SRP Fluids Analysis

Background Report

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DISCLAIMER

ACKNOWLEDGEMENTS

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1 BACKGROUND

1.1 Introduction

This project is sponsored by Salt River Project (SRP) located in Phoenix, AZ who supplies power to one million customers in the Phoenix area. SRP has 12 power plants which use a fuel measurement system that will be evaluated for redesign. The goal is to improve the fuel measurement in both fuel measurement accuracy and to improve the process efficiency of SRP's natural-gas-fired power plants. This project interests SRP because they want their plants to be at the maximum possible efficiency and fuel measurement accuracy so that they may continue serving their 1 million customers. These results would benefit Phoenix as a whole because increased efficiency at SRP's natural gas-fired power plants would result in less waste, saving the consumer money. A more efficient natural-gas process will not only benefit SRP but is important to finding a solution to the energy crisis, especially as natural gas is an increasingly common and cheap energy source.

1.2 Project Description

Following is the original project description given to the SRP Fluids Analysis group from SRP.

> "The project goal will be to improve fuel measurement accuracy and process efficiency at each of SRP's natural-gas power plants. In order to succeed, the project team will collaborate with engineers, operators, and instrument technicians at several SRP power plants. Project scope includes assessment of fuel delivery systems, fuel measurement devices, fuel flow calculations, power plant operations, and multi-department process coordination."

1.3 Original System

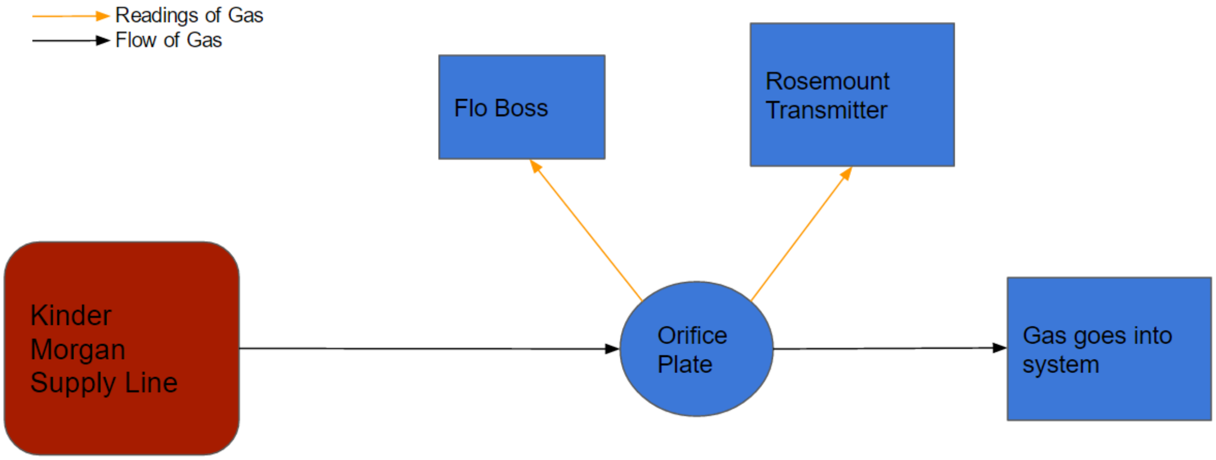


Figure 1.3: Original System Diagram

1.3.1 Original System Structure

SRP buy their natural gas from the company Kinder Morgan, the largest energy infrastructure company in North America. The Orifice Plate is a device used to measure flow rate and restrict pressure or flow rate. The Rosemount and Flo Boss are both connected to the Orifice Plate and both pick up pressures and flow rates. The difference between the two is that the Flo Boss can also read temperatures.

1.3.2 Original System Operation

SRP first receives their natural gas from Kinder Morgan which is then pumped into SRP's fuel measurement system. The gas passes through the orifice plate that measures the gas and sends the readings to the Rosemount transmitter and the Flo Boss which is more of a redundancy for the gas readings. The gas continues past the Orifice Plate and goes into the system where it's put through a process where the temperature is 1000 F making steam. The steam is then put through steam turbines and converted into energy.

1.3.3 Original System Performance

SRP has sent the team a few files that have helped recently with coming up with reasonable redesign ideas and concept generations. SRP provided us with all metering information going from gas composition, differential pressure, to the temperature inside the pipe. SRP also sent the team gas prices and some receipts from Kinder Morgan compared to their metering which shows difference in measurements, which one of your members will be doing an analytical analysis on.

1.3.4 Original System Deficiencies

One main reason SRP needs to redesign their fuel measurement system is because of a 2% error margin. Kinder Morgan supplies SRP with natural gas. Both companies make gas measurements on their portions of the gas transport system, with their measurements differing by 2%. The project goal is to minimize this 2% error while staying within the allotted budget.

2 REQUIREMENTS

The following customer requirements define the project's priorities and identify which goals may conflict with each other. They consider economic, technical, regulatory, and political aspects of the project, offering a more complete and realistic design. Each requirement is weighted to show its importance, which will be useful when making decisions about conflicting goals.

2.1 Customer Requirements (CRs)

The team has created 11 Customer Requirements for this project. The design:

1. Will uphold the standards and comply with the regulations of SRP, with a special consideration for safety. Weighting: 10
2. Must increase the accuracy of the fuel measurement system, either by updating or replacing the current system. Weighting: 10
3. Includes redundancies so that if one part of the design fails, the entire system will continue running, as plant shut downs are extremely expensive to the company. Weighting: 9
4. Be completed under a budget of $3000, as allotted by SRP. Weighting:10
5. Not increase greenhouse gas emissions, to avoid contributing to global warming and adhere to governmental emission regulations. Weighting: 6
6. Be easily adoptable by current operators and easy to use. Weighting: 7
7. Will monitor gas composition in real time, so that leaks or changes in composition can be known. Weighting: 8
8. Adapt to maintain maximum accuracy and efficiency as the plan powers on and off and changes power input. Weighting: 9
9. Will be adaptable to each SRP natural-gas power plant so that the design may be as useful as possible. Weighting: 8
10. Will be reliable, as even small differences in measurements may negatively affect the error margin. Weighting: 8
11. Will meet any applicable EPA regulations. Weighting: 10

2.2 Engineering Requirements (ERs)

The previously listed Customer Requirements were then considered to create more technically specific Engineering Requirements. The design will:

1. Decrease the error in gas measurement to less than 0.5%, ideally to 0.25%.
2. Cost less than the allotted budget of $3000, though the more cost-effective, the better.
3. Withstand measuring between 1,000 and 10,000 mcf/day, which is a measurement difference factor of 10.
4. Be able to withstand up to 100 psig of pressure.
5. Include a weather-resistant computer (or one in a weatherproof box), as the design will be exposed to the elements.
6. Include a flowmeter made of a non-corrosive material.
7. Be compatible with the existing pipe structures, which have diameters of 6 in, 14 in, and 16 in.
8. Include a real-time data display, such as an LCD screen or dial, so the operators may make measurements in the field.
9. Meet SRP and EPA safety regulations.
10. Last at least 15 years, with a design goal of 20 years.
11. Include at least 1 redundancy for every function. This may include leaving some of the existing meters in place, as the company has done with the Rosemont system.
12. Reduce the pressure drop, which is currently 0.02 psi, in order to reduce turbulence.

2.3 Testing Procedures (TPs)

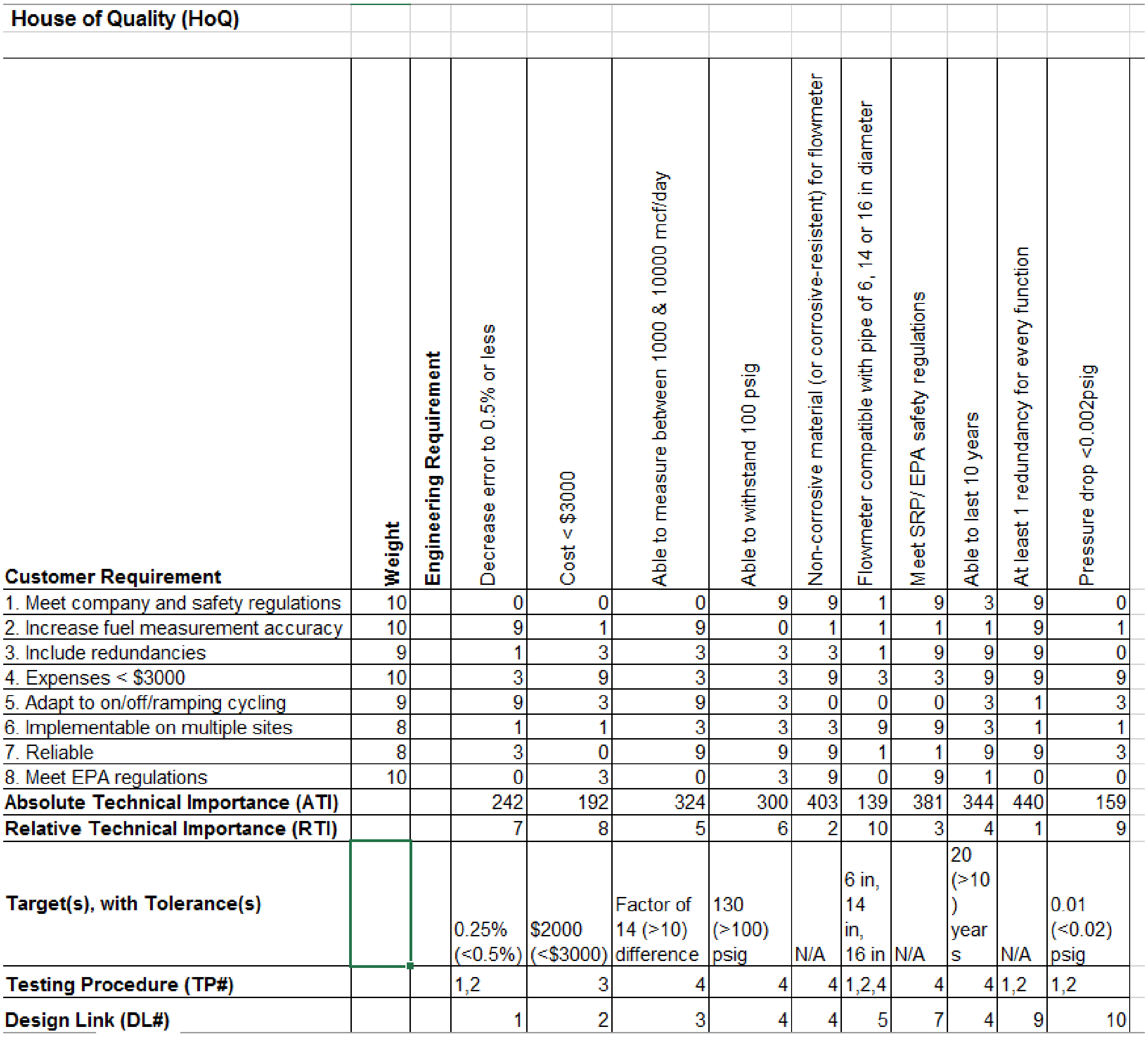
1. The fluid dynamics for each type of meter are to be tested using computer modeling. First, the team will develop MATLAB code to help with more simple math, and then a model of each meter will be tested using Ansys analysis, showing potential losses in energy, laminar and turbulent flows, and overall which meters will perform the best.
2. The team can test various meters in Northern Arizona University's thermofluids lab. This can be done by setting up a loop with a fluid, whose properties can be easily determined or measured, air would be a common fluid to use. This loop of chosen fluid then can be directed through various meters of the team's choosing and pressure differences can be measured with pressure taps and a data acquisition device. This data will allow the team to determine the amount of pressure drop for each meter and infer which meter would be best for the application.
3. economic analysis
4. Because the meter will be purchased from a manufacturer instead of fabricated by the team, manufacturer's specs will be used to evaluate whether certain engineering requirements have been met, such as life expectancy.

2.4 Design Links (DLs)

1. In order to comply with the engineering requirement where the gas measurement has to be less than 0.5%, the team suggested the idea where as long as the design has a very low pressure drop, lower than the existing design, it will satisfy this requirement.
2. The team's design is considered to be a bit off the budget, where the estimated price is $4000 and our allotted budget is $3000. However, our allotted budget could be flexible and might be able to cover the cost.
3. According to the analytical analysis made on the Venturi flowmeter, the team obtained a turndown ratio less than ten, which satisfies this criterion in particular. Also, the Venturi flowmeter withstands measurements between 1000 and 10000 mcf/day.
4. The team will use AISI 1020 steel as the material for the design. The AISI 1020 steel has a tensile strength more than 5000 psi. Therefore, the material that will be used will withstand pressure that exceeds 100 psig. It is also considered to be a non-corrosive material, and meets the required 15 year design life.
5. See number 4
6. The manufacturer who is supplying the venturi meters for our team has the option to change the diameter of the flowmeter to anything necessary. So, it will be easy to purchase meters of the correct diameter to be compatible with the pipe.
7. After inspecting EPA and discussing with SRP their safety regulations. The team can safely say that the final design meets SRP and EPA safety regulations.
8. See number 4
9. There are three units that need to be fitted with flowmeters. So, in order to create a redundancy the team can purchase a total of four flowmeters for the units. Purchasing the extra flowmeter will make it so that in the event of a failure the extra flowmeter can be installed instead of fixing the broken one.
10. To reduce the pressure drop experienced by the existing orifice plate, the team will implement a venturi tube meter, which due to the geometry of the venturi tube, will create less of a pressure drop. This is due to the converging and diverging sections of the pipe keeping the total head of the fluid constant throughout the meter.

2.5 *House of Quality (HoQ)*

A House of Quality (HoQ) demonstrates Customer and Engineering Requirements and how they relate and possibly conflict with each other. It is helpful in understanding goal parameters. At this stage, the HoQ (Appendix) lists the Customer Requirements and their weights out of 10, the Engineering Requirements, and Targets and Tolerances for the Engineering Requirements, which show the design goals.



House of Quality (HoQ)

Customer Requirement	**Weight**	**Engineering Requirement**	Decrease error to 0.5% or less	Cost < $3000	Able to measure between 1000 & 10000 mcf/day	Able to withstand 100 psig	Non-corrosive material (or corrosive-resistent) for flowmeter	Flowmeter compatible with pipe of 6, 14 or 16 in diameter	Meet SRP/ EPA safety regulations	Able to last 10 years	At least 1 redundancy for every function	Pressure drop <0.002psig
1. Meet company and safety regulations	10		0	0	0	9	9	1	9	3	9	0
2. Increase fuel measurement accuracy	10		9	1	9	0	1	1	1	1	9	1
3. Include redundancies	9		1	3	3	3	3	1	9	9	9	0
4. Expenses < $3000	10		3	9	3	3	9	3	3	9	9	9
5. Adapt to on/off/ramping cycling	9		9	3	9	3	0	0	0	3	1	3
6. Implementable on multiple sites	8		1	1	3	3	3	9	9	3	1	1
7. Reliable	8		3	0	9	9	9	1	1	9	9	3
8. Meet EPA regulations	10		0	3	0	3	9	0	9	1	0	0
Absolute Technical Importance (ATI)			242	192	324	300	403	139	381	344	440	159
Relative Technical Importance (RTI)			7	8	5	6	2	10	3	4	1	9
Target(s), with Tolerance(s)			0.25% (<0.5%)	$2000 (<$3000)	Factor of 14 (>10) difference	130 (>100) psig	N/A	6 in, 14 in, 16 in	N/A	20 (>10) years	N/A	0.01 (<0.02) psig
Testing Procedure (TP#)			1,2	3	4	4	4	1,2,4	4	4	1,2	1,2
Design Link (DL#)			1	2	3	4	4	5	7	4	9	10

Figure2.5:House of quality

3 EXISTING DESIGNS

The following information regards existing designs that are currently in use for the entire process of converting natural gas into useable energy. This section will elaborate on current industry practices and the team's rationale as to why these industry practices are relevant to our design process.

3.1 Design Research

In order to get an accurate idea of what the usual practices and industry standards are for natural gas plants the group conducted extensive research into contemporary natural gas systems and subsystems. For system level design the areas that were focused on were the measurement of the natural gas and the general thermodynamic processes that take place for converting natural gas into useable energy. For subsystems the areas that were researched were specific measurement techniques, transportation methods, and turbine designs used in natural gas plants.

The main source of information gathered during our design research was published research and informative articles found via the internet. Specific calculations were difficult to find via open source online information due to the fact that this sort of information is proprietary to each respective natural gas company. However, online research was extremely valuable for obtaining system overviews and rationale as to why certain design decisions are made by natural gas distributors and energy generation companies. Specific information regarding the specifications of our design will be supplied by our client contact at SRP and will be included in subsequent reports.

3.2 System Level

One of the preliminary steps in designing or improving a system is to find out what the standard practices are for similar systems. With this in mind two areas were focused on in the research of existing systems, they were methods of natural gas measurement and methods of converting natural gas into useable energy.

Included in existing designs is an example of a state of the art natural-gas measurement system being used in Turkey and two examples of the two most common methods of natural-gas combustion. These three existing designs were selected because both measurement and energy generation techniques are extremely pertinent to our design process going forward.

3.2.1 Existing Design #1: Turnkey Gas Measurement System

One of the existing systems that was researched was the Turnkey Gas Measurement System designed by Botas, which is the state owned oil and gas company in Turkey. The system was designed to compress natural gas to 75 bar at flow rates that vary between 510,000 and 2,040,000 Sm^3 per hour [1]. This pressure and flow rate need to be maintained during all seasons, which can be a challenge in a country with a volatile climate, like Turkey.

A few of the elements of the Botas systems that differ from similar systems designed by different companies are that the Botas system has all components designed together as a package, instead of separate, and the Botas system has numerous intended redundancies incorporated into it [1]. The benefits of having all of the components designed as one package are that cost is significantly reduced, and the chance of components not integrating with each other successfully is significantly mitigated. The purpose of the redundancies in the system is to attempt to eliminate the risk of one component malfunction causing the system to shut down. In the energy industry downtime can be extremely expensive, so it was determined that it would be more cost effective to allocate more resources to creating redundancies in the design and reduce the chance of the entire system needing to be shut down for maintenance.

3.2.2 Existing Design #2: Simple Cycle Power Plant

One of the existing types of natural gas energy generation systems is the simple cycle natural gas power plant. This system works by performing a basic cycle where natural gas is combusted which causes the gas to expand and rotate a series of blades attached to the shaft. This causes the shaft to turn and spin a generator which produces electricity. One of the issues with simple gas turbines is that the process efficiency is only 20-35% [2]. The benefit of a simple cycle over the other types of cycles is that a simple cycle is much less expensive to initially design and build. This makes it so that for areas where a small amount of energy is need a simple power cycle will make more sense. For areas where a large amount of energy is needed it makes more sense to invest in a more efficient system

3.2.3 Existing Design #3: Combined-Cycle Power Plant

One of the existing systems researched is the combined-cycle power plant. This plant uses gas and steam turbines that produce up to 50 percent more electricity, using the same amount of fuel than the traditional simple-cycle plant [3]. Any heat waste from the system is also rerouted to the steam turbine, and generates more power.

This system works by first the gas turbines burn the fuel put into the system. The gas turbine compresses the air and mixes it with fuel at a high temperature. The heated air moves through the turbine blades making them spin. The fast spinning blades drives the generator that converts some of the energy into useful electrical power. The combined-cycle plant also has a heat recovery system that captures exhaust [3]. A heat recovery system generator (HRSG) captures exhaust heat from the gas turbine, that would've have escaped and been wasted. Then the HRSG takes the heat and sends it to the steam turbine. The steam turbine then takes the excess exhaust waste and makes it into useful electrical power.

3.3 Subsystem Level

Throughout our research of existing system level designs it became apparent that there are three subsystem levels that are the most important to the process of converting natural gas into useable energy. The functional model (Figure 3.1) in the figure below describes the measured flow at SRP's Agua Fria plant. Kinder Morgan sends its fluid to SRP's pipeline to be measured through an orifice plate that is being calculated by a flow computer, the FloBoss. The rest of system is how energy is transformed from mechanical energy to electricity. These subsystems are: measurement of incoming natural gas, transportation of that natural gas, and the different kinds of turbines used to convert combusted gas into energy. In the following sections the importance of these three subsystems and the specific methods used in these subsystems is explained in detail.

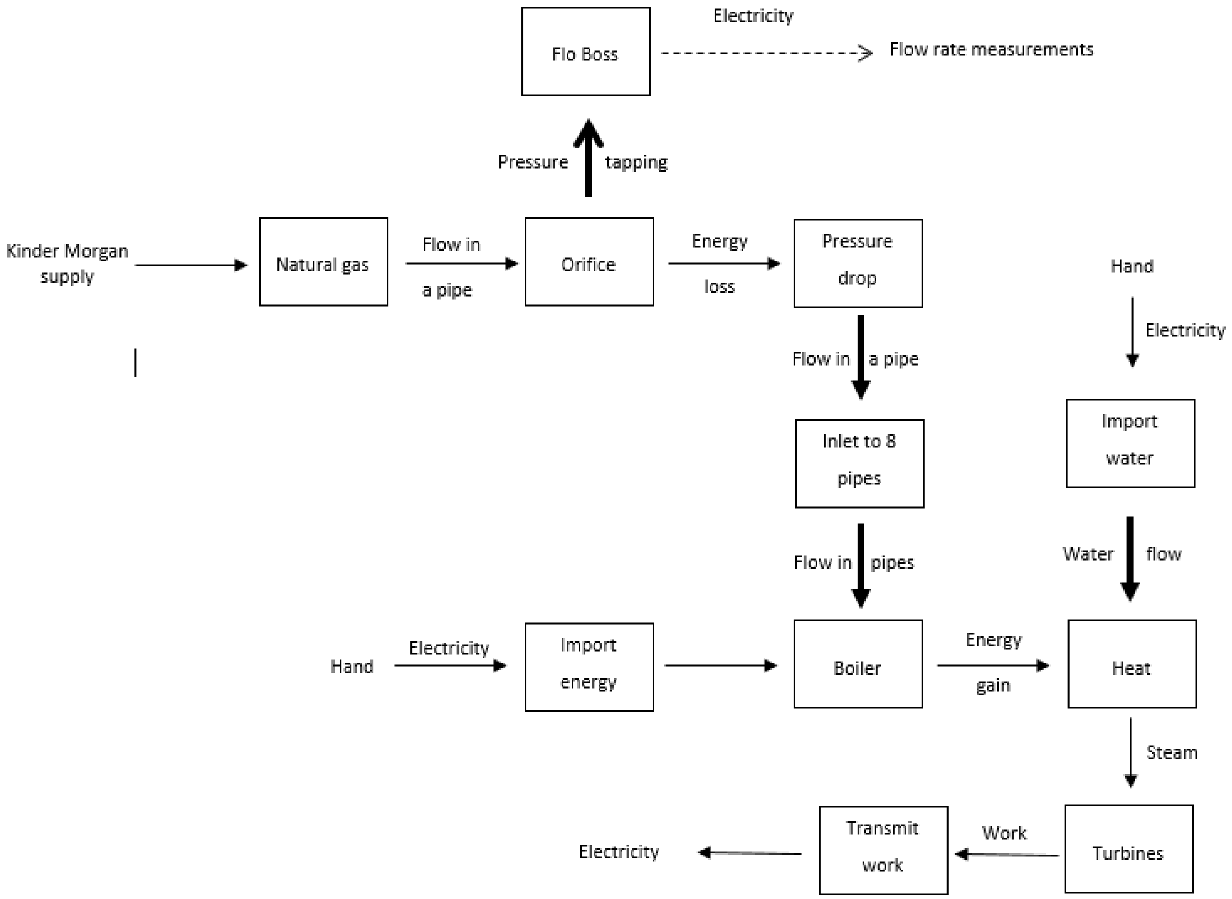


Figure 3.1: Functional model of the natural gas system at the Agua Fria plant

3.3.1 Subsystem #1: Measurement

The general idea of measurement on this subsystem is coming from adsorption operation. There are commonly used sorbents like zeolites or activated carbons. The method and designs to calculate the mass of a gas are various, but the three existing designs that will be discussed here are the Volumetric, Gravimetric, and the Oscillometric chromatographic methods.

3.3.1.1 Existing Design #1: Volumetric – chromatographic

The system shown is a slow processed system, because of the fact that the mixture will go through many steps to be adsorbed, but it still can give accurate measurements not just for natural gas, but also for other gasses. The way it works is by supplying a gas mixture to the storage vessel that has a certain volume and measurement for pressure and temperature [4]. The mixture from there will expand to the adsorption chamber, where it has an adsorbent that will absorb gas. The chamber also has a certain volume and measurement for pressure and temperature, which will allow a specific amount of mass for the rest of the mixture, enabling the amount of absorbed gas to be calculated. The rest of the mixture however will circulate back to the vessel storage by a circulation pump to do the process over and over again. The gas sample will provide the mass concentration, which will eventually derive an equation for the absorbed gas [4].

3.3.1.2 Existing Design #2: Gravimetric – chromatographic

For the gravimetric method a microbalance is placed inside the adsorption chamber instead of two storages as the previous existing design. What this microbalance does is it will deal with weighing the mixture before and after the adsorption operation to have accurate value for the mixture and the gas. The molar mass will be needed as well and it will be calculated as before by taking a gas sample. The process can also be repeated over and over again by a circulation pump [4].

3.3.1.3 Existing Design #3: Oscillometric-Chromatographic

The Oscillometric chromatographic design can calculate the mass by the frequency of oscillations of the sorbent. The number of frequency measured throughout the rotational pendulum can give specific measurement of mass from the Reynold's number equation. A formula can be derived through experiments to calculate the mass adsorbed accurately [4].

3.3.2 Subsystem #2: Transportation

The transportation process of the natural gas is the most important aspect of the gas business, where usually the gas plants are not located near the main markets. In general, natural gas can be transported by pipelines, which is the method that the team will be working with during this project. The transportation of natural gas through pipelines is considered to be very complicated [5]. The pipeline network is very complex and needs to be designed to satisfy the supplier's route desire.

One way to ensure a less turbulent flow of the natural gas through pipelines is to pressurize the gas that is being transported through the pipe. Pressurizing the gas will guarantee to deliver the gas within the range of the desired rates and volumes. In addition, to ensure that the gas always pressurized throughout its transportation, compressor stations are required to compress the natural gas periodically, and this is done by placing compressor stations every 40 to 100 miles [5]. The team is required to measure the natural gas at a constant rate. So, ensuring a constant flow through the pipe will increase the accuracy of the measurements that will be done. Three types of compression engines will be discussed more in depth below.

3.3.2.1 Existing Design #1: Centrifugal Compressor

The Centrifugal Compressor is a mechanical device mainly used for transporting purposes. The Centrifugal Compressor moves the natural gas within the pipeline, which in a way increases the flow speed of the gas because of the impellers that are included. In addition, the rotating blades will increase the pressure of the natural gas that is transported. They are known to change the direction of the gas flow by accelerating the gas flow within.

3.3.2.2 Existing Design #2: Reciprocating Engine

Also called a piston engine, this type of engine aims to generate rotational energy from pressure. The reciprocating engine includes reciprocating pistons that play an essential role in converting the pressure into rotational energy and moves the gas inside the pipe [6]. The reciprocating engine uses the natural gas that is flowing inside the pipe to operate constantly. This engine actually works by expanding the gas at a higher temperature and uses that work to operate the pistons.

3.3.2.3 Existing Design #3: Hot Air Engine

The Hot air engine is a form of compressing gas within the pipeline to help accelerate and move the natural gas to the desired location [7]. The Hot air engine takes advantage of the expansion and contraction of the gas inside the pipe, which are caused by the thermal differentiations, to convert thermal energy to mechanical energy. Based on that, it compresses the gas and pumps it through the pipeline.

3.3.3 Subsystem #3: Flow measurement

During the process of natural gas transportation an accurate measurement of the flow rate is needed in order to supply the correct amount of fuel into the combustion chamber that powers the power plant. In order to get this measurement a multitude of flow measurement techniques are used. A common technique so to to create a pressure drop in the flow and measure properties across the pressure drop. Outside of this technique many others are used that do not have as much impact on the flow of the fluid. In this section these techniques will be discussed in more detail.

3.3.3.1 Existing Design #1: Sonic Flowmeter

A unique technique for measuring flow is with the use of a sonic flowmeter. The way this works is that a device is attached to the flow area that sends a pulse perpendicular through the flow. Once this pulse travels through the flow it is reflected back the way it came through the flow. Once this has made the trip through the flow again the pulse is absorbed by a transceiver. The transceiver records the time it took for the pulse to travel through the flow and from that time the flow rate can be calculated.

3.3.3.2 Existing Design #2: Venturi Tube

A Venturi tube is a flow meter that has a contraction in the pipe making the diameter smaller then getting larger again gradually to make the transition smooth and create less turbulence than an orifice plate. This contraction makes a pressure difference much like the orifice plate where the differential pressure is a key element in finding flow rate. To calculate this pressure difference a manometer is attached to different sections on the Venturi tube, preferably before and at the contraction.

3.3.3.3 Existing Design #3: Coriolis Meter

Over the past five years the Coriolis meter has been one of the fastest growing meter in the market. Just like most meters Coriolis can calculate the mass flow rate of the fluid flowing through it. Most Coriolis meters have two tubes which are made to vibrate in opposite directions of each other due to the magnetic coil. Sensors in the form of magnet and coil assemblies are mounted on the inlet and the outlet of both flow tubes. As the coils move through the magnetic field created by the magnet, they create a voltage in the form of a sine wave. These sine waves are then used to calculate the mass flow rate.

4 DESIGNS CONSIDERED

The following designs were the 10 most plausible designs resulting from the team's brainstorming. They include types of

4.1 *Coriolis Mass Flowmeter*

The Coriolis flow meter is considered to be a solid design, as it offers more advanced technology in comparison with the existing design that Salt River Project unit has. The coriolis mass flow meter measures the mass flow rate of the fluid that is flowing through. The operating principle of this flowmeter is that it has two measuring tubes connected, and these two tubes deform when a fluid is flowing through. The deformation of both tubes is proportional to the mass flow rate of the fluid itself. It also has two sensors attached, one at each tube, these sensors records the motion of the tubes and translates this motion to a phase shifter diagram. The mass flow rate of the fluid is derived by taking the difference between the two phases of the tubes. In addition, the density of the fluid can be computed by determining the frequency of the phase.

Figure 4.1:Coriolis Flowmeter [8]

4.2 *Venturi Flowmeter*

The Venturi flowmeter measures the flow rate of the fluid that is flowing through a pipe or a tube. The theory behind the operating principle of the Venturi flowmeter is Bernoulli's law. The Venturi flowmeter measures the flow rate by decreasing the diameter of the tube along the flow path, which causes a pressure differential. The pressure differential that is created helps compute the flow rate.

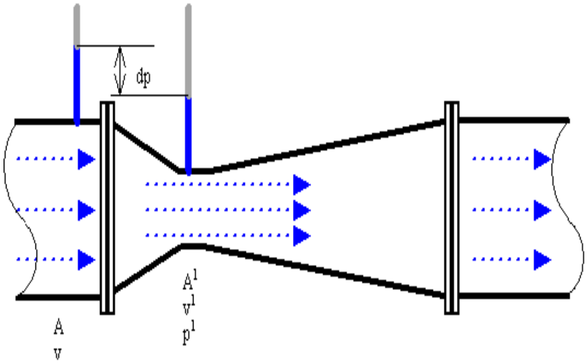


Figure 4.2:Venturi Flowmeter [9]

4.3 Heat Shield

This design involved applying an insulation layer to the pipes in the SRP units. By providing insulation to the pipes, the energy consumption would be reduced by 30 percent. In addition, by limiting the gain and loss of the heat in the pipe and by reducing the energy consumed, the flow meter readings will be more stabilized, and the chance of getting more precise readings will increase. This can be explained by using the relationship between density of a fluid and temperature. When the pipe is exposed to a higher temperature, the fluid will become less dense, most likely giving false readings for density and Reynolds number.

4.4 Turbine meter

A turbine meter uses rotation of a rotor to determine the flowrate in the pipe. This rotation is achieved by having the fluid, natural gas in this case, contact the blades of the rotor as it flows through and the force of the blades cause the rotation. This rotation is inferred into a rotational speed, usually in rpm, by a magnetic pickup. By knowing the gas composition, which is known information, we can calculate the density of the fluid. With both the density and the rpms of the rotor the flow rate then can be calculated by a flow computer.

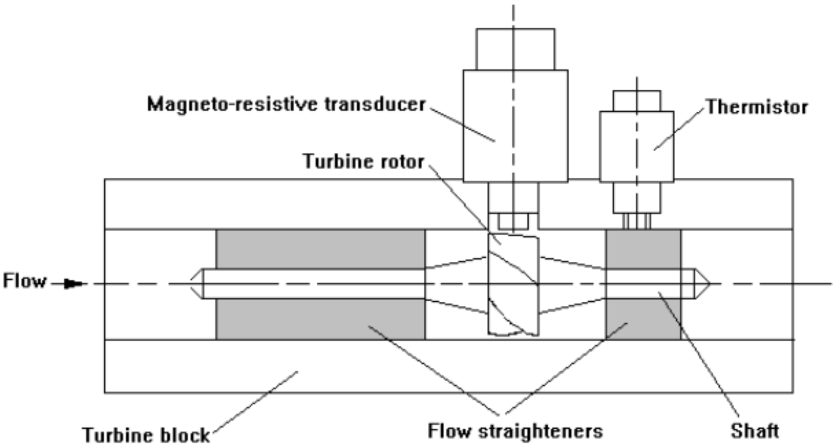


Figure 4.4 Turbine Flow Meter [10]

4.5 New diameter orifice plate

A new diameter for the orifice plate can be used in order to reduce the error found in STP's system. The original diameter can be increased so that the diameter of the orifice plate is closer to the diameter of the pipe than before. This increase in the diameter or the decrease in the difference in diameters will lead to a lower pressure drop and thus overall a lower error. This will lead to less energy loss due to turbulence in the pipe due to the orifice plate's diameter size.

4.6 *Balloon meter*

The balloon meter is a simple system that utilizes a balloon as a storage device and a stopwatch as a timer. A person would fill a balloon with the natural gas in question to a known volume. This is admittedly hard to achieve accuracy with due to human error involved in the process. A stopwatch will be used to time the flow. Knowing the time and volume will then allow this person to calculate the flow rate into the balloon.

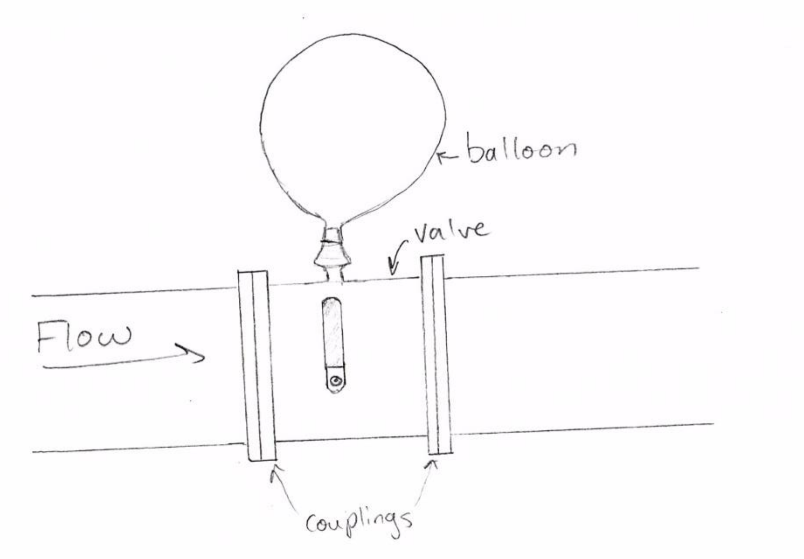


Figure 4.6: Balloon Design

4.7 *Update Flo Boss*

The FloBoss system that SRP has installed now is from the 1990's about 20 years old. Since then there has been many new flow computers invented with higher accuracy and more readings than the one installed. One viable option for updating the computer would be the FloBoss 107E which is a newer and updated version of the 503 which is installed at the SRP power plant. The 107E has new gas control options that the 503 doesn't have. One new control is the option to see the potential energy in MMBtu that the gas contains. The display is updated as well and has color in the display to easily reference what is going on in the system. There is another viable option for the update and that's the 103 Flo Boss. The 103 is a much cheaper version of the 107E and has some downfalls for the reduced price. The 103 still has a high accuracy and still does some chart analysis, but doesn't have nearly as much analysis as the 107E offers.

Figure 4.7: FloBoss 107E Flow Manager [11]

4.8 *Liquefying Gas Design*

Natural gas flows to a chamber that has one inlet and one exit. The exit valve will be closed, as the gas flow will keep compressing the gas inside the chamber. The gas in the chamber will reach a certain pressure, which will make the inlet valve close. Once both valves are closed, the natural gas inside the chamber will be cooled by a condenser, which will allow the natural gas to reach its condensing point (T=-258.7 F) or more if it needed too. The fluid will change its phase to liquid and thus will be easily scaled by a scaler inside the chamber. Once a constant amount of fluid has been calculated, the exit valve will open to send the fluid away and repeat the whole process over again when necessary.

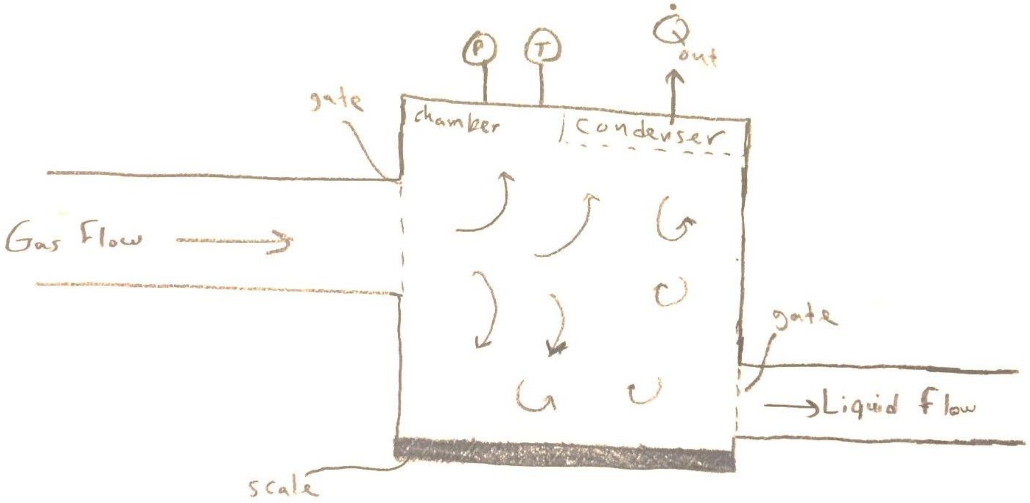


Figure 4.8: Liquefying Design

4.9 *Bio- Inspired Design: Flexible Venturi*

One way nature regulates fluid pressure is the constriction of blood vessels in the body. This change in diameter changes the pressure of the blood flowing through the circulatory system so that it can reach all parts of the body. Thus, the flexible Venturi design comprises a portion of flexible tubing, made of silicon or a similar material, so that the diameters of the flowmeter may be changed as needed at 1 inch segments to create an ideal pressure drop and minimize turbulence after the diameter constriction

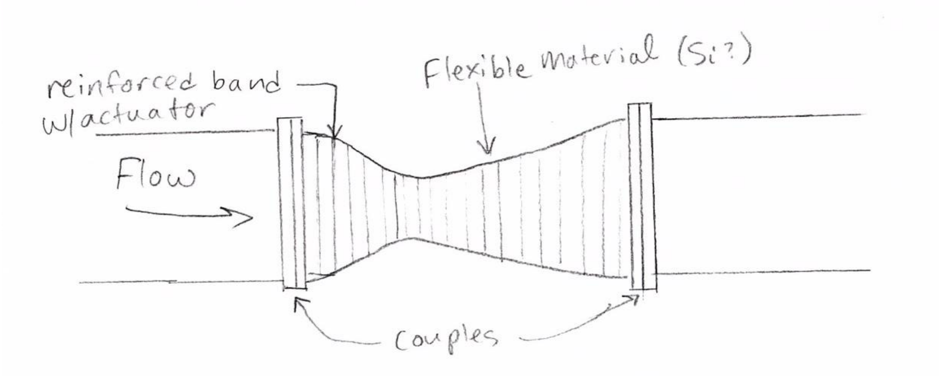


Figure 4.9: Flexible Venturi Design

4.10 *Bio-Inspired Design: Offset Ultrasonic Flowmeter*

This design is inspired by the offset ears of owls. Their offset design allows them to better locate sources of sounds in the dark, especially in the horizontal direction. This principle may be used to modify an already existing Ultrasonic Flowmeter to make it more accurate.

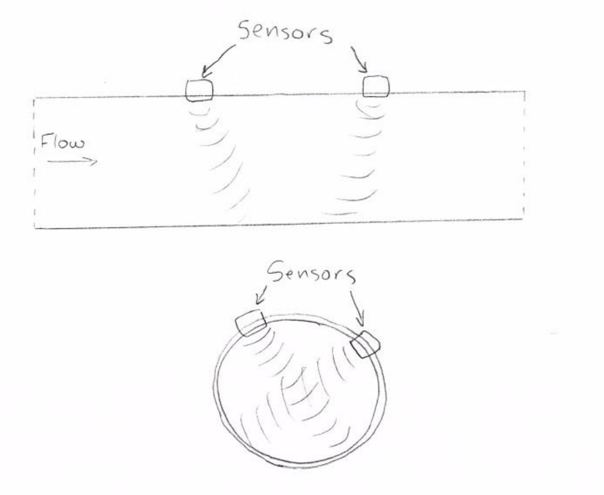


Figure 4.10: Bio-Inspired Ultrasonic Flowmeter

5 Designs Selected

In the following section the design(s) that the team has decided to pursue will be discussed. This section will also discuss the rationale for why the selected design(s) were chosen over the other design options. There were three designs selected for presentation to the client. Three designs were selected instead of choosing one in order to leave our options open based on the feedback we receive from the client. The three designs selected were: improvement of original system (new FloBoss/ changing diameter of orifice plate), Coriolis meter, and sonic flowmeter.

5.1 *Design Description*

A venturi flow meter is considered as one of the obstruction methods that consists of two smooth convergent entrance and divergent outlet. Firgure5.1 shows how generally a venturi flow meter works. The venturi flow meter is being used in the industry, due to its reasonable price and its way of measuring the pressure again right at the throat to calculate the flow rate of the fluid.

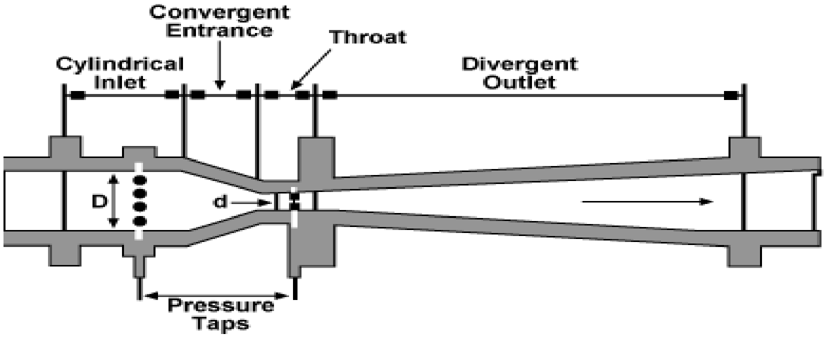


Figure 5.1.1: Venturi flow meter system

The standard angles of venturi convergent entrance and divergent outlet are
$\theta_{entrance} = 21°$

$\theta_{outlet} = 7° \; or \; 15°$

The energy loss in both $7° \; and \; 15°$ are given by experiments
$15° \; gives$:

$\frac{(\delta P)_{loss}}{\delta P}$= 0.436-0.86$\beta$+0.59$\beta^2$, where $\beta = \frac{d}{D}$

$7° \; gives$:

$\frac{(\delta P)_{loss}}{\delta P}$= 0.218-0.42$\beta$+0.38$\beta^2$, where $\beta = \frac{d}{D}$

These two equation can be applied on a wide range of Reynold's numbers, but it can get too accurate with high Reynold's numbers that ranges between 2*10^5 < Re < 2*10^6 and
0.4 < B < 0.75, because experimentally, those values will make the venturi flow meter able to almost neglect the discharge coefficient "C". Also the energy loss with this range of reynold's numbers will give exactly 10% energy loss with the same range of B. The main equation used to calculate the flow rate of a compressible flow is

$$Q = \frac{K*A_2*Y}{\rho}*\sqrt{2*g*\rho*\Delta P}$$

The assumption made for the design selected has the exact same dimensions for the orifice plates except that except that the expansion factor Y will be different in a venturi than an orifice plate, the calculation made in the appendix is based on many assumptions that can be accomplished when designing the flow meter. The calculation might be close between the venturi and orifice, because it is also assumed that the pressure reading of the venturi is the same as the orifice, however, in testing the procedure the venturi should have better readings than the orifice plate based on the research comparison made between them.

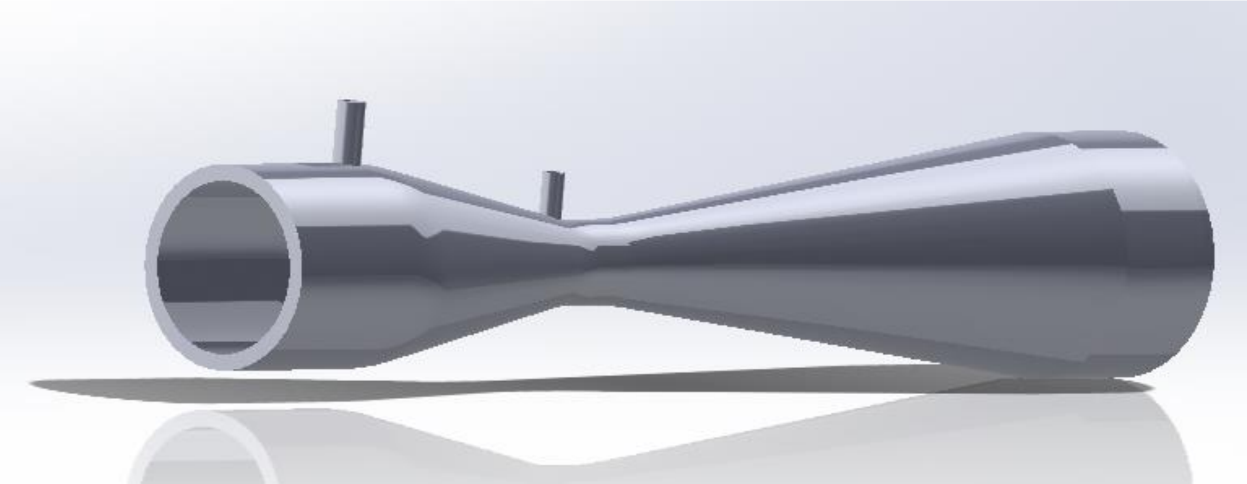


Figure 5.1.2: Venturi design isometric view

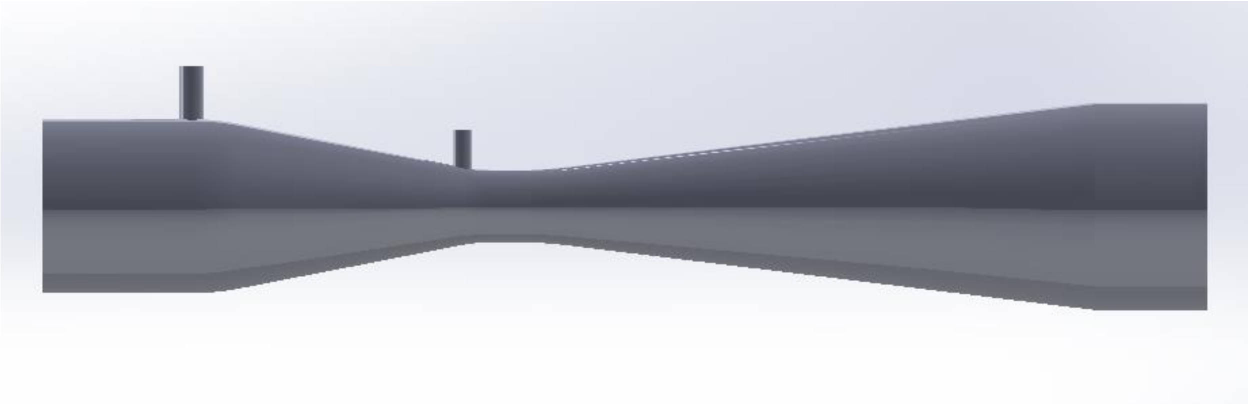


Figure 5.1.3: Venturi design right view

The venturi design shown in the figures is a sample of is expected to be replaced with the orifice meters. The type of metal used has to match the pipes metal, also the geometry of the inlets and outlets will be based on the unit number in SRP.

5.2 Rationale for Designs Selected

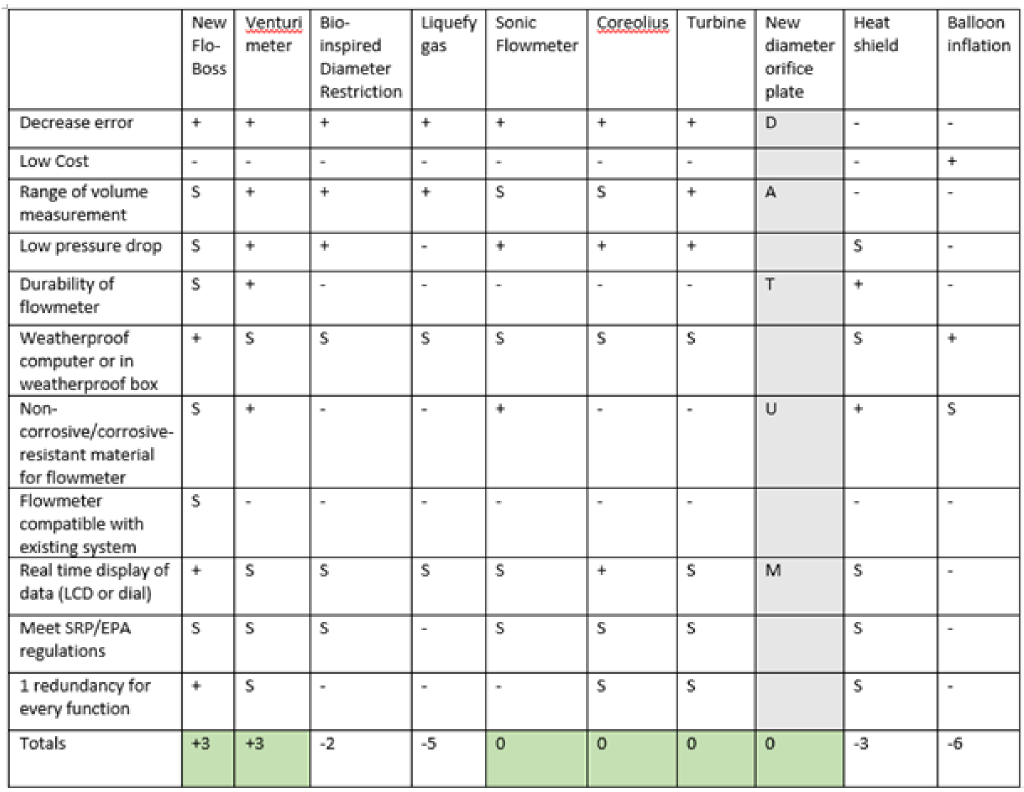
At the beginning of the design process the team compiled a list of ten possible designs. In order to narrow down this list the team imported these ten designs into a Pugh Chart, and a decision matrix. These two methods allow for a more analytical approach to be taken towards design selection. In the following sections these methods will be explained in more detail.

5.2.1 Pugh Chart

A pugh chart is an analytical tool that is used to compare considered designs with a baseline design, this baseline design is called the datum. The way the Pugh Chart works is that a variety of important categories are selected and each design is judged as either better (+) or worse (-) than the datum in each category. All of the +'s and -'s are then added up and the designs with the higher scores are judged to be better by the Pugh Chart.

The selected datum for our Pugh Chart was chosen to be the changing orifice diameter design. This was selected because besides changing the orifice diameter the rest of the system will stay the same with this design. This will allow us to compare the individual components of each considered design with the current design. Our categories in the Pugh Chart were taken fairly directly from the engineering requirements, meaning that the categories on the Pugh Chart correspond one-to-one to the categories on the HOQ.

After completing the scoring process there were six designs that stood above the rest on the Pugh Chart scoring. The highest scoring designs were: new FloBoss, changed orifice plate diameter, Venturi meter, Coriolis meter, turbine meter, and sonic flowmeter



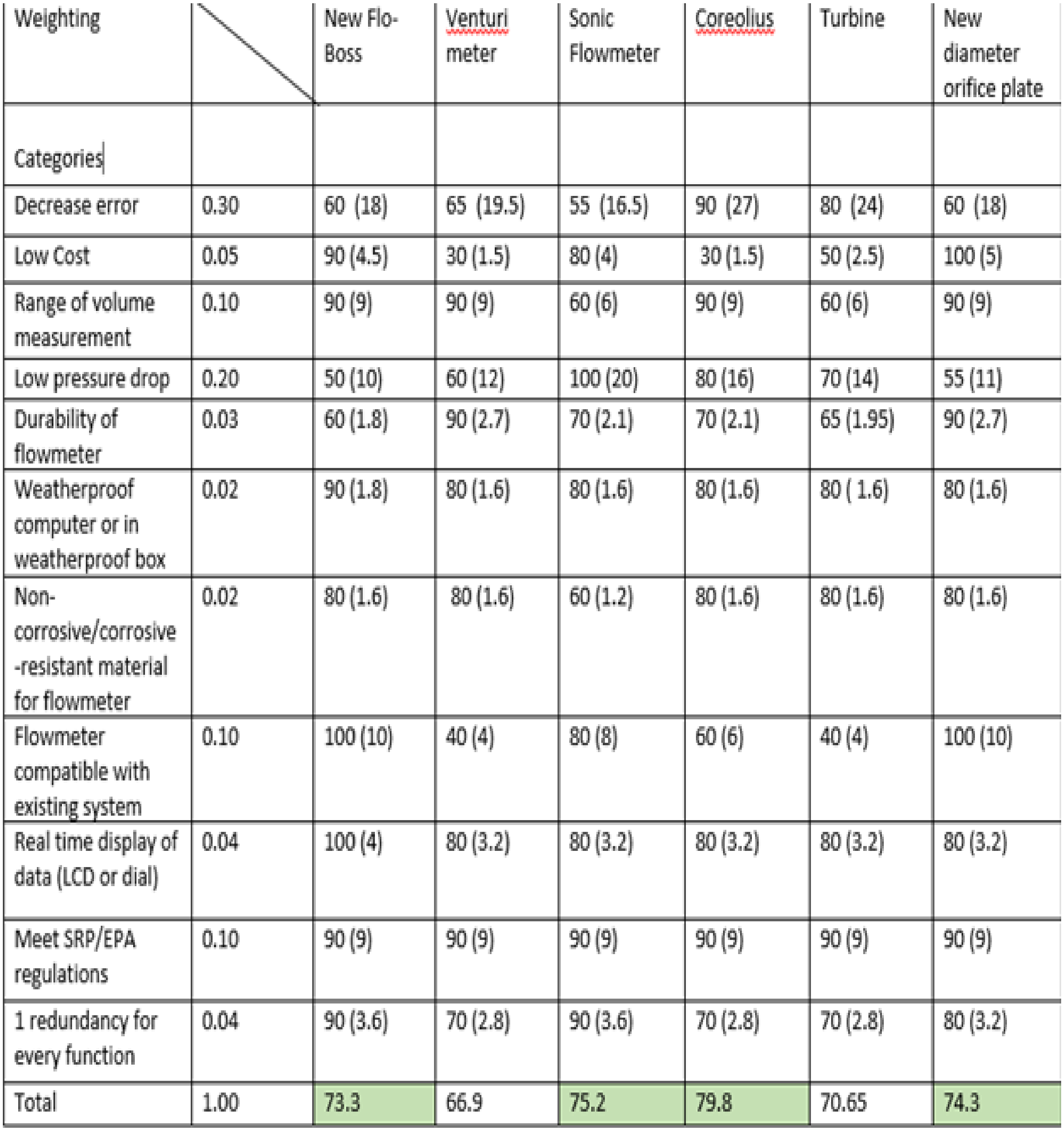
	New Flo-Boss	Venturi meter	Bio-inspired Diameter Restriction	Liquefy gas	Sonic Flowmeter	Coreolius	Turbine	New diameter orifice plate	Heat shield	Balloon inflation
Decrease error	+	+	+	+	+	+	+	D	-	-
Low Cost	-	-	-	-	-	-	-		-	+
Range of volume measurement	S	+	+	+	S	S	+	A	-	-
Low pressure drop	S	+	+	-	+	+	+		S	-
Durability of flowmeter	S	+	-	-	-	-	-	T	+	-
Weatherproof computer or in weatherproof box	+	S	S	S	S	S	S		S	+
Non-corrosive/corrosive-resistant material for flowmeter	S	+	-	-	+	-	-	U	+	S
Flowmeter compatible with existing system	S	-	-	-	-	-	-		-	-
Real time display of data (LCD or dial)	+	S	S	S	S	+	S	M	S	-
Meet SRP/EPA regulations	S	S	S	-	S	S	S		S	-
1 redundancy for every function	+	S	-	-	-	S	S		S	-
Totals	+3	+3	-2	-5	0	0	0	0	-3	-6

Figure 5.2.1: Pugh Chart

5.2.2 Decision Matrix

After completing the Pugh Chart there were six designs that scored significantly higher than the rest, these six designs were then put into a decision matrix. The decision matrix has the same categories as the Pugh Chart, but in the decision matrix these categories are each given a weight based on their importance to the success of the design.

The category that was given the highest weight was the ability of the design to decrease the error in the measurement system. This was given the highest weight because it is imperative that the design decreases the system error as this is the main project goal. Another important category is having a low pressure drop across the measurement apparatus. Having a large pressure drop leads to a larger amount of turbulence which can lead to more error in the system, in addition a large pressure drop causes greater energy loss, which is an outcome that should be mitigated as best as possible. Compatibility with the existing system and meeting EPA/SRP regulations were also major design considerations.



Weighting		New Flo-Boss	Venturi meter	Sonic Flowmeter	Coreolius	Turbine	New diameter orifice plate
Categories							
Decrease error	0.30	60 (18)	65 (19.5)	55 (16.5)	90 (27)	80 (24)	60 (18)
Low Cost	0.05	90 (4.5)	30 (1.5)	80 (4)	30 (1.5)	50 (2.5)	100 (5)
Range of volume measurement	0.10	90 (9)	90 (9)	60 (6)	90 (9)	60 (6)	90 (9)
Low pressure drop	0.20	50 (10)	60 (12)	100 (20)	80 (16)	70 (14)	55 (11)
Durability of flowmeter	0.03	60 (1.8)	90 (2.7)	70 (2.1)	70 (2.1)	65 (1.95)	90 (2.7)
Weatherproof computer or in weatherproof box	0.02	90 (1.8)	80 (1.6)	80 (1.6)	80 (1.6)	80 (1.6)	80 (1.6)
Non-corrosive/corrosive -resistant material for flowmeter	0.02	80 (1.6)	80 (1.6)	60 (1.2)	80 (1.6)	80 (1.6)	80 (1.6)
Flowmeter compatible with existing system	0.10	100 (10)	40 (4)	80 (8)	60 (6)	40 (4)	100 (10)
Real time display of data (LCD or dial)	0.04	100 (4)	80 (3.2)	80 (3.2)	80 (3.2)	80 (3.2)	80 (3.2)
Meet SRP/EPA regulations	0.10	90 (9)	90 (9)	90 (9)	90 (9)	90 (9)	90 (9)
1 redundancy for every function	0.04	90 (3.6)	70 (2.8)	90 (3.6)	70 (2.8)	70 (2.8)	80 (3.2)
Total	1.00	73.3	66.9	75.2	79.8	70.65	74.3

Figure 5.2.2: Decision Matrix

6 Proposed Design

The implementation of our design will be fairly simple. We simply need to purchase 3 units of our selected flowmeter and then install these three units in the existing fuel measurement areas in the SRP power plants. So, the only two major costs in the implementation process will be the cost of purchasing and the cost of installing the system. Pricing for the units was found using the prices given by AFT instrument for their LGW classic venturi tube. This listing was found on Alibaba.com [13], a link to the specific listing can be found in the referances section. Cost of installation were assumed using information found online. The total pricing for the installation is listed in the table below.

Table 6: Installation cost

	Purchasing cost	Installation cost	Total cost
Per unit	$500	$300	$800
Total (3 units)	$1500	$900	$2400

The total budget for our team was listed as $3000 so the installation cost will fall within our budget with a margin for error to account for any unforeseen costs.

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Appendix

Matlab codes for flow rate calculations in orifice plate and venturi

```
clc
clear

%These equations can be applied on obsturction meters (orifice &
venturi)%

%fluid's composition%
Nitrogen=[0.31 0.31 0.31 0.32 0.32 0.31 0.31 0.31 0.31 0.31] %changes
at unit#4&5%
CO2=[1.28 1.28 1.28 1.28 1.28 1.28 1.28 1.28 1.28 1.28] %constant%
Methane=[97.23 97.23 97.23 97.22 97.22 97.23 97.23 97.23 97.23 97.23]
%changes at unit#4&5%
Ethane=[0.93 0.93 0.93 0.93 0.93 0.93 0.93 0.93 0.93 0.93] %constant%
Propane=[0.19 0.19 0.19 0.19 0.19 0.19 0.19 0.19 0.19 0.19]
%constant%
nButane=[0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02]
%constant%
iButane=[0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03]
%constant%
nPentane=[0 0 0 0 0 0 0 0 0 0] %constant%
iPentane=[0 0 0 0 0 0 0 0 0 0] %conastant%
Hexane=[0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01] %constant%
Heptane=[0 0 0 0 0 0 0 0 0 0] %constant%
Octane=[0 0 0 0 0 0 0 0 0 0] %constant%
Nonane=[0 0 0 0 0 0 0 0 0 0] %constant%
Decane=[0 0 0 0 0 0 0 0 0 0] %constant%
H2S=[0 0 0 0 0 0 0 0 0 0] %constant%
Water=[0 0 0 0 0 0 0 0 0 0] %constant%
Helium=[0 0 0 0 0 0 0 0 0 0] %constant%
Oxygen=[0 0 0 0 0 0 0 0 0 0] %constant%
CO=[0 0 0 0 0 0 0 0 0 0] %constant%
Hydrogen=[0 0 0 0 0 0 0 0 0 0] %constant%

%meters setup%

n=[1 2 3 4 5 6 7 8 9 10] %unit#1-#10%
density_air=1.23 %density of air at T=15 celsius in kg/m^3%
patm=14.12841 %atmospheric pressure in psi%
g=32.11277 %gravitational accelaration ft/s^2%
Mu=0.6 %viscosity in cp%
density=[1.588 2.083 0.001 11.895 11.906 11.935 5.734 5.753 5.757
5.778] %denstiy at each orifice plate in kg/m^3%
%http://unitrove.com/engineering/tools/gas/natural-gas-density%


%changing the givens to SI units%

SG=0.5758 %specific gravity for all units%
k=1.3 %specific heat ratio for all units%
Patm=97411.957886 %atmospheric pressure in pa for all units%
G=9.787972296 %gravitational accelaration in m/s^2 for all the units%
```

```
MU=0.0006 %viscosity in N.s/m^2%
Density=SG*density_air %density of natural gas from specific of
gravity in kg/m^3%
R=0.287058 %gas constant of natural gas in KJ/Kg*k%

d0=[8.8712 8.8759 10.2199 3.883 3.883 3.883 2.3748 4.9988 6.0003
7.0009] %orifice diameter in inches for all units (flow meters)%
d1=[14 14 16 6 6 6 4.023 11.937 11.941 11.937] %pipe diameter in
inches for all units (flow meters)%

D0=d0.*0.0254 %diameter in m%
D1=d1.*0.0254 %diameter in m%

B=D0./D1 %diameters coefficient%

A0=(pi./4).*D0.^2 %orifice plate cross-section area in m^2 for all
units (flow meters)%
A1=(pi./4).*D1.^2 %pipe cross-section area in m^2 for all units (flow
meters)%

E=1./sqrt(1-B.^4) %coefficient%


Delta_p=[0.0671479 -0.0842513 0.0420168 0.0167982 -0.0336361 -
0.0757066 0.0587801 0.0503626 -0.0168554 -0.0084084] %change in
pressure in inH2O for all units (flow meters)%
p1=[32.89332 43.31176 0.0269687 246.2265 246.1623 246.1391 125.3776
125.5657 125.6203 125.6866] %static pressure in psi for all units
(flow meters)%


Delta_P=Delta_p.*249.088875 %change in pressure in pa%
P1=p1.*6894.75729 %static pressure in pa%
P2=P1-abs(Delta_P) %pressure after orifice plate in pa%

Tf=[58.48682 60.05267 65.5163 71.51623 70.9614 69.74372 91.4132
90.4752 90.43119 88.81457] %flow tempreture in Fehrenheit for all
units (flow meters)%
Tc=(Tf-32)*(5/9) %flow tempreture in celsius for all units (flow
meters)%
Tk=Tc+273.15 %flow tempreture in kelvin for all units (flow meters)%


%flow rate for incompressible flow%
C=0.965 %discharge coefficient% %0.95<C<0.98 for venturi%
%C=Q_actual/Q_ideal%
K=C*E %coefficient%

Q_ideal=(A0./sqrt((1-
(A0./A1).^2))).*sqrt((2.*G.*abs(Delta_P))./Density) %Ideal flow rate
at each orifice plate in m^3/s 'incompressible flow assumption'%
Q_actual=(K.*A0).*sqrt(2.*G./Density).*sqrt(abs(Delta_P)) %actual
flow rate at each orifice plate in m^3/s 'incompressible flow
assumption'%
M=Q_actual.*Density %mass flow rate in kg/s%
v1=Q_actual./A1 %velocity of natural gas before entering the orifice
plate in m/s%
v2=Q_actual./A0 %velocity of natural gas after entering the orifice
plate in m/s%
```

```
Q_ft=Q_actual.*35.3146667 %flow rate in each orifice plate in ft^3/s%
Q1_ft=Q_ideal.*35.3146667

TD=max(Q_actual)./min(Q_actual) %the turndown of orifice plate%



c=sqrt(k.*R.*Tk) %speed of sound in m/s at each unit%
Ma=v1./c %Mach number for all units (flow meters)%
Re_d1=(Density.*v1.*D1)./MU %Reynold's number of pipes for all units
(flow meters)%
hL=(abs(Delta_P)./Density) %head losses of orifice plate in KJ/KG for
all units (flow meters)%


%flow rate for compressible flow in orifice plate%
Y=1-(0.41+0.35.*B.^4).*(abs(Delta_P)./(k.*P1)) %Expansion factor for
orifice plates%
Q_c_actual=((Y.*K.*A0)./Density).*sqrt(2.*G.*Density.*abs(Delta_P))
%Actual flow rate for the compressible flow in m^3/s%

Q_c_ft=Q_c_actual.*35.3146667 %flow rate in each orifice plate in
ft^3/s%



%flow rate for compressible flow in venturi%
Y1=((P2./P1).^(2./k).*(k./(k-1)).*((1-(P2./P1).^((k-1)./k))./(1-
(P2./P1))).*((1-B.^4)./(1-B.^4.*(P2./P1).^(2./k)))).^0.5 %Expansion
factor for venturi%
Q_c1_actual=((Y1.*K.*A0)./Density).*sqrt(2.*G.*Density.*abs(Delta_P))
%Actual flow rate for the compressible flow in m^3/s%

Q_c1_ft=Q_c1_actual.*35.3146667 %flow rate in each orifice plate in
ft^3/s%


diffrence_between_orifice_and_venturi_pecentage=((Q_c_ft-
Q_c1_ft)./Q_c_ft).*100

%Assumptions made%

%B for venturi is the same as Orifice plate%
%Density of natural gas%
%Gas constant of natural gas 'R'%
%dischage coefficient 'C'%
%venturi pressure readings are the same as orifice pressure readings%
```