a quarter that of 71°C.

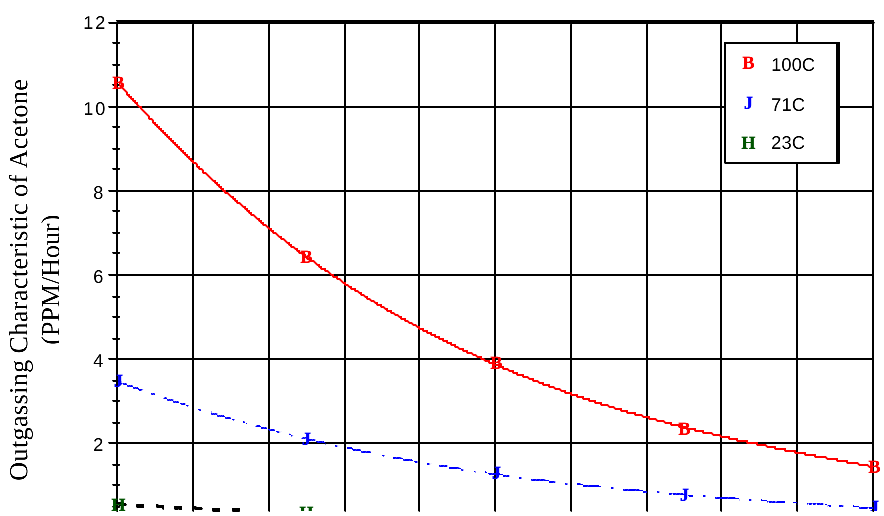
As the life of cryocoolers extends beyond 10,000 hours[3], the tolerance of contaminants in the cooler becomes smaller. Detection of small level of contaminants at the beginning-of-life can often be difficult especially at relatively low temperatures. The current procedure of BAE's gas chromatograph (GC) sampling of the working gas calls for two hours of bake-out time at 71°C before taking data. By elevating the temperature to above 71C, one can increase the outgassing rate (thus resulting in a more accurate reading of the concentration) and shorten the process time.

Although it seems feasible to bake-out coolers at the highest temperature the properties of the cooler materials would allow, precautions must be taken not to expose the motor magnets to temperatures higher than the manufacturer's specification, which may result in irreversible demagnetization of the magnets.

With Equation (2), one can proceed to calculate the outgassing rate (dm/dt) by taking the derivative of the equation.

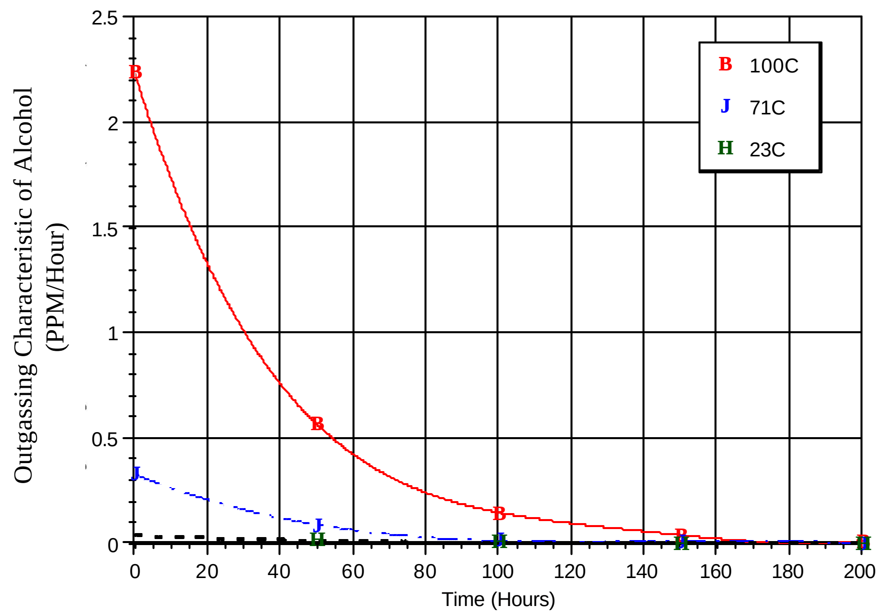
$$dm/dt = (m_o/A)\ \exp^{(BT)}\ \exp^{(-t/A)} \qquad \text{Eq. (3)}$$

The outgassing rates of acetone, alcohol and water at various temperatures are plotted in Figures 8, 9, and 10 respectively. As mentioned before, outgassing at high ambient is far more effective, with a steep rise between 71°C and 100°C. The outgassing rate is about three times higher in 100C compared to 71C for acetone, and about five times higher for alcohol and water.



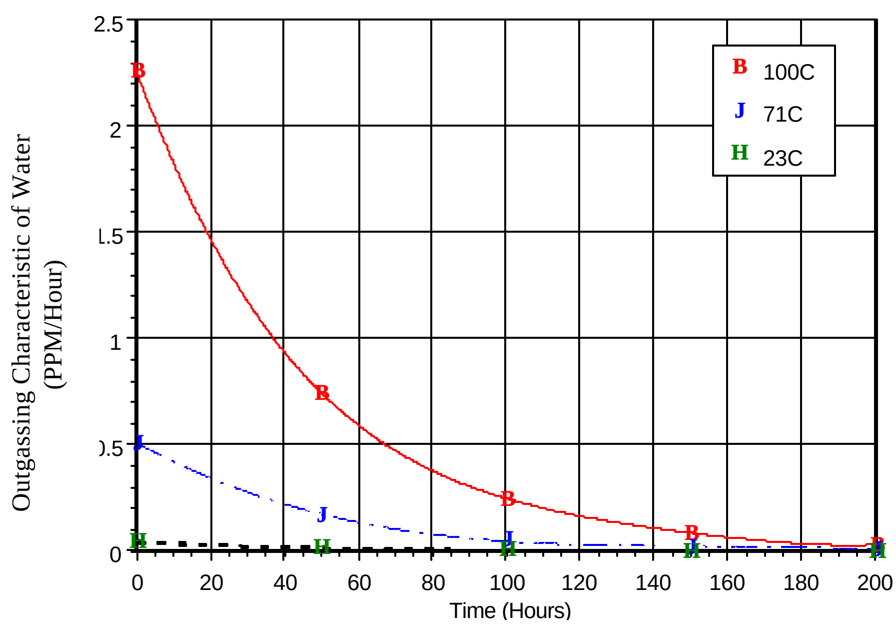
Time (hours)

Figure 8. Outgassing rate of Acetone



Time (hours)

Figure 9. Outgassing rate of alcohol.



Time (hours)

Figure 10. Outgassing rate of water.

CONCLUSIONS

The temperature dependence of outgassing has been studied in this paper. Outgassing curves of acetone, alcohol and water are presented as a function of temperature. It was found that the outgassing of the acetone, alcohol, water and air, is an exponential function of the ambient temperature. Results of this study are very useful for defining bake-out processes of cooler manufacturing. It can also be used to cut down the process time by baking out components and subassemblies at high ambient temperatures.

REFERENCES

1. Kuo, D.T., and Yuan, S.W.K, First Order Life Estimation and Its Correlation with Experimental Data, parallel paper in this conference.

2. Roth.,A., *Vacuum Technology*, North-Holland (1989), pp. 187.

3. Yuan, S.W.K., Kuo, D.T., Cryocooler Contamination Study, to be published in *Proc. of Advances in Cryogenic Engineering*, Vol. 45, 1999.