



Flow Mechanics: Independent Water Supply Network

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ABSTRACT

In this project, we have designed an independent water supply system for a single household of 4. This system is deemed independent because it will acquire its main water supply from a natural source(rain). Our design will be refilled through rainwater and is stored in a cistern for clean water supply. This is considerably a small unit because we intend to service only one household despite this project is an open-ended one, as mentioned by our instructor. Supplying water to a single home helps us build a simple system made up of mechanical devices such as two pumps, a single storage tank, one open roof reservoir to trap rainwater, a timer control valve, and two filtration systems. Since this system is not connected to an actual main water source it can and would be suitable for remote areas, especially in developing countries that do not have constant clean water sources but are not limited to rivers and streams. In this project, we will be able to see firsthand the unique understanding and application of unit operational methodologies as it relates to flow in pipes and channels as well as the transportation and metering of fluids.

INTRODUCTION AND THEORY

A “fluid is defined as a substance that deforms continuously under applied shear stress regardless of magnitude.” For this project, we will be illustrating the flow of fluid through a water supply network. A water supply network can be defined as an infrastructure for the collection, transmission, treatment, storage, and distribution of water to various entities. There are several components of the water supply network. These components include; a water collection point or open roof tank, water purification facilities, a water storage tank, a network of pipes, centrifugal pumps, and a recycling stream to keep the pressure of the pump constant.

For this project, the water collection point will be the open roof tank above the surface. Our water collection tank accumulates water from rain. The rapid sand filter tank and the chlorine treatment serve the purpose of purifying the water being sent to the storage tank. This purified water is later used by the consumer. Through a network of pipes, the water is then distributed to its consumers. There are three criteria that a water transport and distribution system must meet. First, it is to be constructed and/or manufactured of materials that are not harmful to human life. Secondly, it is to be resistant to mechanical and chemical attacks possible to the distribution system. Finally, it must be constructed and manufactured with durable materials.

For this project, there are several hydraulic calculations and concepts necessary to ensure that the water supply network is adequately functioning to deliver safe water to its users. The concepts surrounding water flow in a piping system include; Bernoulli’s equation, elevation head, pressure head, velocity head, and energy losses. Bernoulli’s equation states that for constant flow, an energy balance between two pipes cross-sectional area can be written as

$Z_1 + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + \sigma E$. The elevation head can be defined as the amount of flow of potential energy in one cross-section defined by the elevation. The pressure head defined

by the equation $\frac{P}{\rho g}$ is the amount of flow potential in one cross-section. defined by the water pressure. The velocity head is defined as $\frac{V^2}{2g}$ is the amount of flow kinetic energy in one cross-section. When a fluid is flowing through a pipe, the fluid experiences some resistance due to some of the energy, also known as the head of the fluid lost. Energy losses are separated into major and minor losses. Major losses refer to things such as the roughness of the pipe, the properties of the fluid, the mean velocity, the pipe diameter, and the pipe length. Minor losses are due to the change of the velocity of the flowing fluid in the magnitude or direction (turbulence within the bulk flow as it moves through and fittings). Minor losses tend to occur at valves, tees, bends, reducers, and other appurtenances.

Pumps are used to increase the energy in a water distribution system. The most commonly used type of pump for a water distribution system is the centrifugal pump. The radial turbo-hydraulic pump to be precise. When working with pumps, several essential factors must be considered in the hydraulic calculations. The first is the static suction head, which is the difference in elevation between the suction liquid level and the centerline of the pump impeller. The second is the static discharge head. The static is the difference in elevation between the discharge liquid and the centerline of the pump impeller. Finally, the static head, which is the difference or the sum in elevation between the static discharge and the static suction head.

Other aspects of the pump that must be considered include the pump efficiency, cavitation, and Net Positive Suction Head. Pump efficiency can be defined by the power input delivered from the motor to the impeller of the pump. Generally, cavitation occurs when the liquid pressure at a given location is reduced to the vapor pressure of the liquid. For piping systems with included pumps, cavitation occurs when the absolute pressure at the inlet falls below the vapor pressure of the water. When this occurs, it leads to damages to the pump

impeller, violent vibrations, reduced pump capacity, and reduced pump efficiency. To avoid cavitation, $NPSH_A$, which is the absolute total energy available at the inlet of the pump above the vapor pressure that is responsible for pushing water into the pump has to be greater than the $NPSH_R$, which is the required NPSH that must be maintained or exceeded at the eye of the impeller so cavitation will not occur.

MATERIAL SELECTION & AVAILABILITY COST OF RAW MATERIALS

Raw Material Selection	Cost (Dollars (\$))
500-gallon Galvanised Storage Tank	\$1,333.99
Two (2) Centrifugal Pump	\$10,300
An Open Roof Tank	\$69,250
A Rapid Sand Filter	\$449
Chlorine Treatment plant	\$298.95
A strainer	\$42
A pressure Valve	\$20.50
Seven (7) Valves	\$82.36
Two (2) Bleeding Valves	\$37.76
Seven (7) Elbows	\$7.49
Four (4) Splitters	\$4.86
2800 feet of PVC Schedule 40 pipes	\$830.05
Total Cost	\$82656.96

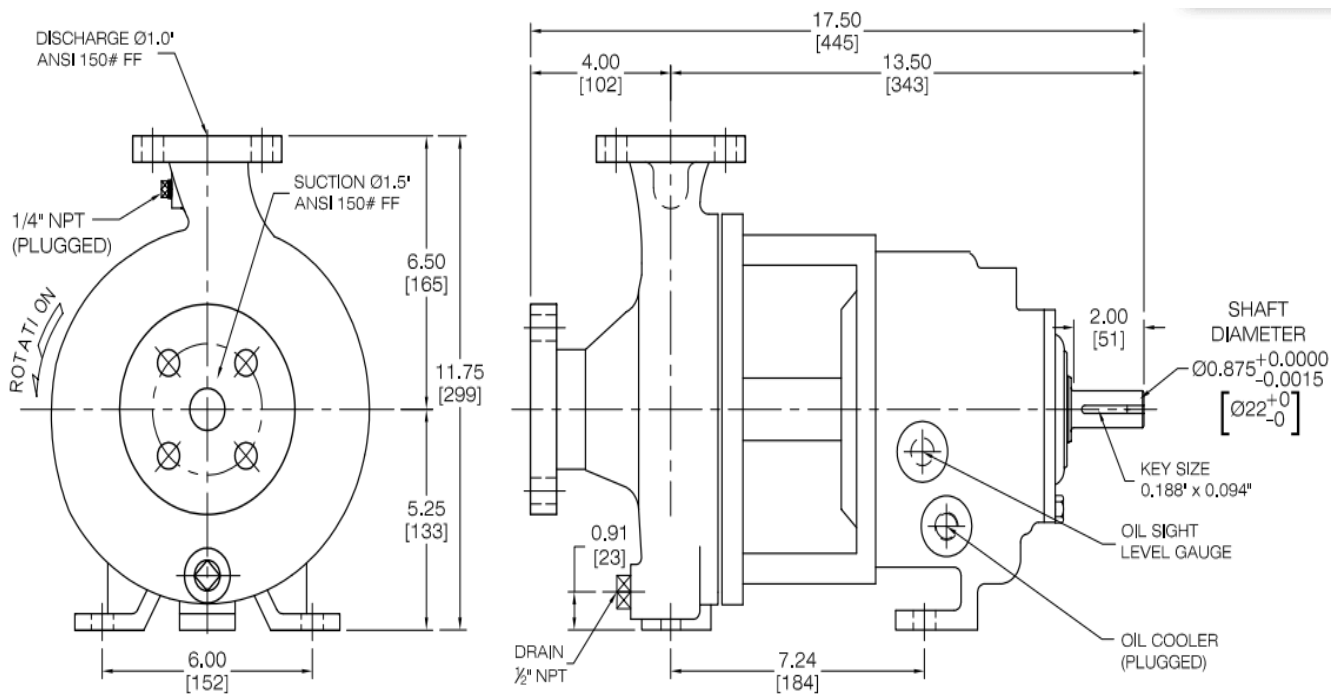
Pipes, Valves, and Fittings in this Design

The transmission of the fluid is the basic part of the water transport and distribution system that represents a large portion of the investment. This is because it consists of various types of pipes, joints, fittings, and connections that operate together with miscellaneous control equipment. The pipe section is not only the most abundant element but also the largest capital investment in the system. For this project, we will be using a flexible type of pipe known as PVC. The entire process will be made from two kinds of pipe diameter, 1 inch, and 1.25 inches. Attached from the open roof reservoir through the sand filter, mixer, and storage tank going into the suction point of both jet pumps in this process is a 1.25-inch diameter schedule 40 pipes. From the discharge point of both jet pumps to the users and recycle cycle stream is a single inch schedule 40 pipes. The pipes in this entire system are joined with a total of seven elbows and four slitters.

The Pumps & Its Specifications

We have two centrifugal pumps in this process. They are both located parallel to each other after the storage tank. The reason we have the pump located after the storage tank is to produce enough pressure to supply water to the users or households. These centrifugal pumps will be supplied from a company called Magnatex Pumps INC. These pumps come under the model 3596s 1x1.5-8. The entire cost and full assembly cost of these pumps will be \$5,300 each. This price includes the pump, mechanical seal, motor, baseplate, coupling to connect the shaft, and guard over the coupling. We built these pumps with the mindset of recirculating the discharge water back into the tank. This unused discharge circulating water flow will help enhance the overall flow into the pump for up to 30 gpm. Information for the pump was given to use by Nicholas Yutzy, the Applications Engineer at Magnatex Pumps Inc. This pump has a sync speed of 1800 rotations per minute. It has a diameter of 7.9 inches, a semi-open impeller, a 1.5-inch

suction inlet, and a 1-inch discharge outlet. With a 3 horsepower sized motor, this pump can deliver up to 20 horsepower and can withstand a weight pressure of up to 275 psig with a maximum temperature limit of 500F. The NPSH required on this pump is 2 feet.



Dimensional Drawing of Magnatex Pumps Inc S 3596s 1x1.5-8 Centrifugal Pump

PROPOSED DESIGN SHOWING KEY RESULTS & FIGURES

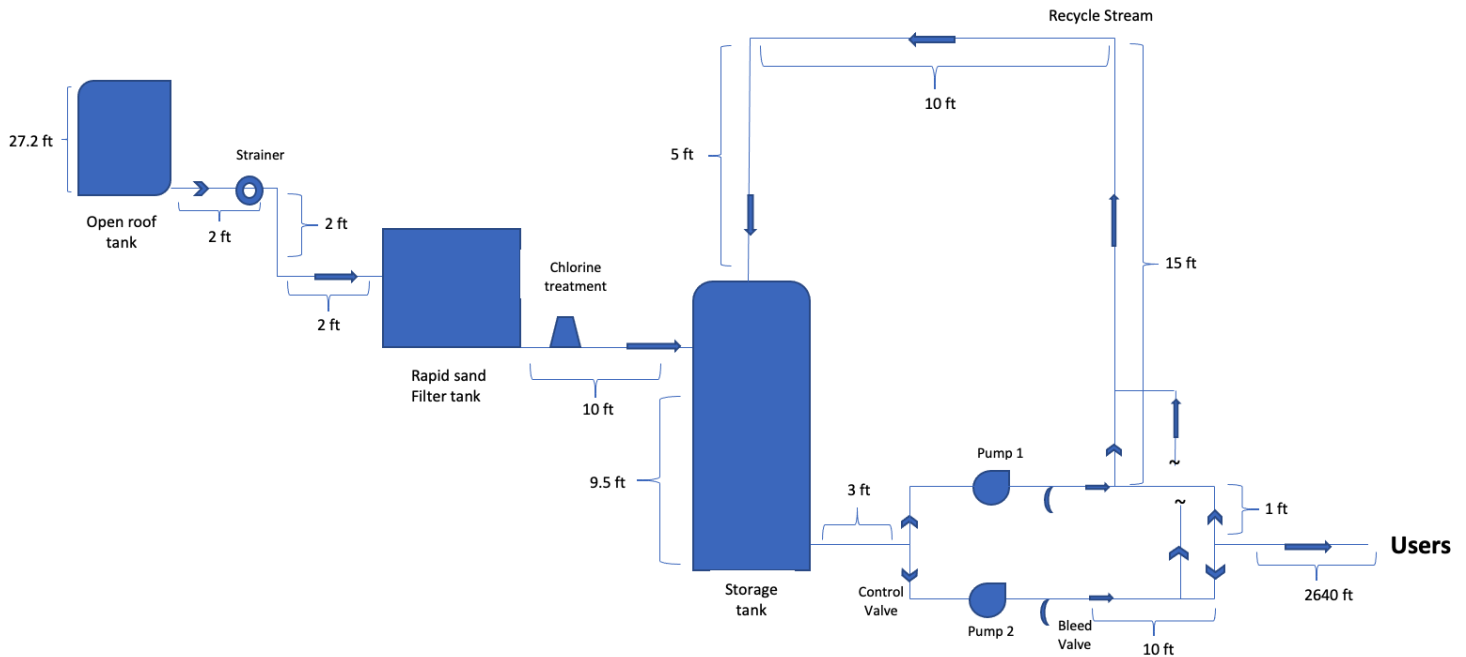


Figure 1. Schematic drawing of water supply network.

Note: Figure not drawn to scale

Assumptions

The users in the household all collectively consume about 10 GPM

The System operates at a steady-state

We used 10 systems over design

We are delivering to a 4-person household

System design is meant for 10 days of water supply

Design Calculations and Results

Open Roof Tank Reservoir

System Basis will be 10% over the ideal case.

$$= [9+(9 \times 0.10)] \text{ GPM}$$

Thus, the flow rate = 10gpm

$$\text{Water Supply per day} = \frac{10 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{1 \text{ hour}} \times \frac{24 \text{ hours}}{1 \text{ day}} = 14400 \text{ gpd}$$

We intend to have water in the storage tank for 10 days. For that reason, we will have 144000 gallons in that storage tank.

If the roof is operating at 90% total volume then,

$$\text{Tank Volume} = \frac{144000 \text{ gal}}{0.9} = 160000 \text{ gallons}$$

Length of the Open Roof Tank

$$\text{We know that Volume}(V) = \frac{\pi d^2}{4} \times h$$

$$h = \frac{4V}{\pi d^2}$$

$$= \frac{4 \times 160000 \text{ gal} \times \frac{0.133681 \text{ ft}^3}{1 \text{ gal}}}{\pi \times (30 \text{ ft})^2}$$

$$h = 30.26 \text{ ft}$$

$$h \approx 31 \text{ ft}$$

Water Height in the 90% filled storage tank

$$= 0.9 \times 30.26 \text{ ft} = 27.23 \text{ ft}$$

Therefore Open roof tank has a height (h) of 31 ft. Its diameter (d) of 30 ft and its volume (V) is 160000 gal.

At the Rapid Sand Filter

Regarding the pipe for our design, the diameter entering the pump is 2 inches while the discharge after leaving the pump is 1 inch in diameter.

$$V = 0.408 \frac{Q}{d^2}$$

Where V is the water velocity in ft/s, Q is the flow rate in gpm, and d being the inside diameter of the pipe in inches.

$$V = 0.408 \times \frac{10 \text{ gpm}}{2^2}$$

$$V = 1.02 \frac{\text{ft}}{\text{s}}$$

Assuming 50% usage of the rapid sand filter tank and resident time of 5mins

$$\text{Then, } 5 \text{ min} \times 10 \frac{\text{gal}}{\text{min}} = 50 \text{ gal}$$

$$\text{Volume} = \frac{50 \text{ gal}}{0.5} = 100 \text{ gallons}$$

$$V = \frac{\pi d^2}{4} \times L$$

L is the height of the sand filter tank

D is the diameter of the sand filter

V is the sand filter tank

$$\text{Therefore, } L = \frac{4 \times 100 \text{ gal} \times \frac{0.133681 \text{ ft}^2}{1 \text{ gal}}}{\pi (2 \text{ ft})^2}$$

$$L = 4.26 \text{ ft}$$

The Water height here is $0.5 \times 4.26 = 2.13 \text{ ft}$

At Storage Tank

Resident Time = 5 min, d = 2 ft, V = 250 gal

$$V = \frac{\pi d^2}{4} \times l$$

$$L (\text{height}) = \frac{4 \times 250 \text{ gal} \times \frac{0.133681 \text{ ft}^3}{1 \text{ gal}}}{\pi (2 \text{ ft})^2}$$

$$L = 10.64 \text{ ft}$$

Assuming the storage tank is operating at 90% capacity,

Water height will be $10.64 \times 0.9 = 9.5 \text{ ft}$

Pump Design

Highest Elevation = 40 ft

The total distance of 2651 ft

Discharge Pressure (Pb) = highest elevation + frictional loss

$$= 40 \text{ ft} + hf$$

$$= 40 \text{ ft} + \frac{fLv^2}{2gd}$$

The discharge pipe is 1 inch

$$V = 0.408 \frac{Q}{d^2} \Rightarrow 0.408 \times \frac{10 \text{ gpm}}{(1 \text{ in})^2} \Rightarrow 4.08 \text{ ft/s}$$

$$\begin{aligned} \text{The viscosity of Water } (\mu) &= 1 \times 10^{-3} \frac{\text{kg}}{\text{m}\cdot\text{s}} \Rightarrow 1 \times 10^{-3} \frac{\text{kg}}{\text{m}\cdot\text{s}} \times \frac{1 \text{ m}}{3.2808 \text{ ft}} \times \frac{2.20462 \text{ lbm}}{1 \text{ kg}} \\ &= 6.72 \times 10^{-4} \frac{\text{lbm}}{\text{ft}\cdot\text{s}} \end{aligned}$$

$$\begin{aligned} \text{Reynolds Number of discharge } Re &= \frac{Dvp}{\mu} = \frac{(62.4 \text{ lbm/ft}^3)(4.08 \text{ ft/s})(0.0833 \text{ ft})}{6.72 \times 10^{-4} \text{ lbm/ft}\cdot\text{s}} \\ &= 31558.8 \text{ turbulent} \end{aligned}$$

Relative Roughness = k/D

$$0.0015 \text{ mm} / 25.4 \text{ mm} = 0.00005$$

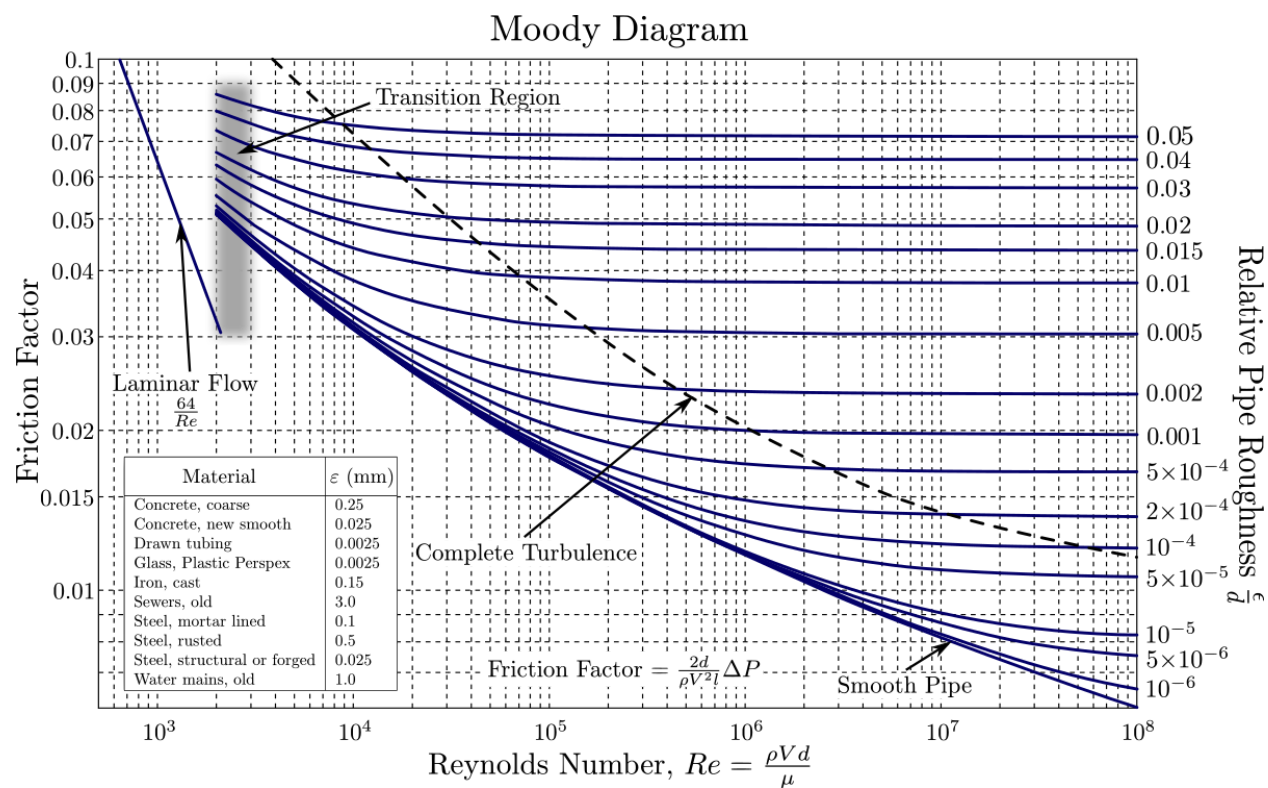


Figure 1: Moody diagram showing the Darcy-Weisbach friction factor f_D plotted against Reynolds number Re for various relative roughness ϵ/D .

From our knowledge on basic equations of fluid flow we applied the Moody's chart as shown in Figure to determine our friction loss at the discharge and suction surrounding the pump as shown below:

$$f = 0.0058$$

$$\text{Discharge Pressure (Pd)} = 40 \text{ ft} + \frac{0.0058 \times 2651 \text{ ft} \times (4.08 \text{ ft/s})^2}{2 \times 32.174 \text{ ft/s}^2 \times 1 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}}}$$

$$= 40 \text{ ft} + 41.147 \text{ ft}$$

$$P_d = 87.75 \text{ ft}$$

Suction Pressure = highest elevation of tank + Friction loss

$$\text{Velocity} = 1.02 \text{ ft/s}$$

$$\text{Suction diameter} = 2 \text{ inch} \approx 0.1667 \text{ ft}$$

$$Re = \frac{\rho v D}{\mu} \Rightarrow \frac{62.4 \frac{\text{lbm}}{\text{ft}^3} \times 1.02 \frac{\text{ft}}{\text{s}} \times 62.4 \frac{\text{lbm}}{\text{ft}^3}}{6.72 \times 10^{-4} \frac{\text{lbm}}{\text{ft} \cdot \text{s}}}$$

$$Re = 15789 \Rightarrow \text{Turbulent flow}$$

$$\text{Relative Roughness of pipe (pvc)} = \frac{0.0015 \text{ mm}}{50.8 \text{ mm}} = 0.00003$$

From the moody's chart $f = 0.0070$

$$\text{Suction Pressure (Ps)} = 9.5 \text{ ft} + \left(\frac{(0.0070)(5 \text{ ft})(1.02 \text{ ft/s})^2}{2(32.174 \text{ ft/s}^2)(0.1667 \text{ ft})} \right)$$

$$P_s = 9.5 \text{ ft} + 3.39 \times 10^{-3} \text{ ft} = 9.503 \text{ ft}$$

Total Dynamic Head

$$TDH = P_D - P_s$$

$$TDH = (87.75 - 9.503) \text{ ft} = 78.25 \text{ ft}$$

Assuming ambient temperature for design

$$T = 25 \text{ degrees celsius}$$

To determine Vapor Pressure, we applied constants from Antoine's Equation in Table B.4 from Elementary Principles of Chemical Processes book for water.

$$\ln P_{sat} = A - \frac{B}{T+C}$$

$$A = 8.10765$$

$$B = 1750.286$$

$$C = 235.00$$

$$\ln P(\text{sat of water}) = 8.10765 - \frac{1750.286}{25235}$$

$$\ln P = 1.376$$

$$P = 23.77 \text{ mmHg}$$

$$23.77 \text{ mmHg} \times \frac{1 \text{ atm}}{769 \text{ mmHg}} \times \frac{14.696 \frac{\text{lb}_f}{\text{in}^2}}{1 \text{ atm}}$$

$$P \Rightarrow 0.4596 \frac{\text{lb}_f}{\text{in}^2} \times \frac{144 \text{ in}^2}{\text{ft}^2}$$

$$P = 66.18 \frac{\text{lb}_f}{\text{ft}^2}$$

Net Positive Suction Head:

$$NPSH_A = (P_s - h_{fs} - Z) - \frac{g_c}{g} \frac{P_{sat}}{\rho}$$

$NPSH_R$ for the pump is 2 ft

$$\begin{aligned} &= 9.5 \text{ ft} - 3.39 \times 10^{-3} \text{ ft} - 5 \text{ ft} - \left(\frac{32.174 \text{ lbm}}{\text{s}^2 \text{ lb}_f} \times \frac{\text{s}^2}{32.174 \text{ ft}} \times \frac{66.18 \frac{\text{lb}_f}{\text{ft}^2}}{62.4 \frac{\text{lbm}}{\text{ft}^3}} \right) \\ &= 9.5 \text{ ft} - 3.39 \times 10^{-3} \text{ ft} - 5 \text{ ft} - 1.06 \text{ ft} \end{aligned}$$

$NPSH_A = 3.44 \text{ ft}$ which is greater than 2 ft.

We can conclude that since the net positive suction head acquired is larger than the net positive suction head required by our pump, it justifies our choice of design for this project is ideal for this water supply network, therefore eliminating any possible cavitation taking place. Cavitation occurs when fluid contains either gaseous or vaporous bubbles which can cause a breakdown in the pipe's material and possibly damage pump mechanisms.

Height of user's building

40 feet high

Hydraulic Horsepower (Input horsepower)

Q gpm is 10 gpm

Total Dynamic Head

$$TDH (psi) = 78.25 ft \cdot \left(\frac{g}{gc} \right) \cdot \rho$$

$$= 78.25 ft \cdot 32.174 \frac{ft}{s^2} \cdot \frac{1 lbf \cdot s^2}{32.174 lbm \cdot ft} \cdot \frac{62.4 lbm}{ft^3}$$

$$TDH \text{ in } psi = 4882.8 \frac{lbf}{ft^2} \cdot \frac{1 ft^2}{144 in^2}$$

$$TDH = 33.91 psi$$

$$Wh = \frac{Q \cdot TDH}{1714.3}$$

$$Wh = \frac{(10 \text{ gpm})(33.91 \text{ psi})}{1714.3}$$

$$Wh = 0.20 hp$$

Pump efficiency

$$\eta = (Wh/Wp)$$

$$= (0.20/1.41) = 14.2\%$$

DISCUSSION

One of the main reason why we choose the portable water design system was because we as chemical engineers we want to positively and directly make an impact on our respective communities and the best way to do that was to come up with something which we all can relate and help improve our sanitary conditions by providing them with the basic necessities of life like good drinking water. This system can be implemented anywhere in the world but most specifically for rural areas where they depend on natural resources and have the chance to store a huge amount and use it for later.

In our system design, we didn't include a recycle stream from the users back to the open roof tank because the cost of recycling the used water through a sewage plant will be more expensive, and most rural areas don't have good sewage treatment plants and the overwater recovery efficiency is about 35% so we thought it will be best to not include it to the design but if it is implemented in a city then the sewage plant stream will be included as demanded by the city policies. Looking at our system, the tank is designed to hold water for up to 10 days if filled and it provides an average household of 4-6 people. The design specifications can be seen above. Immediately after our open roof tank, we have a control valve and the main reason for that is to control the entire flow process.

Assuming that, at some point in time, the users stop using water for any reason but the system is still running, we will need to have some kind of control system to make sure we do not overflow our storage tank. Now, that's where this first control valve comes into play, when the tank gets to 90% total capacity and no water is leaving the tank, the valve automatically stops the flow of water in the system. The second function of this control valve is to shut down the running pump if the water level in the tank is below 2% to prevent cavitation in the pump.

We also have a strainer to take out large particles like leaves and sticks that may have fallen into the open roof tank. The rapid sand filter tank is included because we want to take into account the tiny impurities that may have passed through the strainer and also because we want to make sure the water is safe for consumption.

For our rapid sand filter tank and the storage tank, we have a residence time of five minutes from start-up, this means it will take five minutes for the tank to get to full capacity(90%). We design our system with two pumps in parallel but only one pump will be actively working as the other will serve as backup in case we have to do maintenance or repairs if the active pump fails. We designed the system this way just in case this system is implemented in a rural area where they don't have all the maintenance services people in urban areas have. In that case, they still have drinking water while they wait for the other pump to get fixed. The bleed valves are used to help depressurize the pipes during maintenance as safety is our number one priority. Gloves are used to control the flow of water in the pipes.

Having done our calculations on page 14, the efficiency of the pump was determined to be 14.2%. Since this efficiency is quite low, there are a few reasons for this along with some recommendations to improve the overall efficiency of the pump. The overall efficiency of the system is increased to 30.7% when we include a recycling stream. Some reasons for low pump efficiency come from energy losses caused by friction or leakages originating from pressure differentials within the pump. To improve this process we could install gauges to monitor pump performance. Placing a gauge at the suction and discharge points could serve as the best warning for wear or poor performance caused by a possible blockage or system anomalies. Other improvements would be increasing the flow rate and decreasing the pressure head as shown in a performance chart below in Figure 2 for the pump used in the design.

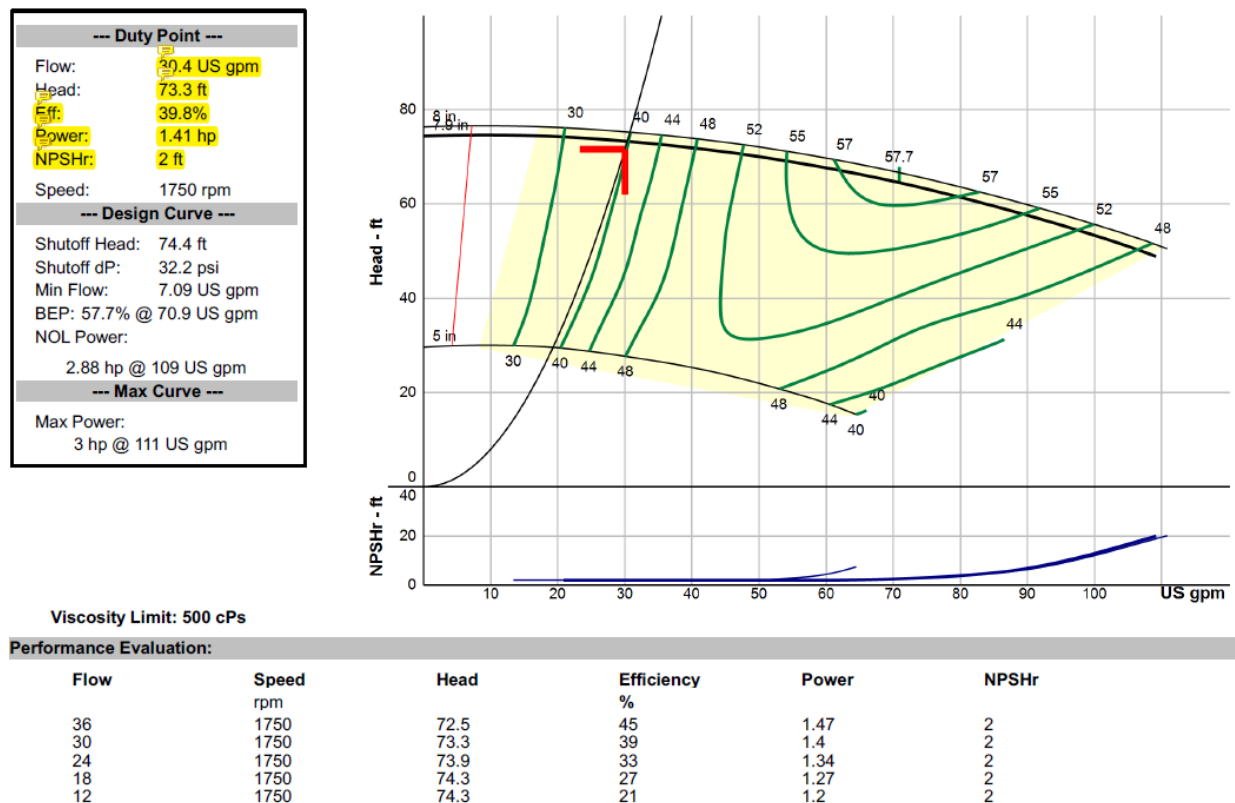


Figure 2: Performance chart for Pump used for design

CONCLUSION

As aspiring engineers to be and intellectual engineering students, taking Dr. Shamim for this class, gave us much insight into how the real world works through this project and we had the chance to interact with other people who share common interests and make some valuable connections which gave us a lot of insight as to how most engineering projects work. In this project, we had the chance to put the knowledge we learned in class into practice, and through that, we learned a lot and that gave us a better understanding of the concepts and how it works in real life. Some of the key concepts which we applied here were the incompressible fluid and with this, we had the chance to apply Bernoulli's equation for a fluid(water) flowing through a pipe. To complete this project we made use of the continuity equation to find the velocity of the fluid leaving the pump. The project helped us utilize our knowledge on Moody's chart, the Darcy Friction factor, centrifugal pumps, hydraulic horsepower, power delivered to fluids, and Reynold's number.

3596

MAGNATEX[®]
 Pumps, Inc.

MAGNATEX[®] 3596 Series Specifications

Liquid Temperature*	-100°F to +500°F (-73° to 260°C)
Maximum Shaft Deflection	0.002 Inch (0.0508mm)
Connections	150# FF std. or 300# RF Optional
L10 Bearing Life	50,000 Hours
Maximum Working Pressure	275 psig (18.96 bar)
Speed	Up to 3550 rpm (2950 @50hz)
Motor	NEMA or IEC Foot Mounted

*For elevated temperatures, contact factory or consider Magnatex mag-drive/sealless options.

Mechanical Seal ANSI Pumps
MAGNATEX[®] 3596 Series

Heavy-duty, world-class quality process pumps built to the latest ANSI/ASME B73.1 standard.

- Competitively priced
- Available in 29 sizes
- Materials include WCB (steel - upgrade from ductile iron), 316SS, CD4MCu, CD4MCuN, Duplex & Super Duplex SS, (1B, 1C, 5A, 6A), Alloy B/C, Nickel, Monel, and Titanium
- Bearing frames, bearing covers, and frame adaptors available in 316SS
- All stainless and alloy wet end components are investment cast, assuring excellent surface finish, as well as eliminating cracks and porosity
- Cast parts are manufactured using state-of-the-art CNC machines to ensure proper fit-up and repeatability
- High tolerance standards closely maintained
- Labyrinth seals are standard to protect the bearing housing from environmental contaminants
- Large metal/glass sight gauge ensures visibility of lubricant to help maintain the proper oil level
- Large bore seal chambers ideal for cartridge seals are standard; Tapered bore with straight vanes, as well as the standard bore for component seals and packing are available
- Inventories are based on WCB (steel) and 316SS; other above materials available
- Shaft kits, Maintenance Kits, and power ends are available
- A variety of seal options and flushing/cooling systems to handle almost all process applications are available
- Sleeved or solid shaft construction available

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