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Memorandum

Date: September 15, 2017

To: Lab Group

From: Terry A. Ring, Experiment Supervisor

Subject: Ring Experiment II-9 - Shell and Tube Heat Exchanger

The client has a heat transfer application for the shell and tube heat exchanger that operates in the transition from laminar to turbulent flow. Your much older boss has suggested that you could use the 1934 Hausen equation to fit experimental data for the tube side heat transfer coefficient that you will be taking for the client. You are skeptical as your more modern heat transfer book by M. N. Ozisik suggests several equations including: Petukhov equation, Notter and Sleicher equation, Sieder and Tate equation and the Dittus and Boelter equation. Develop an experimental protocol to determine which of these equations is the best in fitting the tube side heat transfer coefficient for the shell and tube heat transfer unit in the lab. Please be very concerned about the error analysis when you do the experiments and the data reduction calculations as they may impact the choice of equation you select for the best fit.

Your boss also suggests that you may have an entrance length that should be accounted for separately. To appease him please do an entrance length calculation in your report to assure that neither the momentum nor the heat transfer entrance length are important to the heat transfer analysis you are performing in the laboratory report.

Using this exact unit, you are to determine the maximum flow of a process stream that needs to be cooled from 135°C to 40°C using the cooling water available in the building. What limits the throughput?

Process Stream

T = 135	$TiCl_4$=97 wgt%
P=25kPa	CO_2=2 %
	HCl=1%

The following is text from p. 10-14 in Perry's 5th describing the 1934 Hausen's equation.

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Transition Region

Turbulent-flow equations for predicting heat-transfer coefficients are usually valid only at Reynolds numbers greater than 10,000. The transition region lies in the range $2000 < N_{Re} < 10{,}000$. No simple equation exists for accomplishing a smooth mathematical transition from laminar flow to turbulent flow. Of the relationships proposed, Hausen's equation [Z. *Ver. deut. Ing. Beih. Verfahrenstech.*, No. 4, 91 (1934)] fits both the laminar extreme and fully turbulent extreme quite well.

$$(N_{Nu})_{am} = 0.116(N_{Re}^{2/3} - 125)N_{Pr}^{1/3}\left[1 + \left(\frac{D}{L}\right)^{2/3}\right]\left(\frac{\mu_b}{\mu_w}\right)^{0.14} \quad (10\text{-}49)$$

between 2100 and 10,000. It is customary to represent the probable magnitude of coefficients in this region by hand-drawn curves (Fig. 10-8). Equation (10-40) is plotted as a series of curves (j factor vs. Reynolds number with L/D as parameters) terminating at Reynolds number = 2100. Continuous curves for various values of L/D are then hand-drawn from these terminal points to coincide tangentially with the curve for forced-convection, fully turbulent flow [Eq. (10-49)].

Please include this assignment in your report as an appendix but do not cite it in the body of your report.

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Memorandum

Date: September 15, 2017

To: Lab Group

From: Terry A. Ring, Experiment Supervisor

Subject: Ring Experiment II-10 – Fin-Fan Heat Exchanger

Please operate the Fin-Fan heat exchanger in such a way to experimentally prove which type of tube, copper or stainless steel, should be used in an application where the highest overall heat transfer coefficient is to be needed. Use these experiments to compare the overall heat transfer coefficients measured for the copper and stainless steel under equivalent operating conditions for a wide set of operating conditions (both airflow and water flow) and compare them with those calculated purely from correlations and theory. Do you have enough accuracy in the experiment to prove at a probability of 95% or greater that one has a higher overall heat transfer coefficient than the other?

Using this exact unit, you are to determine the maximum flow of a process stream that needs to be cooled from 135°C to 40°C using the cooling water available in the building. What limits the throughput?

Process Stream

T = 135	$TiCl_4$=97 wgt%
P=25kPa	CO_2=2 %
	HCl=1%

What design of fin-fan heat exchanger should be used for a process stream flow of 1,000 kg/hr.

Please include this assignment in your report as an appendix but do not cite it in the body of your report.

Memorandum

Date: September 15, 2017
To: Lab Group
From: Terry A. Ring, Experiment Supervisor
Subject: Ring Experiment II-11 – Glass Lined Reactor (RTD)

Our client has a CSTR saponification reactor operating in their plant. The saponification reaction used by our client is the saponification of ethyl acetate, (ET-Ac);

Et-Ac + NaOH ←→NaAc + Et-OH

followed by a separation process for sodium acetate, NaAc, from the mixture of the solvent, water, and the reaction byproduct ethanol (ET-OH). They are having trouble with the reactor they have just installed and want to increase the reactor's yield. First of all, they would like to know if their stirred tank reactor is operating as an ideal reactor. They think that the impeller operating at 3 rpm may be too slow for ideal mixing. (Too small of a mixer motor seems to have been purchased and installed.) You will be required to develop a method of experimentally determining if the reactor is operating ideally and specifically determine just how far from ideal this behavior is. Your laboratory work should make measurements of the residence time distribution (RTD) and compare them to what and Ideal residence time distribution should be for this tank. Experiments are required to 1) show what RPM and feed flow rates are required to give ideal CSTR behavior. You will need to take the non-ideal RTD data form the 3 rpm and 2) use it to calculate the reaction conversion for the saponification reaction given above to calculate the predicted reaction conversion using a 1 Molar equimolar fed flow rates. The client knows what his reaction conversion is and we will get follow on work if you are correct in your prediction. Please use kinetics based upon Hovarka, R.B. and Kendall, ;H.B. "Tubular reactor at low flow rates" CEP56(8),58-62(1960).

Please include this assignment in your report as an appendix but do not cite it in the body of your report.

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Memorandum

Date: September 15, 2017

To: Lab Group

From: Terry A. Ring, Experiment Supervisor

Subject: Ring Experiment II-12 – Catalysis Experiment - Water gas shift rxn

The client needs to test a catalyst they have developed for the water gas shift (WGSR) reaction.

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

They would like you to determine a rate expression for this reaction on their proprietary catalyst and compare it to a very cheap substitute rusty Iron Grit that they are considering for a 3rd World client who struggled to pay for engineered catalysts.

Your rate expression should be compared to those found in the catalysis literature. The following information on the reaction mechanism and accompanying figure comes from Wikipedia (Water-Gas Shift) page (https://en.wikipedia.org/wiki/Water-gas_shift_reaction).

Please include this assignment in your report as an appendix but do not cite it in the body of your report.

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Memorandum

Date: September 15, 2017

To: Lab Group

From: Terry A. Ring, Experiment Supervisor

Subject: Ring Experiment II-13 – Stirred Tank Reactor (RTD)

Our client has a CSTR saponification reactor operating in their plant. The saponification reaction used by our client is the saponification of ethyl acetate, (ET-Ac);

Et-Ac + NaOH ←→NaAc + Et-OH

followed by a separation process for sodium acetate, NaAc, from the mixture of the solvent, water, and the reaction byproduct ethanol (ET-OH). They are having trouble with the reactor they have just installed and want to increase the reactor's yield. First of all, they would like to know if their stirred tank reactor is operating as an ideal reactor. They think that the impeller operating at 3 rpm may be too slow for ideal mixing. (Too small of a mixer motor seems to have been purchased and installed.) You will be required to develop a method of experimentally determining if the reactor is operating ideally and specifically determine just how far from ideal this behavior is. Your laboratory work should make measurements of the residence time distribution (RTD) and compare them to what and Ideal residence time distribution should be for this tank. Experiments are required to 1) show what RPM and feed flow rates are required to give ideal CSTR behavior. You will need to take the non-ideal RTD data form the 3 rpm and 2) use it to calculate the reaction conversion for the saponification reaction given above to calculate the predicted reaction conversion using a 1 Molar equimolar fed flow rates. The client knows what his reaction conversion is and we will get follow on work if you are correct in your prediction. Please use kinetics based upon Hovarka, R.B. and Kendall, ;H.B. "Tubular reactor at low flow rates" CEP56(8),58-62(1960).

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Memorandum

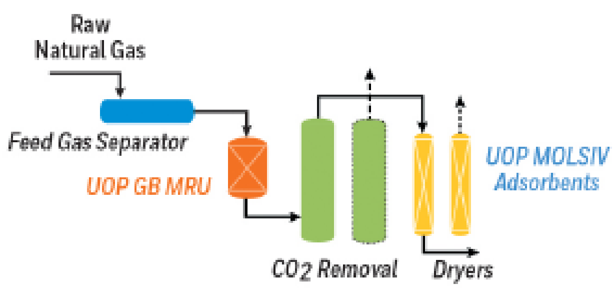
Date: September 15, 2017

To: Lab Group

From: Terry A. Ring, Experiment Supervisor

Subject: Ring Experiment II-14 – Gas Absorber

Our client is struggling to remove CO_2 from a Wyoming natural gas plant using the UOP process sketched below. The cost of the amine absorbent in this process is making the process costly. The raw natural gas in this area has as much as 30% CO2 in the natural gas. Consider the natural gas to be 95% methane, 3 % ethane and 2% propane. All %s are by volume. The plant operates at a production capacity of 200 million ft^3/day at STP. Not far from this natural gas processing plant in western Wyoming are several Trona processing plants which have waste 0.0001 M NaOH solutions available for the modest cost of shipping between the plants. You are to test the use of this NaOH solution for CO2 absorption using the Gas Absorber unit in the lab using CO2 in air. You should gather fundamental information about the mass transfer so that it can be used to design a unit for this Wyoming natural gas processing plant. Be aware that we have to packings in the columns and we need to know which the best to use for this application is.



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Memorandum

Date: September 15, 2017

To: Lab Group

From: Terry A. Ring, Experiment Supervisor

Subject: Ring Experiment II-15 – Vacuum Oven

New technologies being investigated to protect a damaged space shuttle during reentry is to first fill the damaged area with a porous polymeric material and then soak it with water. At the temperatures of space the water will freeze in the pores. The worst-case scenario is for a 4 $inch^2$ area, 1-inch deep hole in the shuttle's skin. Your question is to determine if during reentry the shuttle's skin will be protected by this ice filled repair. For your oral please present the external conditions present at the Shuttle's skin during reentry. To help facilitate your investigations the laboratory has a vacuum drying oven that is steam heated. Professor Ring will supply several examples of the open cell porous polymer material to be tested. This material should be well characterized before it is to be used in your experiments.

Develop a series of experimental tests to determine the time required to remove water and ice from the porous structure at different drying conditions. Compare these measurements to predictions using simultaneous heat and mass transfer. Extrapolate these conditions to those of reentry of the space shuttle and predict if the ice filled repair material is adequate for this application. To do this effectively, you will need to simulate the temperature and pressure conditions that the shuttle will experience during reentry and then predict the rates of sublimation and drying that will take place in this patch material during these reentry conditions. Use risk analysis to determine what are the most important parameters that will lead to a successful patch of this type and determine what the chance of patch failure is during reentry. Astronaut'' lives are riding on you work.

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