Prediction of Getter Bed Regeneration Intervals through Absolute Humidity and Flow Rate

Lucas Aaron Shadler

West Irondequoit High School

Rochester, NY

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Advisor: Wade Bittle

Abstract

The Target Chamber Tritium Removal System (TC-TRS) intercepts deuterium-tritium (DT) from LLE operations to contain DT for proper removal and storage. It combines DT gas with oxygen within a catalyst reaction chamber to form tritiated water vapor. This vapor is passed through a molecular sieve ("getter") bed, where the tritiated water is collected and contained until the bed can be taken offline and the water extracted. Extraction is presently done on a set date each month, yielding varying quantities of condensate depending on the volume of gas passed through the TC-TRS from the OMEGA systems during the water collection period. This method ignores real-time bed fill level knowledge, which could potentially lead to an overflow. A MATLAB code was written to compute the amount tritiated water accumulated in the beds. The code analyzed historic data from the TC-TRS with respect to flow volume and the total tritiated water condensate removed during each time interval. The code utilizes an estimate of the average absolute humidity of the incoming vapor, a quantity that expresses the amount of water per flow volume and is not at present directly measured. The code can be used predict the amount of water collected by a given flow volume. Greater accuracy can be achieved if an absolute humidity sensor is added to the incoming air flow.

1. Introduction

The TC-TRS, or Target Chamber Tritium Removal System[1], effectively removes radioactive isotopes of hydrogen from the OMEGA target chamber and target handling systems during experimental operations. It is necessary to collect these isotopes for proper removal and storage at the LLE facility. Currently each molecular sieve ("getter") bed is taken offline to be regenerated once each month, with bed fill level roughly estimated by active use time. This method poses the risk of varying quantities of condensate removed and in a particularly busy month the bed risks overflow. Thus, using MATLAB[2], computational code was developed that can determine the current capacity to within 30% based on real-time readings of the flow rate into the TC-TRS from the target handling systems and target chamber. Improved accuracy can be achieved through optimization of the placement of the flow rate sensor within the TC-TRS and the addition of a real-time humidity sensor in the incoming air flow path.

2. The TC-TRS

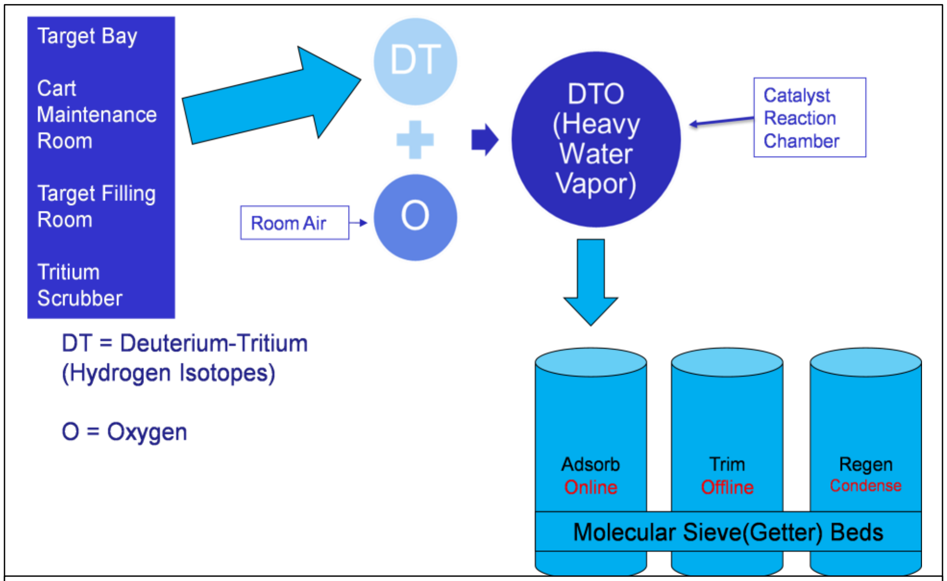

***Figure 1: Schematic path of D-T through the TC-TRS**. Removed condensate is measured from the regeneration bed after it has been taken off-line.*

Deuterium and Tritium are isotopes of hydrogen that are created as waste from OMEGA operations. These isotopes are radioactive, and the lab is required to limit the emissions of DT into the atmosphere. The lab remains well below this limit through the TC-TRS, the key gas processing system in this project. As shown in Figure 1, the D-T is collected from operational areas including the Target Chamber, The Cart Maintenance Room, the Target Filling Room, and the Tritium Scrubber. It is passed through a catalyst reaction chamber, which combines the D-T with Oxygen to create DTO, more commonly known as heavy water. This heavy water passes through a molecular sieve (“getter”) bed, which contains pores sized optimally to capture the heavy water. There are three getter beds stationed in the TC-TRS; one is set to adsorb the water, one to regenerate after the water is collected, and the third to collect any residual water vapor from the bed that’s regenerating, referred to as the “trim” bed. These getter beds operate in a cycle that is currently checked manually at approximately one-month intervals. Although this process proves functional, there have been cases of overflowing, which results in down time for the getter bed and more man hours to reset the bed cycle. Regenerating the beds prematurely also presents an inefficient use of available man-hours.

The first course of action was to look for a function that could describe the relationship between getter bed time spent collecting condensate and how much condensate was removed during the regeneration. With a plethora of historic data to pull from[3], points can be plotted of condensate removed vs. time, as shown in Figure 2. The plotted data was almost completely random, and a closed form expression for condensate removed as a function of time is not attainable. This makes sense, as OMEGA operations change on a daily basis to meet the demands of the target handling schedule and OMEGA target experiments. Thus the problem was approached from a real-time perspective using system sensor data.

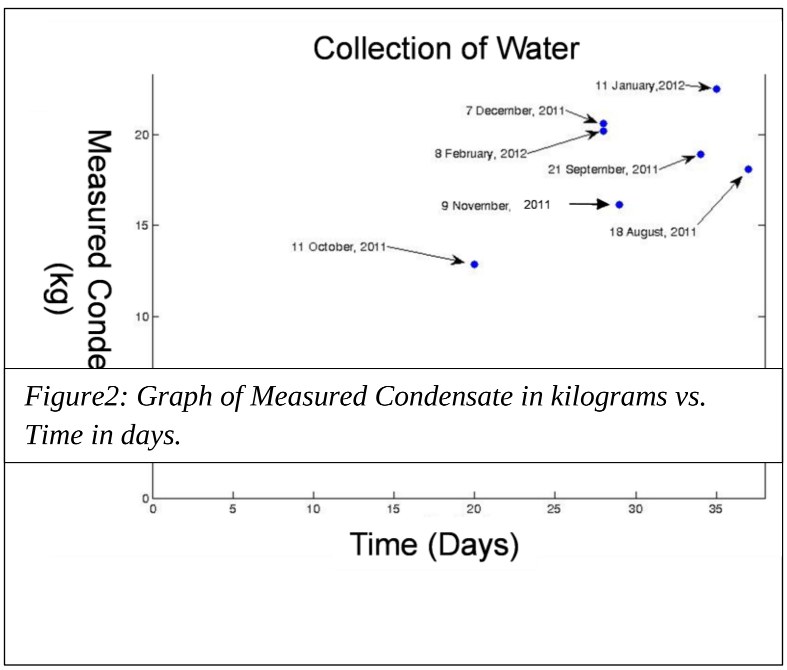

Figure2: Graph of Measured Condensate in kilograms vs. Time in days.

3. Calculation of Condensate Mass

The most accurate measurement for the condensate accumulation rate would be achieved using dew point, pressure, temperature and flow rate sensors positioned in the incoming air flow of the TC-TRS. The flow rate in standard cubic feet per minute (SCFM) can be converted to meters cubed per minute, by equation 1, which assumes standard temperature and pressure

$$Flow\ Rate\ \left(\frac{m^3}{min}\right) = \frac{Flow\ Rate(SCFM)}{35.288}. \quad (1)$$

The flow rate in m^3/min will be in the correct units to fit with the other equations. Dew point can be converted to water vapor pressure by equation 2[4].

$$P_w = A * 10^{\frac{m}{\frac{Tn}{Td}+1}} \quad (2)$$

where A, m and Tn are all constants based upon the temperature range, T_d is the dew point in degrees kelvin (K), and P_w is the water vapor pressure in Pa. The existing TC-TRS vapor pressure sensor data was not used because it also accounted for a carbon backflow. Using the vapor pressure from equation 2, the absolute humidity AH (g/m^3) can be calculated by equation 3

$$AH = \frac{C * P_w}{T} \quad (3)$$

where C = 2.16679 gK/J (a constant), and T is the temperature in degrees kelvin (K).

Utilizing equation 4, the accumulated mass of the heavy water collected during a period of time can be determined.

$$Condensate_{Total}(g) = \sum_{n=1}^{k} AH_n\left(\frac{g}{m^3}\right) * Flow\ Rate_n\left(\frac{m^3}{min}\right) * \Delta t_n\ (min), \qquad (4)$$

where k is the number of sample intervals and Δt_n is the length of a sample interval. This calculation was performed using a MATLAB program. It is assumed in the calculation that AH and Flow Rate remain constant throughout each sample interval. Accuracy may be improved using higher-order integration schemes in which an interpolation function is utilized for those values as determined by the trends of neighboring sample points. To verify the methods utilized the calculated condensate weight was compared with the getter bed condensate measured and recorded in TC-TRS archived operations data.

To demonstrate the meaning of dew point temperature, an experiment was designed where 50 milliliters of room temperature (about 27 degrees Celsius) water was placed into an aluminum soda can. A temperature probe on the inside of it measured the water temperature and an environmental data logger measured the ambient dew point. Ice cold water was gradually added to the water in the can, and the changes in temperature were recorded while observing the outside of the can surface for condensation. Condensation occurred at a temperature reading of 13.26 degrees Celsius, while the reading on the experimental logger for the dew point was 13.3 degrees.

4. Operation of MATLAB Program

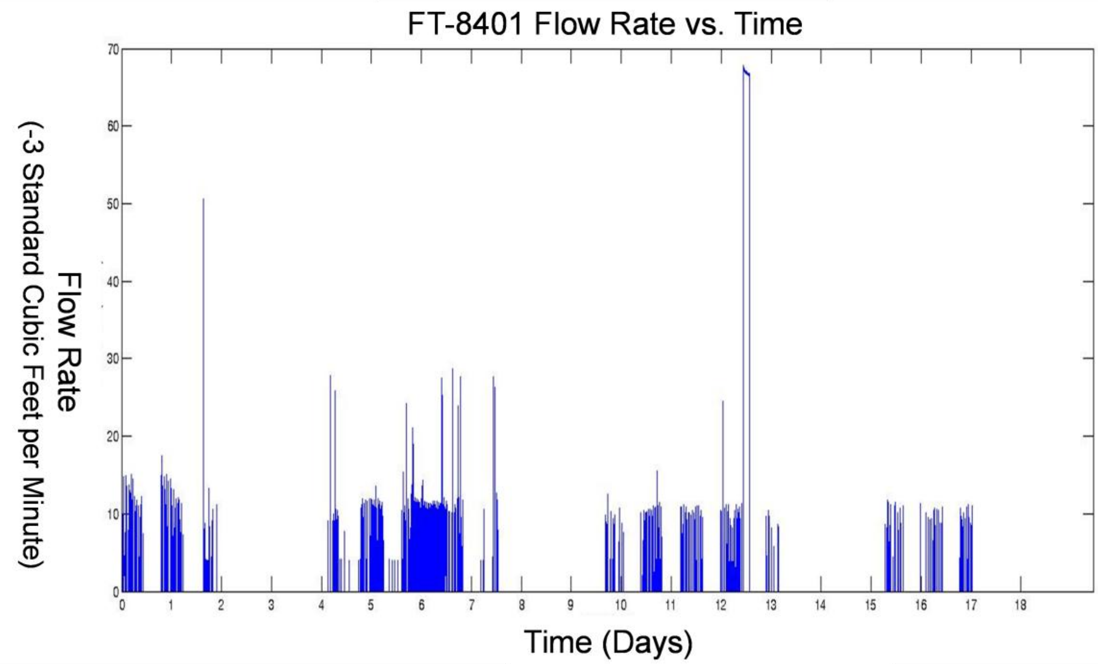

Figure 3: A graph of Flow Rate versus Time. *Each spike represents a purge of condensate into the TC-TRS. In addition, about 3 SCFM of carbon backflow has been removed to reflect only the flow rate of the condensate the TC-TRS removes.*

Figure 3 represents the flow rate over a full adsorption interval for one getter bed. The randomness of these points indicates that the processes within OMEGA that contribute to flow into the TC-TRS were not predictable. Since the flow rate, dew point, pressure, and temperature sensors refresh multiple times every minute, each day yields thousands of data points. TC-TRS files that were archived were reconfigured as CSV, or Comma Separated Variable files. Each file contained the identification of the specific sensor, and the raw data measured.

Initially, the dew point sensor data was used to calculate the condensate based on equations 2-4 since this was assumed to be the most accurate method. Since the measured condensate removed from each archived data set was known, the accuracy of the method could be directly assessed. Unfortunately, it became clear that a large error was produced using the dew point sensor data. The calculations were not close to the archived removed condensate data. It is believed that this error is the result of the dew point sensor being positioned away from the flow-rate sensor, so that the measured dew point is not that of the actual incoming flow. In the future, a dew point sensor placed in the incoming flow would provide an accurate reading.

5. Improved Method

Since a dew point sensor was not available that could relay accurate information on the incoming airflow, an alternate method was pursued toward calculating the incoming absolute humidity. The current approach is based on calculating an average absolute humidity for the incoming air flow utilizing archived data. As stated earlier in equation 4, the total condensate equals the product of each individual flow rate and each individual absolute humidity times the sample interval. An average absolute humidity can then be calculated for each archived data set using equation 5.

$$Average\ AH\ \left(\frac{g}{\mathrm{m\hat{}3}}\right) = \frac{Condensate\ _{Total}(g)}{\sum_{n=1}^{k}(Flow\ Rate_n)*\Delta t_n\ (\mathrm{min})}, \tag{5}$$

Each archived getter bed regeneration average absolute humidity was calculated. By finding the mean of this set, an overall average absolute humidity of 12.5 g/m^3 was determined.

Using this average absolute humidity, the archived data sets were used once more. Using the flow rate data from these sets in Figure 4, the calculated mass of condensate removed was plotted against the measured condensate removed. Overall, the data points lie close to the dashed line, which represents 0% error. The values on some time intervals were overestimated or underestimated up to 30% deviation from the actual condensate removed, Figure 4 indicates that using the average absolute humidity can provide a good estimate of the total condensate in the getter bed at any given time to within less than 30% deviation.

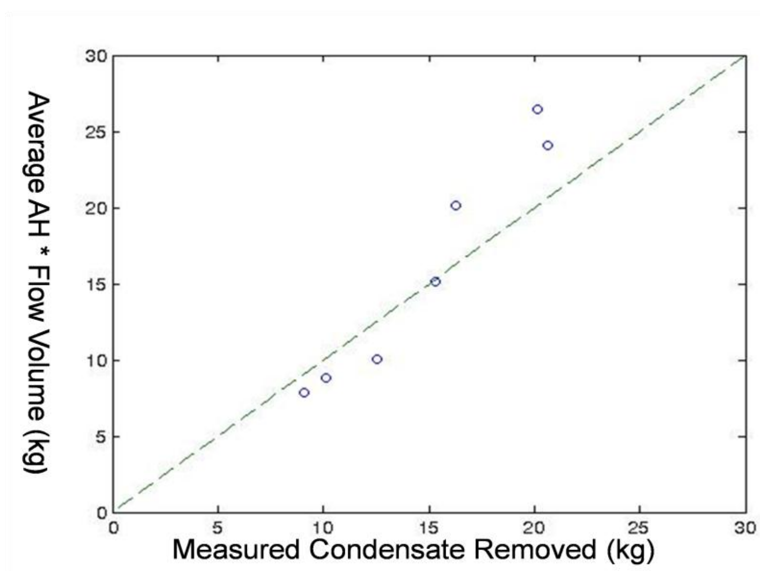

Figure 4: A graph depicting Calculated Condensate Removed versus Actual Condensate Removed. *Each point represents an archived data set and the dashed line represents 0% error.*

6. Conclusion

With the current code, the condensate removed can be calculated to within 30%. This will help workers avoid regenerating the getter beds too early, and can provide a warning when the bed is filling quicker than expected. In the future, a dew point sensor placed in the flow of incoming TC-TRS air has the potential to provide greater accuracy and become a great improvement to the efficiency of the TC-TRS operations at LLE.

7. References

1. OMEGA Target Chamber Tritium Removal System (TC-TRS), UR/LLE drawing number E-TR-I-02, Rev. m, 19 October,2011.
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8. Acknowledgements

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