

September 2007

A Study on the effects of insulation on the glass distillation column of Goddard Hall Lab

Ryan P. Kennedy
Worcester Polytechnic Institute

Follow this and additional works at: <https://digitalcommons.wpi.edu/mqp-all>

Repository Citation

Kennedy, R. P. (2007). *A Study on the effects of insulation on the glass distillation column of Goddard Hall Lab*. Retrieved from <https://digitalcommons.wpi.edu/mqp-all/2950>

This Unrestricted is brought to you for free and open access by the Major Qualifying Projects at Digital WPI. It has been accepted for inclusion in Major Qualifying Projects (All Years) by an authorized administrator of Digital WPI. For more information, please contact digitalwpi@wpi.edu.

**A Study on the effects of insulation on the glass distillation column
of Goddard Hall Lab**

A Major Qualifying Project
Submitted to the faculty of
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

11 July, 2007

Ryan P. Kennedy

Abstract

The purpose of this project was to improve upon the existing experiment of the distillation column for use in the sophomore ChE 2012 and 2014 courses. Based on poor results in previous years of experimentation, new approaches to the operation of the column were desired.

The glass column was insulated and operated at various conditions to analyze performance and heat loss, determine new optimal experimental parameters, and test the fundamental equations of the operation. The results of the experiment showed the insulation setup had little effect on heat loss from the column. This proved to also have little impact on the proper use of the fundamental equations. The Rayleigh equation in particular failed to provide accurate results. However, some limiting parameters were established for an insulated column such as: initial ethanol still composition (under 9 wt% desired) and steam pressure (under 8 psig desired).

While specific goals were not met, a better understanding of the operation of the column was achieved. Insulation of the column is a step in the right direction, and needs to be researched and improved upon. Further recommendations involve upgrading equipment for measuring key values in the collection of experimental data, expressly a specific gravity meter.

Table of Contents

Abstract	1
1. Introduction	3
2. Background	5
Basic distillation	5
Vapor-liquid equilibrium	5
Batch distillation	9
Mass balances	10
3. Methodology	13
4. Results	18
5. Conclusions	24
6. Recommendations	25
7. References	28
8. Sample Calculations	29
9. Appendices	
Appendix A – Experiment data	
Appendix B - Raw sophomore data	
Appendix C – Specific gravity meter specs	

1. Introduction

The Unit Operations laboratory of Goddard Hall houses equipment and auxiliary apparatus that are used in a variety of experiments. The batch glass distillation column is currently the main focus of experiments for Elementary Chemical Processes (ChE 2012), and Advanced Chemical Processes (ChE 2014). These are run in B Term and D Term, respectively, for the sophomore Chemical Engineering sequence. The efficiency of the column serves the purpose adequately for an introductory experiment in batch distillation; however, for the more sophisticated analysis and operation of the column in Advanced Chemical Processes the existing column falls short of accurate and useful data.

A previous MQP done by Jeffrey Cohen [4] researched the possibility of converting the batch distillation unit into a continuously operating unit in order to expand the capabilities of the laboratory and improve the experiment. While continuous operation seemed possible, it created new problems and equipment that would need to be implemented to run properly. A more feasible and less costly improvement was desired.

In order to create a more suitable experiment for ChE 2014, several modifications to the column could be implemented. The overall purpose of this MQP is to create not only a more challenging experiment, but one that demonstrates key concepts taught during the course including: application of the Rayleigh equation, validity of Constant Molal Overflow, non-steady state balances, and non-ideal VLE. The main goal of this MQP is to insulate the existing glass distillation column to provide more control over heat loss in the system. The insulation must be effective but also removable, to allow visual demonstrations for ChE 2012 where the column is introduced. The second goal is to research and attempt to implement a new chemical compound mixture to separate in

the column. The separation of ethanol from water is easily performed considering the size of the distillation column in the Goddard Hall lab. A new mixture could be used concurrently with the ethanol/water system, to provide teams with a different experience; if a fairly difficult separation is found, it could be incorporated into the Unit Operations courses for seniors. In doing so, this would give the sophomores a fuller experience operating the column and could also give the seniors another option for Unit Operations.

The results from the ChE 2014 class of 2007 will also be used in the analysis of the project.

2. Background

Basic Distillation.

Distillation is a separation method for chemical compounds, based on their relative volatilities. By using differences in relative volatilities (and therefore temperature), the compound with the lower boiling point can be separated from a two-component or multi-component system.

In the ethanol/water system contained in the Goddard lab, the mixture is heated so that the majority of ethanol is vaporized while the water remains, for the most part, in the liquid phase. Cooling the vapor product will yield a liquid mixture with a high concentration of ethanol.

Determining and predicting concentrations of the vapor and liquid are complex and have been studied in great depth. The concentrations of the vapor and liquid phases are related through vapor-liquid equilibrium (VLE). Every system will have a unique equilibrium depending on the materials involved.

Vapor-Liquid Equilibrium.

By rough definition, equilibrium between two components is the point where temperature, pressure, and fractions (concentrations) cease to change. The idea of equilibrium is that the species continue to vaporize and condense, but the rates have equalized and by simple observation the system does not change. Equilibrium conditions

are often described in terms of three relations: thermal, mechanical, and chemical potential.

Thermal equilibrium states that heat transfer ceases and the temperatures of the two phases are equal. At equilibrium [1]:

$$T_{\text{vapor}}=T_{\text{liquid}}$$

Mechanical equilibrium states that the forces between the phases balance. In the case of a staged distillation, this equates to the pressures of the phases being equal. At equilibrium [1]:

$$P_{\text{vapor}}=P_{\text{liquid}}$$

Chemical equilibrium is more complicated. At equilibrium conditions there is no change in concentration; however, the concentrations of the vapor and liquid are not equal. If this were true, no separation would be achieved. The steps to conclude the following equilibrium condition are numerous, and require an understanding of thermodynamics. At equilibrium [1]:

$$(\text{chemical potential } i)_{\text{vapor}}=(\text{chemical potential } i)_{\text{liquid}}$$

Important to note is that this definition of equilibrium chemical potential requires that the vapor and liquid concentrations be related in some way. Experimentation can determine this relationship. However, equations have been derived that can predict the equilibrium relationship between the concentrations at given conditions.

One mathematical way equilibrium data is represented is through K-values, or distribution coefficients. Where:

$$K_A = \frac{y_A}{x_A}$$

As one would expect, the K-value depends on temperature, pressure, and composition. However, for most systems the K-value is independent of composition. For light hydrocarbons, the remaining temperature and pressure relationship has been observed and calculated to fit an expression and table of constants or a correlating chart. The equation [1]:

$$\ln(K) = \frac{a_{T1}}{T^2} + \frac{a_{T2}}{T} + a_{T6} + a_{p1} \ln(p) + \frac{a_{p2}}{p^2} + \frac{a_{p3}}{p}$$

Where T and p are the temperature and pressure of the system, and the a values are constants for specific compounds. This equation can be used to solve for the K-value and therefore the equilibrium data if temperature and pressure of the system are known. DePriester charts [1] fit this equation to a plot, which can be used in the same way to find K if the temperature and pressure are both known.

In ideal systems, Raoult's Law and Dalton's Law simplify the calculations necessary to find the equilibrium relationship. Raoult's Law states that the partial pressure of a species is equal to the vapor pressure multiplied by the concentration (mole fraction) in the liquid [2]:

$$p_A = x_A (VP)_A$$

From Dalton's Law:

$$y_A = \frac{p_A}{P}$$

Combining to form

$$y_A = \frac{(VP)_A x_A}{P}$$

Rearranging this equation and equating to the K-value equation yields a Raoult's Law K-value:

$$K_A = \frac{y_A}{x_A} = \frac{(VP)_A}{P}$$

Vapor pressure can be easily correlated from the Antoine Equation, in the form of:

$$\log(VP) = A - \frac{B}{T + C}$$

Where A, B, and C are constants for pure compounds.

For non-ideal conditions, a correction factor known as the activity coefficient is included in the K-value calculation:

$$K = \frac{\gamma_A (VP)_A}{P}$$

Equations correlated for detailed use of activity coefficients such as the Margules, Van Laar, and Wilson methods which are based on empirical calculations.

The difficulty in using the expression for K-values is that K is largely dependent on temperature, which can vary significantly in a distillation column. By taking the ratio of the K-value for the two species, the temperature dependence is removed. This is defined as the relative volatility:

$$\alpha_{AB} = \frac{K_A}{K_B} = \frac{y_A/x_A}{y_B/x_B}$$

For systems where Raoult's Law is valid, the K-values can be replaced with Raoult K-values yielding:

$$\alpha_{AB} = \frac{(VP)_A}{(VP)_B}$$

Thus, relative volatility is easily solvable using the Antoine equation for vapor pressures.

Rearranging the compositions, and solving for y_A yields [1]:

$$y_A = \frac{\alpha_{AB}x_A}{1 + (\alpha_{AB} - 1)x_A}$$

When alpha is constant.

This equation is key for representing binary vapor-liquid equilibrium.

Batch Distillation.

In simple terms, batch distillation consists of charging a feed pot with solution, heating the contents by reboiling, and removing the desired product from the top. The glass column in Goddard hall consists of a reboiler, nine stages, and a condenser. Reflux is returned to the column, and distillate is withdrawn continuously after a short start-up period of total reflux. Figure 2.1 is a simple sketch of a similar column setup.

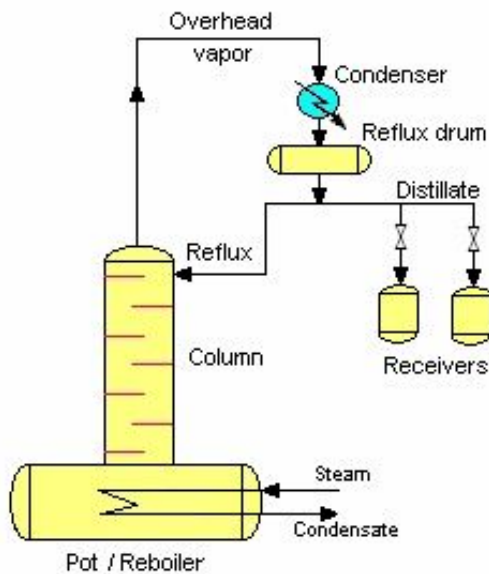


Figure 2.1. A simple batch distillation column setup.

Mass balances.

The total amount of bottoms and distillate collected are important in batch distillation, therefore mass balances around the system are important and are in this form[1]:

$$F = W_{final} + D_{total}$$

$$Fx_F = x_{W,final}W_{final} + D_{total}x_{D,avg}$$

Where F is feed charge, W is the amount left in the charge pot, and D is the distillate removed. The symbol W is used because most often the leftover liquid is waste.

Typically in batch systems F, x_F , and either $x_{W,final}$ or $x_{D,avg}$ are specified. In order to solve for the unknowns, a third equation is necessary. This equation is known as the Rayleigh equation, and is derived from a differential mass balance. The standard mass balance equation is IN-OUT+GEN-CONS=ACC. Given a differential amount removed from the system(dW), of concentration x_D , the balance would be:

$$-OUT = ACC$$

$$-x_D dW = -d(Wx_W)$$

Expanding:

$$-x_D dW = -Wdx_W - x_W dW$$

Rearranging and integrating yields the Rayleigh equation [1]:

$$\ln\left(\frac{W_{final}}{F}\right) = - \int_{x_{W,final}}^{x_F} \frac{dx_W}{x_D - x_W}$$

This can be used for single and multistage batch units, however for multistage units more work needs to be done for the equation to be solvable.

For a multistage batch distillation, the concentrations x_D and x_W are no longer in equilibrium. The relationship between these needs to be determined before the Rayleigh equation is valid. Material balances on any given stage will obtain the desired relationship. These are given by:

$$V_{j+1} = L_j + D$$

$$V_{j+1}y_{j+1} = L_jx_j + Dx_D$$

$$Q_c + V_{j+1}H_{j+1} = L_jh_j + Dh_D$$

By assuming a Constant Molal overflow, the vapor and liquid flow rates will be constant and the energy balance can be neglected. Constant molal overflow implies that the liquid and vapor molar flow rates do not change between stages or throughout the column.

Combining and solving for y_{j+1} :

$$y_{j+1} = \frac{L}{V}x_j + \left(1 - \frac{L}{V}\right)x_D$$

Using this information, coupled with a McCabe-Thiele diagram of equilibrium data, the relationship between x_D and x_W is found by drawing the operating line (of slope L/V) starting from x_D . Stepping off stages, the equilibrium value of x_W can be determined.

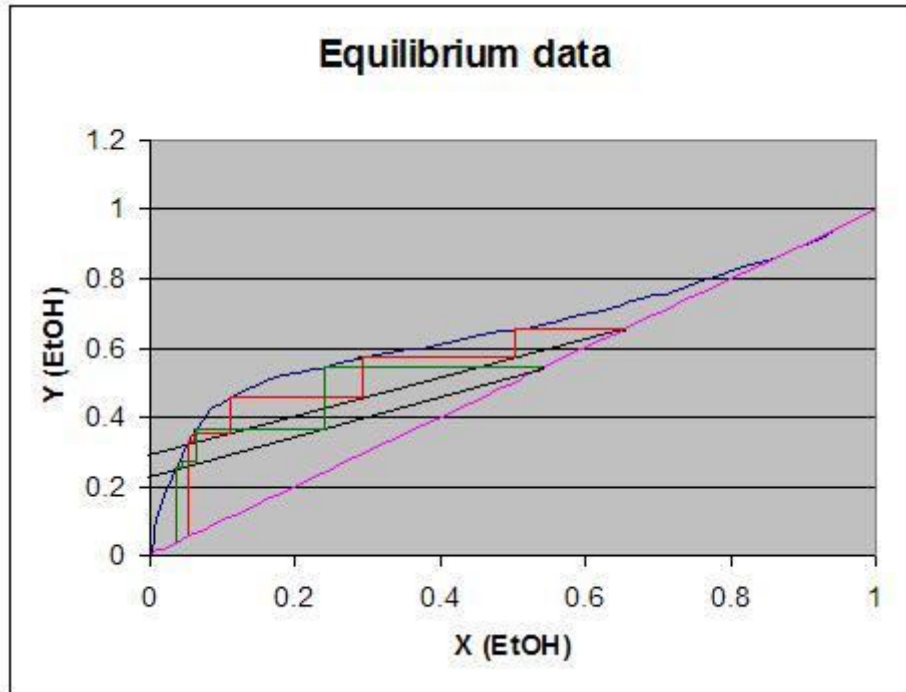


Figure 2.2. An example McCabe Thiele diagram showing two x_D values stepped off at identical reflux ratios.

Figure 2.2 is a general example of the use of a McCabe Thiele diagram for the experiments performed in this project. The straight black lines are the internal reflux ratio which create the operating line of the column. Starting at an x_D value, they extend to the equilibrium data for ethanol and water. The red lines represent the stage calculations for the higher value of x_D , at a total of five stages. The green lines represent the stage calculations for a second value of x_D at a total of four stages. This diagram is to illustrate that during the operation of the column, the value of x_D falls as more distillate is removed. The slope of the operating line is to remain constant, as the reflux ratio remains constant.

3. Methodology

The theoretical equations in the previous section cover ideal operation of a distillation column. However, the glass column in the Goddard Hall lab does not operate at ideal conditions. Heat loss in the column is a key factor in the purpose of this MQP. The energy balance that was neglected in the assumptions plays a role in how the calculations of W_{final} and the other parameters are performed. The heat loss in the column produces a set of collected data that, when applied to the theoretical equations and assumptions poorly calculates the desired values. In order to rightly assume that the energy balance is not necessary, the column must be sufficiently insulated so as negligible heat is lost.

The original intent of the project was to test a range of reflux ratios, initial ethanol compositions, and steam pressures at insulated and non-insulated states in order to compare the two. Initial ethanol weight percentages of 5, 10, and 15 were to be used, a reduction from the 20-25 wt% used in previous years' column experiments. There was no set limit on steam pressure other than the max for the column of 14 psig. Reflux ratio was to be kept relatively low, in order to reduce operating time. Three variable parameters allows for a large number of experiments to be performed. However, not all configurations are possible to accomplish during the scope of this project. The most important experimental procedure was to keep the non-insulated and insulated conditions identical when varying the initial ethanol composition.

The insulation chosen was fiberglass home insulation. It was inexpensive, relatively easy to install, and fit for the operating conditions of the column (temperature

range). Insulation was installed to the glass staging and to the reboiler sections of the column. The insulation was layered on the stage section to provide the most complete coverage. The thickness on this section ranges from 4-8 inches. The reboiler section was given one layer of insulation, which was about 4 inches thick.

The non-insulated column operated without flooding at all ethanol concentrations up to 15 wt.% as expected. After repeated trials with insulation on the column, it was found that approaching 9 wt.% ethanol would cause flooding even at low steam pressures (5-6 psig). Flooding was observed at the top plate of the column, being the only visible section of the stages. Flooding is defined by the presence of excess liquid entrainment on the stages of the column. In this case, only the top stage is visible. The entrained liquid was backed up, causing a distillate run-off without setting the reflux mechanism.

Operating parameters

From these early observations, a new set of limiting parameters was established. Table 3.1 lays out the parameters necessary to perform the experiment which is evaluated in the following Results section.

Runs: Insulated and Non- insulated	External Reflux Ratio	Steam pressure (psig)	Initial ethanol Pot concentration
1	0.2	6	5 wt%
2	0.3	7	5 wt%
3	0.4	7	5 wt%

Table 3.1. Operating conditions for the main experiment data.

The students in ChE 2014 were instructed to operate within these ranges for ethanol concentration, external reflux ratio, and steam pressure. To keep operating times as short as possible, the reflux ratio was limited to between 0.2 and 0.4. Steam pressure was to be no lower than 5 psig and no higher than 8 psig. To avoid flooding conditions, initial ethanol composition was constrained to values less than 9 wt.%.

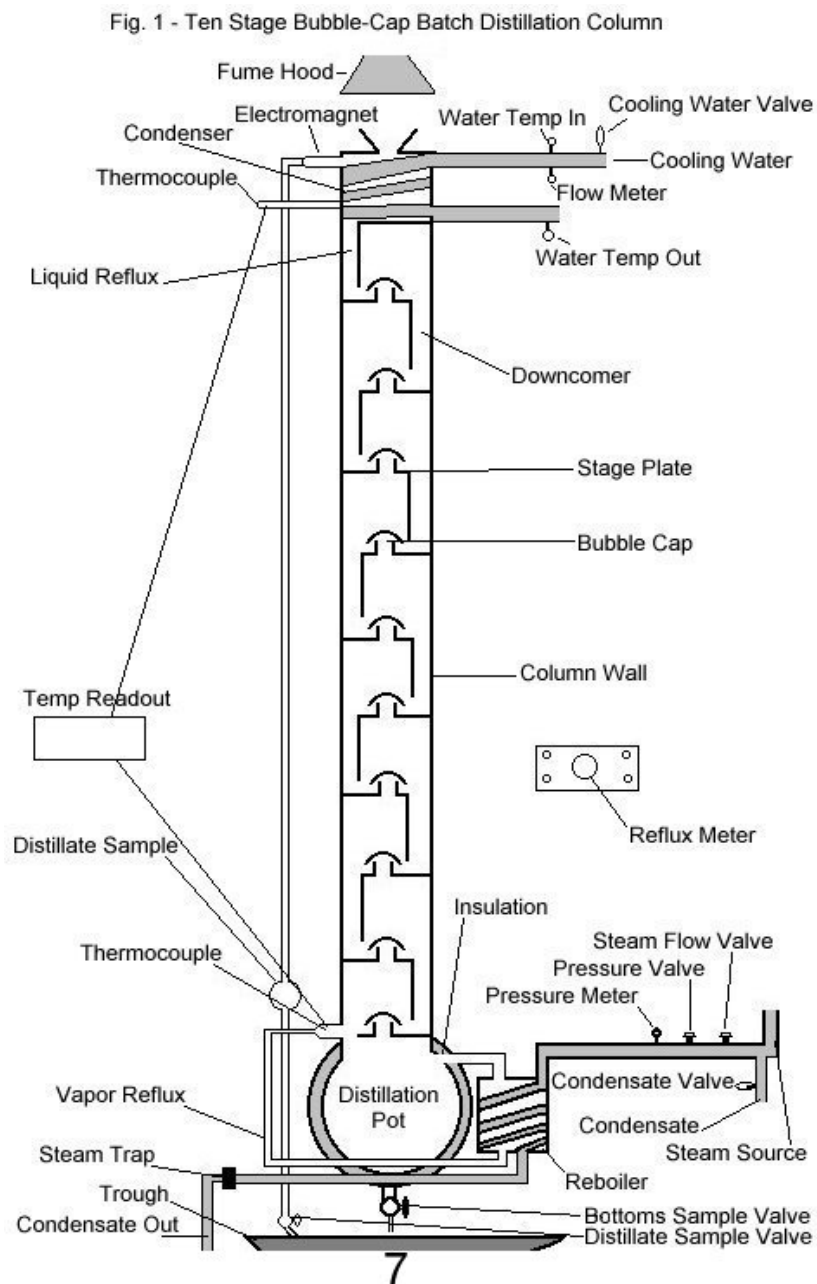


Figure 3.1. Schematic of the glass distillation column as provided by the ChE 2012/2014 course.

The figure above represents closely the layout of the distillation column found in Goddard Hall lab. The following is a general operating guide for the column. It is important to take all necessary safety precautions while using the equipment, such as wearing a hard hat and goggles.

Basic Experimental Procedure

- Turn on cooling water flow to the condenser.
- Fill initial still pot to desired ethanol concentration.
- Turn on steam to desired pressure level.
- Run column at total reflux until equilibrium is achieved.
- Set reflux ratio mechanism to desired value and power it on.
- Record all temperatures and flow rates at this zero time point.
 - Steam, distillate, top stage, still pot, and condenser temperatures
 - Distillate and bottoms sample, distillate flow rate, steam condensate flow rate
 - Total distillate
- Continue to record all values at intervals.
- Run column until approximately 80% of initial ethanol is removed in the distillate.
- Turn off reflux mechanism
- Turn off steam.

4. Results

The main purpose of this project was to improve the distillation experiment of the sophomore sequence. The reduction of heat loss and operating time were the two main goals by which this would be accomplished. The following sections detail the results of the experiments done on the insulated and non-insulated column including: comparisons of heat loss, operation time, operating temperatures, distillate flow rate, and material balances, and the effect of experiment parameters. The general result of the experimentation is that insulation is contributing in improving operating time and allowing for a more steady distillate flow rate; however, significant heat loss changes did not occur. Further research and experimentation is suggested, and will be reviewed in a later section.

The first main objective of the project was to reduce the heat loss through the glass column. Insulation was added to the stage section and to the reboiler.

Heat loss data in kJ/min		
Reflux ratios	Non-insulated	Insulated
0.2	-210	-192
0.3	-195	-200
0.4	-201	-205

Table 4.1. Heat loss data for insulated and non-insulated experiments at varying reflux ratios.

The initial ethanol weight percent for all experiments above was approximately five. For the external reflux ratio of 0.2, a steam pressure of 6 psig was used. For the reflux ratios of 0.3, and 0.4, the steam pressure was 7 psig. The heat loss was found using the general equation:

$$Q_{\text{loss}} = Q_{\text{In}} - Q_{\text{Out}}$$

Where

$$Q_{\text{in}} = m\Delta H_{\text{steam}}$$

$$Q_{\text{out}} = mC_p\Delta T_{\text{Cooling water}}$$

See Sample Calculations for an example.

For the insulated experiments, enthalpy loss from the distillate removal was taken into consideration. Using the temperature of the distillate sampled and the flow rate, the equivalent kJ/min value was obtained. The heat loss equation was then:

$$Q_{\text{loss}} = Q_{\text{In}} - Q_{\text{Out}} - H_D m_D$$

However, these values were on the order of 1-2 kJ/min; relative to the heat in and out from the reboiler and condenser, these values are negligible. From Table 1, it is clear that there is little to no reduction of the heat loss. The greatest change is an 18 kJ/min reduction for a reflux ratio of 0.2. From this data alone, it appears that the insulation had no effect on the distillation column whatsoever. The following comparisons provide at least some evidence that the insulation shows some promise.

First and most importantly, the distillate flow rate measurements support the use of insulation. The intention of using insulation was to hold the distillate flow rate constant for the duration of the experiment. In order to properly use the Rayleigh equation, two assumptions are made: that heat loss is zero, and that as distillate

composition changes, the operating line remains at a constant slope. A constant distillate flow rate corresponds to a constant operating line slope. Therefore, to improve data analysis a constant flow rate is desired.

Figure 4.1 below is a graph of distillate flow rate versus time at operating conditions of: 0.2 reflux ratio, 6 psig steam, 5 wt.% initial ethanol. Displayed are both insulated and non-insulated runs at the same conditions. The measured flow rates are identical until the 60-70 minute mark, at which point the insulated column has run to completion. The non-insulated column required more time, and in that span the flow rate dropped to a lower value for two samples. In this case, insulation appears to have reduced operating time but not necessarily provided a constant distillate flow. The distillate flow is identical from the start of each experiment until the insulated column finishes. The distillate flow is only affected later, as the non-insulated experiment runs on towards the one hundred minute mark.

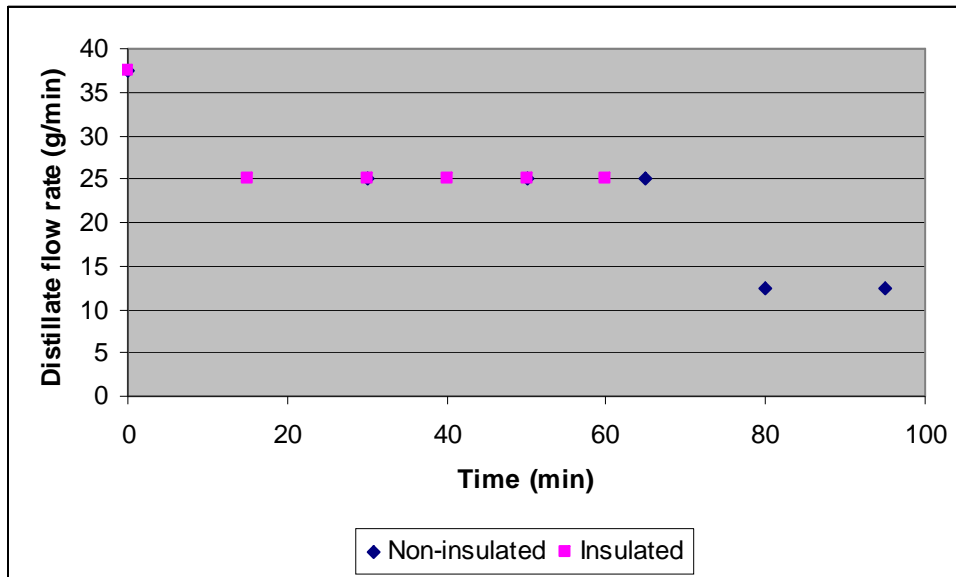


Figure 4.1. Insulated and non-insulated distillate flow rate versus time at a reflux ratio of 0.2.

Figure 4.2 below plots the second set of distillate flow rate measurements at a reflux ratio of 0.3, steam pressure of 7 psig, and 5 wt.% initial ethanol. In this case, the distillate flow rates begin at different values and then converge. The insulation provided a higher distillate flow rate for a time, however it ended up being reduced to the same value from the non-insulated column at approximately the same run-time. While the insulation does not seem to cause a more steady distillate flow rate, it does seem to affect the run-time of the experiment. A twenty-five minute difference may not seem like much, but reduction of operating time is crucial. Reduced operating time is helpful for students, and it also is necessary in order to attempt running two experiments per day.

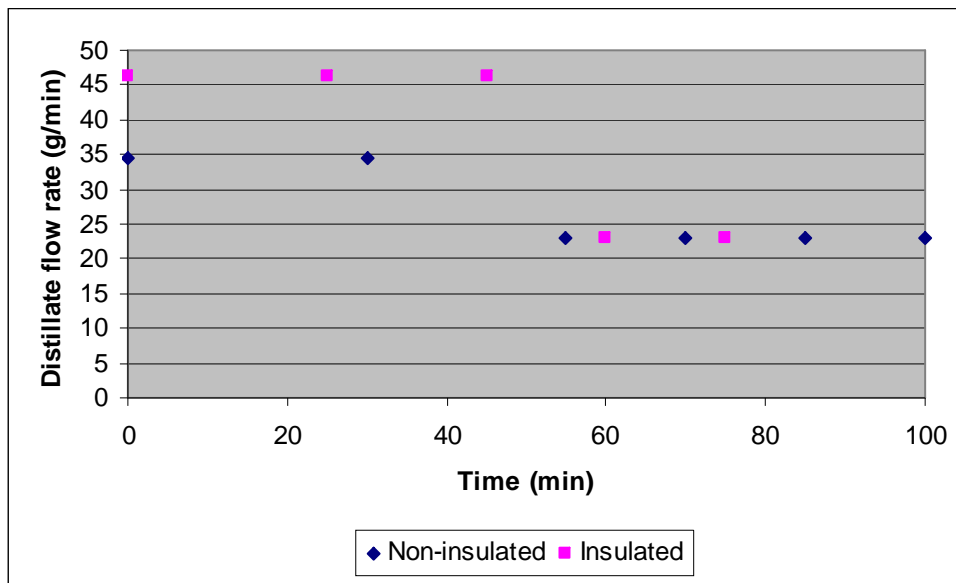


Figure 4.2. Insulated and non-insulated distillate flow rate versus time at a reflux ratio of 0.3.

Figure 4.3 below is the final data set of distillate flow rates. The conditions are identical to the above, except for reflux ratio operated at 0.4. In this case, both experiments seem to follow the same downward trend, with a plateau finishing the run. The important difference being the insulated experiment starts at a higher flow rate, and

generally stays at a higher rate. During the insulated run, the distillate is at a constant rate for more than half of the operating time.

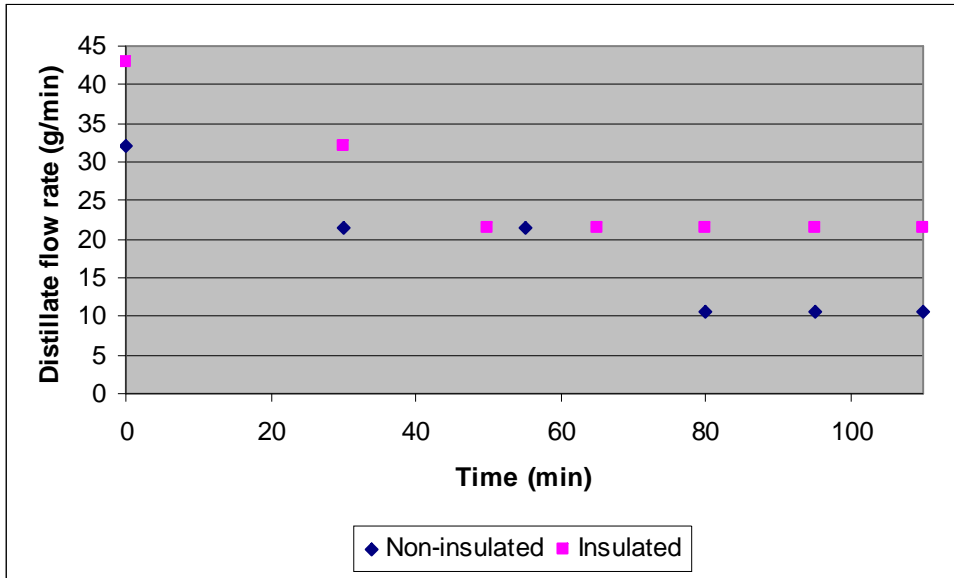


Figure 4.3. Insulated and non-insulated distillate flow rate versus time at a reflux ratio of 0.3.

From the distillate flow rate data, it appears that insulation has some beneficial effect on keeping the flow constant as much as possible, and also on column operation time. The main point to recognize is that the insulation is not ideal. The heat loss data, as well as the flow rate data are indicators that the amount of insulation on the column is insufficient for the purposes of the experiment desired.

While it may seem insignificant, it may be worthwhile to note the temperatures of the steam condensate. A slight increase in average condensate temperature was observed between the non-insulated and insulated runs. The conditions in these cases are identical to those described previously. Steam pressures for a specific reflux ratio were constant between the insulated and non-insulated experiments yet the insulated experiment remains consistently higher. The differences in temperature could be within error of the

thermocouple, but a slightly higher average temperature suggests the reboiler insulation is keeping the steam temperature higher.

Average condensate temperature (°C)			
	Non-insulated	Insulated	Saturated Steam at pressure
0.2	107.6	108.2	109.9
0.3	109.2	109.5	111.3
0.4	109.2	109.5	111.3

Table 4.2. Average steam condensate temperatures at insulated and non-insulated conditions.

The data from the sophomores covers the range of reflux ratios, steam pressures, and initial ethanol concentrations as described previously. The raw data can be found in Appendix B. Due to the heat loss being almost unaffected by the insulation of the column, these additional data sets will not be analyzed in depth as it does not bring any new information to the experiment.

Group	Reflux ratio	Steam pressure	Ethanol Wt.%
One	0.2	8	8
Two	0.3	6	8
Three	0.4	6.5	7
Four	N/A	5	5
Five	N/A	8	6

Table 4.3. Sophomore data: operating values of reflux ratio, steam pressure, and initial ethanol weight percent.

5. Conclusions

The main conclusion to be drawn from this project is that more research and experimentation must be done, in order to improve the quality of the laboratory experience. The insulation as it is, does not provide the reduction in heat loss required to achieve a constant distillate flow rate and ultimately a useful application of the Rayleigh equation. The one improvement that does seem to be changed by insulation is a reduction in operating time, if only slight.

The goal for this project was to improve the experiment for the sophomore ChE 2014 class. While the specific objectives were not complete successes, the project provided more insight into the workings of the column and operating conditions. With growing class sizes, a reduction in operating time becomes more important than in the past.

6. Recommendations

First and foremost, improving upon the insulation is the best way towards achieving the original goal of this project. Currently, the staging and reboiler were fitted with at least 4” of fiberglass insulation. The staging sections have slightly more in some areas due to double wrapping. Currently non-insulated are the condenser, and the area just above the top tray of the main column. The still pot has insulation from a previous year, which has deteriorated slightly and is only 2-3” thick. Future work could be to insulate the top areas of the column, and re-insulate the still pot. Using the thermal conductivity (k) value of fiberglass, $0.04 \text{ W/m}^2 \text{ K}$, and assuming all heat loss (q) is from exposed areas (A), one can calculate the required thickness (t) of insulation by this equation:

$$q = (t / k) * A * \Delta T$$

Where ΔT is the change in temperature between the inside of the column and ambient.

A sample calculation using heat loss data from Table 4.1:

$q = 192 \text{ kJ/min}$ (Over a 60 minute operation time) = 3200 W

$k = 0.04 \text{ W/m}^2 \text{ K}$

A (Surface area of the still) = $4 \pi r^2 = 1.82 \text{ m}^2$ (Assuming $d = 2.5 \text{ ft}$)

$\Delta T = (\text{Inside} - \text{ambient}) = 100^\circ\text{C} (\text{max}) - 23^\circ\text{C} = 77^\circ\text{C} = 350 \text{ K}$

Solving for t yields 0.2 m or about 8 inches.

Fiberglass insulation of about 8” would be needed on areas such as the still pot and reboiler, which have relatively high areas and high temperature differences with the ambient air. Also recommended is to extend the column insulation to include the section just below the condenser.

With the column fully insulated, retention of heat may become a problem for fast cool-down. To perform two experiments per day, an efficient method for cooling the column must be established. This problem presents more of a challenge than fitting the column with insulation. One possible solution is to have two separate charges for the still pot. By draining the column of the remaining hot liquid at the end of each run, the column and peripheral glass may cool down enough against the ambient temperature in a reasonable amount of time.

A second way to improve the experiment does not directly involve the distillation column. The specific gravity meter currently used in the laboratory has had many problems, and has been a cause of much frustration as well as poor data. It is recommended that a new instrument replace this meter.

The problems with the existing device are severe. During a majority of the ChE 2014 class this year, the meter was not functioning correctly and no cause could be determined. Numerous attempts to correct the readings met with failure. While the specific gravity measurement is not necessary to determine the ethanol concentration, it is mainly used as a teaching tool. The use of specific gravity requires a small calculation in order to obtain concentration, while the use of temperatures simply involve reading from a chart. To be used as an effective teaching tool, the operation of the meter needs to be easy to understand, reliable, and quick. The existing specific gravity meter utilizes up to 10 mL of injected sample liquid to determine the composition. Rinsing with de-ionized water in between each sample is recommended, and arguably mandatory. It is hypothesized that failure to rinse with DI water caused contamination issues inside the device; thus, samples of ethanol and pure water do not accurately read their correct

values. The injection method of this meter is not suited to first time operation by sophomore students. Ethanol samples are left too long inside the instrument, and it is possible that water rinses are overlooked. Another problem with this sampling system, is that a typical sample is usually limited in volume; therefore, there are a limited amount of times it can be tested in the specific gravity meter.

A new and different specific gravity meter should solve a few of the aforementioned problems. Cole Parmer produces a type of meter (EW-25755-00) that is relatively the same cost as a brand new model of the existing device. Their device works by dipping a probe into the sample solution. By this method, a sample can be measured any number of times without losing or wasting the solution. The model in consideration covers the perfect range of specific gravities needed for the ethanol/water experiment: between 0.750 and 1.000, and is accurate to ± 0.03 units. The probe still requires water to cleanse, however rinsing the probe is easier than performing an injection. The switch to this instrument can keep the use of specific gravity in calculating composition, and also avoid the hassle of the injection method. Full technical details can be found in Appendix C.

One original objective for this project was to research new binary pairs for possible use in ChE 2014, or for Unit Operations. At this time, it is inadvisable to consider different pairs other than ethanol/water. Since the insulation of the column leaves many more channels of research and development, it is best to focus on improving this aspect before moving on to new operating systems.

References

1. Wankat, Phillip C., Equilibrium Staged Separations, Prentice Hall: New Jersey (1998).
2. Smith, J.M., H.C. Van Ness, and M.M. Abbott, Introduction to Chemical Engineering Thermodynamics, 6th Edition. McGraw Hill, Inc. New York (2001).
3. Perry, R.H. and D.W. Green., Perry's Chemical Engineers' Handbook, 7th Edition. McGraw Hill, Inc. New York (1997).
4. Cohen, Jeffrey M. "Distillation Dynamics", WPI. (1995).
5. Cole-Parmer Instrument Company, Specific Gravity meters.
http://www.coleparmer.com/catalog/product_view.asp?sku=2575500

Sample Calculations

Rayleigh equation

Using x_D and x_W data from the experiments, the Rayleigh equation:

$$\ln\left(\frac{W_{final}}{F}\right) = - \int_{x_{W,final}}^{x_F} \frac{dx_W}{x_D - x_W}$$

Can be solved by using a simple method.

X_D	X_W	$1/(x_D-x_W)$
0.8815	0.0312	1.18
0.8697	0.0312	1.19
0.8703	0.0224	1.18
0.8242	0.0167	1.24
0.7955	0.0199	1.29
0.9132	0.0159	1.11

The values of x_D and x_W are taken from experiment 4, the insulated run of the column at a reflux ratio of 0.2.

The area of the integral can be evaluated by this simple equation:

$$A = (x_F (\text{Feed/Charge}) - x_{W, Final}) [\text{Avg } 1/(x_D-x_W)]$$

So

$$A = (0.312-0.0159) * [2*1.18 + 1.19 + 1.24 + 1.29 + 1.11] / 6$$

$$A = (0.296) * 1.198$$

$$A = 0.35$$

$$W_{Final} = \text{Charge} * e^{-A}$$

$$W_{\text{Final}} = 2,572 \text{ g} * e^{-0.35}$$

$$W_{\text{Final}} = 1812 \text{ g}$$

However, without a way to check this calculated result from experimental data, there is not much use for the equation. Since W_{Final} in the actual experiment must be found using the average x_D of the solution. Due to the specific gravity meter not working, most of the values of x_D are suspect, if not completely nonsense. Values used at sample times are acquired using temperature data, unfortunately the final amount cannot be measured in this way. So while the Rayleigh equation could provide useful data, current equipment is limiting the analysis of the method.

Heat Loss

The general heat loss equation as given earlier is:

$$Q_{\text{loss}} = Q_{\text{In}} - Q_{\text{Out}}$$

Where

$$Q_{\text{in}} = m\Delta H_{\text{steam}}$$

$$Q_{\text{out}} = mC_p\Delta T_{\text{Cooling water}}$$

Q_{in} deals with steam flow rate and the enthalpy of steam.

From the same experiment as above, the steam flow rate was measured at 2.03 mL/s or 0.122 kg/min. ΔH_{steam} was found using steam tables. For steam at 6 psig, $H_{\text{sat liq}} = 454.10$ kJ/kg and $H_{\text{sat vap}} = 2691.2$ kJ/kg

$$\Delta H_{\text{steam}} = 2237.1 \text{ kJ/kg}$$

$$Q_{\text{in}} = 272 \text{ kJ/min}$$

Q_{out} is determined using the cooling water data.

The mass flow of the cooling water is calculated to be 4.138 kg/min from a 1.093 gal/min average. C_p for water is equal to 4.193 kJ/ kg K. From the experimental data, the cooling water temperatures were 284.7 K and 280.37K respectively.

$$Q_{\text{out}} = -78.4 \text{ kJ/min}$$

$$\text{Therefore } Q_{\text{loss}} = -192.1 \text{ kJ/min}$$

Appendix A : Experimental Data

Experiment 1 : Non insulated

L/D = .2	Steam	6 psig				
Operating Time estimate =	W = 52 L	xWo =	Specific grav =		6.33% volume	
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Column						
Time from start (Min)	0	30	50	65	80	95
Temp (Dist)	77.1	77.5	78	79.7	81.2	81.8
Temp (Bottom)	95.6	96.6	97	97.4	97.7	97.9
Temp (Steam)	107.6	107.8	107.6	107.6	107.7	107.7
Condensate flow (ml/s)	2	2	2	2	2	2
Cooling Water						
Flow (gpm)	1	1.02	1.06	1	1	1.06
Temp In (F)	44.5	44	45	46	46	46
Temp Out (F)	51	49	50	50	50	49
Sample (Dist)						
Weight beaker (g)	50	50	50	50	50	50
Wt samp + beak (g)	80	70	70	70	60	60
Time (s)	48	48	48	48	48	48
D(mL/s)	0.854167	0.625	0.583333	0.583333333	0.416667	0.208333
D (g/s)	0.625	0.416667	0.416667	0.416666667	0.208333	0.208333
Wt samp (g)	30	20	20	20	10	10
Specific grav	0.8177	0.8203	0.8291	0.8403	0.8517	0.8579
Vol % Ethanol	94.5	94	91.2	88	84	82.4
Wt % Ethanol (xD)	0.917379	0.909633	0.87317	0.831303106	0.782895	0.762433
Sample (Bottoms)						
Weight beaker (g)	50	50	50	50	50	50
Wt sample +beak (g)	80	90	80			
Vol (mL)	32	40	30			
Wt samp (g)	30	40	30			
Specific grav	0.996	0.9967	0.9971	0.9978	0.998	0.9984
Wt. % Ethanol (xW)	2.15	1.75	1.51	1.13	1.03	0.84

Measured flow rate	51.24	mL/min	37.5	g/min
	37.5	mL/min	25	g/min
	34.98	mL/min	25	g/min
	34.98	mL/min	25	g/min
	25.0002	mL/min	12.5	g/min
	12.48	mL/min	12.5	g/min

avg mass flow	0.022917	kg/min
Distillate energy/mass	83.68	kJ/kg

Heat In	-268.758	kJ/min
Heat Out	56.34737	kJ/min
Heat Loss	210.4929	kJ/min
Distillate enthalpy	1.917667	kJ/min

Experiment 2 : Non insulated

L/D = .3	Steam	7 psig				
Operating Time estimate	W = 52 L	xWo =	Specific grav =		6.33% volume	
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Column						
Time from start (Min)	0	30	55	70	85	100
Temp (Dist)	77.6	77.7	80.8	84.1	85	87.5
Temp (Bottom)	93.4	95.3	96.4	97	97.5	97.7
Temp (Steam)	109.2	109.3	109.3	109.1	109.3	109.3
Condensate flow (ml/s)	2	2	2	2	2	2
Cooling Water						
Flow (gpm)	1.1	1.16	1.1	1.12	1.12	1.1
Temp In (F)	45	44	44	45	45	44
Temp Out (F)	56	52	51	51	51	50
Sample (Dist)						
Weight beaker (g)	50	50	50	50	50	50
Wt samp + beak (g)	80	80	70	70	60	70
Time (s)	52	52	52	52	52	52
D(mL/s)	0.923077	0.769231	0.557692	0.461538462	0.346154	0.346154
D (g/s)	0.576923	0.576923	0.384615	0.384615385	0.192308	0.384615
Wt samp (g)	30	30	20	20	10	20
Specific grav	0.8246	0.8259	0.8484	0.864	0.8697	0.882
Vol % Ethanol	92.7					
Wt % Ethanol (xD)						
Sample (Bottoms)						
Weight beaker (g)	50	50	50	50	50	50
Wt sample +beak (g)	80	80	110	80	70	90
Vol (mL)	28	35	70	32	25	50
Wt samp (g)	30	30	60	30	20	40
Specific grav	0.994	0.994	0.994	0.9978	0.9978	0.9998
Wt. % Ethanol (xW)	3.28	3.28	3.28			

Measured flow rate	55.38	mL/min	34.61538
	46.152	mL/min	34.61538
	33.4614	mL/min	23.07692
	27.6924	mL/min	23.07692
	20.772	mL/min	23.07692

Heat In	-268.22	kJ
Heat Out	72.24	kJ
Heat Loss	195.98	kJ

Experiment 3 : Non insulated

L/D = .4	Steam	7 psig				
Operating Time estimate	W = 52 L	xW _o =	Specific grav =		6.30% volume	
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Column						
Time from start (Min)	0	30	55	80	95	110
Temp (Dist)	97.7	79.1	85.4	88	88.1	90.7
Temp (Bottom)	95.3	96.5	97.3	97.8	98.2	98.4
Temp (Steam)	110	109.2	109.1	109.2	109.1	109.2
Condensate flow (ml/s)	2	2	2	2	2	2
Cooling Water						
Flow (gpm)	1.2	1.16	1.22	1.22	1.2	1.2
Temp In (F)	46	47	46	47	46	45
Temp Out (F)	54	54	52	51	51	51
Sample (Dist)						
Weight beaker (g)	50	50	50	50	50	50
Wt samp + beak (g)	80	70	70	60	60	60
Time (s)	56	56	56	56	56	56
D(mL/s)	0.803571	0.571429	0.357143	0.321428571	0.357143	0.214286
D (g/s)	0.535714	0.357143	0.357143	0.178571429	0.178571	0.178571
Wt samp (g)	30	20	20	10	10	10
Specific grav	0.8419	0.8347	0.8621	0.8801	0.8866	0.9076
Vol % Ethanol	87.5	89.5	80.5	74	71.3	62.8
Wt % Ethanol (xD)	0.825009	0.851145	0.741224	0.667437791	0.638371	0.549258
Sample (Bottoms)						
Weight beaker (g)	50	50	50	50	50	50
Wt sample +beak (g)	80	80	80	90	80	70
Vol (mL)	25	33	38	42	30	23
Wt samp (g)	30	30	30	40	30	20
Specific grav	0.9944	0.9955	0.9962	0.9966	0.9967	0.997
Wt. % Ethanol (xW)	3.04	2.46	2.03	1.82	1.75	1.59

Measured flow rate	48.21	mL/min	32.14286
	34.284	mL/min	21.42857
	21.426	mL/min	21.42857
	19.284	mL/min	10.71429
	21.5226	mL/min	10.71429
	12.852	mL/min	10.71429

Heat In	-268.273	kJ/min
Heat Out	65.7	kJ/min
Heat Loss	201.0832	kJ/min
Distillate enthalpy	1.489504	kJ/min

Experiment 4 : Insulated

L/D = .2	Steam	6 psig				
Operating Time estimate	W = 52 L	xWo = 5%	Specific grav =		6.3% Vol	
INSULATED	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Column						
Time from start (Min)	0	15	30	40	50	60
Temp (Dist) (oC)	77	77.7	78.2	78.7	80.7	79.2
Temp (Bottom) (oC)	95.3	96.4	97.1	97.7	98.3	97.7
Temp (Steam) (oC)	108.3	108.2	108.3	108.2	108.2	108.2
Condensate flow (ml/s)	2.2	2	2	2	2	2
Cooling Water						
Flow (gpm)	1.06	1.08	1.08	1.1	1.12	1.12
Temp In (F)	45	45	45	45	45	46
Temp Out (F)	53	53	53	52	51	55
Sample (Dist)						
Weight beaker (g)	50	50	50	50	50	50
Wt samp + beak (g)	80	70	70	70	70	80
Time (s)	48	48	48	48	48	48
D(mL/s)	0.666667	0.625	0.625	0.625	0.625	0.625
D (g/s)	0.625	0.416667	0.416667	0.416666667	0.416667	0.625
Total D removed (L)	0	0.64	0.6	0.35	0.3	0.35
Wt samp (g)	30	20	20	20	20	30
Reflux Temperature (oC)	20.8	22.5	23.2	22.7	22.2	22.2
Specific grav	0.8275	0.8305	0.83	0.8427	0.8492	0.8188
Vol % Ethanol	91.9	91	91	87.5	85.1	94.2
Wt % Ethanol (xD)	0.881574	0.869787	0.870311	0.824225703	0.795483	0.913238
Sample (Bottoms)						
Weight beaker (g)	50	50	50	50	50	50
Wt sample +beak (g)	90	70	80	90	90	80
Vol (mL)	50	28	40	40	40	38
Wt samp (g)	40	20	30	40	40	30
Specific grav	0.9943	0.9942	0.9958	0.9969	0.9963	0.997
Wt. % Ethanol (xW)	3.12	3.12	2.24	1.67	1.99	1.59
Total D removed (L)	2.422					

Measured flow rate	40.0002	mL/min
	37.5	mL/min
	37.5	mL/min
	37.5	mL/min
	37.5	mL/min
Heat calculations	Total	
Heat In (Steam)	-272.933	kJ/min
Heat Out (CW)	78.4	kJ/min
Heat Loss	192.0932	kJ/min
Distillate enthalpy	2.440109	kJ/min

xd	xw	1/(xd-xw)
0.8815	0.0312	1.176056
0.8697	0.0312	1.192606
0.8703	0.0224	1.179384
0.8242	0.0167	1.23839
0.7955	0.0199	1.289324
0.9132	0.0159	1.114454

Experiment 5 : Insulated

L/D = .3	Steam	7 psig			
Operating Time estimate	W = 52 L	xWo = 6%	Specific grav =		7.45% Vol
INSULATED	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Column					
Time from start (Min)	0	25	45	60	75
Temp (Dist) (oC)	77	77.4	79.3	87.3	91.2
Temp (Bottom) (oC)	95.1	96.1	96.8	97.4	97.8
Temp (Steam) (oC)	109.6	109.4	109.4	109.5	109.5
Condensate flow (ml/s)	2.2	2.5	2.2	2.2	2.1
Cooling Water					
Flow (gpm)	1.14	1.1	1.1	1	1
Temp In (F)	47	47	46	45	45
Temp Out (F)	59	57	55	55	55
Sample (Dist)					
Weight beaker (g)	50	50	50	50	50
Wt samp + beak (g)	90	90	80	70	70
Time (s)	52	52	39	52	52
D(mL/s)	1.057692	0.942308	0.871795	0.480769231	0.480769
D (g/s)	0.769231	0.769231	0.769231	0.384615385	0.384615
Total D removed (L)	0	1.45	0.875	0.45	0.3
Wt samp (g)	40	40	30	20	20
Reflux Temperature (oC)	17.5	22	22	22	22.7
Specific grav	0.8202	0.8228	0.8517	0.8664	0.9052
Vol % Ethanol	94	93.2	84.4	79	63.6
Wt % Ethanol (xD)	0.909744	0.899151	0.786623	0.723801939	0.55773
Sample (Bottoms)					
Weight beaker (g)	50	50	50	50	50
Wt sample +beak (g)	110	80	70	80	90
Vol (mL)	58	35	26	35	42
Wt samp (g)	60	30	20	30	40
Specific grav	0.9955	0.9974	0.9978	0.9984	
Wt. % Ethanol (xW)	2.43	1.38	1.12	0.85	0.833333

Measured flow rate	63.462	mL/min
	56.538	mL/min
	52.302	mL/min
	28.842	mL/min
	28.842	mL/min

Heat Calculations		
Heat In (Steam)	-300.293	kJ/min
Heat Out (CW)	96.56	kJ/min
Heat Loss	200.6533	kJ/min
Distillate enthalpy	3.08	kJ/min

Experiment 6 : Insulated

L/D = .4		Steam	7 psig				
Operating Time estimate		W = 52 L	xWo = 5%	Specific grav =		6.3% Vol	
INSULATED	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Column							
Time from start (Min)	0	30	50	65	80	95	110
Temp (Dist) (oC)	76.7	78.1	85.6	89.8	91.4	92.2	93.3
Temp (Bottom) (oC)	95.2	96.4	97.2	97.7	98.1	98.4	98.6
Temp (Steam) (oC)	109.3	109.2	109.3	109.3	109.3	109.3	109.2
Condensate flow (ml/s)	2.4	2.2	2.1	2.1	2.2	2.2	2.1
Cooling Water							
Flow (gpm)	1.04	1.2	1.2	1.2	1.2	1.2	1.2
Temp In (F)	51	50	51	52	52	52	52
Temp Out (F)	61	59	60	60	60	59	59
Sample (Dist)							
Weight beaker (g)	50	50	50	50	50	50	50
Wt samp + beak (g)	90	80	70	70	70	70	70
Time (s)	56	56	56	56	56	56	56
D(ml/s)	0.892857	0.714286	0.5	0.5	0.357143	0.357143	0.267857
D (g/s)	0.714286	0.535714	0.357143	0.357142857	0.357143	0.357143	0.357143
Total D removed (L)	0	1.3	0.68	0.34	0.3	0.25	0.2
Wt samp (g)	40	30	20	20	20	20	20
Reflux Temperature (oC)	20.1	22.5	22.6	22.4	22.8	22	21.5
Specific grav	0.8468	n/a	n/a	n/a	n/a	n/a	n/a
Vol % Ethanol							
Wt % Ethanol (xD)							
Sample (Bottoms)							
Weight beaker (g)	50	50	50	50	50	50	50
Wt sample +beak (g)	80	90	80	80	80	80	70
Vol (mL)	36	44	30	29	30	28	28
Wt samp (g)	30	40	30	30	30	30	20
Specific grav	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Wt. % Ethanol (xW)							

Measured flow rate	53.574	mL/min
	42.852	mL/min
	30	mL/min
	30	mL/min
	21.42	mL/min
	21.42	mL/min
	16.068	mL/min

Heat Calculations		
Heat In (Steam)	-292.364	kJ/min
Heat Out (CW)	87	kJ/min
Heat Loss	205.3636	kJ/min

Appendix B : Student Raw Data

Group 1

Pressure= 6 psig
reflux ratio = 0.3

running until 80 % ethanol

		Bottoms sample				Distillate				
real time	fake time (min)	temp (C)	mass (g)	volume (mL)	xw	temp (C)	mass (g)	volume (mL)	flow rate (mL/min)	xd
	0	92.8	50	50		76.7	20	20	20	
	20	94.2	60	77		76.8	30	38	38	
	40	94.6	50	50		76.8	30	31	31	
	60	95.5	20	29		76.7	20	28	28	
	75	96.1	50	60		76.9	20	26	26	
	90	96.5	60	63		76.7	20	28	28	
	105	96.8	40	40		76.7	20	28	28	
	120	97.2	30	30		76.8	10	20	20	
	135	97.4	30	21		76.9	10	25	25	
	150	97.8	30	23		77.3	10	22	22	
		Condenser H2O			Steam					
real time	fake time (min)	temp in (F)	temp out (F)	flow rate (gal/min)	temp (C)	mass	volume	flow rate (mL/min)		
	0	52	62	1.63	107	60	64	128		
	20	51	60.05	1.62	107	60	60	120		
	40	51.5	60.05	1.62	108	40	48	96		
	60	51.5	59.5	1.62	107	40	48	96		
	75	51.25	58.5	1.599	108	40	42	84		
	90	51.5	58.25	1.5998	108	50	48	96		
	105	50	56	1.598	107	40	39	78		
	120	51	57	1.59	107	40	37	74		
	135	50.5	56.5	1.598	107	40	35	70		
2:58	150	51	56.5	1.6	107	30	32	64		

Grup2

Time	DistillateTemp C	DistillateFlowRate g/min	DistillateVolume mL	BottomsMassg	BottomsTempC	SteamFlowRate g/min
225	766	30	37	-	932	140
245	766	30	50	80	939	140
305	767	40	40	50	947	140
325	767	30	30	30	956	160
345	768	30	40	50	961	120
405	769	30	40	40	97	100
425	77.7	20	25	30	972	100
445	823	20	20	20	976	200
500	87.7	97.7	18	20	97.7	80
515	89.9	97.9	15	30	97.9	80
	SteamTempC	SteamVolumeL	Condenser Temp InF	Condenser TempOut F	Condenser FlowRate g/min	
225	1089	-	48	63	1.22	
245	1091	73	49	62	1.2	
305	1089	72	48.5	60	1.2	
325	109	80	48	60	1.18	
345	1091	59	48	58.5	1.16	
405	109	46	47	57	1.16	
425	1089		47	56.5	1.16	
445	1089	100	47.5	56	1.18	
500	1089	40	48	57	1.18	
515	1089	41	48.5	57	1.18	

Group 3

Temps	Fontop		4L cylinder for overall comp... sample						Reflux	020
	Conlat									
				D1min	S30sec				Fov gal/min	

Time	234	254	314	334	354	414	434	454	514	534
Sample	0	1	2	3	4	5	6	7	8	9
Fd	40ml/min	50ml/min	50ml/min	38ml/min	35 ml/min	35 ml/min	30ml/min	30 ml/min	20ml/min	20ml/min
Fs	160ml/min	158ml/min	152ml/min	138ml/min	150 ml/min	116 ml/min	110ml/min	180 ml/min	120ml/min	100ml/min
Fov	12	12	12	12	12	12	12	12	12	12
Td	766C	77.1C	766C	766C	766C	767C	768C	782C	801C	842C
Tb	928C	981C	944C	952C	962C	967C	976C	978C	98C	984C
Ts	1102C	1103C	1103C	1103C	1102C	1105C	1103C	1105C	1103C	1103C
Vd	30g	90g	40g	30g	30g	20g	30g	20g	10g	10g
Vb	70g	30g	70g	70g	50g	60g	60g	60g	80g	40g
Vs	80g	70g	67g	60g	70g	50g	50g	90g	60g	50g
Towin	48F	48F	48F	47F	47F	48F	48F	48F	47F	48F
Tow at	66F	65F	64F	62F	61F	60F	61F	59F	58F	59F
Vd	40mL	50mL	50mL	38mL	35mL	35mL	30mL	30mL	20mL	20mL
Vb	75mL	30mL	80mL	20mL	50mL	70mL	60mL	60mL	80mL	40mL
Vs	80mL	78mL	76mL	68mL	75mL	58mL	55mL	90mL	60mL	50mL

Grup4

	Top					Bottom					Seam Top		Seam Bottom	
Time	Volume	Mass	SG	Vl%	Temp	Volume	Mass	SG	Temp	Temp1	Temp 2	Flowrate (ml/min)	Flow	Temp
0	44	40	0.827	92	768			1.009	953				110 ml/min	1068
20	345	30	0.8308	91	769	42	30	1.012	957	485	565	588		
40	32	30	0.8367	89	773	33	30	1.01	965	47.8	55	58		
60	27	20	0.85	85	78	24	30	1.012	968	47	54	555		
80	21	20	0.8655	79.5	792	28	30	1.01	972	45	52	55	80	1068
100	13	10	0.9002	66	849	68	70	1.016	975	44.8	51	542		
115	12	10	0.9091	62	867	86	80	1.015	981	45	50	565	66	
130	11	10	0.8981	69	885	29	30	1.016	982	45	50	62	98	1068
145	10	10	0.948	42	906	51.5	50	1.0075	983	45	50	58	130	
155	10	10	0.929	53	914	33.5	30	1.0164	983	45	50	57.5	66	1068
165	9	10	0.996	27	913	40	40	1.012	984	45.5	50.5	58	64	107
Total	2235	200	0.975	73.2	921.6	435	420	11.136	10703	4886	519	5735	504	5342
Average	2235	20	0.979	73.12	921.6				10703					

Group 5

Time	Bttons m(g)	Bttons V(ml)	Dist. t(s)	Dist. m(g)	Dist. V(ml)	Cond t(s)	Cond m(g)	Cond V(ml)
8.20	50	47	46	50	65	20	40	47
8.40	30	33	40	40	52	10	20	26
9.10	60	64	40	40	54	20	40	39
9.20-9.35	50	51	40	40	45	10	40	40
9.46-10.01	60	59	40	40	49	10	30	27
10.10-10.25	50	49	40	30	39	10	30	33
10.33-10.46	60	55	40	20	32	10	20	17
10.57	70	70	40	40	25	10	20	15

Time	Water (x2g/h)	Time	Bttons T(°C)	Cond T(°C)	Dist. T(°C)	Coding in	Coding out	Overall mL
8.20	0.8	8.20	94.1	110.6	77.1	49	62	#NAME?
8.40	0.79	8.40	94.8	110.7	77.1	48	59	900
9.10	0.79	8.59-9.10	95.8	110.7	77.2	49	59	625
9.20-9.35	0.8	9.20-9.35	96.7	110.5	77.2	48	58	600
9.46-10.01	0.8	9.46-10.01	97.6	110.5	77.4	47	56	560
10.10-10.25	0.8	10.10-10.25	98	110.5	77.6	48	56	500
10.33-10.46	0.79	10.33-10.40	98.3	110.6	79.5	47	55	375
10.57	0.8	10.57-11:12	99	110.7	92.8	46	54	

Appendix C : Specific gravity meter

Celsius Models - Product Detail

EW-25755-00 (1 of 3) [\[Next\]](#)

Celsius Models



[click to enlarge](#)

EW-25755-00

Low-cost specific gravity meter; specific gravity range; 0.750 to 1.000 SGU; probe dimensions; 4"W x 8 1/4"H x 1 1/2"D; °C model

Qty:
[Add To Cart](#)

\$1695.00 / each (USD) Available in 26 days.

Product Rating (0 ratings) [Write a Review](#)

Differential pressure measuring technique eliminates errors

Meters are simple to use—just dip probe into test liquid, then rinse probe with clean water after each use. Sample contamination due to inadequate probe cleaning between measurements is virtually eliminated. Meters are made from ABS plastic and are factory calibrated to ensure accuracy. Meter includes a PTFE-coated 316 stainless steel probe with flexible connector, four AA batteries, wrist strap, and case.

Low-Cost Meters 25755-00 through -24 are ideal for general-purpose testing. Custom ranges other than the ranges offered below are available—call our Application Specialists for details.

Specifications

Specific gravity range	0.750 to 1.000
Specific gravity resolution	0.001 SGU
Specific gravity accuracy	±0.03 SGU
Temp range	0 to 50°C
Temp resolution	0.1°C
Temp accuracy	±0.8°C
Max sample viscosity	400 cp
Probe immersion depth	5"
Display	two-line, alphanumeric LCD; backlit
Dimensions	Meter: 4"W x 8-1/4"H x 1-1/2"D Probe: 8"L x 1-1/4" dia
Power	four AA batteries (included)

Accessories

EW-09376-01 BATTERIES, 1.5 V, AA, 4/PACK

Availability: In Stock
Price: \$6.00/PK
Qty:
[Add To Cart](#)

Custom Ordering Solutions

Let us find the exact product you need. We have access to suppliers full lines— for products beyond what you see here. Call 800-323-4340, ext 6334. [See details](#)

Literature

- [07-08 Catalog](#)
- [05-06 Catalog](#)

PRODUCT REVIEWS SUMMARY

Be the first to review this product. [Write a Review](#)