4-16-2009

Senior Design Final Report: Destination Distillation

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Repository Citation
Browning, M. B.; Buckner, B.; Harl, B.; Simpson, C.; and van Moorsel, G., "Senior Design Final Report: Destination Distillation" (2009). *Engineering Senior Design Reports*. 20.
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Senior Design Final Report

ENGR-4382

4/16/2009

Destination Distillation

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1 Introduction

The goal of this project is to retrofit the distillation column owned by the Trinity Engineering Department in order to make it safe and easy to use in the learning environment. A final design has been agreed upon, parts have been ordered, installed and tested, and the final design is complete and determined to be working as it should.

1.1 Background

The distillation process is a member of the unit operations group. The distillation column is currently used as a teaching mechanism in the unit operations class and demonstrates a concrete example of theoretical ideas. This project is modeled after the real life application of retrofitting existing systems in the real world. Currently, there are many degrading plants around the world, most operating as large steady state systems. Controls technology has advanced a great deal, and a common controls application is to retrofit old systems with new systems. This is where the idea for the project originated.

This type of project requires background in all three fields of engineering studied at Trinity. That is to say, the principles of mechanical, chemical and electrical engineering have been utilized to analyze the problems in the column. A distillation column separates a mixture according to the volatility of each component in the mixture. For instance, in the column at Trinity, a mixture of isopropanol and water is used. When the mixture is fed into the column, it begins to separate; the more volatile substance rises and the less volatile substance falls to the bottom.

1.2 Problem Description

The project encompasses industrial applications through the redesign of specific aspects of the column, not the re-engineering of the distillation process. At the beginning of the project, the distillation column was in a state of disrepair and was difficult to use. In short, the controls were old and the system needed a face lift. In order to make this column usable, the group had to satisfy several goals. The group first had to analyze the condition of the column, and develop an outstanding issue list, which can be viewed in Appendix A. These things had to be resolved in order for the column to physically work properly.

The next task was to develop a control system that sufficiently controls the new and old components of the column. This is an important goal of the project, as it will make the use of the column easier, so that it can be used more often. In previous years, the column has needed about a week of preparation to be used. Now, the column should be able to be used at any time with minimal set up time. This objective contributes to modeling of real life engineering practice in this project.

In this report, the group presents the status of design construction, the testing methods, and the testing results of each major aspect of the design. These include the flow meter, the pre-heater, temperature measurement with thermocouples, level measurement, the reflux system, and the Programmable Logic Controller (PLC) used to control the column as a whole.

1.3 Constraints

As is the case with any design problem, there are several constraints that apply to the retrofit of the distillation column. The two most important constraints are time and money. The project must be completed by the end of the school year, and it must not exceed its budget, which is $2700. Since this distillation column is for the use of professors and students, it must be in a state that allows it to be operated easily by its users and applicable for class use. Since the start-up time for the column was so long before, this constraint will ideally make the start-up easier and shorter. In addition to reducing the start-up time, the retrofitted column must reduce safety hazards, which include the previously existing pre-heater and any leaks or ventilation problems in the column. Control system automation must be incorporated into the column in order to measure and control temperatures, flow rates, and the levels in the bottoms. Also, all of the operations within the distillation column must be between approximately 80 and 100°C in order to keep the cycle moving correctly, and the column parts must be chemically compatible with the selected isopropanol solution.

1.4 Criteria

The criteria include ease of operation, robustness, ease of installation and compatibility, compactness, and cost. Ease of operation involves the ability to easily take a sample of the distillate and set up the column for class use. Also, temperature, flow, and level monitors should be accurate and easily controlled. As far as robustness goes, the column should be in a state to be used for many years to come at the completion of the project. This criterion includes a more reliable electrical system and pre-heating operations. The new parts should interface well with available computer programs and the mechanical functionality of the distillation column in order to meet the ease of installation and compatibility criterion. In order to be compact, the final design and the new parts should take up as little room in the first floor lab as possible, which will additionally aid in completing major goals of the project, such as reducing heat loss in the system. Cost must be considered when determining how much money in allocated to each aspect of the retrofit.

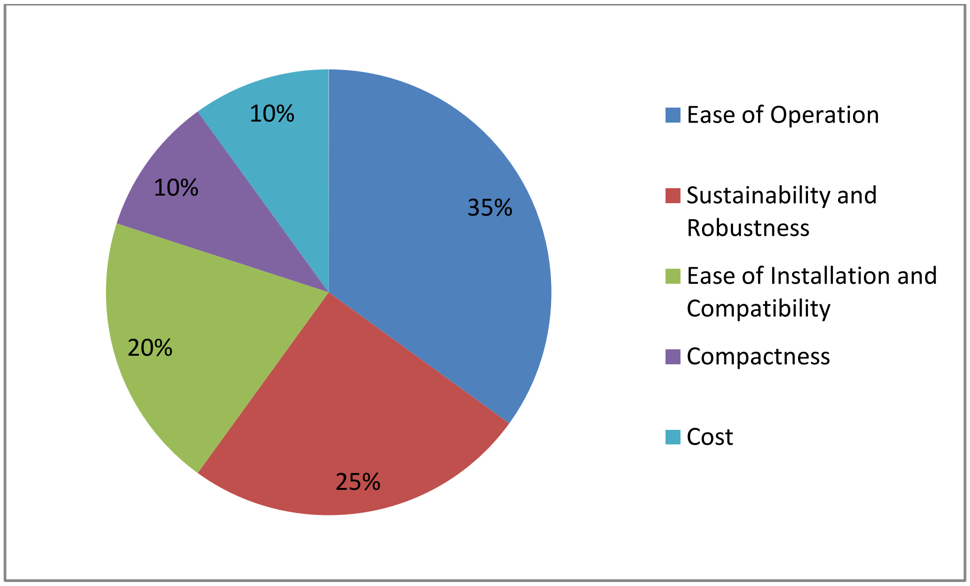


Figure 1. Criteria Weights

2 Final Design

The final design of the column did not come about easily or quickly for the group. In some cases, the original choice of alternatives worked the first time, while in others, different aspects of the column had to be reconsidered in order to fully meet the design criteria. This section describes the final designs of each major part of the column.

2.1 Flow Meter

The list of flow meters to choose from was largely limited by the volume of flow through the feed pipe. The volumetric flow rate of 30 mL is very low for flow measurement devices and heavily constricts the possible choices, especially since the cost of these precise devices rise sharply and can very quickly exceed the project's budget. Basically, in order to manipulate the system so a flow meter within the price range could be bought, the flow within the pipe must be maximized. The column's current feed pump has two knobs, one controlling stroke length and one controlling stroke rate. Setting the stroke length to 100% maximizes the instantaneous flow rate, the flow rate of the fluid while the pump is stroking. With the stroke length at max, each stroke pumps about 2.5 mL. Using this value and the target flow rate of 30 mL, the pump will need to stroke about 13 times a minute. The pump's maximum stroke rate is 125 strokes per minute. Using this value, the time per stroke is estimated at 0.25 sec/stroke. Using these values an estimated instantaneous flow rate of 454.2 mL/min is found. This higher value allowed for a better selection of flow meters.

Omega's FP-5061 is a micro flow sensor whose range is 113.5 – 2649.5 mL/min, using a paddlewheel design. This meets the projects requirements perfectly. The range allows for the flow to be varied up or down from the planned 30 mL, and the flow meter will still be able to accurately measure flow. The flow meter has an open collector NPN transistor output with a 10 mA maximum sink. The meter outputs 2.629 pulses for every mL of fluid that passes through it, as stated by the Omega specification sheet in Appendix I. These current pulses will be read by the controller and correlated to the flow rate of the fluid. The body of the flow meter is made of polyphenylene sulfide, providing high material strength and chemical corrosion resistance, meaning it will easily work with the chemical composition of the isopropanol mixture.

The main advantage of having found a flow meter to measure the flow is the ease of its incorporation into the distillation column. The meter is only 100 mm long so its installation was easily accomplished by inserting it in the small gap left by the previous preheater. It has a simple ¼” NPT connectors, so it was readily inserted into the feed line with the use of ¼” pipe to ¼" tubing connections on either side. Teflon tape was also wrapped around the fittings to prevent any leakage. The flow meter comes with a very long sheilded wire, so it was very easy to connect to the PLC; all that is required is a 10 kΩ pull up resistor between the output and ground. The temperature rating of the flow meter is only 80 °C, which is lower than what the anticipated feed temperature of 91.1°C, so the meter is installed before the preheater. This should not pose a problem since there is an adequate amount of tubing between the feed pump and the location where the heating tape is installed.

2.2 Pre-Heater

In order for the distillation process to work properly, the incoming feed liquid must be at or close to its saturation temperature. In the case of the water-isopropanol mixture that is used in the column at Trinity, this is approximately 90°C. The feed tank is at room temperature, so the feed line must be heated in some way so that the column can run as it should. The original pre-heater was a large cylindrical heater with a hollow core that the feed line snaked through several times. It shorted out a few years ago and was determined to be unsafe to use. Also, it took up a significant amount of space on the floor and its set-up allowed a lot of heat to be lost before the feed entered the column. Therefore, one of the main tasks of this project was to come up with a suitable means of pre-heating the feed line. Several options were considered for this task, and the final decision was to use heating tape.

Heating tape is a long, thin, resistive heat generator that can be used for fast and efficient direct contact heating of pipes. It is simply affixed to the piping in a spiral and plugged into a wall outlet. The final heating schematic includes two 96” by ½” pieces of high temperature heating tape and one 48” by ½” piece of silicon rubber heating tape with built-in adjustable thermostat control. Because the tapes were wrapped around the tubing, the 96” pieces actually take up about 62” of the feed line length each, and the 48” piece takes up about 31”. One of the high temperature tapes has been installed with one end as close to the column entrance as possible in order to reduce heat loss. Also, a thermocouple has been installed in the line about six inches below the end of the tape. This is used to measure the temperature of the feed right before it enters the column. The second piece of high temperature tape is installed directly below the first piece. A thermocouple has been placed in contact with the middle of this tape so that the temperature of the tape can be measured as a safety precaution. The rubber heating tape is installed directly below the second piece of high temperature tape. All three lengths of tape are covered in ½" thick fiberglass insulation to reduce heat loss, and the insulation has been wrapped with duct tape in order to prevent users from touching the fiberglass.

The high temperature tapes are each connected to a solid state relay that is connected to the PLC. They have a large amount of power (13.1 W/in^2) and are capable of reaching very high temperatures, so as a safety precaution, it is likely that they will not ever be run at their full capacity. The third piece of heating tape mainly serves as a backup, in case the two high temperature pieces are not getting the feed temperature as high as it needs to be for a given flow rate.

Heating tape does a very good job of meeting the criteria for this project. It will be very easy for future users to operate, because it is controlled by the PLC. The tape is moisture and chemical resistant, and its maximum temperature is higher than the needed temperature. Therefore, it is very robust, and it should function correctly for a long period of time. Also, the tape was relatively easy to install and insulate. Because it is insulated and controlled by the PLC, it is a safe means of pre-heating the feed line. It is compact, as it only adds a couple of inches of diameter to part of the feed line and it does not take up space on the floor of the first floor lab. Also, it is relatively cost efficient, and it took up a small percentage of the overall budget, especially when compared to other pre-heating alternatives.

2.3 Thermocouples

The various temperatures on the column will be measured with T-type thermocouples. A thermocouple is essentially two different metals, that produce a voltage when combined and exposed to a temperature gradient (two different temperatures). The thermocouples were acquired from Omega. The group decided on the JMTSS-125G-12-copper-constantan thermocouple. These thermocouples are sheathed in stainless steel and are not grounded, which increases their accuracy. The selection of the thermocouple is quite simple; the implementation of the thermocouples into the column is more complicated. There are four types of locations in the column in which temperatures need to be measured. These include the bottoms temperature, feed temperature, reflux temperature, and tray temperatures. The bottoms temperature and feed temperature can be easily measured. A thermocouple is inserted directly into the bottoms for a reading, and thermocouples are inserted into the feed line via a T-fitting for the feed measurement. Also, the reflux temperature can be acquired by simply measuring the temperature of the reflux tubing. However, the tray temperature is a more difficult measurement to acquire. The trays are attached to each other via a ceramic gasket. Each gasket has a hole bored into it which goes all the way to the glass column. Through experimentation, which involved measuring temperatures on various locations in each tray, it has been determined that inserting the thermocouples through the existing holes on the trays to the glass portions on the column is the best option. Aluminum plugs and silicone grease help to provide good thermal contact, which results in accurate temperatures. In summary, one thermocouple is used to measure the bottoms, and one thermocouple is used to measure the reflux. Another two thermocouples are used to measure the in-line feed temperature and the temperature of one of the heating tapes. Four thermocouples are used to measure the tray temperatures. There are eight trays, and a temperature measurement will be made at every other tray.

Once the thermocouples were installed on the distillation column they were integrated into the PLC. This required the use of a reference junction. A thermocouple needs a temperature difference to produce a voltage difference. It is essential to know one of the temperatures being measured. This is usually done by inserting one thermocouple lead into an ice bath at 0^{o}C and another lead into the environment of the desired temperature measurement. This produces reliable voltage gradients which can be used to make a temperature reading. The voltage difference is quite small, so the signal needs to be amplified. An input card designed specifically for the PLC will be used for the thermocouple signal condidtioning. The card is a four channel input module from Direct Logic. The Input card works with all types of thermocouples and has a resolution of 0.1 degrees Celsius.

2.4 Level Measurement

The final design for monitoring the re-boiler level uses differential pressure by setting up a pressure transducer in a closed-end manometer set-up. The initial part of the design uses some of the existing 2.5” pipe connected to the re-boiler through the 1” evacuation pipe exiting the re-boiler. The original design had a pressure tap to atmosphere so the pipe had an equivalent level of fluid. The group has changed that pressure tap to include a valve so that the level in the reboiler and level pipe can be equalized and calibrated as the operator desires. The system is shown in Fig. 2.

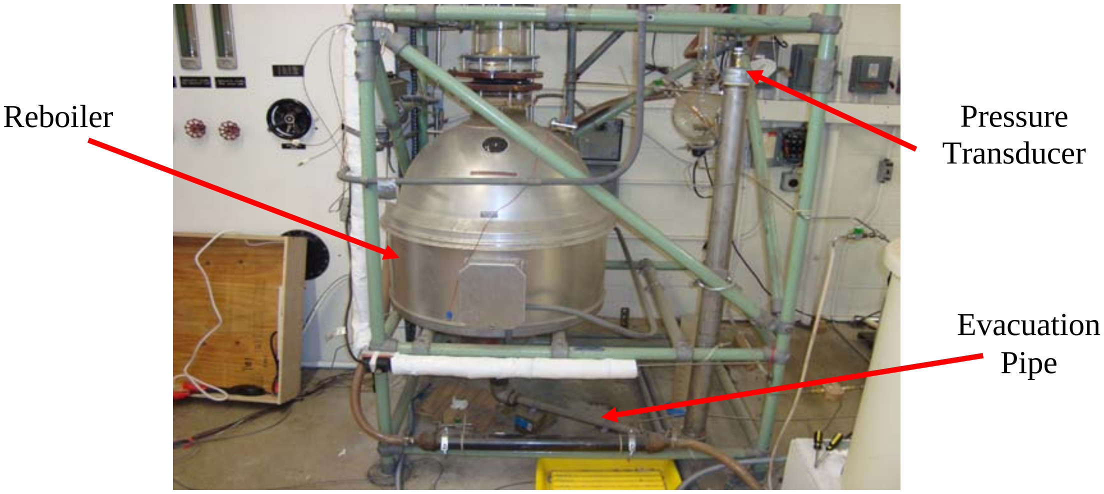


Figure 2. Basic schematic for the connection of the re-boiler and pressure pipe

For the connection of the pressure tranducer and the pressure tube, a 2.5” cap was installed with a ¼” tap drilled in the top. A ¼” NPT male to 1/8” NPT female reducer was installed so that the 1/8” NPT male pressure transducer can be screwed in, closing the system. The orientation appears as in Fig. 3.

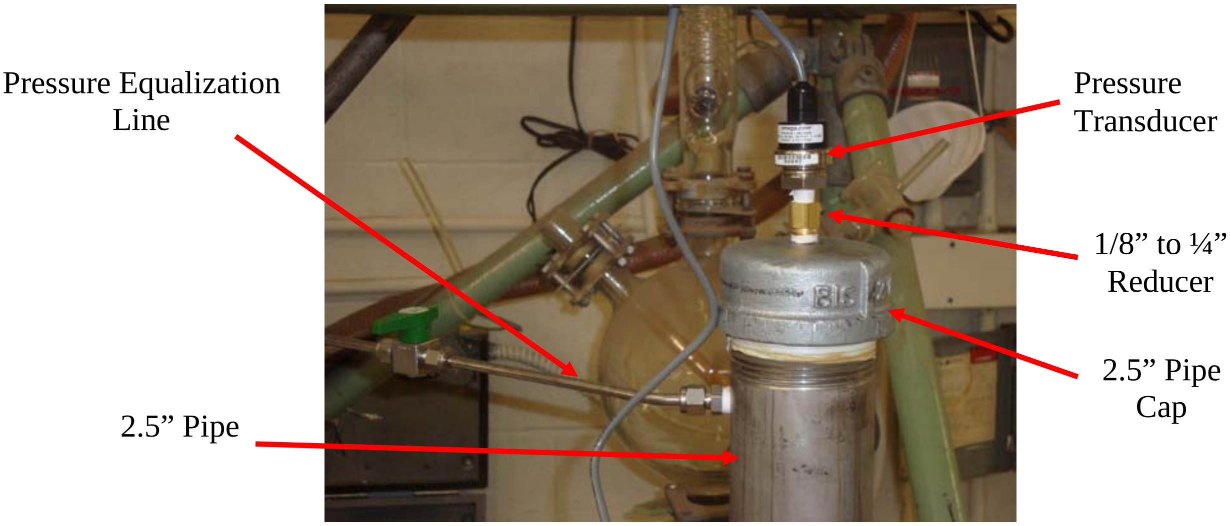


Figure 3. Installed level gauge

This design works by monitoring the changing voltage reading from the pressure transducer. In order to size the proper pressure transducer, calculations were done to find out if the change in voltage can be monitored to watch a one inch change in fluid level. For an order of magnitude calculation, the maximum gauge pressure possible will be considered. To do so, the group first assumed that the re-boiler shape is a sphere, allowing the group to find a volume after measuring the radius. The group found the radius to be approximately 33.9 cm giving the re-boiler a volume of 0.164 m^3. In order to do a worst case scenario calculation, the fluid density was considered to be the same as water, 1000 kg/m^3. The pressure in the tank will be at a maximum found by Eq. 1 which yields 26.7 inches of water, or 0.97 psig. The pressure is in gauge, because the pressure transducer measures differential pressure against atmospheric pressure.

$$P = \rho g h = \left(1000 \frac{kg}{m^3}\right)\left(9.81 \frac{m}{s^2}\right)\left(2 * 33.9ee^{-2} m\right)\left(\frac{1inH_2O}{248.8Pa}\right) = 26.7inH_2O \qquad \text{Eq. 1}$$

In order to meet design requirements, the device has to be able to measure a level change of at least one inch. Consideration was be given to the question of whether or not the pressure transducer and the controller will be able to monitor very small changes. The output signal on the transducer is a 0-5 V output, representing the range 0-1 psig. Therefore, the PLC will have to be capable of monitoring a voltage change of 36 mV, as shown in the calculation shown in Eq. 2. On the PLC side, the analog card can read 4096 counts translating to 0.97 mV per count, found with the calculation demonstrated in Eq. 3. The pressure transducer is actually able to measure a smaller change than one inch, so the pressure transducer meets the design requirement.

$$\frac{\Delta V}{1inch} = \frac{\Delta P}{1inch} = \left(1inH_2O\right)\left(\frac{14.7psi}{407inH_2O}\right) = 0.036psig = 36mV \qquad \text{Eq. 2}$$

$$\frac{\Delta V}{\#ofcounts} = \frac{4V}{4096} = 0.97mV \qquad \text{Eq. 3}$$

In terms of what the pressure transducer will need for power and communications, it has a 4 wire pigtail extending from the top. The power needed by the unit is 9-30VDC. Two of the four wires are used for powering the unit, one for positive and one for negative voltage. This power will be supplied by the PLC. The other two wires are for the pressure signal sent to the PLC. One of the wires is carrying the voltage output and the other wire is a ground wire. The wiring schematic is shown in Fig. 4.

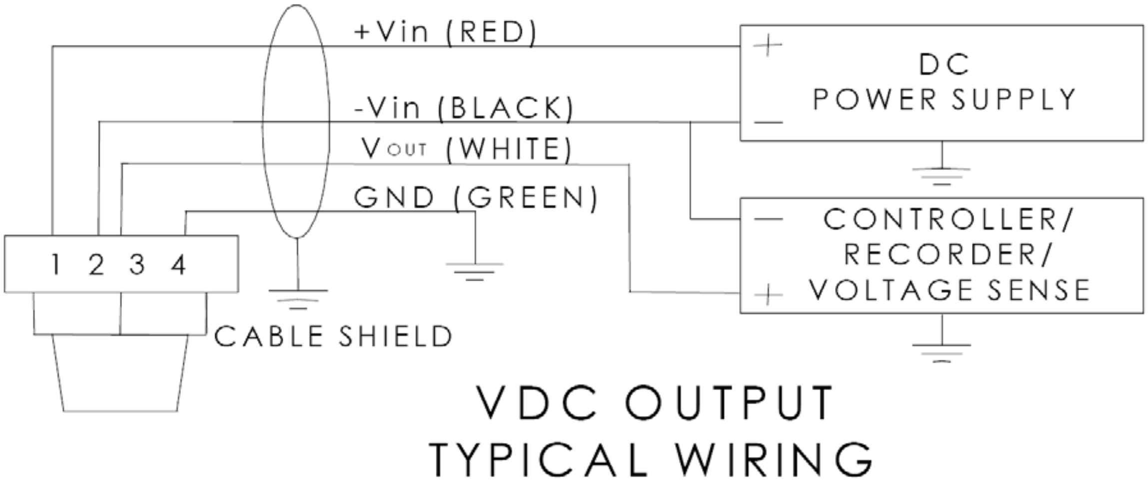


Figure 4. Output wiring diagram for Pressure Transducer[4]

The PLC level device controls the level through a bottoms pump. The bottoms pump evacuates the fluid from the reboiler and places it into one of two tanks for the bottoms fluid. As the level gets too high, above the set pressure of 0.95 psig, the pump will turn on and evacuate the reboiler for 2 minutes. The reboiler pump is controlled through the PLC, which uses a solid state relay to control the power provided to the pump.

2.5 Reflux System

The original reflux system at the top of the column required a new power supply. This was based on measurements taken and on specifications of the current solenoid, which will continue to be used in the column. A new power supply was recommended by Acopian, a company specializing in high voltage applications. To summarize the overall specifications, the device supplies 250VDC and 50W of power. The power supply runs off of a wall plug. A solid state relay is placed between the output of this power supply and the solenoid so that the PLC can control the reflux rate. A fuse is placed in line on the load side of the relay to protect the power supply. Another safety precaution, a reversed biased diode, is used to ensure that when the solenoid is turned off, no current flows back into the power supply. There will be no other parts or systems, other than the reflux, running off of this supply.

This design choice fits the group’s criteria well. It can be integrated into the system easily, as the wiring to the existing solenoid is already in place. The power supply is also fairly easy to use. Everyone in the group is familiar with how a basic power supply works. The group has no reason to believe that this new power supply will not be a long term and long lasting solution.

2.6 Programmable Logic Controller

The group decided to use a programmable logic controller (PLC) to control the instrumentation in the column. There are many companies that manufacture PLCs and beyond that, many models that they produce. As wall power can be made readily available, a PLC that requires 90-240VAC input power was chosen. As an output, direct current (DC) input and sinking output ports were selected because the system utilizes one wire with a constant voltage or current. A model that has ample space for instrumentation interface was also needed. The chosen model has room for four modules, with the type of module picked according to the needs of the column. An analog voltage input module was bought, along with two thermocouple cards, which filter and amplify the voltage output from the thermocouples. Currently, all outputs can be sourced through the DC voltage of the actual base and the use of solid-state relays.

As is previously stated, the PLC will interface with almost all of the instruments on the column. The temperature measurements taken by various thermocouples, placed according to the P&ID in Appendix B. The group decided on using eight thermocouples, which was dictated by monetary constraints. One thermocouple is placed directly on the surface of the first high-temperature heating tape to regulate the pipe temperature in the feed line. Another is placed in-line on the run of the second high-temperature pre-heater. The PLC has a drum sequencing that works like pulse width modulation. This allows for the two heating tapes to be controlled with the same time-scale and commands, but set at different percentages of full power. One heating tape runs at 50% of full power, while the other runs at 25%. The in-line and heating tape temperatures can be used to shut off power to the pre-heater, using a solid state relay, if the temperature gets too hot. This same output will be used to discontinue power to the pre-heater if the feed pump is off. This is done in order to prevent overheating of the system due to the lack of cold fluid in the pipes, which removes heat from the pipes.

A few more inputs are used to complete the system. The level control and flow meter require an analog voltage input (with input meaning from the device to the PLC). Both of these signals are manipulated in the PLC ladder logic to reflect their respective correlations derived from testing. The flow meter requires a timer to count pulses in one minute intervals before it performs the correlation steps. The reflux system at the top involves the use of discrete voltage output so that it can be set to a certain set point for percent reflux. Equation 4 shows how to calculate the reflux rate, which ideally will be between two and five. The variable L is the reflux, which goes back into the column and D is the distallite, which leaves the column. The group chose a reflux rate of five. A timer is used in ladder logic to set L to be 50 and D to 10. This means that the reflux is off for 50 seconds and on for 10.

$$R= L/D \qquad \text{Eq. 4}$$

The PLC chosen will work well not only for the technical reasons listed above, but also because the PLC fits previously established criteria well. The PLC is very robust in that there is much room for expansion. Many discrete inputs and outputs will be left open, as well as analog outputs and analog current inputs. The PLC works well with all of the instruments which have been added to the column. The PLC is also small relative to the size of the column and the space that the group has to work with. There are some negative sides to the PLC. It can become very costly very quickly, but so the group kept it within its allocated space within the budget. Lastly, initial operation of the PLC requires programming using ladder logic, which the entire group was not familiar with. After initial programming, though, the group was easily able to build up to more difficult code. Overall, the PLC has proved to be an excellent choice for this column.

2.7 Additional Considerations

In addition to the main components of the project, a few extra things were added to the column to make it safer and easier to use. The first of these is a sample spigot on the feed line. It is installed between the pump and the flow meter, and it can be used to manually measure the flow rate and to analyze a small sample of the feed fluid. A stop valve is installed downstream of the spigot that can be used to block the flow past that point. Then, the spigot can be turned, and a sample of the feed can be collected in a vesicle of some kind before turning the spigot off and reopening the line.

Also, there is an open vent at the top of the column that releases fumes when the column is in use. Plastic tubing was purchased to fit over the opening of this vent and directed to the window in the second floor lab. This allows the fumes to escape outside rather than collecting in the labs and causing unpleasant smells for those who are present.

There are several sensitive electronic components included in the final design, such as the PLC, the reflux power supply, and the solid state relays. Because these components are in a potentially harsh environment with fumes and other materials capable of damaging them, there is a need to protect them. Therefore, a box was built and set up next to the column that holds all of these components. This also is beneficial in that it centralizes all of the main electronic elements.

3 Testing Methods

The group has chosen a method for testing each aspect of the design in order to determine if it will meet the goals of the project. This section contains the goals and the testing methods used to determine if the goals can be met for each of the main parts of the retrofit.

3.1 Flow Meter

In order to test the flow meter, it was hooked up to a data acquisition system (DAQ) so that LabView would be able to acquire and plot the data from it. A simple virtual instrument (VI) was created which took the voltage from channel 1 and plotted it versus time. Since it is known that the voltage comes in pulses, a count of these pulses was taken. Then, knowing the time of the count, a count rate could be determined. Pin 37 was used as the counter input. The VI was set up so that the user can specify a time step for which to count pulses. For example, it could be set to 10 seconds, and then the counter would count pulses for those ten seconds and display the results and start counting again. To find the average rate of pulses, this pulse count was divided by the length of the time step, and the resulting counts per second were also displayed on the VI.

Soon after installing the flowmeter it was discovered that it was leaking through what seemed to be a crack in its casing. The cause of this crack is still unknown; it could have come from Omega that way or it could have been caused by an accident in its use. Either way, since it had been used, Omega informed the group that it was no longer under warranty and that they would charge $75 just to look at it, so it was decided to attempt to fix this problem ourselves. The casing was disassembled and epoxy was applied to the crack. There was still some leaking after this so more epoxy was applied, and now the leak seems to have been plugged.

Using the this VI to count the pulses from the flow meter, a test was developed in order to find a coorelation between the volumetric flow rate through the flow meter and the pulses from the flow meter counted by the PLC. This test was performed in a pretty simple way. The pump was set to a specific setting of 20% of its maximum stroke rate, and then turned on. A valve in the system was opened for one minute, allowing the volume of liquid pumped for that minute to be measured in a graduated cylinder. The valve was then closed, allowing the flow to go through the flow meter while a VI was taking a count. This was also done for a minute and the count was recorded using the VI. This test was repeated for various settings of stroke rate, ranging from

15% to 45%, with a count being taken for each value. These numbers where then plotted and a linear trend line was applied, which resulted in an equation coorelating the flow rate in the tubing to the counts per minute measured by the PLC or VI.

3.2 Pre-Heater

Initial heat transfer calculations (Appendix F) preformed by the group showed that the 48" long piece of rubber heating tape would be sufficient for the heating needs of the column. It was originally installed directly below the column entrance and the in-line thermocouple, with a thermocouple on its surface. The two thermocouples were connected to LabView, and the feed pump was turned on. It was expected that the tape's surface would be at a temperature slightly below its maximum temperature of 218°C and that the feed line temperature would be at or close to its saturation point temperature of 91.1°C. However, even with the heating tape at its full power capacity, it only reached a temperature of approximately 115°C, and the feed line temperature was only raised to about 40°C. These numbers were significantly below what was expected from the calculations, and they proved that the rubber heating tape was not capable of meeting the distillation column's needs.

After discussing the problems with the heating tape company, Brisk Heat, it was discovered that they assume a much lower efficiency, on the order of 70%, while the group assumed an efficiency of 90% in the calculations. Therefore, the tape loses a lot more heat than was considered in the group's computations. This accounted for some of the difference in the temperature readings and the calculations, but not all. A spigot was installed in the feed line in order to facilitate taking samples of the feed, and the flow rate was measured by filling a graduated cylinder from the spigot and then measuring the amount of fluid that came out in one minute. This flow rate was found to be $7.15 \text{ X } 10^{-4}$ kg/s, but the flow rate that was used in the group's calculations (found during a previous project with the column) was $4.4 \text{ X } 10^{-4}$ kg/s. Therefore, the actual flow rate during testing was more than one and a half times greater than that used in the calculations. When these two factors are added into the heat transfer calculations, the disparities between the calculated and actual temperatures decrease significantly, and it is obvious that the rubber heating tape is not capable of heating the feed line on its own.

Given the specifications of the project, Brisk Heat recommended the use of the two pieces of high temperature heating tapes. Once they were purchased and installed in the final configuration, they were connected to variacs and tested. Each heating tape needed to be plugged into a variac for a couple of reasons. First of all, the safety of running the high temperature tapes at full power was unknown. Also, it was possible that the tapes needed to be set to different percentages of their maximum voltage in order to heat the feed line according to the specifications. Variacs allowed the group to determine whether this was the case, and if so, at which percentages the tapes should be set to while the column is running. The thermocouple on the second piece of heating tape and the in-line thermocouple were read through LabView over a period of a few hours while the entire column was running. During this time, the variacs were adjusted to different configurations, and the resulting heating tape and feed line temperatures were observed. Since the heating tapes are capable of reaching such high temperatures (up to 760 °C), the group was confident in their ability to get the feed line to its needed temperature. Therefore, the main purpose of testing was to determine how the tapes should be connected to the PLC and at what percentages of their power they should be set to while the column is running.

3.3 Thermocouples

It was necessary to test the thermocouples to ensure that each one works properly. Each thermocouple was tested at four different temperatures: 30, 60, 75, and 100 ^{o}C. The test setup is quite simple. A hot water bath was used to heat water to a specific temperature, and a mercury thermometer was placed in the bath along with each thermocouple. After the bath was heated to a specific temperature, the thermometer and thermocouple were placed into the bath. The two instruments could not touch the bottom of the bath, and they needed to be kept close together to ensure uniformity. The measurement of each instrument was recorded and compared to make certain that the thermocouple was working properly. The thermocouples were connected to a data acquisition unit which was connected to a computer running LabView. The computer displayed the thermocouple output in volts.

3.4 Level Measurement

The level gauge was tested using a DAQ to measure and collect voltage data while an apparatus varied pressure. The simulation is different from the application for the pressure transducer (PT) in the actual column. The difference is that the pressure is applied using regulated compressed air as opposed to the manometer setup that is used in the column. The setup difference will cause no error when changing how the PT is used, but it should be noted that there is a difference in application and testing configurations.

For the test, the PT was connected to a compressed air tube in the same line and at the same pressure as a digital manometer, which measures pressure in inches of water. This allowed the tester to vary the pressure and monitor it with a calibrated apparatus at the same time. While monitoring the pressure with the hydrometer, the voltage readings were taken using a DAQ to collect the data and LabView to read the voltages. The tester varied pressure between 0 and 18.5 inches of water and voltage measurements were taken, with 15 data points taken total.

To demonstrate this procedure visually, it has been broken up with corresponding figures below.

1. Assemble test apparatus as shown in Fig. 5. The apparatus used to deliver compressed air and modify pressure was made available by Dr. Wilson Terrell Jr. Note that at this point no pressure should be on the system.

Figure 5. Level meter testing configuration

2. Attach the air hose to both the pressure transducer and digital manometer as shown in Fig. 6.

Figure 6. Hose connections to PT and digital manometer

3. Wire the PT to the DAQ.
4. Attach provided compressed air to the system Fig. 7.

Figure 7. Connecting compressed air to system

5. Start VI to begin capturing data. As the pressure is increased, record pressure and voltage readings. Pressure is changed with the air in the regulator valve, the fine regulator and the bleed valve as in Fig. 8.

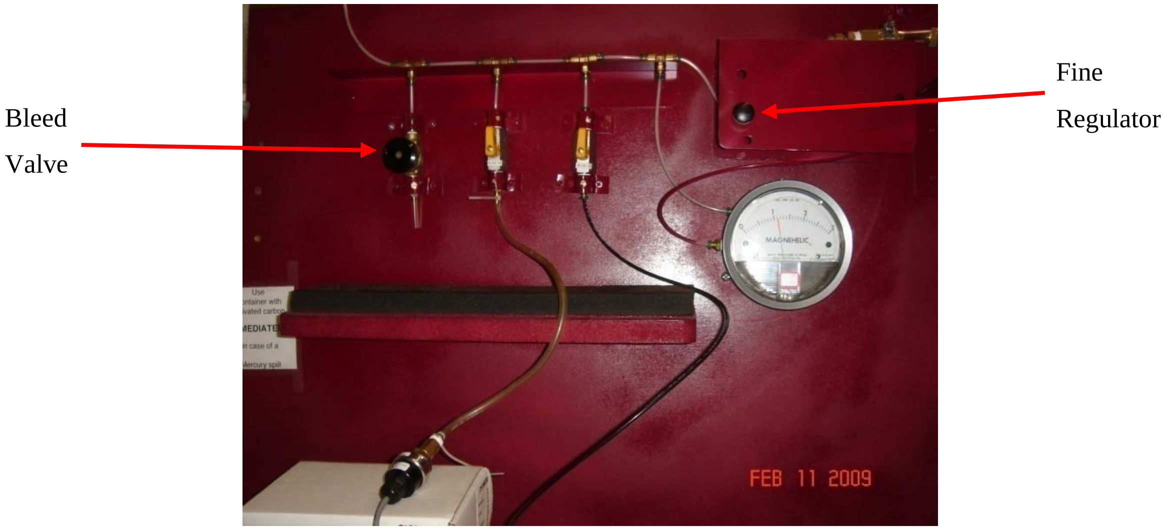


Figure 8. Fine and bleed valve pressure tuning

6. Continue on until pressure is at 1 psig.
7. Plot data in excel and check for relationship between level (pressure) and voltage.

3.5 Reflux System

As the power supply is a pre-fabricated item, the testing was easy and ran smoothly. Before installation, this power supply was tested using a digital multimeter (DMM). The multimeter was set to DC voltage. Probes were connected according to color on the DMM. The other end of the probe was held against the terminal screws (black to ground and red to the positive output). The measurement of the voltage across the power supply came to 240.6 V, which was expected .

Once the power supply was installed, the test for reflux solenoid operation was performed. With one person on the ground floor and one person at the top watching the reflux, the solenoid was charged.

3.6 Programmable Logic Controller

Multiple tests were run to ensure that the PLC program will perform as is needed by the group. The thermocouple cards were tested directly using the group's thermocouples. The group attempted to read room temperature from the thermocouples through the PLC. The analog inputs and digital inputs and outputs required more extensive testing before installation.

The tests for the digital inputs and outputs were performed using two switches and an LED. If either one or both of the switches are on, the LED will light up. The following logic was put into ladder logic (see Fig. 9). The switches were wired between +V and two separate inputs on the PLC. The ladder logic must bear the name of that input (i.e. X0 or X1), but for the sake of simplicity of the figure, it is referred to as S1 and S2 in the drawing. The LED is already built into the PLC base, so it was easy to view the output. All four combinations of on/off were tested. Since this is an OR operation, if either or both of the switches are on, the light should be on.

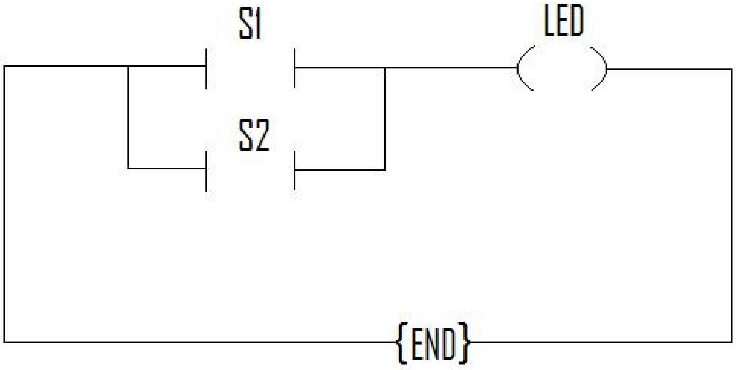


Figure 9. PLC digital test

The analog test is slightly more complicated. As seen in Fig. 10, the group used a comparison to ensure that the analog system was working. This will not be the actual logic used for reading the flow meter or level meter. These operations only require some simple arithmetic, but that is not very helpful for testing. The group used two oscilloscopes to create two separate waves, one sine and one square. Initially, the same frequency and amplitude was used. To ensure that the DC offset is off, the DC offset knob must be pulled out. When one of the wave's amplitudes is increased, the corresponding LED should light up. The input from the waves will be wired like the switches, described above.

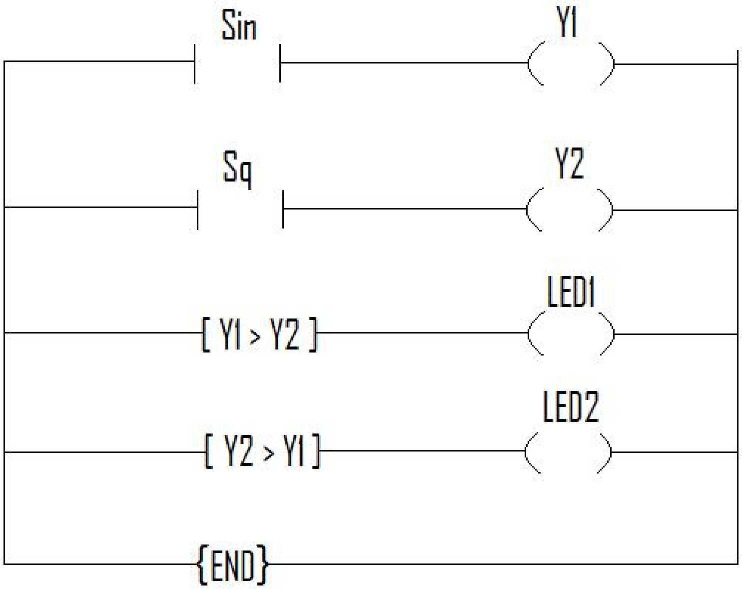


Figure 10. PLC analog test

More detailed description of the tests described above, and all other subsection testing are shown in Appendix G. Each system was tested separately in order simplify debugging. Each system can be proven to work before all of the programs are put together and cross-referenced. In addition to reading the analog signal, the flow meter test required using a counter. To test this, the group simply viewed the output LED to see that the light was on (outputting) after 60 seconds. Since the PLC has a screen that displays the time, which shows the seconds counting, it is easy to see how much time has elapsed. The testing for the reflux was done in exactly the same way except with different time intervals.

The thermocouples also needed to be tested to ensure that the signals are read correctly by the ladder logic. During this test, a light was set to turn on if the thermocouple reads a temperature over 10^oC. The thermocouples read room temperature, which is around 25^oC. This test was also performed to ensure that the thermocouple is not reading too high by having the light turn on if the thermocouples read below 30^oC.

The pre-heater requires drum sequencing as described in Section 2.6. To test this, again, the LEDs built into the PLC were used. One was expected to flicker on and off every second, while the other was on for one second and off for three. The two lights were never on at the same time. The pre-heater will turn off if the flow meter sees no flow. For this, another counter is used which takes a sample that is less than a minute, because the group does not want to leave the pre-heater on for an entire minute if nothing is flowing through the pipes. The last dependent function turns on the bottoms pump if the level indicator reads below a certain level. For both of the dependent functions, a signal generator was set a certain voltage, then reduced. For the pre-heater, this turned the drum sequencing off. The bottoms pump turned on if it sensed a low enough level.

4 Testing Results

Each component was eventually found to work as it should. This section discusses the results of each test and any relevant information and data that was determined from testing.

4.1 *Flow Meter*

Upon turning on the pump after the flow meter was correctly wired, the VI immediately began to display a nice plot of the voltage pulses. These pulses were very close together during the actual stroke of the pump and then diminished between the pump strokes, so it appears that the pulses are proportional to the flow rate of the fluid passing through the flow meter. However, pulse rate is more important, and there is a small problem. With the count time interval at one second, the pulses per second vary greatly. It is assumed that this is because during some of the seconds the pump may have stroked twice and some it only stroked once. In other words, the stroke rate does not match up with the count rate. In order to make up for this, the count length was increased to 10 and then to 30 seconds, hoping that this reduced the variations of pulse rate from one count to the next. The time that seemed to work the best in our testing was a count interval of one minute. Using this time length and the testing procedure mentioned in the flow meter test section a good set of data was collected and a correlation was found, which can be seen below.

$$Y = 5.24x - 128.64 \qquad \text{Eq. 5}$$

Where X equals the flow rate in mL and Y is the counts per minute. $R^2 = 0.9412$ for this correlation.

4.2 *Pre-Heater*

In the testing, the high temperature heating tapes functioned well with the given flow rate, and the rubber heating tape with the adjustable thermostat was not even needed. It will remain on the feed line for times when the column is run at a higher flow rate or in case the high temperature tapes are not functioning as expected. With the middle piece set to 70% of the maximum AC voltage (50% of the power) and the top heater set to 50% of its maximum AC voltage (25% of the power), the in-line feed temperature was maintained at 81.5^{o}C with a middle tape temperature of 103^{o}C. Although the in-line temperature was slightly below the actual saturation temperature, heating tape extends beyond this point of measurement, which indicates that the temperature of the fluid entering the column will be slightly above this. Also, the group has been assured by their advisor, Dr. Collins, that the distillation process works correctly when the feed is slightly lower than the saturation temperature.

In order to use the high temperature heating tapes in conjuction with the PLC, they are connected to solid state relays (via extension cords) that feed into the PLC. The PLC is programmed so that if there is no flow through the line, the heating tapes will be turned off. Also, the extension cords allow the tapes to be cut off manually if needed. The PLC is programmed so that the heaters experience pulse width modulated power set to 50% for the middle piece and 25% for the top piece.

4.3 Thermocouples

Each thermocouple was tested at four different temperatures. These temperatures were compared against the measurement of the thermometer. The chosen temperatures accurately sampled the temperatures that the thermocouples will be exposed to in the distillation column. The thermocouples are first tested at 30ºC. All eight thermocouples were tested, and the raw data from the testing can be viewed in Appendix E.

The average difference in temperature was 0.75ºC. This is well within the thermocouple's error limit. This trend continued at every temperature tested. At 60 and 75^{o}C, the average error was over the 1^o tolerance, but that was due to the limit of error in the mercury thermometer.

From the tests conducted, it can be determined that the thermocouples work as advertised. Each thermocouple accurately measures temperature. The thermocouples will never have to measure temperatures below 0^o or higher than 100 ºC. However, if a situation was to arise where the thermocouples have to read a greater range of temperatures they could easily do so. The thermocouples are rated from -250 ºC to 350 ºC. The thermocouples were also tested once they were installed on the column. The unit-ops class used the column and temperature data was taken as shown in Appendix E.

The reflux and bottoms temperatures are accurate, the tray temperatures are off by a few degrees from our initial testing, but this is the best temperature reading which can be measured without boring into the trays.

4.4 *Level Measurement*

Testing was conducted using the specified procedure in section 3.4. The data obtained was used to find a pressure versus voltage graph which was fit with a linear correlation. The data can be found in Appendix E, and the graph can be seen in Fig. 11. The correlation itself can be found in Eq. 6.

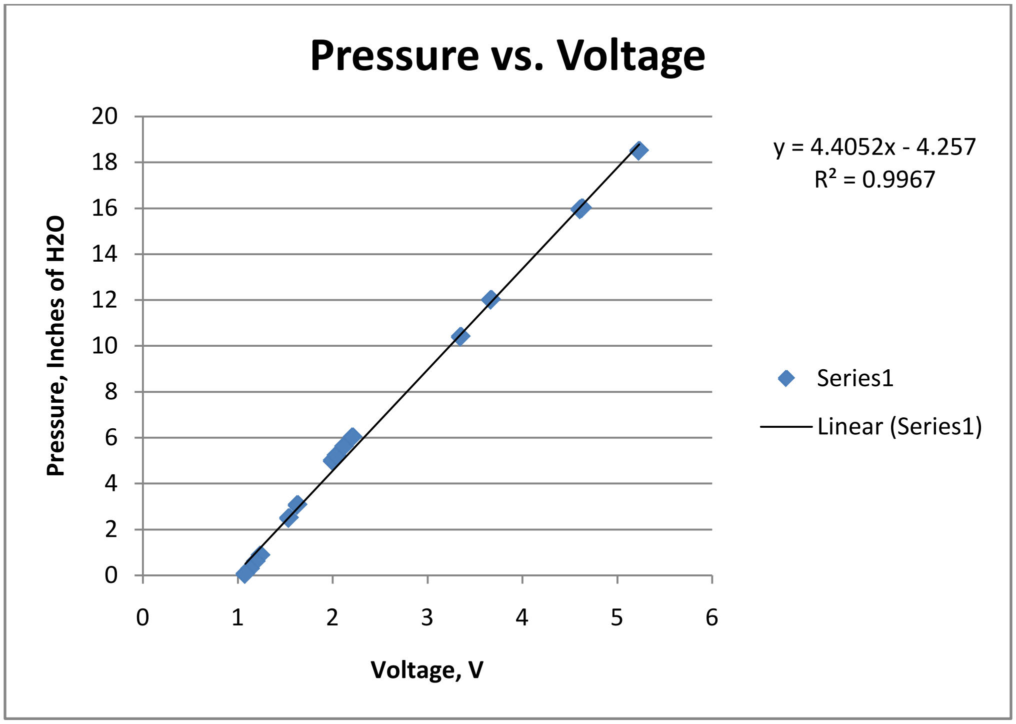


Fig. 11. Pressure versus time PT correlation

$$P = 4.4502V - 4.257 \qquad \text{Eq. 6}$$

The fit of the graph is encouraging. An R^2 value of 0.9967 means the linear curve fits the data well. The testing shows that the PT is capable of measuring the level in the bottoms. The bottoms should never be operated completely full or completely empty, so the PT will allow the PLC to monitor the system and make the proper decisions about the re-boiler level.

4.5 *Reflux System and PLC*

The solenoid repeatedly worked during initial testing without any issues. Then, the system was put under a rigorous testing when the Unit Operations class ran the column; the class had a reflux rate set to 4, and the solenoid operated normally, at least one time per minute.

5 Conclusions and Recommendations

The original goals set forth for this project were to replace the pre-heater and the valves that control the fluid flow, measure the feed temperature, increase the reflux reader range, improve the level indicator in the bottoms, build a controller to monitor temperatures in each plate and the level in the bottom, incorporate a sample valve for the product, and install a means of measuring the feed rate. These goals were in the problem statement written at the beginning of the project, and it was stated that a successful project will end with the distillation column in a state in which it is safe and easy to use, so that it can be used more often.

With the exception of monitoring the temperatures in each plate in the column, the group has achieved all of these goals according to the original expectations. Thermocouples were only installed in every other plate in the column due to monetary and PLC card space constraints. However, measuring every other plate still gives users a good indication of what is happening during the distillation process. Also, some areas such as the controller have been improved beyond the initial goals. The PLC is able to control the pre-heater, the flow meter, the thermocouples, and the level in the bottoms, rather than simply measuring the thermocouple temperatures and and controlling the bottoms level. The added ventilation system and the electronics box also went beyond what was originally set forth.

Overall, each part of the column is at least at the level intended at the beginning of the project, and some parts are at an even higher level. Also, the column no longer presents any safety hazards, and it is much easier to set up for use. It will be a positive means of learning in the future, and it will allow students to experience use of a PLC while learning about the distillation process. Therefore, the group considers the project a success and they are excited about the potential future use of the distillation column at Trinity.

6 Bibliography

1. **Brisk Heat Corporation.** Brisk Heat. *Brisk Heat Web site.* [Online] 2008. http://www.briskheat.com.
2. **Omega Engineering, Inc.** Omega. *Micro-Flow Sensors For Low Flow Water Applications*. [Online] 2008. http://www.omega.com/Green/pdf/FP5060.pdf
3. **Omega Engineering, Inc.** Omega. *Compact Pressure Transducers: All Stainless Steel Wetted Parts.* [Online] 2008. http://www.omega.com/Pressure/pdf/PX481A_PX481AD.pdf
4. **Omega Engineering, Inc.** Omega. *PX180B Instruction Sheet.* [Online] 2008. http://www.omega.com/Manuals/manualpdf/M4182.pdf
5. **Acopian**. *Gold Box: Unregulated Power Supplies.* [Online] 2008. http://www.acopian.com/single-u-goldbox-d.html
6. **Direct Logic**. *PLC Spec Sheet*. [Online] 2008. http://web2.automationdirect.com/static/specs/d006dd2.pdf

7 Appendix A: Outstanding Issue List

1. Replace pre-heater and valves that control feed flow
2. Measurement of feed temperature and tray temperatures
3. Improve reflux performance
4. Redesign level control for re-boiler
5. Incorporate a sample valve for the product
6. Means of measuring the feed rate
7. Incorporate control

8 Appendix B: Piping and Instrumentation Diagram

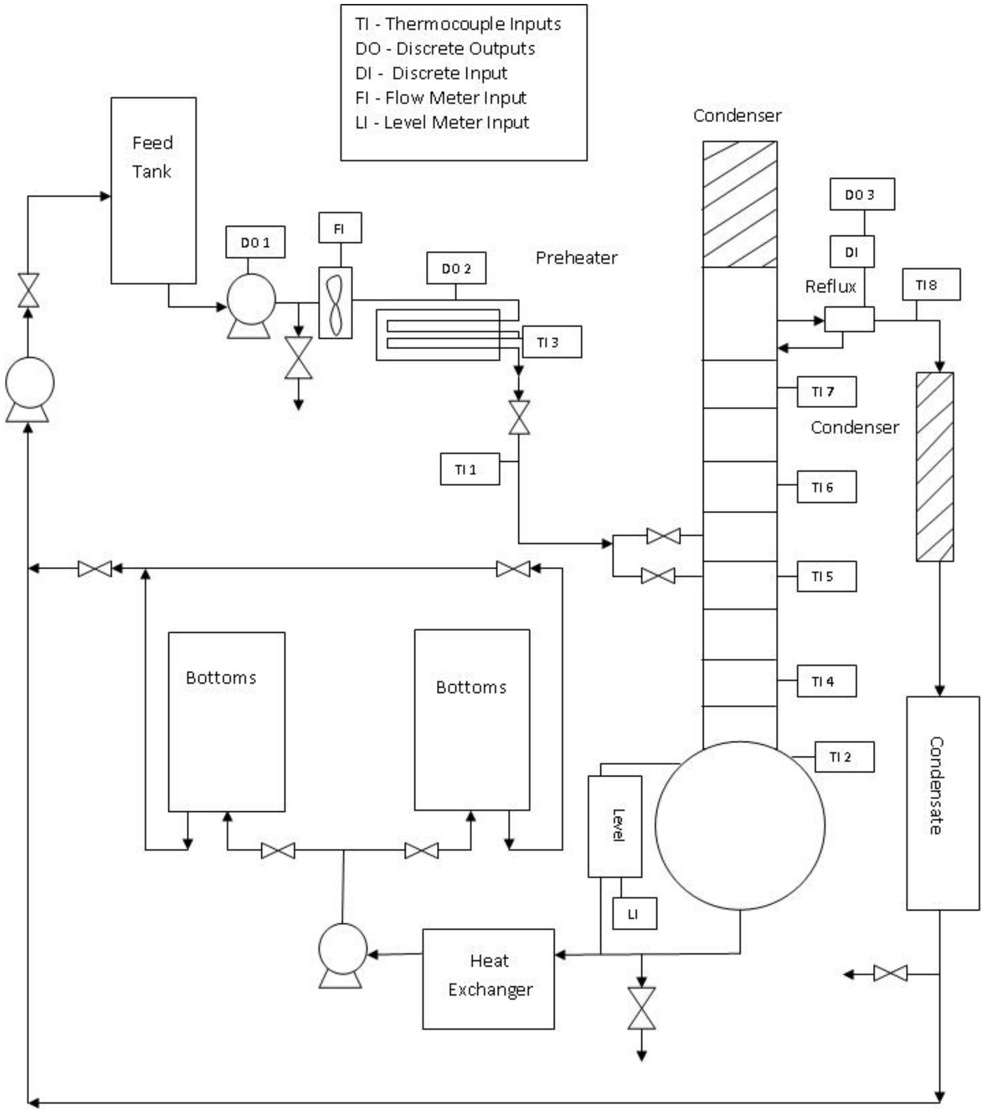
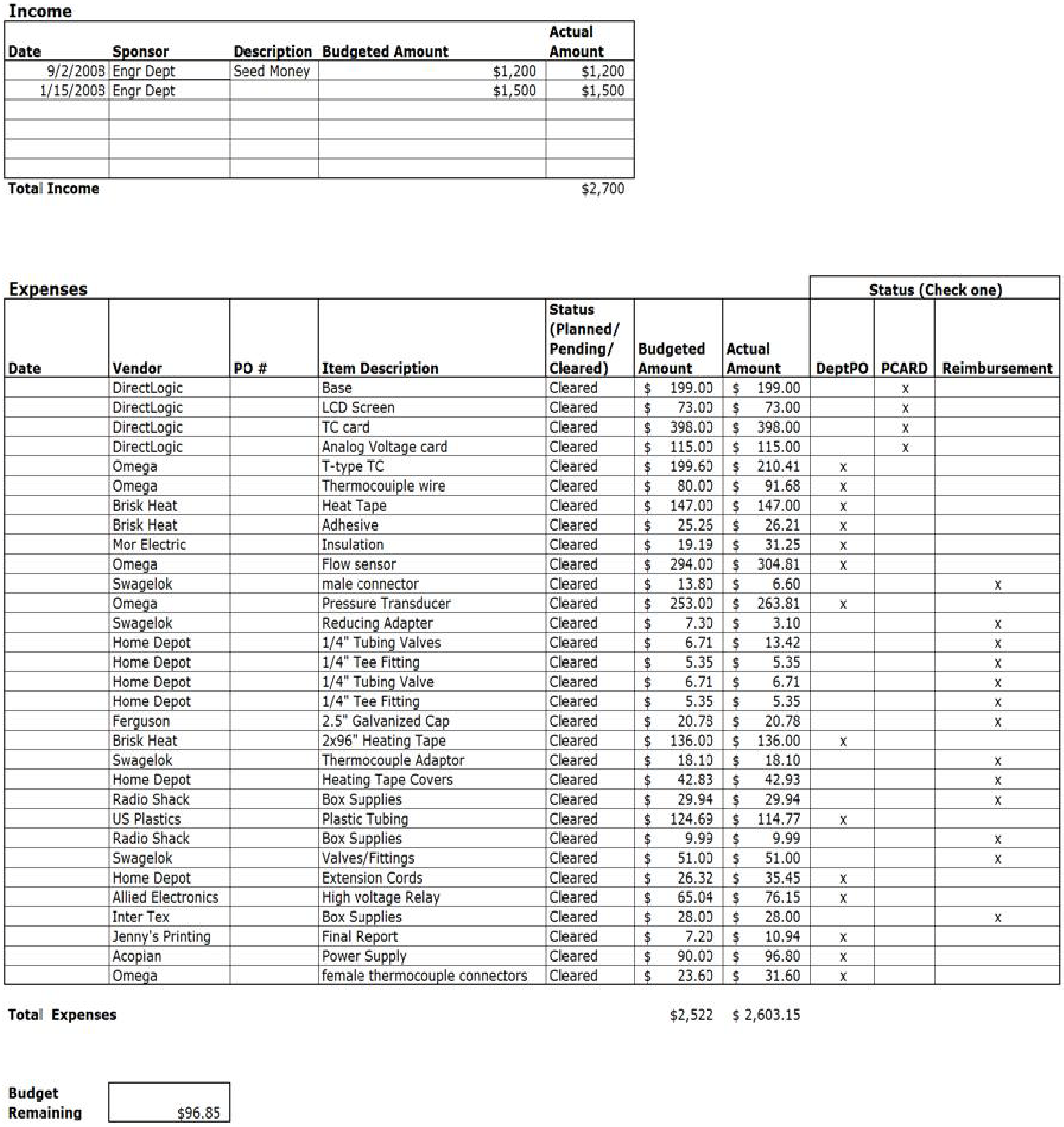


Figure 11. P&ID

9 Appendix C: Final Budget Spreadsheet



Income

Date	Sponsor	Description	Budgeted Amount	Actual Amount
9/2/2008	Engr Dept	Seed Money	$1,200	$1,200
1/15/2008	Engr Dept		$1,500	$1,500
Total Income				$2,700

Expenses

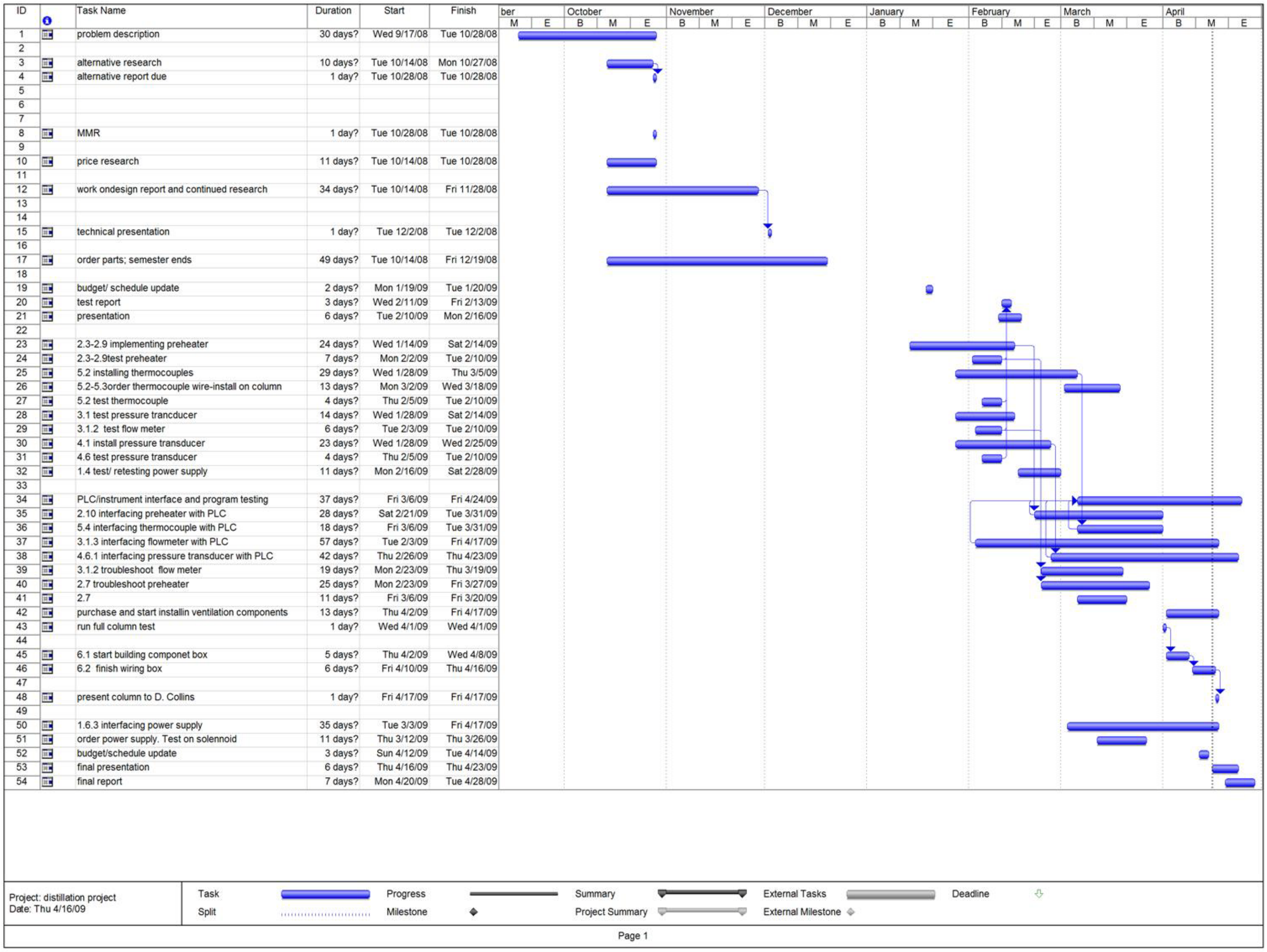
							Status (Check one)		
Date	**Vendor**	**PO #**	**Item Description**	**Status (Planned/ Pending/ Cleared)**	**Budgeted Amount**	**Actual Amount**	**DeptPO**	**PCARD**	**Reimbursement**
	DirectLogic		Base	Cleared	$ 199.00	$ 199.00		x	
	DirectLogic		LCD Screen	Cleared	$ 73.00	$ 73.00		x	
	DirectLogic		TC card	Cleared	$ 398.00	$ 398.00		x	
	DirectLogic		Analog Voltage card	Cleared	$ 115.00	$ 115.00		x	
	Omega		T-type TC	Cleared	$ 199.60	$ 210.41	x		
	Omega		Thermocouiple wire	Cleared	$ 80.00	$ 91.68	x		
	Brisk Heat		Heat Tape	Cleared	$ 147.00	$ 147.00	x		
	Brisk Heat		Adhesive	Cleared	$ 25.26	$ 26.21	x		
	Mor Electric		Insulation	Cleared	$ 19.19	$ 31.25	x		
	Omega		Flow sensor	Cleared	$ 294.00	$ 304.81	x		
	Swagelok		male connector	Cleared	$ 13.80	$ 6.60			x
	Omega		Pressure Transducer	Cleared	$ 253.00	$ 263.81	x		
	Swagelok		Reducing Adapter	Cleared	$ 7.30	$ 3.10			x
	Home Depot		1/4" Tubing Valves	Cleared	$ 6.71	$ 13.42			x
	Home Depot		1/4" Tee Fitting	Cleared	$ 5.35	$ 5.35			x
	Home Depot		1/4" Tubing Valve	Cleared	$ 6.71	$ 6.71			x
	Home Depot		1/4" Tee Fitting	Cleared	$ 5.35	$ 5.35			x
	Ferguson		2.5" Galvanized Cap	Cleared	$ 20.78	$ 20.78			x
	Brisk Heat		2x96" Heating Tape	Cleared	$ 136.00	$ 136.00	x		
	Swagelok		Thermocouple Adaptor	Cleared	$ 18.10	$ 18.10			x
	Home Depot		Heating Tape Covers	Cleared	$ 42.83	$ 42.93			x
	Radio Shack		Box Supplies	Cleared	$ 29.94	$ 29.94			x
	US Plastics		Plastic Tubing	Cleared	$ 124.69	$ 114.77	x		
	Radio Shack		Box Supplies	Cleared	$ 9.99	$ 9.99			x
	Swagelok		Valves/Fittings	Cleared	$ 51.00	$ 51.00			x
	Home Depot		Extension Cords	Cleared	$ 26.32	$ 35.45	x		
	Allied Electronics		High voltage Relay	Cleared	$ 65.04	$ 76.15	x		
	Inter Tex		Box Supplies	Cleared	$ 28.00	$ 28.00			x
	Jenny's Printing		Final Report	Cleared	$ 7.20	$ 10.94	x		
	Acopian		Power Supply	Cleared	$ 90.00	$ 96.80	x		
	Omega		female thermocouple connectors	Cleared	$ 23.60	$ 31.60	x		
Total Expenses					$2,522	$ 2,603.15			

Budget Remaining	$96.85

10 Appendix D: Bill of Materials and List of Vendors

Bill of Materials and List of Vendors		
Company	Contact Info	Items Purchased
Acopian	www.acopian.com	Power Supply
	1-610-258-5441	
Allied Electronics	www.alliedelec.com	High Voltage Relay
	1-866-433-5722	
Automation Direct	www.automationdirect.com	PLC Base
	1-800-633-0405	LCD Screen
		Thermocouple Card
		Analog Voltage Card
Brisk Heat	www.briskheat.com	1/2" X 48" Rubber Heating Tape w/ Adustable Thermostat Control
	1-800-848-7673	Fiberglass Adhesive Tape
		1/2" X 96" High Temperature Heating Tape
Ferguson	www.ferguson.com	2-1/2" Galvanized Cap
	1-210-344-4950	
Home Depot	www.homedepot.com	1/4" Tubing Valves
	1-210-824-9677	1/4" T-Fittings
		Extension Cords
Intertex	www.intertexelectronics.com	Relay
	1-800-820-3908	
Mor Electric	www.heatersplus.com	1/2" thick Fiberglass Insulation
	1-616-784-1121	
Omega		T-type Thermocouples
		Thermocouple Wire
		Flow Sensor
		0-1 psig pressure transducer
		Female Thermocouple Connectors
Radio Shack	www.radioshack.com	Power Strips
	1-210-366-0217	Fuses
		Fuses
Swagelok	www.swagelok.com	2x 1/4" compression to 1/4" female NPT tube fittings; brass
	1-210-681-7043	1/4" male NPT to 1/8" female NPT reducer, brass
		Thermocouple tubing adaptor
		2x 1/4" stainless steel tube caps
		1/4" stainless steel 3-way T
		Brass compression ferrels
		Stainless steel compression ferrels
US Plastics	www.usplastic.com	Plastic Tubing
	1-800-809-4217	

11 Appendix E: WBS and Schedule



ID	ℹ	Task Name	Duration	Start	Finish
1	▦	problem description	30 days?	Wed 9/17/08	Tue 10/28/08
2					
3	▦	alternative research	10 days?	Tue 10/14/08	Mon 10/27/08
4	▦	alternative report due	1 day?	Tue 10/28/08	Tue 10/28/08
5					
6					
7					
8	▦	MMR	1 day?	Tue 10/28/08	Tue 10/28/08
9					
10	▦	price research	11 days?	Tue 10/14/08	Tue 10/28/08
11					
12	▦	work ondesign report and continued research	34 days?	Tue 10/14/08	Fri 11/28/08
13					
14					
15	▦	technical presentation	1 day?	Tue 12/2/08	Tue 12/2/08
16					
17	▦	order parts; semester ends	49 days?	Tue 10/14/08	Fri 12/19/08
18					
19	▦	budget/ schedule update	2 days?	Mon 1/19/09	Tue 1/20/09
20	▦	test report	3 days?	Wed 2/11/09	Fri 2/13/09
21	▦	presentation	6 days?	Tue 2/10/09	Mon 2/16/09
22					
23	▦	2.3-2.9 implementing preheater	24 days?	Wed 1/14/09	Sat 2/14/09
24	▦	2.3-2.9test preheater	7 days?	Mon 2/2/09	Tue 2/10/09
25	▦	5.2 installing thermocouples	29 days?	Wed 1/28/09	Thu 3/5/09
26	▦	5.2-5.3order thermocouple wire-install on column	13 days?	Mon 3/2/09	Wed 3/18/09
27	▦	5.2 test thermocouple	4 days?	Thu 2/5/09	Tue 2/10/09
28	▦	3.1 test pressure trancducer	14 days?	Wed 1/28/09	Sat 2/14/09
29	▦	3.1.2 test flow meter	6 days?	Tue 2/3/09	Tue 2/10/09
30	▦	4.1 install pressure transducer	23 days?	Wed 1/28/09	Wed 2/25/09
31	▦	4.6 test pressure transducer	4 days?	Thu 2/5/09	Tue 2/10/09
32	▦	1.4 test/ retesting power supply	11 days?	Mon 2/16/09	Sat 2/28/09
33					
34	▦	PLC/instrument interface and program testing	37 days?	Fri 3/6/09	Fri 4/24/09
35	▦	2.10 interfacing preheater with PLC	28 days?	Sat 2/21/09	Tue 3/31/09
36	▦	5.4 interfacing thermocouple with PLC	18 days?	Fri 3/6/09	Tue 3/31/09
37	▦	3.1.3 interfacing flowmeter with PLC	57 days?	Tue 2/3/09	Fri 4/17/09
38	▦	4.6.1 interfacing pressure transducer with PLC	42 days?	Thu 2/26/09	Thu 4/23/09
39	▦	3.1.2 troubleshoot flow meter	19 days?	Mon 2/23/09	Thu 3/19/09
40	▦	2.7 troubleshoot preheater	25 days?	Mon 2/23/09	Fri 3/27/09
41	▦	2.7	11 days?	Fri 3/6/09	Fri 3/20/09
42	▦	purchase and start installin ventilation components	13 days?	Thu 4/2/09	Fri 4/17/09
43	▦	run full column test	1 day?	Wed 4/1/09	Wed 4/1/09
44					
45	▦	6.1 start building componet box	5 days?	Thu 4/2/09	Wed 4/8/09
46	▦	6.2 finish wiring box	6 days?	Fri 4/10/09	Thu 4/16/09
47					
48	▦	present column to D. Collins	1 day?	Fri 4/17/09	Fri 4/17/09
49					
50	▦	1.6.3 interfacing power supply	35 days?	Tue 3/3/09	Fri 4/17/09
51	▦	order power supply. Test on solennoid	11 days?	Thu 3/12/09	Thu 3/26/09
52	▦	budget/schedule update	3 days?	Sun 4/12/09	Tue 4/14/09
53	▦	final presentation	6 days?	Thu 4/16/09	Thu 4/23/09
54	▦	final report	7 days?	Mon 4/20/09	Tue 4/28/09

Project: distillation project
Date: Thu 4/16/09

12 Appendix F: Initial Heat Transfer Calculations

Material Properties at entrance

$$\mu_1 = \textbf{Visc}\left[\text{'isopropanol'}, T=25, P=101.325\right]$$

$$\mu_2 = \textbf{Visc}\left[\text{'Water'}, T=25, P=101.325\right]$$

$$\rho_1 = \rho\left[\text{'isopropanol'}, T=25, P=101.325\right]$$

$$\rho_2 = \rho\left[\text{'Water'}, T=25, P=101.325\right]$$

$$Pr_1 = \textbf{Pr}\left[\text{'isopropanol'}, T=25, P=101.325\right]$$

$$Pr_2 = \textbf{Pr}\left[\text{'Water'}, T=25, P=101.325\right]$$

$$k_1 = \textbf{k}\left[\text{'isopropanol'}, T=25, P=101.325\right]$$

$$k_2 = \textbf{k}\left[\text{'Water'}, T=25, P=101.325\right]$$

$$cp_1 = \textbf{Cp}\left[\text{'isopropanol'}, T=25, P=101.3\ [kPa]\right]$$

$$cp_2 = \textbf{Cp}\left[\text{'Water'}, T=25, P=101.325\right]$$

$$\rho_i = 0.5 \cdot \rho_1 + 0.5 \cdot \rho_2$$

$$\mu_i = 0.5 \cdot \mu_1 + 0.5 \cdot \mu_2$$

$$Pr_i = 0.5 \cdot Pr_1 + 0.5 \cdot Pr_2$$

$$k_i = k_1 \cdot 0.5 + 0.5 \cdot k_2$$

$$cp_i = cp_1 \cdot 0.5 + 0.5 \cdot cp_2$$

Material Properties at exit

$$\mu_3 = \textbf{Visc}\left[\text{'isopropanol'}, T=Tmo, P=101.325\right]$$

$$\mu_4 = \textbf{Visc}\left[\text{'Water'}, T=Tmo, P=101.325\right]$$

$$\rho_3 = \rho\left[\text{'isopropanol'}, T=Tmo, P=101.325\right]$$

$$\rho_4 = \rho\left[\text{'Water'}, T=Tmo, P=101.325\right]$$

$$Pr_3 = \textbf{Pr}\left[\text{'isopropanol'}, T=Tmo, P=101.325\right]$$

$$Pr_4 = \textbf{Pr}\left[\text{'Water'}, T=Tmo, P=101.325\right]$$

$$k_3 = \textbf{k}\left[\text{'isopropanol'}, T=Tmo, P=101.325\right]$$

$$k_4 = \textbf{k}\left[\text{'Water'}, T=Tmo, P=101.325\right]$$

$$cp_3 = \textbf{Cp}\left[\text{'isopropanol'}, T=Tmo, P=101.3\ [kPa]\right]$$

$$cp_4 = \textbf{Cp}\left[\text{'Water'}, T=Tmo, P=101.325\right]$$

$$\rho_o = 0.5 \cdot \rho_3 + 0.5 \cdot \rho_4$$

$$\mu_o = 0.5 \cdot \mu_3 + 0.5 \cdot \mu_4$$

$$Pr_o = 0.5 \cdot Pr_3 + 0.5 \cdot Pr_4$$

$$k_o = k_3 \cdot 0.5 + 0.5 \cdot k_4$$

$$cp_o = cp_3 \cdot 0.5 + 0.5 \cdot cp_4$$

Constants

$$D = 0.0041148\ [m]$$

$$vol = 5.0 \times 10^{-7}\ [m^3/s]$$

$$Tm = 55.65\ [C]$$

$$D_o = 0.25\ [in]$$

$$L = 30.55 \cdot \left| 0.0254 \cdot \frac{m}{in} \right|$$

$$Tmo = 91.1\ [C]$$

$$Tmi = 25\ [C]$$

$$\dot{m} = \frac{0.88}{2\ [g/s]}$$

$$q_{tape} = 5.4\ [W/in^2]$$

Entrance Calculations

$$V = \frac{vol}{\pi \cdot \left[\frac{D}{2}\right]^2}$$

$$As = \pi \cdot L \cdot D$$

$$Re_i = V \cdot \rho_i \cdot \frac{D}{\mu_i}$$

$$x_{fd,hi} = 0.05 \cdot Re_i \cdot D$$

$$x_{fd,ti} = 0.05 \cdot Re_i \cdot Pr_i \cdot D$$

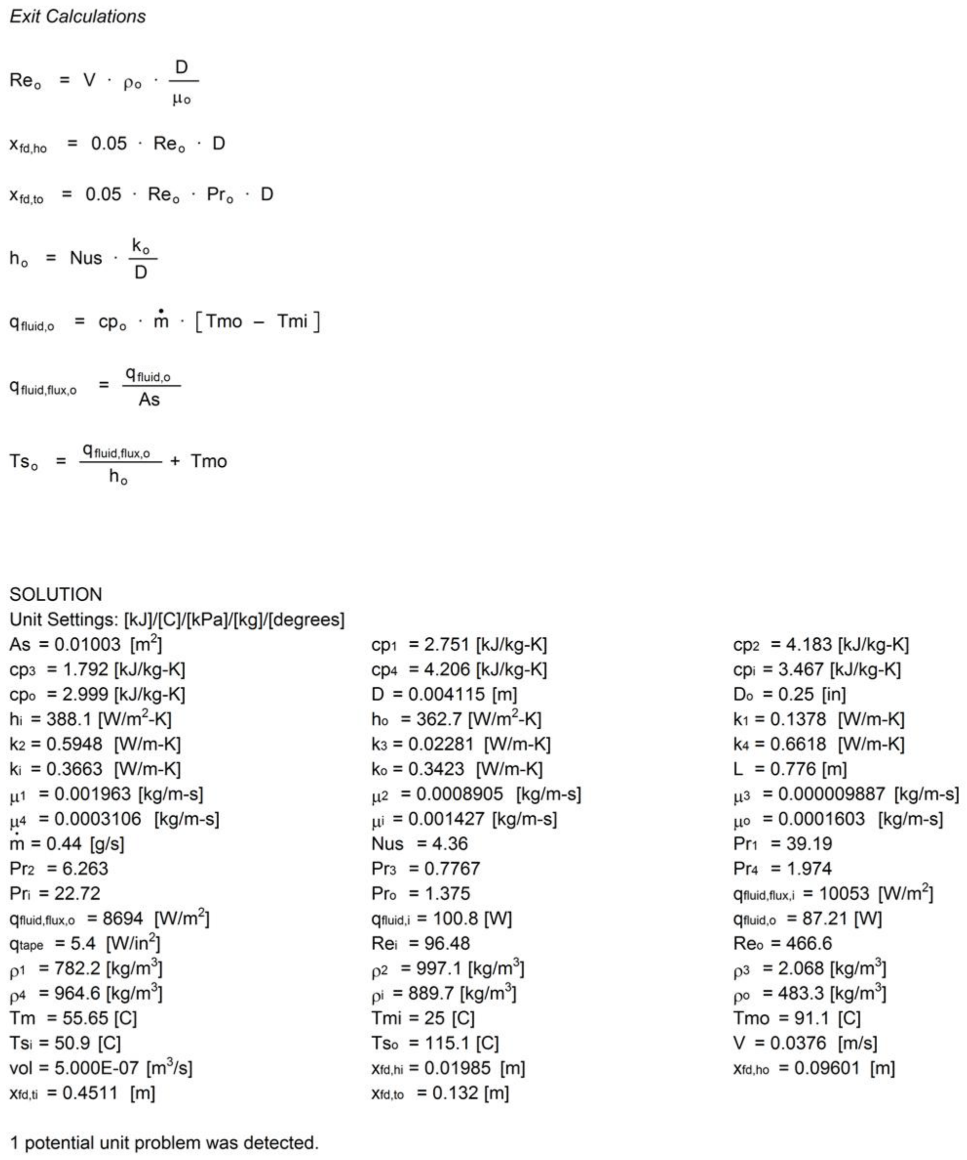
$$Nus = 4.36$$

$$h_i = Nus \cdot \frac{k_i}{D}$$

$$q_{fluid,i} = cp_i \cdot \dot{m} \cdot \left[Tmo - Tmi\right]$$

$$q_{fluid,flux,i} = \frac{q_{fluid,i}}{As}$$

$$Ts_i = \frac{q_{fluid,flux,i}}{h_i} + Tmi$$



Exit Calculations

$$Re_o = V \cdot \rho_o \cdot \frac{D}{\mu_o}$$

$$x_{fd,ho} = 0.05 \cdot Re_o \cdot D$$

$$x_{fd,to} = 0.05 \cdot Re_o \cdot Pr_o \cdot D$$

$$h_o = Nus \cdot \frac{k_o}{D}$$

$$q_{fluid,o} = cp_o \cdot \dot{m} \cdot [Tmo - Tmi]$$

$$q_{fluid,flux,o} = \frac{q_{fluid,o}}{As}$$

$$Ts_o = \frac{q_{fluid,flux,o}}{h_o} + Tmo$$

SOLUTION

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

$As = 0.01003$ [m^2]

$cp_1 = 2.751$ [kJ/kg-K]

$cp_2 = 4.183$ [kJ/kg-K]

$cp_3 = 1.792$ [kJ/kg-K]

$cp_4 = 4.206$ [kJ/kg-K]

$cp_i = 3.467$ [kJ/kg-K]

$cp_o = 2.999$ [kJ/kg-K]

$D = 0.004115$ [m]

$D_o = 0.25$ [in]

$h_i = 388.1$ [W/m^2-K]

$h_o = 362.7$ [W/m^2-K]

$k_1 = 0.1378$ [W/m-K]

$k_2 = 0.5948$ [W/m-K]

$k_3 = 0.02281$ [W/m-K]

$k_4 = 0.6618$ [W/m-K]

$k_i = 0.3663$ [W/m-K]

$k_o = 0.3423$ [W/m-K]

$L = 0.776$ [m]

$\mu_1 = 0.001963$ [kg/m-s]

$\mu_2 = 0.0008905$ [kg/m-s]

$\mu_3 = 0.000009887$ [kg/m-s]

$\mu_4 = 0.0003106$ [kg/m-s]

$\mu_i = 0.001427$ [kg/m-s]

$\mu_o = 0.0001603$ [kg/m-s]

$\dot{m} = 0.44$ [g/s]

$Nus = 4.36$

$Pr_1 = 39.19$

$Pr_2 = 6.263$

$Pr_3 = 0.7767$

$Pr_4 = 1.974$

$Pr_i = 22.72$

$Pr_o = 1.375$

$q_{fluid,flux,i} = 10053$ [W/m^2]

$q_{fluid,flux,o} = 8694$ [W/m^2]

$q_{fluid,i} = 100.8$ [W]

$q_{fluid,o} = 87.21$ [W]

$q_{tape} = 5.4$ [W/in^2]

$Re_i = 96.48$

$Re_o = 466.6$

$\rho_1 = 782.2$ [kg/m^3]

$\rho_2 = 997.1$ [kg/m^3]

$\rho_3 = 2.068$ [kg/m^3]

$\rho_4 = 964.6$ [kg/m^3]

$\rho_i = 889.7$ [kg/m^3]

$\rho_o = 483.3$ [kg/m^3]

$Tm = 55.65$ [C]

$Tmi = 25$ [C]

$Tmo = 91.1$ [C]

$Ts_i = 50.9$ [C]

$Ts_o = 115.1$ [C]

$V = 0.0376$ [m/s]

$vol = 5.000E-07$ [m^3/s]

$x_{fd,hi} = 0.01985$ [m]

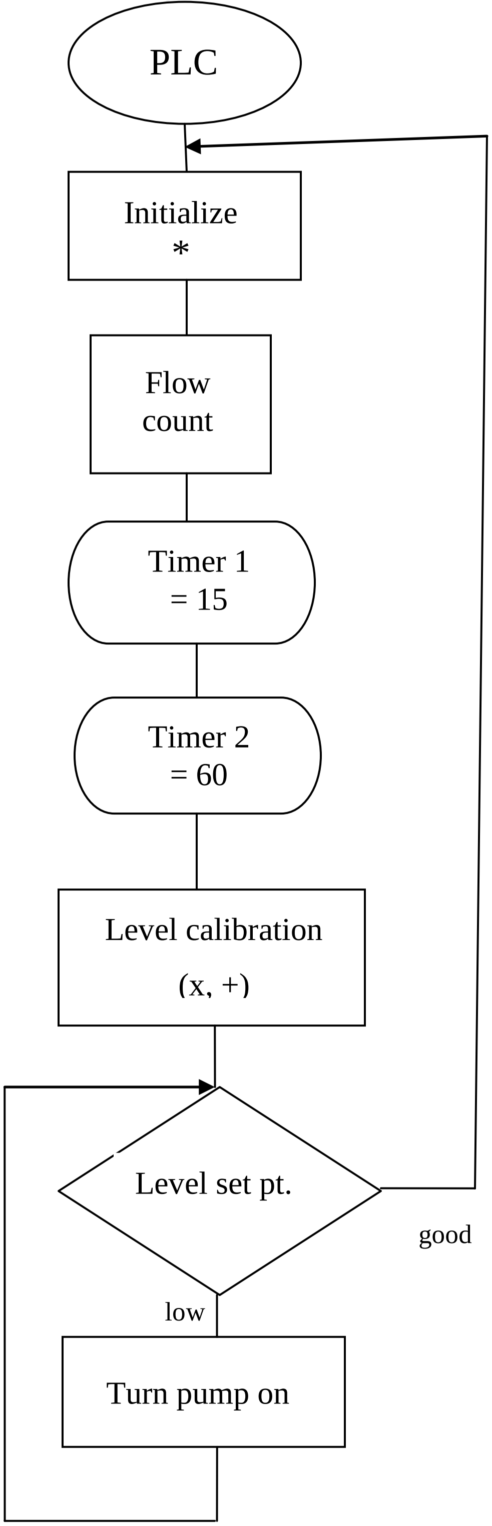
$x_{fd,ho} = 0.09601$ [m]

$x_{fd,ti} = 0.4511$ [m]

$x_{fd,to} = 0.132$ [m]

1 potential unit problem was detected.

13 Appendix G**:** PLC LadderLogic Test Schematics



* Note: Initialize scans cards, prepares formatting and settings, and sets data storage locations.

Figure 12. Column flow chart

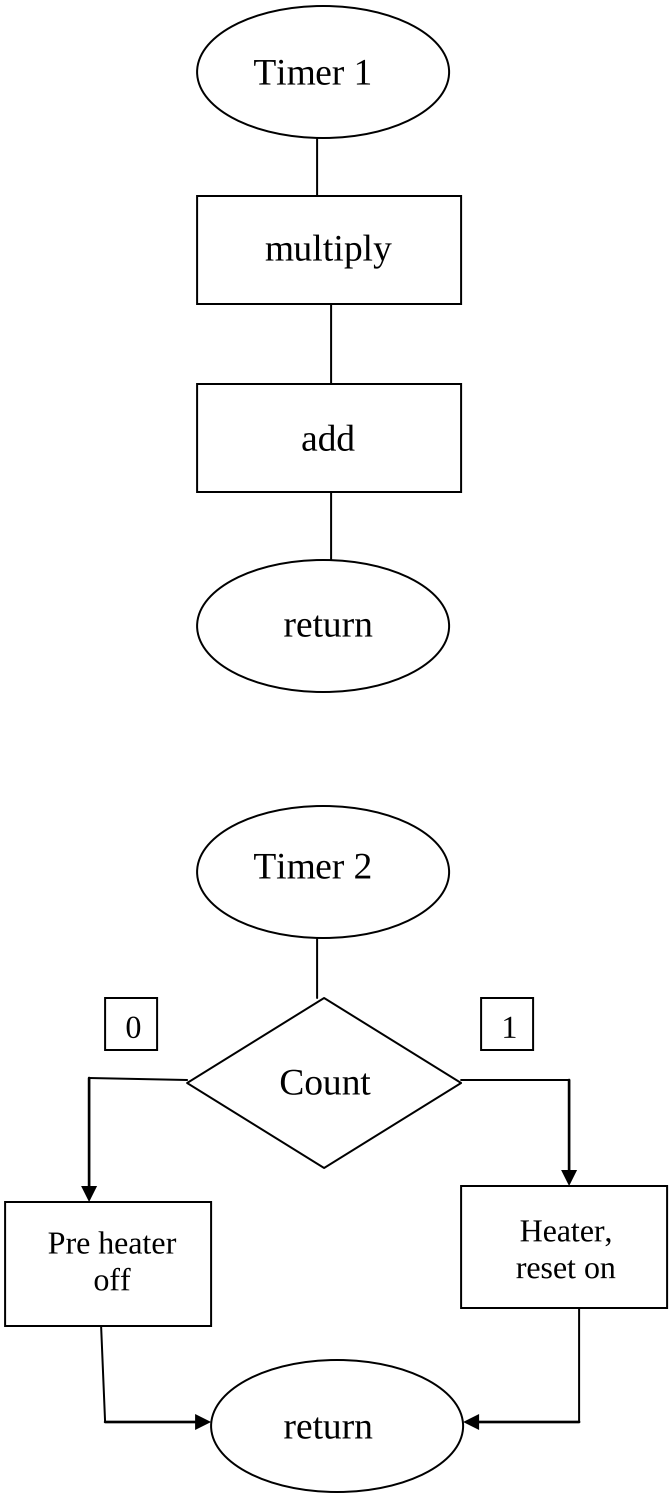


Figure 13. Column sub-routines

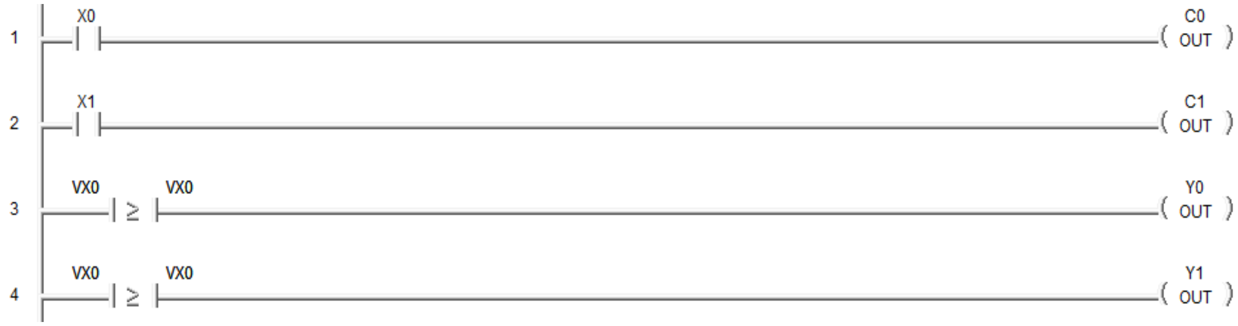


Figure 14. Analog Input Test

Figure 15. Digital Input Test

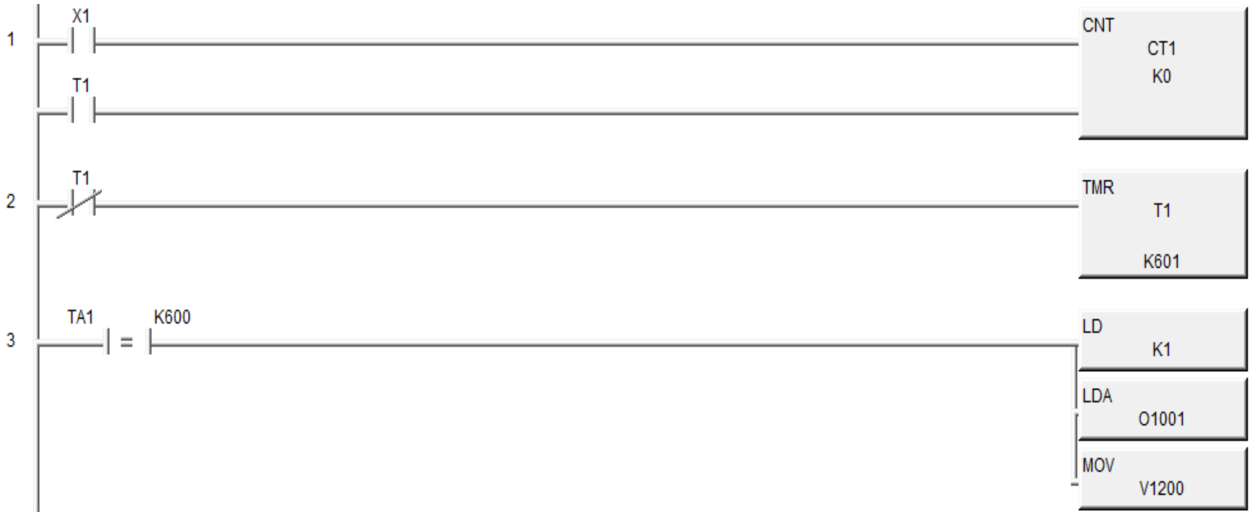


Figure 16. Flow Meter Pulse Count Test

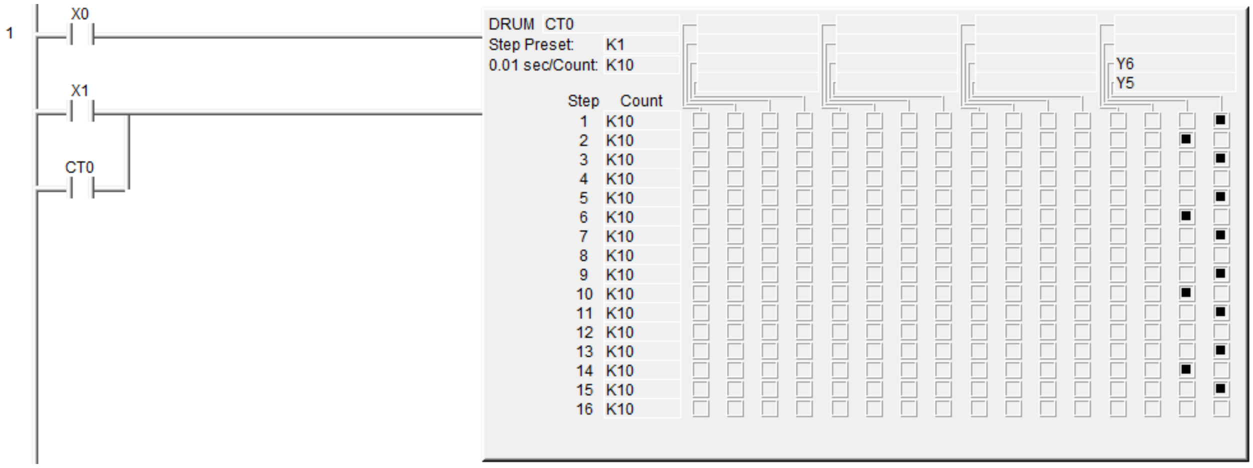


Figure 17. Heating Tape Control Test

Figure 18. Reflux Control Test

Figure 19. Thermocouple Card Read Test

14 Appendix H: Raw Testing Data

Table 1. Thermocouple Testing Raw Data

30^{o}C			**60^{o}C**		
Sample	**TC**	**Thermometer**	**Sample**	**TC**	**Thermometer**
1	29.7	30.1	1	59.18	60.5
2	29.7	30.2	2	59.2	61
3	29.7	30.5	3	59.17	60.5
4	29.7	30.7	4	59.22	60
5	29.9	30.6	5	59.24	60
6	29.6	30.5	6	59.25	60
7	29.6	30.4	7	59.24	60
8	29.6	30.5	8	59.24	60
Average	29.6875	30.4375	**Average**	59.2175	60.25
Difference	0.75		**Difference**	1.0325	
75^{o}C			**100^{o}C**		
Sample	**TC**	**Thermometer**	**Sample**	**TC**	**Thermometer**
1	76.1	77.5	1	99.2	100
2	75.9	76.5	2	99.1	100.5
3	76.3	77.5	3	99.5	100.5
4	73.85	76.5	4	100.2	100.5
5	75.78	76.5	5	101.5	100
6	75.69	76.5	6	100.1	102
7	75.79	77	7	101	100
8	76.18	76.5	8	101.5	100.6
Average	75.69875	76.8125	**Average**	100.2625	100.5125
Difference	1.11375		**Difference**	.25	

Table 2. Unit Ops Class Thermocouple Data

Thermocouple Placement	Temperature (°C)
Reflux	81
Tray 8	75
Tray 6	78.5
Tray 4	78.7
Bottoms	83
In-Line Feed	81.5
Heating Tape	83

Table 3. Pressure Transducer Testing Raw Data

Pressure, Inches of H_2O	**Voltage, V**
5	2
5.22	2.04
5.61	2.12
6.02	2.21
10.4	3.35
18.5	5.23
15.95	4.61
16	4.63
12.01	3.67
3.07	1.63
2.5	1.54
0.87	1.24
0.6	1.19
0.28	1.13
0.06	1.08

15 Appendix I: PLC Information and Specification Sheets

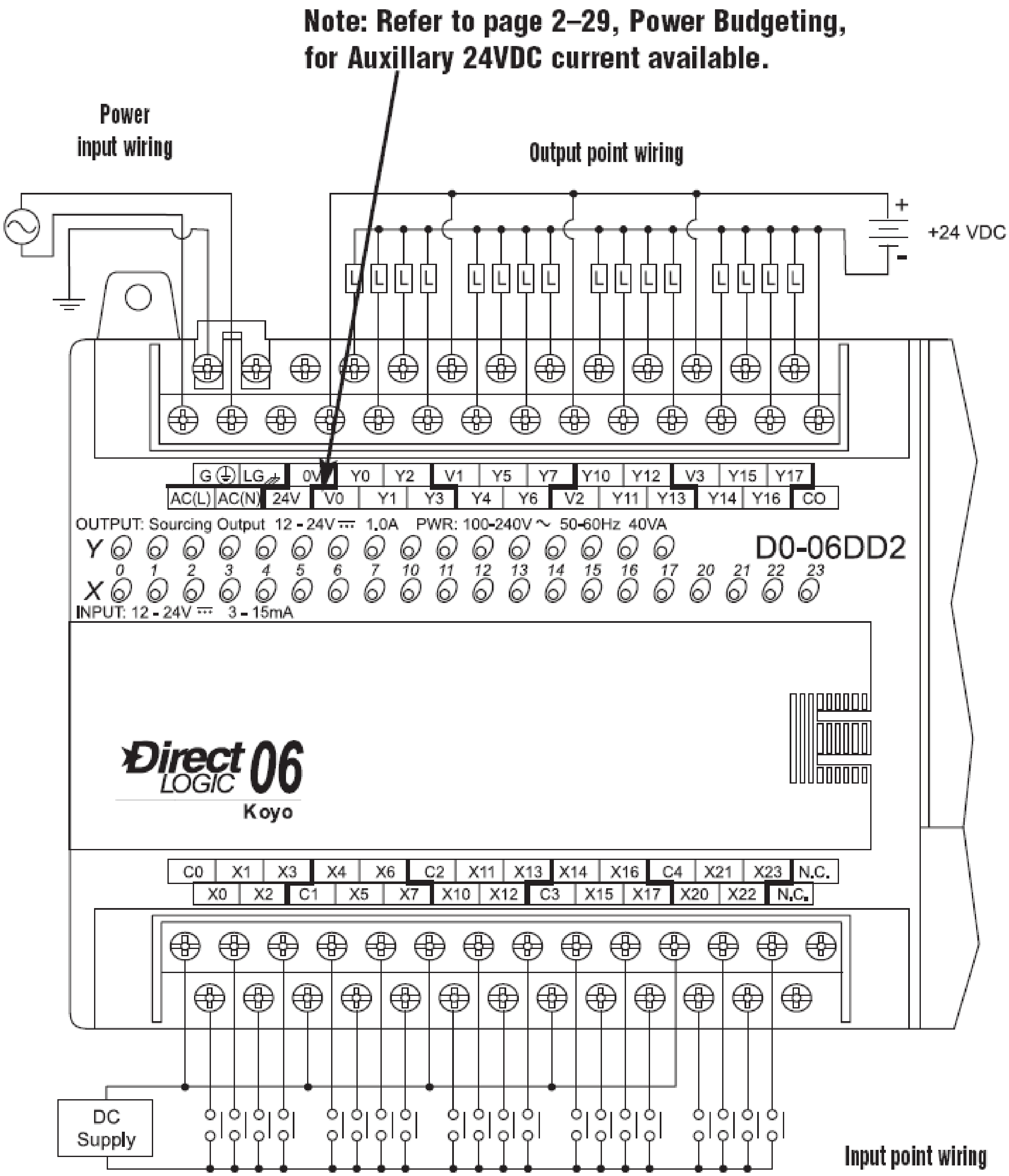


Figure 20. PLC Schematic (6)

12th Edition

Heating Tapes

BriskHeat® XtremeFLEX® HSTAT Silicone Rubber Heating Tapes with Adjustable Thermostat Control

Product Highlights

- ✓ Useful for a wide range of applications
  - Process temperature control
  - De-icing
  - Supplemental heat
- ✓ Easy dial adjustable thermostat control sets up to 425°F (218°C)
- ✓ True heating tape: flexible down to 1/4" (25mm) diameter
- ✓ Rapid heat up
- ✓ Plug and play: eliminates electrical hard wiring
- ✓ CE 73/23/EEC. See page A-1 for more information.

Moisture and Chemical Resistant

No Additional Control Needed!

Temperatures up to 425°F (218°C)

New!!

Specifications:

- Adjustable thermostat: 50 to 425°F (10 to 218°C)
- Maximum exposure temperature: 450°F (232°C)
- Silicone rubber extruded outer sheath
- Fiberglass knitted and braided construction
- Moisture and chemical resistant
- Power density: 6.0 watts/in^2 (0.009 watts/mm^2)
- Suitable for electrically conductive surfaces
- 120 or 240VAC
- 6 feet (2m) long power cord
- 120VAC model includes NEMA 1-15 plug

Ordering Information:

HSTAT

Width in (mm)	Length in (mm)	Total Watts	Part No. 120VAC	Part No. 240VAC (No plug)
0.5 (13)	24.0 (610)	72	HSTAT051002	HSTAT052002
0.5 (13)	48.0 (1220)	144	HSTAT051004	HSTAT052004
0.5 (13)	72.0 (1830)	216	HSTAT051006	HSTAT052006
0.5 (13)	96.0 (2440)	288	HSTAT051008	HSTAT052008
0.5 (13)	120.0 (3050)	360	HSTAT051010	HSTAT052010
1.0 (25)	24.0 (610)	144	HSTAT101002	HSTAT102002
1.0 (25)	48.0 (1220)	288	HSTAT101004	HSTAT102004
1.0 (25)	72.0 (1830)	432	HSTAT101006	HSTAT102006
1.0 (25)	96.0 (2440)	576	HSTAT101008	HSTAT102008
1.0 (25)	120.0 (3050)	720	HSTAT101010	HSTAT102010
2.0 (51)	24.0 (610)	288	HSTAT201002	HSTAT202002
2.0 (51)	48.0 (1220)	576	HSTAT201004	HSTAT202004
2.0 (51)	72.0 (1830)	864	HSTAT201006	HSTAT202006
2.0 (51)	96.0 (2440)	1152	HSTAT201008	HSTAT202008
2.0 (51)	120.0 (3050)	1440	HSTAT201010	HSTAT202010
3.0 (76)	24.0 (610)	432	HSTAT301002	HSTAT302002
3.0 (76)	48.0 (1220)	864	HSTAT301004	HSTAT302004
3.0 (76)	72.0 (1830)	1296	HSTAT301006	HSTAT302006
3.0 (76)	96.0 (2440)	1440	HSTAT301008	HSTAT302008
3.0 (76)	120.0 (3050)	1440/1800	HSTAT301010	HSTAT302010

*** Plug not included on 240VAC Models**

Wrap, Set, and Heat

Valves
Pipes Lines
Bearings
Pumps
Filter Housings
Actuators
And More!!

Adhesive Tape

Provides intimate contact with surface to be heated. A heating tape essential!

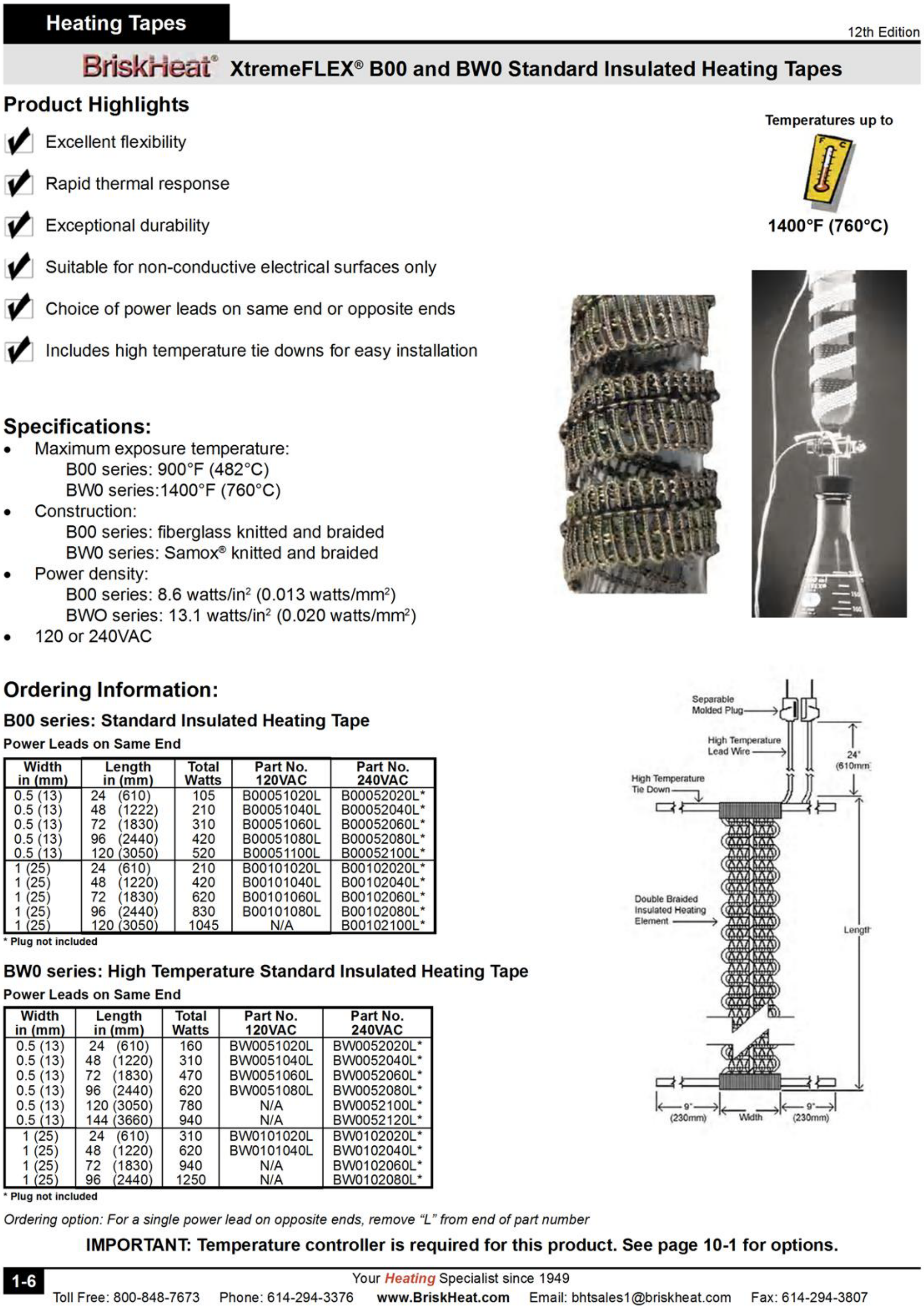
Part Number	Material	Width in (mm)	Length Yards (m)	Temperature Limit
PSAT04	Fiberglass	0.5 (13)	4 (3.6)	350°F (176°C)
PSAT36A	Fiberglass	0.5 (13)	36 (32.9)	350°F (176°C)
AAT260	Aluminum	2.0 (51)	60 (54.8)	350°F (176°C)
AAT2180	Aluminum	2.0 (51)	60 (54.8)	550°F (288°C)

Your *Heating* Specialist since 1949

Toll Free: 800-848-7673 Phone: 614-294-3376 **www.BriskHeat.com** Email: bhtsales1@briskheat.com Fax: 614-294-3807

1-3

Figure 21. Heating Tape Spec Sheet (1)



Heating Tapes

12th Edition

BriskHeat® XtremeFLEX® B00 and BW0 Standard Insulated Heating Tapes

Product Highlights

- ✓ Excellent flexibility
- ✓ Rapid thermal response
- ✓ Exceptional durability
- ✓ Suitable for non-conductive electrical surfaces only
- ✓ Choice of power leads on same end or opposite ends
- ✓ Includes high temperature tie downs for easy installation

Temperatures up to 1400°F (760°C)

Specifications:

- Maximum exposure temperature:
  - B00 series: 900°F (482°C)
  - BW0 series:1400°F (760°C)
- Construction:
  - B00 series: fiberglass knitted and braided
  - BW0 series: Samox® knitted and braided
- Power density:
  - B00 series: 8.6 watts/in^2 (0.013 watts/mm^2)
  - BWO series: 13.1 watts/in^2 (0.020 watts/mm^2)
- 120 or 240VAC

Ordering Information:

B00 series: Standard Insulated Heating Tape

Power Leads on Same End

Width in (mm)	Length in (mm)	Total Watts	Part No. 120VAC	Part No. 240VAC
0.5 (13)	24 (610)	105	B00051020L	B00052020L*
0.5 (13)	48 (1222)	210	B00051040L	B00052040L*
0.5 (13)	72 (1830)	310	B00051060L	B00052060L*
0.5 (13)	96 (2440)	420	B00051080L	B00052080L*
0.5 (13)	120 (3050)	520	B00051100L	B00052100L*
1 (25)	24 (610)	210	B00101020L	B00102020L*
1 (25)	48 (1220)	420	B00101040L	B00102040L*
1 (25)	72 (1830)	620	B00101060L	B00102060L*
1 (25)	96 (2440)	830	B00101080L	B00102080L*
1 (25)	120 (3050)	1045	N/A	B00102100L*

* Plug not included

BW0 series: High Temperature Standard Insulated Heating Tape

Power Leads on Same End

Width in (mm)	Length in (mm)	Total Watts	Part No. 120VAC	Part No. 240VAC
0.5 (13)	24 (610)	160	BW0051020L	BW0052020L*
0.5 (13)	48 (1220)	310	BW0051040L	BW0052040L*
0.5 (13)	72 (1830)	470	BW0051060L	BW0052060L*
0.5 (13)	96 (2440)	620	BW0051080L	BW0052080L*
0.5 (13)	120 (3050)	780	N/A	BW0052100L*
0.5 (13)	144 (3660)	940	N/A	BW0052120L*
1 (25)	24 (610)	310	BW0101020L	BW0102020L*
1 (25)	48 (1220)	620	BW0101040L	BW0102040L*
1 (25)	72 (1830)	940	N/A	BW0102060L*
1 (25)	96 (2440)	1250	N/A	BW0102080L*

* Plug not included

Ordering option: For a single power lead on opposite ends, remove "L" from end of part number

IMPORTANT: Temperature controller is required for this product. See page 10-1 for options.

1-6 Your *Heating* Specialist since 1949

Toll Free: 800-848-7673 Phone: 614-294-3376 **www.BriskHeat.com** Email: bhtsales1@briskheat.com Fax: 614-294-3807

Figure 22. High Temperature Heating Tape Spec Sheet (1)

MICRO-FLOW SENSORS

For Low Flow Water Applications

FP-5061, $294, shown larger than actual size.

FP-5060

$294

All Models

1 YEAR WARRANTY

MADE IN USA

- ✓ **Measures Flow Rates as Low as 0.03 GPM, 0.11 LPM**
- ✓ **Splash-Proof**
- ✓ **All Plastic Construction**

The FP-5060 Series micro-flow sensors are constructed of polyphenylene sulfide and have high material strength. The series offers two flow ranges, starting at 0.03 GPM, for clean process liquids, regardless of fluid color. These sensors can be connected to flexible tubing or rigid pipe and use standard hardware for mounting. Having only one moving part reduces their operating cost and maintenance requirements.

SPECIFICATIONS

Output Signal: Open collector NPN transistor, 10 mA max sink

Cable Length: 7.5 m (25')

Mounting: Horizontal surface ±30°

Linearity: ±1% of full range

Repeatability: 0.5% of full range

Maximum Viscosity: 20 cP

Pressure/Temperature:
0 to 80°C (32 to 176°F) @ 80 psi max

Wetted Materials:
- Sensor base, cover and rotor shaft: glass-filled polyphenylene sulfide
- Rotor: PEEK™, natural, unfilled
- Rotor O-ring: FKM
- Cover O-ring: FKM

Compatible Meters:
DPF700 (page M-5),
DPF70 (page M-22),
FPM-5500 (page F-43),
FPM-5740 (omega.com/fpm5740)

Maximum Pressure Drop:
25 psi @ max flow

Power Requirements:
5 to 24 Vdc @ 10 mA max

Dimensions: 100 L x 81 W x 36 mm H (3.96 x 3.2 x 1.42")

Weight: 250 g (9.6 oz)

🟨 ***MOST POPULAR MODELS HIGHLIGHTED!***

To Order *(Specify Model Number)*

Model No.	Price	Port Type	Flow Range LPM (GPM)
FP-5061	$294	¼ NPT	0.11 to 2.6 (0.03 to 0.7)
FP-5062	294	ISO 7/1-R¼	0.11 to 2.6 (0.03 to 0.7)
FP-5063	294	¼ NPT	1.13 to 12.11 (0.3 to 3.2)
FP-5064	294	ISO 7/1-R¼	1.13 to 12.11 (0.3 to 3.2)

Accessories

Model No.	Price	Flow Range
DPF701	$260	Rate or total panel meter, see page M-5 for complete details
FW-317	63	Reference Book: Instrumentation and Control Systems

Comes complete with operator's manual, and 7.5 m (25') of cable.

Ordering Examples:* *FP-5063,* *micro-flow sensor, 0.3 to 3.2 GPM,* *$294.

FP-5061, *micro-flow sensor, 0.03 to 0.7 GPM, and* ***DPF701,*** *meter, $294 + 260 =* ***$554.***

F-91

Figure 23. Low Flow Flow Meter Spec Sheet (2)

COMPACT PRESSURE TRANSDUCERS
ALL STAINLESS STEEL WETTED PARTS

PX481A Series
1 to 5 Vdc Output

Starts at $245

- Digitally Compensated for Excellent Total Accuracy and Interchangeability
- Gage, Absolute, Vacuum, and Compound Ranges Available
- Rugged, Compact Design
- RFI/EMI Protection
- 316L Stainless Steel Wetted Parts
- 1 to 5 V Output
- Cable and Connector Styles

OMEGA's PX481A Series transducers are designed for general industrial and commercial requirements and offer excellent performance in a wide range of applications. They are based on proven micro-machined silicon technology, providing high reliability, long-term stability, and low cost.

The PX481A is fully digitally compensated for the effects of pressure and temperature change. It is extremely accurate, with less than 0.3% FS reference accuracy and less than 1% FS over its compensated temperature range. Wetted parts are made of 316L stainless steel for a wide range of media compatibility.

PX481A-015G5V, $245, shown larger than actual size.

PX481AD-015G5V, $255, shown larger than actual size.

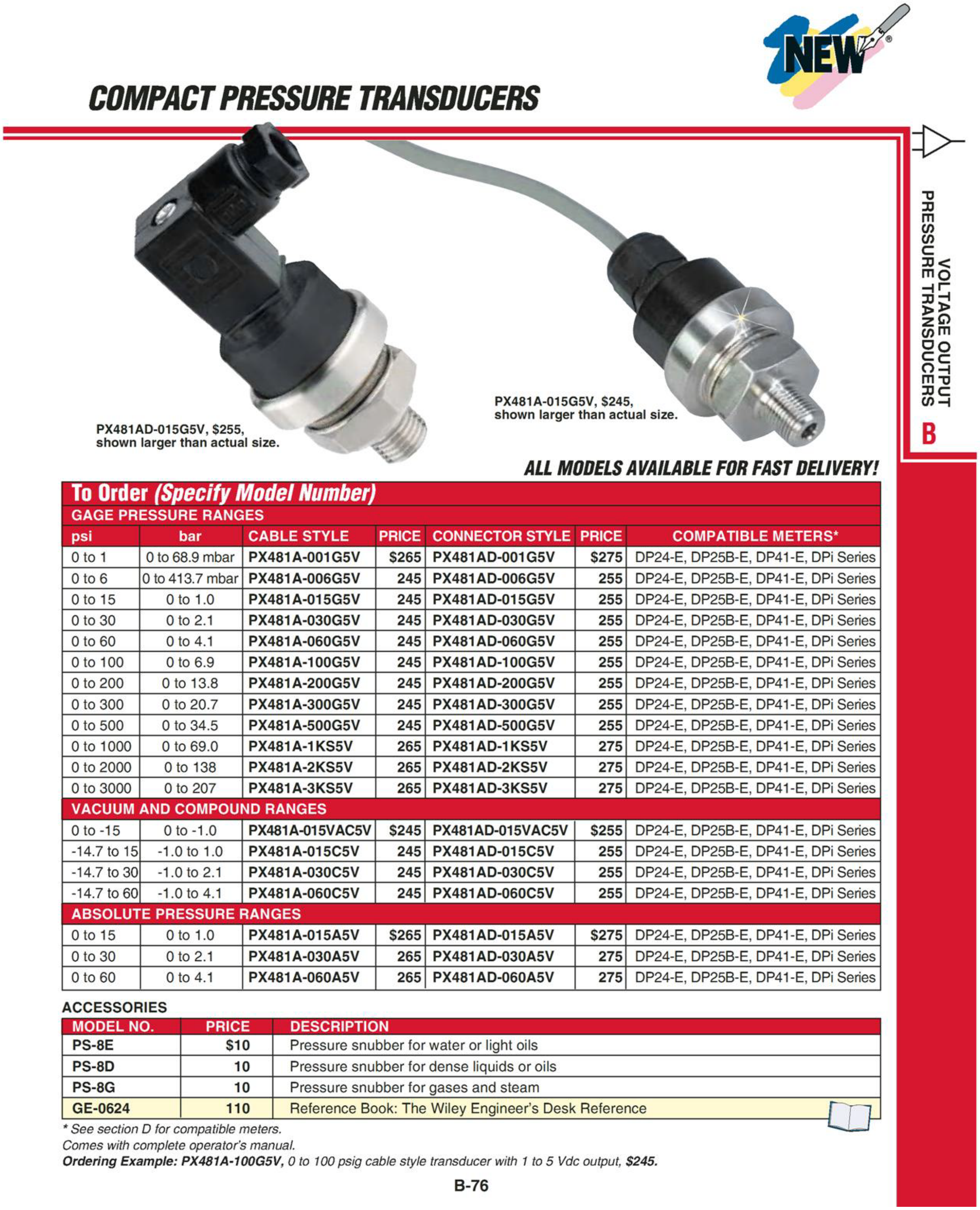
WIRING:

Color	Pin	
Red	1	Ex +
Black	2	Common
White	3	Out +
Green	4	N/C

SPECIFICATIONS

Excitation: 9 to 30 Vdc
Output: 1 to 5 Vdc (3 wire)
Load Resistance: 50,000 v minimum
Accuracy: 0.3% BFSL maximum (includes linearity, hysteresis and repeatability)
Operating Temperature: -40 to 80°C (-40 to 176°F)
Compensated Temperature: -25 to 75°C (-13 to 167°F)
Process Temperature: -40 to 100°C (-40 to 212°F)
1-Year Stability: <0.25% FS
Proof Pressure: 2x FS
Burst Pressure: 3x FS
Wetted Parts: 316L stainless steel
Vibration: 10 g, 55 to 2000 Hz
Shock: 30 g
Process Connection: ⅛ NPT male
Electrical Connection: 18" 24-gage cable or DIN 43650-A connector
Dimensions: 1⅛ hex; 72 H x 29.7 mm Dia. (2.84 x 1.17") [DIN connector adds 51 mm (2") to height]
Weight: 142 g (5 oz.)

Figure 24. Pressure trasducer specification sheet, part 1 (3)



NEW

COMPACT PRESSURE TRANSDUCERS

VOLTAGE OUTPUT PRESSURE TRANSDUCERS

B

PX481AD-015G5V, $255, shown larger than actual size.

PX481A-015G5V, $245, shown larger than actual size.

ALL MODELS AVAILABLE FOR FAST DELIVERY!

To Order *(Specify Model Number)*

psi	bar	CABLE STYLE	PRICE	CONNECTOR STYLE	PRICE	COMPATIBLE METERS*
GAGE PRESSURE RANGES						
0 to 1	0 to 68.9 mbar	**PX481A-001G5V**	**$265**	**PX481AD-001G5V**	**$275**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 6	0 to 413.7 mbar	**PX481A-006G5V**	**245**	**PX481AD-006G5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 15	0 to 1.0	**PX481A-015G5V**	**245**	**PX481AD-015G5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 30	0 to 2.1	**PX481A-030G5V**	**245**	**PX481AD-030G5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 60	0 to 4.1	**PX481A-060G5V**	**245**	**PX481AD-060G5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 100	0 to 6.9	**PX481A-100G5V**	**245**	**PX481AD-100G5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 200	0 to 13.8	**PX481A-200G5V**	**245**	**PX481AD-200G5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 300	0 to 20.7	**PX481A-300G5V**	**245**	**PX481AD-300G5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 500	0 to 34.5	**PX481A-500G5V**	**245**	**PX481AD-500G5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 1000	0 to 69.0	**PX481A-1KS5V**	**265**	**PX481AD-1KS5V**	**275**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 2000	0 to 138	**PX481A-2KS5V**	**265**	**PX481AD-2KS5V**	**275**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 3000	0 to 207	**PX481A-3KS5V**	**265**	**PX481AD-3KS5V**	**275**	DP24-E, DP25B-E, DP41-E, DPi Series
VACUUM AND COMPOUND RANGES						
0 to -15	0 to -1.0	**PX481A-015VAC5V**	**$245**	**PX481AD-015VAC5V**	**$255**	DP24-E, DP25B-E, DP41-E, DPi Series
-14.7 to 15	-1.0 to 1.0	**PX481A-015C5V**	**245**	**PX481AD-015C5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
-14.7 to 30	-1.0 to 2.1	**PX481A-030C5V**	**245**	**PX481AD-030C5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
-14.7 to 60	-1.0 to 4.1	**PX481A-060C5V**	**245**	**PX481AD-060C5V**	**255**	DP24-E, DP25B-E, DP41-E, DPi Series
ABSOLUTE PRESSURE RANGES						
0 to 15	0 to 1.0	**PX481A-015A5V**	**$265**	**PX481AD-015A5V**	**$275**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 30	0 to 2.1	**PX481A-030A5V**	**265**	**PX481AD-030A5V**	**275**	DP24-E, DP25B-E, DP41-E, DPi Series
0 to 60	0 to 4.1	**PX481A-060A5V**	**265**	**PX481AD-060A5V**	**275**	DP24-E, DP25B-E, DP41-E, DPi Series

ACCESSORIES

MODEL NO.	PRICE	DESCRIPTION
PS-8E	**$10**	Pressure snubber for water or light oils
PS-8D	**10**	Pressure snubber for dense liquids or oils
PS-8G	**10**	Pressure snubber for gases and steam
GE-0624	**110**	Reference Book: The Wiley Engineer's Desk Reference

** See section D for compatible meters.*

Comes with complete operator's manual.

Ordering Example: PX481A-100G5V,** 0 to 100 psig cable style transducer with 1 to 5 Vdc output, **$245.

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Figure 25. Pressure transducer specifications sheet, part 2; PX481A-001G5V (3)