EXAM 5 Spring 96, Part V

INTEGRATED

Make sure that you read the directions on the cover page before beginning.

Recently a truck owned by the Chicken Ranch Trucking Company was involved in an accident that ultimately resulted in 195 gallons of liquid sulfuric acid (H_2SO_4) being spilled onto the road. The sulfuric acid was being shipped from Houston, Texas to Dallas, Texas via Interstate 45 in specially designed 32.5 gallon barrels since this chemical is considered hazardous by the Environmental Protection Agency (EPA). According to the police report, the truck driver failed to observe the reduced overpass height in Buffalo, Texas and as the truck sped under the overpass, six of the barrels simultaneously slammed into the bridge. The police report includes eyewitness accounts that say “the barrels basically broke up on impact with the bridge”, sending the sulfuric acid flying everywhere. While the driver of the truck admits that he missed the height restriction sign on the overpass, he is steadfast in his story that he was only traveling at a speed of 60 MPH (the barrel manufacturer claims that at a speed of 60 MPH the barrels should have been able to withstand the force of impact).

As a result of this accident the Chicken Ranch Trucking Company has decided (along with a little prodding from the EPA) to carry a limited amount of a neutralizing substance in the event that a hazardous spill occurs in a remote location. One common way of neutralizing acid spills is with sodium bicarbonate ($NaHCO_3$). When sodium bicarbonate reacts with sulfuric acid, the products are sodium sulfate (Na_2SO_4), carbon dioxide (CO_2) and water, all of which are harmless.

An investigation of this accident has been initiated by the Department of Transportation, DOT, and a team of investigators has decided to begin by evaluating the design of the transportation barrel. The barrel manufacturer claims that the specially designed transport barrels can absorb 100 kilojoules of impact energy before their integrity is breached. As a first step towards determining whether or not the barrel manufacture produced a faulty design or the truck driver was speeding, the investigation team has decided to conduct a series of experiments. A number of barrels were filled with sulfuric acid (the sulfuric acid density is 15.37 pounds per gallon and the mass of the empty barrel is 50 pounds) and then they were individually launched on an air table platform and allowed to collide with a large kryptonite rectangular block. The kryptonite block is also positioned on the air table platform and has a mass that is 10 times the mass of a full barrel. The design of the experiment is such that when the barrel collides with kryptonite block it bounces back along the same line it was launched from. After the collision, the kryptonite block slides along the air table and is brought to rest by a “spring like” a stopping mechanism. The “spring like” stopping mechanism is reacting the force of the kryptonite block with a force given by $F_{spring} = -k_1\delta - k_2\delta^3$ where δ is the amount the spring is compressed and k_1 and k_2 are 30 000 N/m and 1 000 N/m^3, respectively. The maximum compression of the stopping device, C_{max} (in meters), is a function of the original speed of the barrel approximately given by $C_{max}(v_0) = 0.04v_0$ where v_0 (in meters per second) is the initial launch speed of the barrel. In the design of the experiment it was assumed that all the kinetic energy lost in the collision, defined as E_{crunch}, is absorbed by the barrel.

Your team’s task is to evaluate the “first pass” experimental information and determine whether or not the energy limits established by the manufacture are reasonable.

SPECIFICALLY YOU ARE BEING ASKED TO:

1. The typical truck will be required to clean up a 10-barrel spill. What mass of sodium bicarbonate will be required to neutralize the spilled acid?

2. Analyze the experiments and plot E_{crunch} vs v_0 (0 to 50 m/s) and determine what launch speed corresponds to the 100 000 joule energy limit set by the manufacture.

3. Write a short paragraph, in non-technical language, describing your results.

EXAM 6 Spring 96, Part V

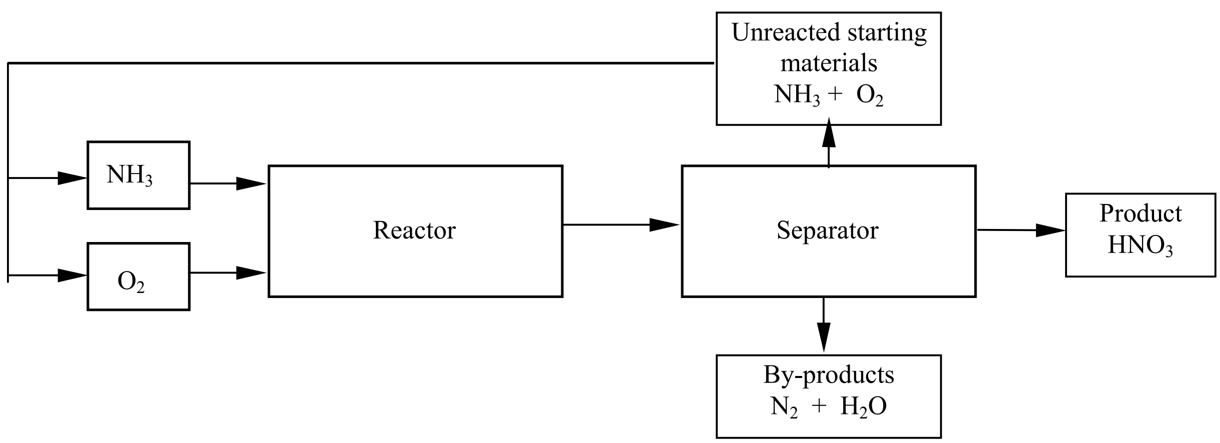
INTEGRATED

Make sure that you read the directions on the cover page before beginning.

Nitric acid, HNO_3, is one of the leading industrial chemicals, with annual production in excess of 8 million tons. The chemical research department of your company has proposed a new method of production for this important compound, using ammonia and oxygen as starting materials. The key to the method is a new catalyst that greatly enhances the rate of the necessary chemical reactions. If the scheme can be implemented successfully, it could become highly profitable for the company.

The research chemists have studied the new reaction extensively, and believe that it holds great promise. Another team in your department has tried unsuccessfully to optimize the reaction by balancing masses, so your boss is requesting your engineering team to determine a better way of optimizing the reaction scheme for large-scale production.

The proposed production scheme works as shown below.



The reactant stream entering the reactor will be controlled so that it always contains 2 moles of O_2 for every 1 mole of NH_3, and the mixed reactants are to be pumped through the reactor at a rate of 1000 kg/h. Nitric acid is formed according to reaction #1 below. Unfortunately, an undesirable side reaction is also possible, as shown by reaction #2.

$$NH_3 + 2\,O_2 \rightarrow HNO_3 + H_2O \quad \text{(reaction \#1)}$$
$$4\,NH_3 + 3\,O_2 \rightarrow 2\,N_2 + 6\,H_2O \quad \text{(reaction \#2)}$$

After leaving the reactor, the stream enters a separator, which isolates the various chemical compounds present. The product HNO_3 is collected, packaged, and sold. The by-products, N_2 and H_2O, are disposed of, while the unreacted NH_3 and O_2 are collected and fed back into the reactant stream.

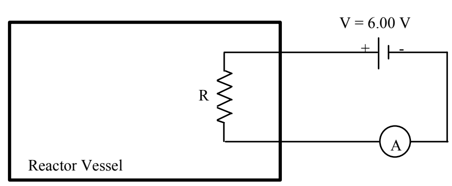
The yield of each reaction will depend on the temperature at which the reactor operates. Data obtained in a laboratory test show that the amounts of N_2, NH_3, and HNO_3 coming out of the separator all depend on the reactor temperature. For N_2 and NH_3, the form of this dependence is given below. (T is the reactor temperature in Kelvin.)

$$F_{N2} = 28.6\ (\text{kg/h})\ \{1 - e^{-aT}\}$$
$$F_{NH3} = 347\ (\text{kg/h})\ \{e^{-bT}\}$$

where $a = 0.0001\ K^{-1}$
$b = 0.01\ K^{-1}$

The desired temperature in the reactor is to be maintained with a large coil of wire wound around the reactor vessel, forming an electrical resistance heater. The heater will control the temperature inside the reactor through the use of a platinum resistance thermometer sensor that will be placed inside the reactor vessel and is in direct contact with the reactants.

The platinum resistance thermometer unit is powered by a constant voltage source that drives a current through the platinum resistor and a sensitive ammeter. The ammeter, along with the power supply (the constant voltage source), is located outside the reactor vessel as shown in the wiring schematic shown below.



The magnitude of the current measured by the ammeter is fed into the control circuitry of the resistance heater in order to vary the heater current and thereby regulate the reactor temperature. The resistance in the thermometer is a function of temperature (°C) and obeys the following relationship:

$$R(T) = 1 + \alpha(T - 20)$$

where R is the resistance (Ω), T is the temperature and for platinum $\alpha = 3.0 \times 10^{-3}\ °C^{-1}$.

WHAT YOU ARE SPECIFICALLY BEING ASKED TO DO:

1. Recall that the number of atoms of each element is always conserved in a chemical reaction. Use the accounting principles you have learned to write an expression for the number of moles of HNO_3 produced per hour as a function of reactor temperature.

2. Find the temperature at which the reactor should operate in order to obtain the largest possible yield of nitric acid per hour.

3. Plot the relationship between the current in the resistance thermometer and the temperature (°C) in the reactor. From the graph determine the current in the thermometer at the optimum reactor temperature.

4. The president of the company is concerned that fluctuations in temperature will drastically alter production. Write a memo to the president, in non-technical language, explaining your position on the sensitivity of the reaction yield to temperature.

EXAM 7 Spring 96, Part V

INTEGRATED

Make sure that you read the directions on the cover page before beginning.

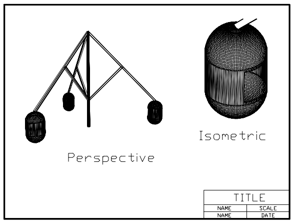
Six ***F***lags Entertainment Corporation is interested in another thrill ride for their theme parks. They have expressed an interest in something that spins, moves up and down and basically makes people feel like they are defying gravity. They have hired your company, *B&H Fun Rides*, to do the initial creative brainstorming and preliminary design of the new ride. Another team has already done some of the preparatory work and has proposed a conceptual design as shown in the drawing below (see Fig. 1). They call it "**The Centrifuge**". Your boss has now passed the project to your team to do some of the initial analysis.

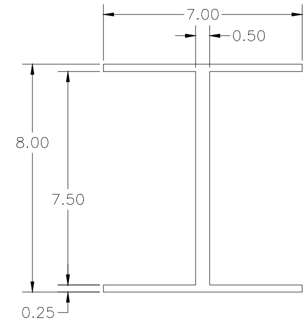
The ride is expected to carry three passengers and enable them to experience an acceleration of 3 g's. At the start of the ride, the support arms will be in a rotated down position so that the angle between the center post and support arm is nearly 0°. Before the ride begins to rotate, the arms will swing upward forming a 45° angle between the center post and support arm. The cross-member stabilizing the support arm will move in a similar but opposite manner and also forms a 45° angle with the center post.

Each passenger will ride in his or her own basket, which will remain vertical throughout the duration of the ride. The basket will be a 1-inch thick shell and is anticipated to be constructed as a cylinder whose outer dimension is 4 feet in diameter and 4 feet tall with hemispherical ends providing additional length. Passengers will enter and depart the basket through a 2½-foot wide 3-foot tall opening that has been cut through the center of the cylinder facing the center of the ride. For purposes of this preliminary analysis your team has assumed the effective density of the basket shell to be 25 pounds per cubic foot.

The original design team has proposed that the support arms be 40 feet in length and the cross-member stabilizing struts be 20 feet long, with each component being fabricated using W8 X 40 I-beams (see Fig. 2 for details). The support arms will be fastened to the center spindle pole via a pinned joint thus allowing them to freely rotate up and down. The cross-member stabilizing struts will be secured at the midpoint of the support arms and anchored to a collar that will slide up and down the 12-inch diameter spindle pole. As part of the design team's preliminary report, they have recommended, for both economical as well as strength reasons, that the structure be fabricated of ASTM A36 steel. A member of your team has already retrieved some information about this type of steel that appears in the table shown below:

ASTM A36 Steel Properties	
E (psi)	29 000
σ_y (psi)	36 000
σ_u (psi)	58 000
ρ (lb/ft^3)	498





Your team's primary task will be to do the initial sizing of the motor used to drive the center spindle. For your analysis you may assume that each passenger weighs 175 lbs.

WHAT YOU ARE SPECIFICALLY BEING ASKED TO DO:

1. You will produce a drawing similar to Fig. 1 including a completed title block.

2. You will estimate the moment of inertia of the entire system about the center spindle by an appropriate means.

3. You will determine the constant torque required to accelerate "**The Centrifuge**" from rest to the required angular velocity ω_0 in 60 seconds assuming no frictional drag.

4. If you assume that there is a frictional drag acting which produces a vertical torque $\tau = -c\omega$, where c is a constant 150 lb-ft-sec, determine the time for the ride to the reach operating angular velocity ω_0 with the applied torque found in part 3. You should first determine an exact solution to the problem and then use Euler's method to determine an approximate solution wherein you will determine an appropriate step size to use (make sure you justify your selection).

5. Write a memo to your boss detailing your findings, as well as discuss the "potential" hazards to the passenger if the ride was to speed up out of control.

EXAM 8 Spring 96, Part V

INTEGRATED

Make sure that you read the directions on the cover page before beginning.

You and your team work for a engineering consulting company that specializes in designing and evaluating production plant layouts for optimal productivity and performance. Your company has been hired by the ***B**ryant **G**as **C**ompany* to make an assessment of the operation on their proposed number 2 tetrafluoroethylene, C_2F_4, gas bottling production line. This particular production line will primarily produce tetrafluoroethylene destined for use by the various companies that manufacture Teflon®.

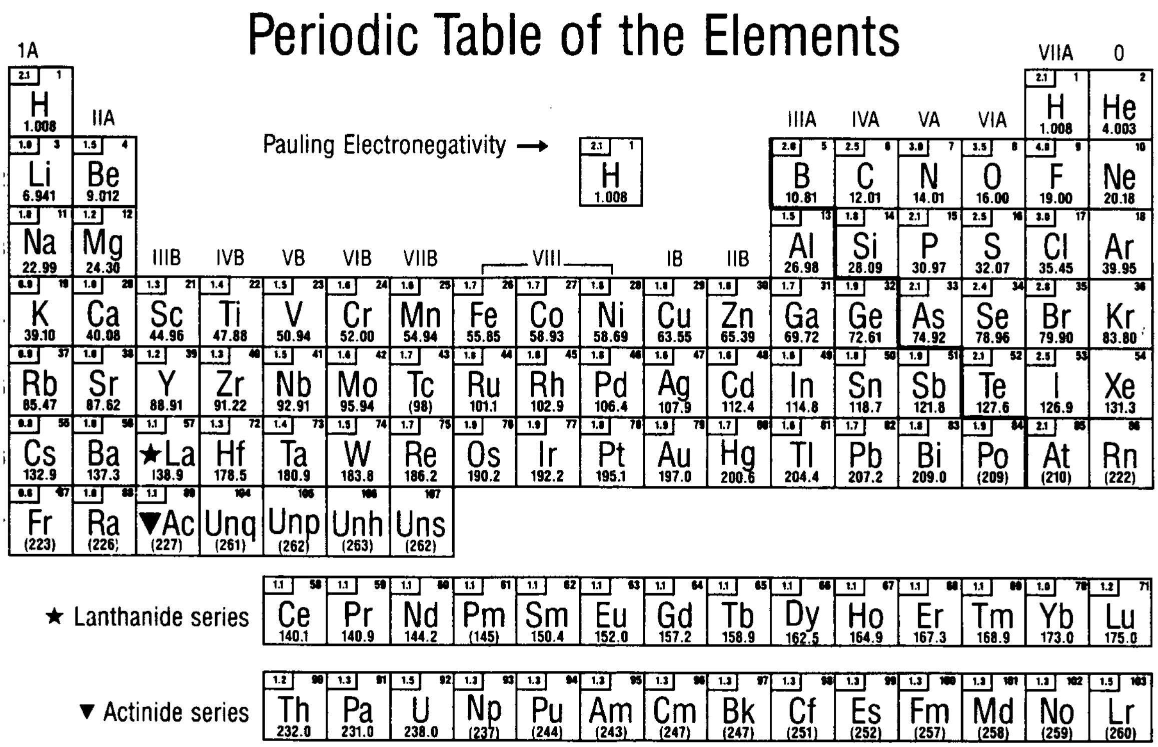
The proposed process of bottling of C_2F_4 is relatively straightforward. Approximately 1200 grams of liquid tetrafluoroethylene, at a temperature of -60°F, will be pumped into an empty *6061-T6* aluminum cylinder which is 4 feet tall, has an outside diameter of 8 inches, and a ½ inch wall thickness. Welded ½ inch aluminum flat caps will seal the ends of the cylinder. The "fill stage" of the bottling process will begin when a cylinder moves into position and a fill tube and pressure probe assembly is lowered into the cylinder through a one-way access port located on the top cap of the cylinder. The liquid C_2F_4 will then be pumped into the cylinder wherein it will evaporate into a gas as the cylinder is warmed to a temperature of 77°F (this will take approximately 90 seconds) and then the pressure in the tank will be measured to ensure that it is correctly filled. If the gas-filled cylinder passes this pressure inspection it will be moved on to the shipping station, otherwise the gas will be recovered and the tank returned to be re-filled.

It is envisioned that when the cylinder reaches the shipping station, a transfer arm will rotate the cylinder, place it on a delivery ramp, and release it. The ramp will be used to deliver the cylinder to a loading area for subsequent shipment. Your team has inspected the facility plans and measured the ramp length to be 25 feet with an angle of 10° from horizontal. When the gas-filled tanks reach the bottom of the ramp, they will be captured by a conveyor belt sorting machine for distribution and loading into shipping trucks.

In order to ensure appropriate synchronization of the transfer arm release and the sorting machine, it is necessary to know the travel time of each cylinder as it rolls down the ramp. In addition, knowing the cylinder velocity when it arrives at the bottom of the ramp would provide some of the necessary information to analyze the force exerted on the sorting machine arresting pads.

Your boss has assigned your team the task of evaluating the feasibility of some of the key elements of the proposed number 2 tetrafluoroethylene gas bottling production line. A member of your team has already gathered some of the information that may or may not be pertinent to the problem and it is shown below.

Material Properties of 6061-T6 Aluminum	
Density - lb/in^3	0.098
Young's Modulus - psi	$9.9x10^6$
Coefficient of Thermal Expansion at 0°F - in/in/°F	$12.4x10^{-6}$
Ultimate Stress - psi	$4.2x10^4$
Yield Stress - psi	$3.5x10^4$



$R = 8.314\ J\ K^{-1}\ mol^{-1}$ 1 atm = 760 torr

$N_A = 6.02257 \times 10^{23}$ /mol

$R = 0.08206\ L\ atm\ K^{-1}\ mol^{-1}$ 1 atm = 14.7 psi 1 gal = 3.78 L

$R = 62.36\ L\ torr\ K^{-1}\ mol^{-1}$ 1 atm = 101.5 kPa 1 gal = 231 in^3

1 lb_f = 4.4482 N 1 lb_m = 0.45359 kg

$k = 1.381 \times 10^{-23}$ J/K

WHAT YOU ARE SPECIFICALLY BEING ASKED TO DO:

1. In order to program the controller that will accept or reject a gas tank as being filled, determine the equilibrium pressure of the gas-filled cylinder when the tank is full.

2. Estimate the moment of inertia of the tank.

3. Knowing that $a_{Center\ of\ Mass} = r\alpha$ and $v_{Center\ of\ Mass} = r\omega$ estimate the velocity of the cylinder when it reaches the bottom of the ramp.

4. Estimate the transit time of the cylinder down the ramp.

5. Write a memorandum, in non-technical language, to the CEO of the ***B**ryant **G**as **C**ompany* discussing the pertinent information regarding the proposed number 2 tetrafluoroethylene gas bottling production line. Also include a summary paragraph describing what additional information would be necessary in order to analyze the force on the arresting pads of the sorting machine.