Addendum I for Biodiesel Production: A Storage, Pump, Pipeline Transportation, and Safety Specification Alongside a Market Opportunity Assessment for Full Scale Production Capacity

Comm 10/10
Design 80/80
Opp. Design 10/10
Safety 10/10
80/80

Pod # 3

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Date: September 23rd, 2015

Terific report once again. Thanks,

My Champions
Executive Summary

In order to properly feed the reactor and produce biodiesel, a system of storing and transporting of raw feed materials (e.g. methanol and refined soybean oil) in a safe, efficient, and continuous manner is necessary for full scale production. The piping system and storage materials must be properly assessed in order to withstand 20 years of use whilst also balancing the amount of initial capital spent on the construction of the facility. Special precautions including the use of a nitrogen blanket and the use of 300 series austenitic stainless steel for the methanol storage and 316 stainless steel for the soybean oil storage prevent impurities from entering the mixture and decrease corrosion rates. The use of PVC 40 schedule piping was analyzed and specified for the transportation of both feed liquids. A pump horsepower of 1.7 and .3 was calculated for the respective methanol and oil streams. A comprehensive safety analysis is essential for ensuring plant compliance with all regulations, and a thorough analysis was conducted in this manner. Furthermore, a market opportunity assessment comparing government subsidies, consumer demand promoted by positive legislation, and close proximities to significant soybean production revealed a highly auspicious capacity for biodiesel production and profitability in the greater Midwest area.

Introduction

Per the additional request of the company, the consulting group conducted an opportunity assessment to scale the size of the plant from the previously provided scalable values to a specific operating capacity given a competitive market. Specifying the operation capacity of the plant provides an essential first step for crucial tasks, such as sizing pumps, pipes, storage tanks, reactors, etc. These systems can be properly analyzed in a meaningful manner after realistically specifying the operating capacity of the production facility.

This addendum details the necessary steps to determine the operation capacity of the plant as well as typical commercial storage conditions of the refined soybean oil as well as the methanol, in accordance with industry safety standards, needed for the specification of the pump and piping system from the storage tank farm to the biodiesel reactor.

In addition to specifying the biodiesel plant operation capacity, the consulting group performed a safety analysis accounting for ASTM standards, corrosiveness of methanol to carbon steel, as well as standard auxiliary equipment used to mitigate risks associated with the storage and transportation of methanol.
Scope of Work

The scope of work for this addendum concerned the specification of a piping and pumping system for the delivery of refined soybean oil and methanol to the biodiesel reactor given a specified product flow rate.

An economic opportunity assessment was completed in regards to potential placements for the plant. These assessment compared various items such as the following: proximity to feedstocks, government subsidies, and changing legislation that mandates an increase in the demand for biodiesel in the coming years which allowed for the specification of a yearly production of biodiesel.

This yearly production was assumed to be done on a constant around-the-clock production schedule, accounting for one week of dead time due to mechanical failures, plant maintenance, etc. This action specified the flow rate of product as well as the incoming feed streams from the refined soybean oil and methanol tanks, based on the material balance discussed in the previous report.

After the flow rates of the soybean oil and methanol were found, typical storage and safety conditions were applied to the reactant streams to specify physicochemical properties; viscosity and density are assumed to be weak functions of pressure in comparison to temperature due to the liquid state of the reactor. This is justified in the relative increase in activity of temperature in comparison to the increase in activity due to concentration increases (pressures). After the physicochemical properties of density and kinematic viscosity were known, the pumping and piping systems were specified using design heuristics and a variety of mathematical expressions, seen in Appendix A. Alongside these expressions, a variety of material and fluid specifications were quantified.

In parallel with the specification of the properties of the system, industrial standards for methanol and refined soybean oil were identified and applied to the specification of the process. This included safety standards for methanol from Methanol Institute to specify the materials of the storage tank and pipes along with various chemical or mechanical failures, e.g. tank fire or corrosion. Typical industrial storage conditions for triglyceride were also located; subsequently, these conditions specified the initial state variables of our pipe system.

Description of Work

Formulation of Mathcad Program

The consulting group was given a distance of 500 feet from the feed storage tanks to the reactor with a single valve along the line. Based on these initial parameters, Mathcad was
utilized in order to simultaneously solve for the following parameters: velocity, Reynold’s number, the diameter of the pipe, and the amount of head loss as a result of frictional losses along the length of the pipe and nine coupling units.

As depicted in the Modified Bernoulli’s Equation in Equation 1; the system was specified between labeled points 1 and 2, as depicted within Figure 1, seen below.

$$\frac{P_1}{p} + \frac{v_1^2}{2} + g \cdot z_1 - \left( \frac{P_2}{p} + \frac{v_2^2}{2} + g \cdot z_2 \right) = h_{\text{tr}} \cdot g$$

(1)

**Figure 1**: An overall PFD between the storage tanks and the main reactor.

With the system operating at a steady state between these points, the respective fluid velocities into the piping system are expected to equal the fluid velocities moving into the reactor. Without a change in height of the overall system, all kinematic and potential energy terms fall out of the expression. The major head losses of the system were attributed to the frictional losses along the length of the pipe. Since the entire length of 500 feet of piping cannot be transported without being cut into smaller segments and connecting the pieces, the minor head losses were attributed to the couplings that connect these smaller segments together. Due to lengths of piping potentially being transferred on 50’ trailers, the given section of 500 feet of piping was split into 10 sections of 50 feet each with 9 couplings in all. The minor head losses are attributed to the frictional losses at each of these nine couplings.

The overall loss in pressure between point one and point two, as depicted in Figure 1, was based on the heuristic which stated that a pressure loss of 2 psi per 100 feet of piping and a minimum of 10 psi per valve would be a great estimate (Lewin, Seider, et al., 2009). In order to assure the appropriateness of the design basis, a decision was made to estimate a pressure drop of 15 psi across the control valve to ensure proper operation. With a flowrate basis of ten million gallons per year, these factors were taken into account in order to simultaneously solve the system of equations in order to calculate a necessary pipe diameter of 2.2 cm (.9 in) and 3.9
cm (1.5 in) for the respective methanol and soybean oil streams. The horsepower necessary for
the piping systems in the methanol and soybean oil streams, respectively was found to be 1,240
W (1.66 hp) and 207 W (.28 hp). Overall, the refined opportunity assessment and the
mathematical model lead to the newly constructed material balance tables. The resulting system
of equations may be found in Appendix A.

**Table No. 1: Material Balance Reporting Template for Feed Streams**

<table>
<thead>
<tr>
<th>No.</th>
<th>Formula</th>
<th>Name</th>
<th>Mole Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H₂O</td>
<td>Water</td>
<td>0 0 0 1</td>
</tr>
<tr>
<td>2</td>
<td>NaOH</td>
<td>Sodium Hydroxide</td>
<td>0 0 1 0</td>
</tr>
<tr>
<td>3</td>
<td>C₃H₅O₃H₃</td>
<td>Glycerol</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>4</td>
<td>CH₃O(COR)</td>
<td>Methyl Ester</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>5</td>
<td>C₂H₅O₃(COR)₃</td>
<td>Triglyceride</td>
<td>1 0 0 0</td>
</tr>
<tr>
<td>6</td>
<td>C₃H₇O₃(COR)₂H₁</td>
<td>Diglyceride</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>7</td>
<td>C₃H₇O₃(COR)H₂</td>
<td>Monoglyceride</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>8</td>
<td>CH₃OH</td>
<td>Methanol</td>
<td>0 1 0 0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>T (°C)</td>
</tr>
<tr>
<td>P (atm)</td>
</tr>
<tr>
<td>H (J/hr)</td>
</tr>
</tbody>
</table>
Table No. 2: Material Balance Reporting Template for Product Streams

<table>
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<tr>
<th>No.</th>
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<th>Name</th>
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</tr>
</thead>
<tbody>
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<td>1</td>
<td>H₂O</td>
<td>Water</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>NaOH</td>
<td>Sodium Hydroxide</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>C₃H₅O₃H₃</td>
<td>Glycerol</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>CH₃O(COR)</td>
<td>Methyl Ester</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>C₃H₇O₃(COR)₃</td>
<td>Triglyceride</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>C₃H₇O₃(COR)₂H</td>
<td>Diglyceride</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>C₃H₇O₂(COR)H₂</td>
<td>Monoglyceride</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>CH₃OH</td>
<td>Methanol</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1</td>
</tr>
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</table>

Process Conditions

<table>
<thead>
<tr>
<th></th>
<th>T (°C)</th>
<th>P (bar)</th>
<th>H (J/hr)</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>65</td>
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<tr>
<td></td>
<td>65</td>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Specification of materials relating to piping systems

When looking at the products expected to be transported, the negative chemical interactions, environmental breakdown, cost, and efficiency of transport were taken into account. Specifying the material of construction for the transportation of methanol required research and reference the amount of chemical resistance of various types of transportation piping materials. Around this alcohol, both carbon steel and polyvinyl chloride (PVC) have a positive/very good rating with respect to chemical resistance. (Uni-Bell, 2013).

In terms of absolute roughness and the overall efficiency of transferring liquids across these respective surfaces, PVC piping and other drawn tubing bears a much lower absolute roughness coefficient than alternative kinds of metal piping. As a result of this discrepancy, moving a fluid across carbon steel would require more energy and horsepower than the piping system composed of PVC ("Absolute Roughness", 2012).

In addition to added efficiency, the PVC piping material was calculated to have a resistance to a theoretical pressure greater than the pressure supplied by the system. After calculating the amount of power that needed to be supplied by the pump in order to properly
propel the liquids over a given distance, the following equation was utilized in order to calculate the amount of pressure experienced inside the pipe after the pump:

\[ H (\text{ft}) = 2.31 \cdot \frac{P \,(\text{psi})}{SG} \, . \quad (2) \]

Incorporating the amount of head supplied by the pump and the specific gravity of both fluids, internal pressures of 24.95 psi and 57.68 psi resulted for the methanol and soybean oil streams, respectively. These values were compared to the maximum operating capacities of schedule 40 PVC pipes from a manufacturer’s specification sheets and were found to be well within the maximum operational capacity ("PVC Pipe-Schedule 40", 2015).

In addition to these respective characteristics, the cost of materials is an important point to pursue. A basic cost ratio comparison shows that carbon steel is over double the price, per foot, when compared to schedule 40 PVC piping ("Piping Materials").

Overall, as a result of the above comparative analysis, a determination was made to use PVC schedule 40 pipe over a mild carbon steel piping material. While both materials have similar chemical resistances to the processed fluids (methanol and refined soybean oil) and they are both able to withstand the operating pressures of the system, a lesser degree of degradation to weather effects, a lower cost, and a lower friction factor is associated with the use of schedule 40 PVC piping.

**Specification of the pumps for both pipelines**

In terms of materials of construction, carbon steel is rated as a grade A material for pumps moving methanol and soybean oil ("Chemical Compatibility Guide," 2013). Nevertheless, to further increase the lifetime of the device, the 300 series austenitic stainless steel will promote a higher chemical resistance and promote the longevity of the apparatus. ("Atmospheric Above Ground," 2011) Comparing the two most common pumps in industry, centrifugal and positive displacement pumps, a number of benefits arise from utilizing centrifugal pumps for this process. ("Centrifugal Pumps," 2010). While the efficiency and possible flow rate of a centrifugal pump dramatically decreases as the viscosity dramatically increases, neither fluid is viscous enough to have a significant impact. Ultimately, a centrifugal pump has higher efficiency than a positive displacement pump based on the viscosities of the fluids in use. ("When to Use," 2007). The volumetric flow rates of each pipeline satisfy the heuristic for a single stage centrifugal pump being capable of pumping at a rate of 15-5000 gpm (Walas, 2002). Furthermore, due to the use of fluids which have a lower viscosity and the ability of the pump to have a higher efficiency, the use of a centrifugal pump is the most appropriate for both pipelines.
Specification of the storage tank conditions

Due to methanol being a flammable, explosive, and corrosive material, special precautions need to be in place in order to ensure the longevity and safety of the storage system. At a minimum and due to the corrosive capabilities of the fluid, specially coated carbon steel must be used in order to prevent quick degradation. In this case, the use of 300 series austenitic stainless steel is preferred based on its much longer life cycle and a decreased likelihood of inputting impurities into the mixture (“Atmospheric Above Ground,” 2011). Due to its potentially explosive properties, a pressurized nitrogen blanket is to be kept above the liquid mixture while maintaining a concentration of methanol below the lower explosive limit (LEL) of 6.7% (“Lower and Upper,” 2001). The temperature of the liquid should also be kept below 11.1°C in order to remain below the flash point of the liquid (“Atmospheric Above Ground,” 2011). Desiring to remain far below this point, a 0 °C temperature was chosen for the liquid. The vapor pressure for the liquid may then be found using Antoine’s equation:

\[ \log_{10}(P) = A - \left( \frac{B}{T + C} \right) \]  
(Ambrose, Sprake, et al. 1975) (3)

Taking into account this vapor pressure and the total pressure of the gas above the liquid, the composition of methanol in the nitrogen gas can be found above the liquid layer with the following expression:

\[ y_{\text{Methanol}} = \frac{P_{\text{Sat, Methanol}}}{P_{\text{Total}}} \]  
(4)

With Equation (4), the amount of methanol in the nitrogen gaseous mixture is calculated to be 3.9 percent, which is below the lower explosive limit. With this total pressure inside the tank and the outlet being at the bottom of the tank, the amount of nitrogen dissolved into the methanol is kept at a minimum.

With soybean oil’s flash point being much higher than methanol at around 317°C, many less precautions need to be in place for the safe storage of soybean oil (“Physical Properties,” 2005). At this temperature, a nitrogen blanket is not necessary to keep the oil from catching fire, though one is preferred to prevent premature oxidation of the triglycerides into fatty acids. The pressure inside the tank is also allowed to remain at one atmosphere. A mild steel is not appropriate for the storage of oily fatty acids; instead, a storage container constructed of 316 stainless steel should be used (Berger, 2010).

Safety analysis for proper material handling, use, and storage

Accounting for safety is of crucial importance when designing a biodiesel production facility. Ensuring that all safety regulatory codes are being followed and that a great amount of
attention is consistently driven toward safety is a top priority. Historically, biodiesel plants have a poor record of plant safety due to such a high amount of highly flammable and toxic substances used in the process. There also is a record of methanol fires and plant explosions from biodiesel plants. Due to this, a close look at the process safety needs to be done.

One of the main safety issues identified is the lack of safe storage, handling, and use of hazardous substances. The first step toward improving on this is to create a Process Safety Management (PSM) program. Code 29 in the code of federal regulations under CFR 1910.119 requires that a PSM program is mandated if more than 10,000 pounds (1,517 gallons) of methanol is present in a production facility (Moss, 2010). The PSM must consist of 14 elements at minimum which are the following: employee participation, process safety information, process hazard analysis, operating procedures, training, contractors, pre-start up safety review, mechanical integrity, hot work permit, management of change, incident investigation, emergency planning and response, compliance audits, and trade secrets. (Ross, 2013) With a PSM program in place, this can account for ensuring a safer procedure of production and chemical handling. When deciding equipment for production it is also important to take into account the material used and any safety issues associated with that material. Piping, tubing, and valves must meet chemical compatibility and durability requirements. Biodiesel can often degrade natural rubber hoses and gaskets, which leads to fuel leaks and spills. Materials such as brass, bronze, copper, lead, tin, and zinc should also be avoided due to potential interference with the chemical reaction (VSU – VA Cooperative Extension).

Proper storage of chemicals will also improve on production safety. Methanol is one of the most dangerous chemicals at biodiesel facilities and therefore requires the most care when storing. Methanol tanks must be grounded to account for potential hazards from static discharge. All methanol piping and valves should be properly labeled and must have the direction of flow indicated. Tank farms for methanol storage must also have above ground piping (Methanol Institute, 2013). Unlike the storage of soybean oil, an inert nitrogen blanket is needed in order to prevent an in-tank fire. It was determined that producing a total pressure of 1 atmosphere (101.3 kPa or 1 bar) would be sufficient enough to lower the vapor fraction of methanol below the lower explosive limit of 6.7%, on a molar basis (“Lower and Upper,” 2001).

In addition to developing a PSM program. A complete layer of protection analysis (LOPA) will be developed in order to account for different accident scenarios that may occur during production. LOPA can best be defined as a “simplified method of risk assessment that provides the much-needed middle ground between a qualitative process hazard analysis and a traditional, expensive quantitative risk analysis.” (“Layer of Protection Analysis,” 2001). LOPA begins with identifying a certain accident scenario and fully evaluate initiating event frequency, independent layers of protection, and consequences to provide an order-of-magnitude estimate of risk.
Biodiesel production safety regulations

Several OSHA regulatory codes that must be followed for biodiesel storage, use, and handling. The following two OSHA codes must be obliged by for biodiesel production: OSHA 1910.106 and OSHA 1910.119. OSHA 1910.106 is a standard in place for all flammable and combustible liquids; the standard states that all sources of ignition must be eliminated “in locations where flammable vapors may be present.” Sources of ignition may include open flames, lightning, smoking, cutting and welding, hot surfaces, frictional heat, sparks (static, electrical, and mechanical), spontaneous ignition, chemical and physical-chemical reactions, and radiant heat. OSHA 1910.119 is OSHA’s Process Safety Management Regulation and exists to protect plants and workers from catastrophic releases of toxic, flammable, and explosive chemicals (“Process Safety Management for Biodiesel”).
Overall Material Balance for Biodiesel Production from Refined Soybean Oil Methanol and Sodium Hydroxide as the Base Catalyst

Opportunity Assessment

Plant Location
A comparison of multiple markets demonstrated that the Midwestern United States provided the most lucrative opportunities for biodiesel production. This data is based on parameters such as bio-fuel friendly populations, reduced shipping costs of feedstock to the facility and biodiesel to the consumer, and government subsidies and tax allowances (Afdc.energy.gov, 2015). Upon review of various Midwestern states, it is our recommendation to locate the facility in the state of Ohio, and specifically in Mansfield, Ohio. This determination was made after an analysis of soybean production, government assistance for biodiesel production, and cost comparison per acre of industrial properties throughout the state (Cityfeet.com, 2015).

Supply and Demand
Ohio currently has two producers of biodiesel with a combined annual capacity of 69 million gallons per year (US Energy Information Administration); however, Ohio is in the top five states for soybean planted acreage and can provide a consistent feedstock that is close to the plant location in order to minimize shipping costs (USDA.gov, 2015). Additionally, Ohio has passed regulation requiring “all newly acquired state agency vehicles must be capable of using an alternative fuel” with alternative fuels being defined as “fuel blends containing at least 20% biodiesel (B20)” (Afdc.energy.gov, 2015). This translates into a market that is highly promising in terms of supply for the feedstock, increased demand exceeding current production capacity, and a state government that is very pro-biodiesel.

Overall Costs and Government Incentives
Overall production costs are estimated to be $1.60 to $2.00 per gallon utilizing soybean oil as feedstock (Coltrane). The current price for biodiesel just in the state of Ohio is $4.01 to $4.25 per gallon (Altfuelprices.com, 2015). With a production capacity of 10 million gallons per year, the overall gross production costs would be approximately $16 to $20 million per year, with a gross profit of $40.1 to $42.5 million per year, allowing for a potential net profit margin between $22.5 and $24.1 million per year. Ohio also has very beneficial incentives for biodiesel production such as, Clean Diesel School Bus Fund Retrofits Grant Program, which allows for grants to upgrade school buses to biodiesel consumption, thereby increasing overall demand, and the Alternative Fuel Transportation Program which “will provide loans for up to 80% of the cost to convert fleet vehicles to alternative fuel and for the purchase and installation of fueling facilities offering E85; fuel blends containing at least 20% biodiesel (B20)” and “also provide funding for up to 80% of the incremental cost of purchasing and using alternative fuel for businesses, nonprofit organizations, public school systems, and local governments” (Afdc.energy.gov, 2015).

Overall Market Increase for Soybean Demand & Biodiesel Production

A projected increase in soybean demand by 2020 to a total of 3.6 billion pounds per year will be able to sustain the production of approximately 500 million gallons per year of biomass-biodiesel (USDA Agricultural Projections to 2020). Current Federal Regulations are requiring a US production of 1 billion gallons of biomass-biodiesel per year since 2007, and up through 2022 (http://www3.epa.gov, 2015). In June 2015, 122 million gallons of biodiesel were produced from approximately 911 million pounds of feedstocks. 474 million of that was from soybeans (US Energy Information Administration).
Discussion of Findings

PVC piping diameters of 3.9 and 2.2 cm are readily available for purchase for the construction of the piping system; these sizes appear to be realistic for a typical production facility. Purchasing and incorporating pumps that input power at a rate of 207 and 1,241 Watts would not prove to be too difficult. The safety analysis of both feedstocks has shown to produce valuable methods by which efficiency/longevity of materials may be increased and the likelihood of critical failure may be decreased. The opportunity assessment also showed an especially pertinent and valuable probability of success in one part of the greater Midwest area.

Conclusion

Through the opportunity assessment, a sizable opportunity exists for the utilization of biodiesel as an alternative fuel source to fossil fuels. Substantial amounts of research went into the levels of a supply and demand for the product, the amounts of government incentives, and considerations on plant location. After identifying a suitable full-scale production capacity, a safety analysis was conducted to more fully evaluate criterion of the plant. This allowed for the determination of pipe and pump sizing. Overall, the use of 3.9 and 2.2 cm diameter PVC piping and pumps that input power at a rate of 207 and 1,241 Watts was found to produce the wanted outcome for a feasible and efficient production process. This is supported by the calculations performed in the Description of Work. By conducting the opportunity assessment, determining the pipe/pump sizings, and revising the overall material balance, the design process is more properly set up for future specifications and modeling.

Future Work

The development of an opportunity assessment identifying full-scale production capacity and specifications of pipe and pump sizes, along with the revision of the overall material balance of the biodiesel reactor grants an improved understanding of the current biodiesel design. In addition to the items previously stated, subsequent analyses are needed to further specify and design this system. As a large discrepancy currently exists between the temperature of the feed streams inside of the pipe and the necessary temperature within the reactor, these analyses include the use of heat exchangers for the two feed streams to the reactor. Further unit operations requiring analysis include, but are not limited to, the following: compressors, exchangers, tanks, separators, reactors, and pre-reaction operations. Other future works will involve an economic analysis to determine cost-effectiveness, as well as additional design parameters to include, but not limited to, fully specified heat exchangers, storage tanks, and potential marketing strategies.
for byproducts. Furthermore, small scale experiments are desired to obtain experimental kinetic and thermodynamic data on the proposed biodiesel process.
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Appendices

Appendix A: Mathematical Program for Calculating Necessary Pipe Diameters and Pump Specifications for the Respective Methanol and Soybean Oil Pipeline Transportation Streams
Appendix A:
Mathematical Program for Calculating Necessary Pipe
Diameters and Pump Specifications for the Respective
Methanol and Soybean Oil Pipeline Transportation Streams

Methanol

Knowns/Defined Variables

\[ T_w := 0 \, \text{C} \quad \text{These are the conditions inside of the storage tank and are, therefore, the} \]
\[ P := 1 \, \text{atm} \quad \text{conditions inside of the pipeline.} \]
\[ \text{visc} := \frac{824325}{1000} = 8.243 \times 10^{-4} \, \text{Pa} \cdot \text{s} \quad (Xiang, Laesecke, Huber, 2006) \]
\[ p := 809.89 \, \frac{\text{kg}}{\text{m}^3} \quad (Xiang, Laesecke, Huber, 2006) \]
\[ L := 500 - 3048 = 152.4 \, \text{m} \quad \text{This length was specified by the employer.} \]
\[ L_{pd} := 6894.75 \cdot 2.5 = 6.895 \times 10^3 \, \text{Pa} \quad \text{Pressure drop due to frictional losses over the length of the} \]
\[ V_{pd} := 6894.757 - 15 = 1.034 \times 10^5 \, \text{Pa} \quad \text{Pressure drop due to frictional losses associated with the} \]
\[ \text{valve based on written heuristics. (Lewin, Seider, et al)} \]
\[ \Delta P := L_{pd} + V_{pd} = 1.724 \times 10^5 \, \text{Pa} \quad \text{Total pressure drop.} \]
\[ Q := 6.00119955023 \, \frac{\text{m}^3}{\text{s}} \quad \text{The specified flow rate from the opportunity} \]
\[ \text{assessment was converted to m/s}^3. \]
\[ g := 9.81 \quad \text{Gravity} \]
\[ K_f := 0.04 \, \frac{\text{m}}{\text{s}^2} \quad \text{Resistance coefficient for a coupling/connection between two sections of pipe.} \]
\[ p_i := \frac{355}{113} \quad \text{The amount of power, in SI and english units, for} \]
\[ \text{the amount of power needed to be supplied by a} \]
\[ \text{pump.} \]
\[ \text{Power} := Q \cdot \Delta P = 1.241 \times 10^3 \, \text{Watts} \]
\[ HP := \text{Power} \cdot 0.00134102209 = 1.664 \, \text{Horsepower} \]
Guess Values

\[ v_1 := 6 \quad \text{Velocity at point 1} \]
\[ v_2 := 1 \quad \text{Velocity at point 2} \]
\[ \text{vavg} := \frac{(v_1 + v_2)}{2} \quad \text{Average velocity} \]
\[ hlt := 1 \quad \text{Total head loss} \]
\[ h_l := 1 \quad \text{Major head loss} \]
\[ h_{lm} := 1 \quad \text{Minor head loss} \]
\[ f := .01 \quad \text{Darcy friction factor} \]
\[ D := .03 \quad \text{Diameter of the pipe} \]
\[ Re_{\infty} := 1000 \quad \text{Reynold's Number} \]

Given

Relevant Equations

\[ Q = \frac{\pi D^2 \cdot \text{vavg}}{4} \quad 1) \text{Flowrate Equation: showing the relationship between Ac, average Velocity, and the overall flowrate.} \]
\[ Re = \frac{(p \cdot \text{vavg} \cdot D)}{\text{visc}} \quad 2) \text{The expression for Reynold's number: (inertial forces)/(viscous forces). Re<2100 qualifies as laminar flow.} \]
\[ P = Q \cdot \Delta \text{p} \quad 3) \text{Power Equation: showing the relationship between the overall flowrate, the pressure drop of the system, and the required power to overcome that drop.} \]
\[ \text{vavg} = \frac{(v_1 + v_2)}{2} \quad 4) \text{Equation for the to find the average velocity between point 1 and point 2.} \]
\[ h_l = \frac{\text{vavg}^2}{2g} \cdot f \cdot \frac{L}{D} \quad 5) \text{Equation for the major head losses as a result of frictional forces across the length of the pipe (with the Darcy Friction Factor).} \]
\[ h_{lm} = K \left( \frac{\text{vavg}^2}{2g} \right) \quad 6) \text{Equation for the minor head losses as a result of the frictional forces across each one of the pipe connections.} \]
\[ h_{lt} = h_l + h_{lm} \quad 7) \text{Equation for total head loss (major + minor) = total} \]
\[ \left( \frac{v_1^2 - v_2^2}{2g} \right) + \frac{\Delta \text{p}}{p \cdot g} = h_{lt} \quad 8) \text{Modified Bemoulli's Equation incorporating the total head loss with no change in height.} \]
\[ \frac{\pi D^2 \cdot v_1}{4} = D^2 \frac{\pi}{4} \cdot v_2 \quad 9) \text{Equation showing the relationship between the Area and velocity at the two specified points. (A1V1=A2V2). In this case, the area and diameter of the pipe remains constant.} \]
\[ f = \frac{64}{Re} \quad 10) \text{Friction Factor Epression for laminar flow. The system of equations was initially solved with the Colebrook Equation, until a low Reynold's number was realized.} \]
**Solutions**

\[
\text{Find}(v_1, v_2, v_{avg}, h_{lt}, h_l, h_{lm}, f, Re, D, P) = \\
\begin{array}{|c|c|}
\hline
& 0 \\
0 & 19.466 \\
1 & 19.466 \\
2 & 19.466 \\
3 & 21.695 \\
4 & 20.923 \\
5 & 0.773 \\
6 & 1.542 \cdot 10^{-4} \\
7 & 4.15 \cdot 10^5 \\
8 & 0.022 \\
9 & 1.241 \cdot 10^3 \\
\hline
\end{array}
\]

- Velocity_Point1
- Velocity_Point2
- Average_Velocity
- Total_Head_Loss
- Major_Head_Loss
- Minor_Head_Loss
- Friction_Factor_Coefficient
- Reynolds_Number
- Diameter_of_Pipe
- Power_Required
Appendix A:
Mathematical Program for Calculating Necessary Pipe
Diameters and Pump Specifications for the Respective
Methanol and Soybean Oil Pipeline Transportation Streams

Refined Soybean Oil

Knowns/Defined Variables

$T_0 := 25$ °C  
These are the conditions inside of the storage tank and are, therefore, the
conditions inside of the pipeline.

$P := 1$ atm

$\text{visc} := \frac{53.5}{1000} = 0.0535 \text{ Pa} \cdot \text{s}$  \("Physical Properties of Fats and Oils", 2005)

$p := 920 \frac{\text{kg}}{\text{m}^3}$  \("Physical Properties of Fats and Oils", 2005)

$L := 500 \cdot 0.3048 = 152.4 \text{ m}$  
This length was specified by the employer.

$f := 0.15 \cdot D := 0.35 \cdot V_1 := 6 \times 10^{-6} \text{ Pa}$  
Pressure drop due to frictional losses over the length of the
pipe based on written heuristics. (Lewin, Seider, et al)

$V_{pd} := 6894.757 \cdot 15 = 1.034 \times 10^5 \text{ Pa}$  
Pressure drop due to frictional losses over the length of the
pipe based on written heuristics. (Lewin, Seider, et al)

$\Delta P := L_{pd} + V_{pd} = 1.724 \times 10^5 \text{ Pa}$  
Total pressure drop.

$Q := 0.00119955023 \frac{\text{m}^3}{\text{s}}$  
The specified flow rate from the opportunity
assessment was converted to m/s³.

$g := 9.81 \frac{\text{m}}{\text{s}^2}$  
Gravity

$K := 0.04$  
Resistance coefficient for a coupling/connection between two sections of pipe.

$\pi := \frac{355}{113}$

$\text{Power} := Q \cdot \Delta P = 206.765 \text{ Watts}$  
The amount of power, in SI and english units, for
the amount of power needed to be supplied by a
pump.

$\text{HP} := \text{Power} - 0.00134102209 = 0.27 \text{ Horsepower}$
Guess Values

\( \chi_{1} := 6 \quad \text{Velocity at point 1} \)

\( v_{2} := 1 \quad \text{Velocity at point 2} \)

\( v_{\text{avg}} := \frac{(v_{1} + v_{2})}{2} \quad \text{Average velocity} \)

\( h_{\text{lt}} := 1 \quad \text{Total head loss} \)

\( h_{l} := 1 \quad \text{Major head loss} \)

\( h_{\text{lm}} := 1 \quad \text{Minor head loss} \)

\( f := 0.01 \quad \text{Darcy friction factor} \)

\( D := 0.03 \quad \text{Diameter of the pipe} \)

\( \text{Re}_{\infty} := 1000 \quad \text{Reynold's Number} \)

Given

Relevant Equations

\( Q = \frac{\pi}{4} \cdot D^{2} \cdot v_{\text{avg}} \quad 1) \text{Flowrate Equation: showing the relationship between } Ac, \text{ average Velocity, and the overall flow rate.} \)

\( \text{Re} = \frac{(p \cdot v_{\text{avg}} \cdot D)}{\text{visc}} \quad 2) \text{The expression for Reynold's number: (inertial forces)/(viscous forces).} \quad \text{Re}<2100 \text{ qualifies as laminar flow.} \)

\( P = Q \cdot \Delta \text{P} \quad 3) \text{Power Equation: showing the relationship between the overall flowrate, the pressure drop of the system, and the required power to overcome that drop.} \)

\( v_{\text{avg}} = \frac{(v_{1} + v_{2})}{2} \quad 4) \text{Equation for the to find the average velocity between point 1 and point 2.} \)

\( h_{l} = \frac{v_{\text{avg}}^{2}}{2g} \cdot f \cdot \frac{L}{D} \quad 5) \text{Equation for the major head losses as a result of frictional forces across the length of the pipe (with the Darcy Friction Factor)} \)

\( h_{\text{lm}} = K \left( \frac{v_{\text{avg}}^{2}}{2g} \right) \quad 6) \text{Equation for the minor head losses as a result of the frictional forces across each one of the pipe connections.} \)

\( h_{\text{lt}} = h_{l} + h_{\text{lm}} \quad 7) \text{Equation for total head loss (major + minor) = total} \)

\( \frac{(v_{1}^{2} - v_{2}^{2})}{2g} + \frac{\Delta \text{P}}{p \cdot g} = h_{\text{lt}} \quad 8) \text{Modified Bernoulli's Equation incorporating the total head loss with no change in height.} \)

\( \frac{\pi}{4} \cdot D^{2} \cdot v_{1} = D^{2} \frac{\pi}{4} \cdot v_{2} \quad 9) \text{Equation showing the relationship between the Area and velocity at the two specified points. (A1V1=A2V2). In this case, the area and diameter of the pipe remains constant.} \)

\( f = \frac{64}{\text{Re}} \quad 10) \text{Friction Factor Expression for laminar flow. The system of equations was initially solved with the Colebrook Equation, until a low Reynold's number was realized.} \)
**Solutions**

<p>| | |</p>
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<td>9</td>
<td>206.765</td>
</tr>
</tbody>
</table>

\[
\text{Find}(v_1, v_2, \text{vavg}, \text{hlt}, hl, hlm, f, Re, D, P) = \]

- Velocity_Point1
- Velocity_Point2
- Average_Velocity
- Total_Head_Loss
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