

# *LTA 8*

## *NASA - AMATYC - NSF Project Coalition*

*Kennedy Space Center*

**Space - Age Cleaning**

*Mathematics for Engineering Technology*

**Chemical  
Materials  
Systems**



*Capital Community-Technical College*



STS-79 Space Shuttle Atlantis departs the VAB for the 2nd time with its destination Launch Pad 39A, visible in the distance.

# LTA 8

## Space - Age Cleaning

*Mathematics for  
Chemical Engineering Technology  
Materials Engineering Technology  
Systems Engineering Technology*

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Michael Haddad started at Kennedy Space Center in the Payload Experiment Integration Mechanical and Fluids Branch assembling, modifying, servicing and testing flight hardware payloads. In 1988 he specialized in Hypergolic Propellants and was responsible for ground processing flow for Shuttle planetary, observatory, and satellite class payloads. Michael currently serves as a senior Space Station systems engineer responsible for test and verification of Space Shuttle systems. He was a finalist for the Astronaut Corps, 1998.

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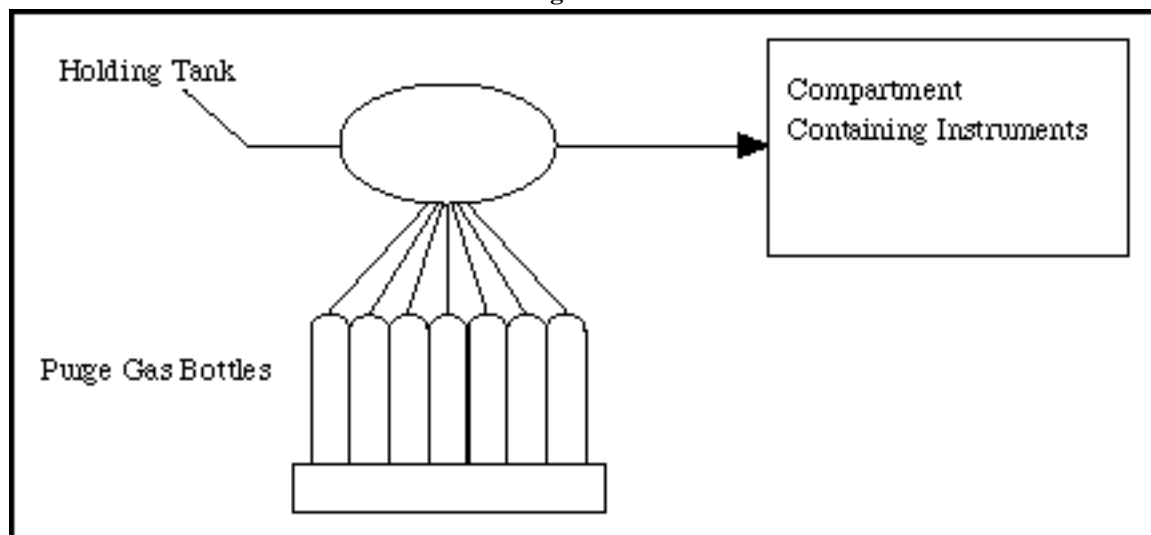
## LTA 8

### Space-Age Cleaning

#### Background

Most space missions involve using special, sensitive instruments which may be one of a kind. Scientists spend large amounts of time and money to design, construct, and build these instruments so they perform optimally in the vacuum of space - an environment that is essentially free of contaminants. Dirt, dust, moisture, and contamination from chemicals in our air can all cause a very sensitive instrument to malfunction. For this reason, it is critical to keep these instruments clean and free of contaminants. This is done by keeping the instrument in a closed compartment and passing ordinary clean air through the container. The process of passing air through the compartment in order to keep the instrument clean is called **purging**. If the compartment is in a large building, such as the Vehicle Assembly Building at the Space Center, then the purging can be accomplished by using a large tank of air. However, once the compartment is loaded onto a Shuttle or other spacecraft and during transportation to the launch pad, a portable purge system is needed. The portable purge system consists of a number of portable tanks of air that simultaneously feed into a holding tank which then has a line to the compartment where the instrument is housed. The situation looks something like this:

Figure 1



It is critical to have a sufficient number of tanks of air so that the purging can take place for the required amount of time. Once the Shuttle gets out to the launch pad, a large tank located at the site can again be used.

## Part 1 - A Space-Age Cleaning Problem

We are ready now to address the problem of determining the number of purge gas bottles needed for the trip from the Vehicle Assembly Building (VAB) to the launch pad. This is not a simple trip! The vehicle that carries the shuttle out to the launch pad is called a **crawler** and weighs 6 million pounds! It moves *very* slowly. When empty its maximum speed is 2 miles per hour, and when fully loaded its maximum speed is only 1 mile per hour. The trip from the VAB to the launch pad takes about 8 hours. As you can imagine, getting everything ready for the transport of the Shuttle involves many steps. Since many people need access to the Shuttle, the portable purging system needs to be set up and activated for a few days before the actual trip begins. Likewise, there may be delays in switching over to the large air tank at the launch pad. Michael Haddad, a Systems Integration Engineer with NASA, uses a 7 day guideline for the time required for the portable purging system.



**Figure 2: Photo of a K-bottle** The first part of our problem is to focus on the actual tanks of compressed air. These are called K-bottles and contain ordinary clean, dry air that is under pressure. They look like oxygen tanks (Figure 2). The tanks have a volume of 1.5 ft<sup>3</sup>. You may know from your own experience blowing up a balloon or from Spinoff 8C that if you increase the pressure on a gas, you can compress or squeeze more gas into a particular space. The air in the K-bottles is under a pressure of 2200 lbs/in<sup>2</sup>. To get a feel for this type of measurement, think of a square with 1 inch sides. This square would have a force of 2200 lbs applied to it. For comparison, our normal atmosphere has a pressure of 14.7 lbs/in<sup>2</sup>. As we let the air out of the tank, the excess pressure is released, and the air expands. If we let the air out of the tank into a room where the pressure is much lower than that of the bottle, the air would have a volume much larger than 1.5 ft<sup>3</sup>. The purge process involves releasing air into a compartment that holds delicate instruments. In order to prevent contaminants from getting into the compartment through the outlet valve, the pressure in the compartment is kept at 14.8 lbs/in<sup>2</sup>, which is slightly higher than ordinary atmospheric pressure. We need to find the volume that the air inside a K-bottle will occupy if its pressure is reduced from 2200 lbs/in<sup>2</sup> to 14.8 lbs/in<sup>2</sup>. To do this we can use a restricted version of the Ideal Gas Law which states that if the temperature is held constant while the pressure and volume of a given gas changes, then the products of the pressure and volume before and after the change must be equal.

$$P_1V_1 = P_2V_2$$

$P_1$  and  $V_1$  are the pressure and volume of the air in its compressed form in the K-bottle, and  $P_2$  is the pressure in the compartment (14.8 lbs/in<sup>2</sup>).  $V_2$  is the volume that the air from a K-bottle will occupy if its pressure is allowed to change to 14.8 lbs/in<sup>2</sup>.

- 1) Clearly identify the values for  $P_1$ ,  $V_1$ , and  $P_2$ . Remember that  $V_2$  is the unknown. Then substitute these values into the gas law equation making sure you include the units, and solve for  $V_2$ .

Volume of air at 14.8 lbs/in<sup>2</sup> in one K-bottle = \_\_\_\_\_

Just as you use a nozzle to regulate how fast water flows from a hose, the air coming out of a K-bottle can be regulated. The rate at which air flows out of a K-bottle and into the compartment is the **flow rate**. You can think of this as measuring the volume of air which passes a particular point in a set amount of time. Common units used for flow rate are cubic centimeters (volume) per second (time). Since this rate uses cm<sup>3</sup> and the volume of air is in ft<sup>3</sup>, we will need to convert the volume from ft<sup>3</sup> to cm<sup>3</sup>.

- 2) Convert from ft<sup>3</sup> to cm<sup>3</sup>. (You will need to account for changing from ft<sup>3</sup> to in<sup>3</sup> and from in<sup>3</sup> to cm<sup>3</sup>.) Recall that 2.54 cm = 1 in, so  $(2.54 \text{ cm})^3 = 1 \text{ in}^3$ .

Volume in cm<sup>3</sup> = \_\_\_\_\_

Since we will use this number many times throughout our investigation of this problem, it would be a good idea to store it in your calculator. On a TI-82<sup>TM</sup> or TI-83<sup>TM</sup>, type in your number and then STO ► ALPHA V (note that V is above the 6). You can store the value in any letter you want, but V here can stand for volume.

The flow rate is usually determined by the scientist in charge of the instrument, and it can vary from one instrument to another. We will assume for now that a flow rate of 100 cm<sup>3</sup>/sec has been specified. Since we now know the number of cm<sup>3</sup> of air at a pressure of 14.8 lbs/in<sup>2</sup> in one K-bottle, and we know it is being used up at the rate of 100 cm<sup>3</sup>/sec, division will help us find out how many seconds it will take to use up all the air in one K-bottle.

- 3) Use division, with careful consideration of the unit measurements, to determine how many seconds one K- bottle will last.

One K-bottle lasts \_\_\_\_\_ seconds. (Round your answer to two decimal places.)

Of course, we are interested in days, not seconds, so the next step is to use unit analysis to convert seconds to days.

- 4) Convert seconds to days.

One K-bottle lasts \_\_\_\_\_ days. (Round your answer to two decimal places.)

- 5) Use this information to determine the number of K-bottles needed to purge for 7 days.

Final answer to calculations rounded to two decimal places = \_\_\_\_\_

Whole number of K-bottles needed to purge for 7 days at a rate of  $100 \text{ cm}^3/\text{sec}$  = \_\_\_\_\_

- 6) You will now be repeating these calculations for two more flow rates. To make the process easier, take time to write a list of the mathematical operations you performed on the volume  $V$  (in steps 3, 4, and 5) to get the number of bottles. You can then use this list as a guide for repeating the calculations.

- 7) Suppose that instead of requiring the air to flow at the rate of  $100 \text{ cm}^3/\text{sec}$ , the scientist specifies only  $60 \text{ cm}^3/\text{sec}$ . Repeat the necessary calculations to determine the number of K-bottles needed.

Final answer to calculations rounded to two decimal places = \_\_\_\_\_

Whole number of K-bottles needed for 7 days at a rate of  $60 \text{ cm}^3/\text{sec}$  = \_\_\_\_\_

- 8) Repeat your calculations once more for a flow rate of  $120 \text{ cm}^3/\text{sec}$ .

Final answer to calculations rounded to two decimal places = \_\_\_\_\_

Whole number of K-bottles needed for 7 days at a rate of  $120 \text{ cm}^3/\text{sec}$  = \_\_\_\_\_

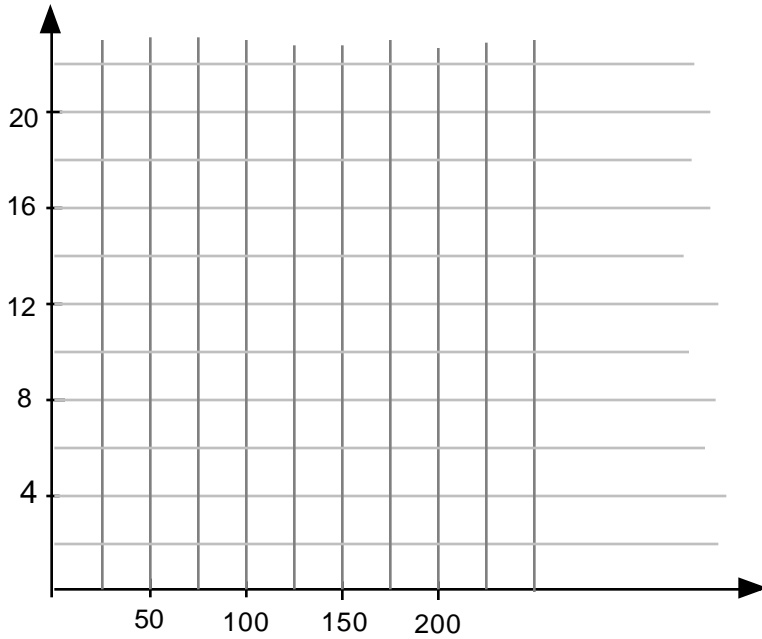
- 9) Summarize the results of problems 5, 7, and 8 in the following table:

**Table 1**

Flow rate (cubic centimeters/second)	Whole number of K-bottles needed
60	
100	
120	

10) Examine your table and write down any patterns you observe.

11) Now use flow rate as your input value and number of bottles as your output value, and construct a graph of the three ordered pairs in Table 1. Be sure to label your axes.



12) Is there a linear relationship between number of bottles needed for 7 days and the flow rate? How does the data in the table support your answer?

13) Find the equation of the line that expresses the relationship between the number of bottles and the flow rate.

Equation of line: \_\_\_\_\_

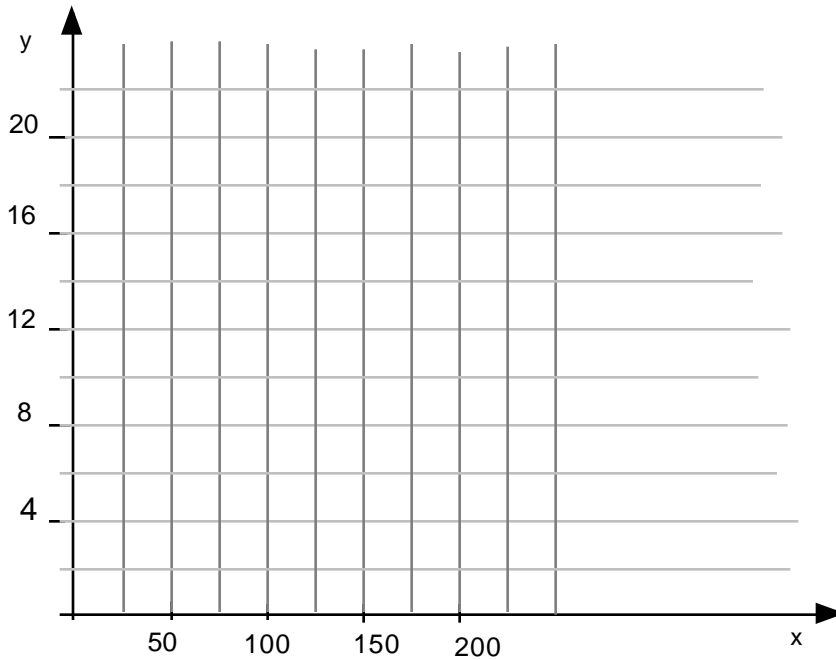
Identify the meaning of the variables  $x$  and  $y$  and explain the equation in words. Your explanation should make it clear what the equation can be used for.

14) Scientists tell us that flow rates can reasonably range from 50 to 200 cm<sup>3</sup>/sec. Use your formula to compute the number of purge gas bottles needed at these extremes.

Number of bottles needed at a flow rate of 50 cm<sup>3</sup>/sec = \_\_\_\_\_

Number of bottles needed at a flow rate of 200 cm<sup>3</sup>/sec = \_\_\_\_\_

15) Redraw your graph so that it is complete for this situation; that is, it starts at  $x = 50$  and ends at  $x = 200$ . Be sure to label your axes.



### Part 2 - A Reality Check

There is, unfortunately, a flaw in all of this reasoning. It isn't really possible to completely empty the bottles of gas. You may know from your experience with pressurized spray cans that there is a point at which you can't get anything more out even though there is still a little bit of air left inside. As the container is emptied, the pressure inside decreases. There will be a point when the pressure inside the bottle has decreased to a point where there is not enough pressure to force the rest of the material out. (Given an opening, a substance at a higher pressure will flow towards a region of lower pressure.) So to compensate for this, Mike Haddad, NASA Engineer, recommends a "safety factor" of 10%. That means that once you determine how many K-bottles you need to last for  $x$  days, you should add 10% more to your answer.

- 1) Take your formula for the number of bottles needed and rewrite it to account for this 10% increase. (Take your answer plus 10% of your answer.)

Revised formula for the number of bottles needed: \_\_\_\_\_

- 2) Complete the following table to reflect the revised situation.

- 2) Complete the following table to reflect the revised situation.

**Table 2**

Flow rate (cubic centimeters/second)	Whole number of K-bottles needed
50	
60	
100	
120	
200	

- 3) An important part of working on a project is summarizing the results. Suppose you were the engineer in charge of this project and you had to write a report to your supervisor summarizing Parts 1 and 2. Your report should begin with a brief but clear statement of the project objective. This should be followed by the major outcomes of your analysis. This should include both your equations and an interpretation. Your supervisor will need to know how to use the results of your work but would not want to read through all of the details. For example, starting out with the volume in cubic feet and converting to cubic centimeters is a detail and should not be included. After brainstorming with your group, write this report on separate paper.

### Part 3 - Delays

You may be aware that the schedules for launches of orbiting space vehicles often change. There can be delays due to mechanical problems, weather related problems or computer failures. These possibilities can create a situation where the number of K-bottles is insufficient for the lengthened time needed for purging. Let's consider the following situation:

You have already determined that 11 K-bottles are needed to ensure that purging can occur for seven days at 100 cm<sup>3</sup>/sec. Suppose purging has already taken place for two days when Hurricane Thomas threatens to hit Cape Canaveral. The launch is delayed pending weather outcomes. You are told that the purging will need to be extended for 2 more days. Due to the complexity of accessing and changing K-bottles, you don't have the option of adding more K-bottles. Since the number of days and the number of K-bottles are fixed, you have no choice but to decrease the flow rate so that the remaining air lasts longer.

Realistically, you might not know how many more days you will need to add on. In order to avoid repeatedly computing the flow rate for a different number of days, you can use variables to create an equation that shows the relationship.

- 1) Determine the total amount of air at 14.8 lbs/in<sup>2</sup> in the 11 K-bottles. Your answer should be in cm<sup>3</sup>. (Recall that we stored the volume of one bottle in V on the calculator.)

Total volume of air = \_\_\_\_\_

- 2) As noted in Part 2, it is not really possible to completely empty the bottles. In fact, remember that we added 10% to take care of this. Let's assume, then, that only 90% of the air can be obtained from the bottles. Calculate the amount of *available* air.

Amount of available air = \_\_\_\_\_

- 3) Use this value to determine the volume of air that would have been used each day for the original 7 days.

Amount of air per day = \_\_\_\_\_

- 4) Since two days have gone by, there is a 5 day supply of air left. Determine the amount of air that is left.

Amount of air remaining = \_\_\_\_\_

- 5) Now assume at the end of the first two days the flow rate is changed to  $r$  cm<sup>3</sup>/sec. Use this flow rate and the total amount of air remaining at the end of two days to develop a formula that expresses the number of days the air supply will last in terms of  $r$ . Unit analysis will be helpful. Let  $d$  = the number of days. Write your result as an equation that relates  $d$  to  $r$ . Round the constant in your formula to two decimal places.

- 6) Since flow rate will depend on the number of days, use the formula you developed in Exercise 5 to express  $r$  in terms of  $d$ .

$r =$  \_\_\_\_\_

- 7) The number of days  $d$  must be at least 5, since the original number of days was 7 and you have used up 2. Create a table to calculate flow rates for values of  $d$  ranging from 5 to 30 in steps of 5. Round your answers to two decimal places.

**Table 3**

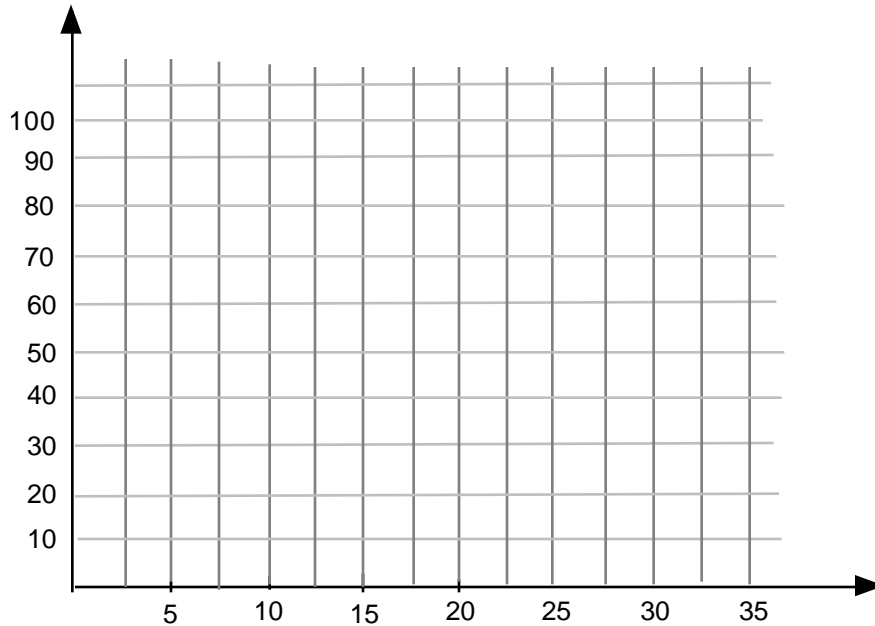
Number of days, $d$	Flow rate, $r$ (cubic centimeters/second)
5	
10	
15	
20	
25	
30	

- 8) Examine the values in the table and specifically describe what happens to the flow rate as the number of days increases.

- 9) From this description, what would you expect the graph to look like? Why?

9) From this description, what would you expect the graph to look like? Why?

10) Graph the equation you derived in Exercise 6, making sure that you appropriately label the axes.



11) Suppose you know that in order to keep the instrument clean, the flow rate cannot be less than  $20 \text{ cm}^3/\text{sec}$ . What is the maximum number of days you can continue to purge? Explain how you got this answer.

12) Write another memo to your supervisor outlining the result of your investigation so that your supervisor can plan for unexpected emergency situations. Once again, begin with a clear statement of your objective and follow this with a summary of your conclusions. Include both the equation and an interpretation.

#### **Part 4 - Wrap-Up**

- 1) Look back over the work you have done in this LTA. Write a summary of the different mathematical ideas you have used.
- 2) Comment on the change in your level of understanding of the mathematics you used.
- 3) Compare working on typical textbook problems and solving a mathematical problem based on a real-life application. How are they the same? How are they different?