Mechatronic Steam Valve

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1. Introduction/Overview of Initial Design Goals

The overarching goal of the valve portion of GreenSteam has been to find a low power, fast actuating, highly reliable, mechatronic valve solution to best optimize the power output of the proposed GreenSteam engine. This report is a summary of the research conducted to this end.

Time was initially invested into finding quick, cheap, off the shelf options. This was done to create figures for engine designers to pull from as well as create a solution that already had extensively tested specs and was easy to replace. Eventually this led to initial research into the best mechanism and materials suited for high heat/pressure actuation.

Preliminary investigation was done into the feasibility of custom mechatronic, and mechanical, solutions.

An additional reading list has been compiled for use in onboarding additional members to the GreenSteam Valve team.

The research presented below has been conducted with an emphasis on small scale valves which might be appropriate for an engine of approximately 1 cubic inch per cylinder, operating at speeds at or below 500RPM. Additional assumptions include a supply pressure which can be varied to meet the valve's capabilities and steam temperatures around 150-170 degrees celsius.

2. Valve Actuation Solutions explored

2.1 Piezoelectric

Piezoelectric Valves have been tested extensively to be reliable in high heat, corrosive environments, as well as in vacuum(tech briefs cite). With extremely fast actuation times(numbers here), precise control, and low power draw, Piezo actuated valves are an incredibly enticing solution to the design goals of Green steam.

Unfortunately, Piezoelectric actuated valves are not readily available to be purchased, and require the use of a Piezoelectric actuation vendor (such as dynamic-structures) to create custom solutions. Additionally, the cost of Piezoelectric actuators is prohibitively high. Despite this there may be hope in securing a cast aside example that Dynamic-Structures has laying around, or another Piezoelectric actuation engineering.

Over the course of Spring 2020, conversations were started with Dynamic-Structures in regards to consulting on how to best utilize a piezoelectric valve for the use in a GreenSteam engine. Talks, unfortunately, have been on hiatus due to inconsistent communication. However, as these were started during the the beginning of the COVID 19 pandemic, dialogues will be attempted to be restarted during summer of 2020.

Advantages: Low power draw, high speed, incredible precision/control of actuation
Disadvantages: Very very complicated, very high costs, minimal literature

2.2 Solenoid

Solenoid valves have a serious advantage of being the industry standard for electronically controlled valves. Given this, there are plenty of options on the commercial market. Unfortunately, many of these options are intended for low temperature applications, with low speed requirements.

There are however, several manufacturers who produce solenoid valves intended for operation with steam. Over the course of this quarter, a spreadsheet has been created containing the specification of these valves for future reference, which can be found in Appendix A. A brief summary of these options and their capabilities can be seen in image 2.1.

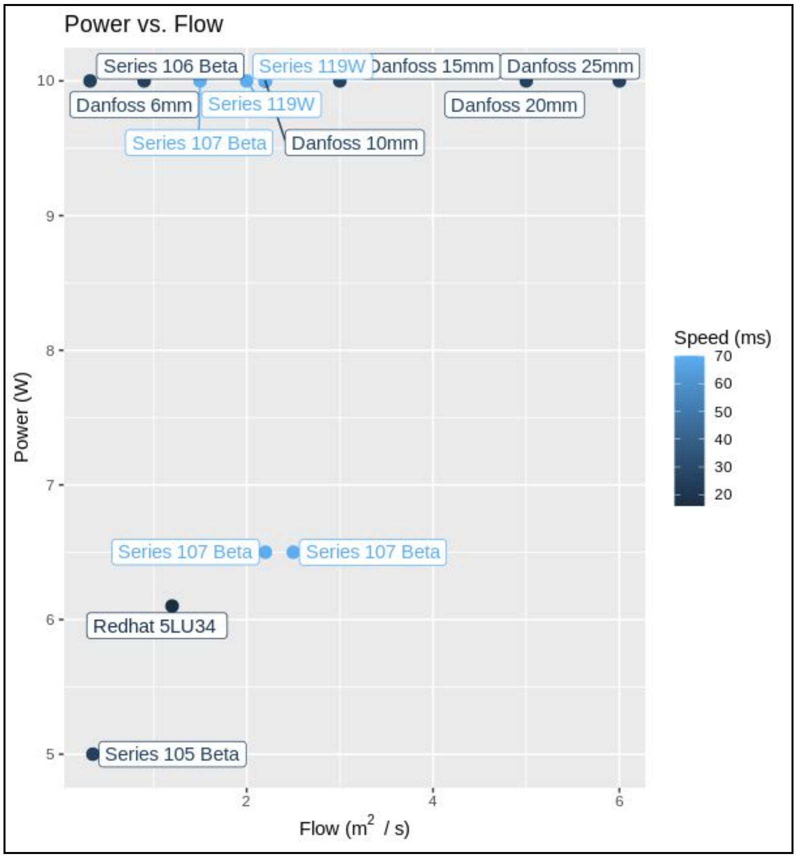


Image 2.1

To summarise, off the shelf components lend themselves to larger, slower operating engines, as these engines will naturally minimize the number of valve actuations needed per minute, and capitalize on the fact that existing hardware is usually intended for use with large scale commercial steam applications. This could drive the argument for a larger, slower RPM GreenSteam engine.

Of the smaller options on the market (which would be compatible with the proposed 1 cubic inch prototype engine) there are several which would act as viable options. These are options which are cost effective, have sufficiently high operating speed, temperature, and pressure to run a small steam engine for test and proof of concept purposes. However, their power draw is greater than the energy output which can be expected from an engine of such size, meaning that they would not be viable for creating a functional generator at this scale. Recommendations for a valve to be used for test purposes may be found below.

Advantages: Fast, Simple, Industry standard / cheap

Disadvantages: Not ideal for high temperature environments

2.3 Solenoid w/Pneumatic Servo assist

Pneumatic assisted solenoid valves are common in applications where low power consumption is important. Essentially, they operate by using a small solenoid to operate a pressure driven servo which controls the primary flow. This means that the majority of the energy is drawn from the pressurized fluid rather than an electric source.

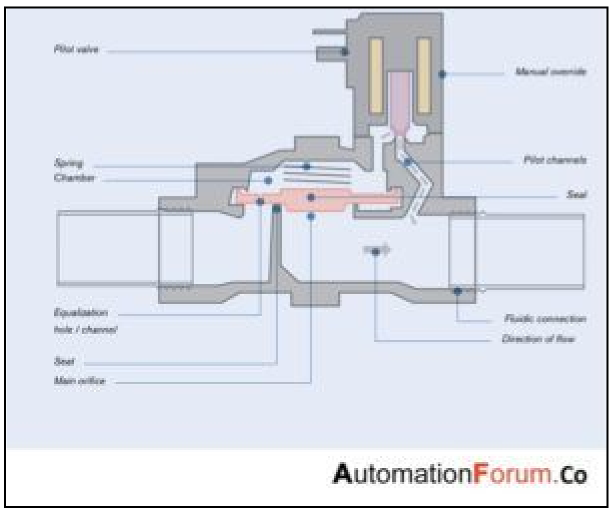


Image 2.2

Use of pneumatic assist in a currently proposed GreenSteam Engine poses some issues. These problems are mostly derived from the added complexity or the servo, which is continuously exposed to the corrosive environment caused by the steam. Their operating speed is also highly dependent upon the pressure differential across the valve, which would add significant complexity to the valve timing software for our application, as well as additional sensor requirements.

For the remainder of this document, we will lump all off the shelf vales together, and include servo assisted valves with normal solenoid valves in future discussion and graphics. We have been careful to consider only servo assisted values which are capable of withstanding the temperature and pressure, and have made conservative assumptions about this performance in our application in order to compare them to directly servo driven alternatives.

Advantages: Low power draw, high speed

Disadvantages: Dependent on pressure, added complexity

2.4 Motor Driven Valves

Options are available on the market for valves driven by electric servo motors instead of solenoids. These alternatives offer higher flow rates, and low idle power draw, but were not considered in this report due to their slow operating speeds.

Advantages: High flow rate, low idle power consumption

Disadvantages: Slow operating speeds

3. In House Options

Having spent the quarter exploring various off the shelf valve options, they all leave something to be desired. Even the lowest power consumption options draw a significant amount of power in comparison to the size of engine they are able to operate.

Given these findings, a variable method to maximise the power output of a small steam generator it would be worth exploring the idea of designing a custom valve solution.

For this, the most promising option is the bash valve which would enable us to use the mechanical energy of the piston to open the valve, thus removing losses from version between mechanical and electrical energy, while maintaining our ability to control the timing of the valve’s closing action, and therefore the power output of the engine.

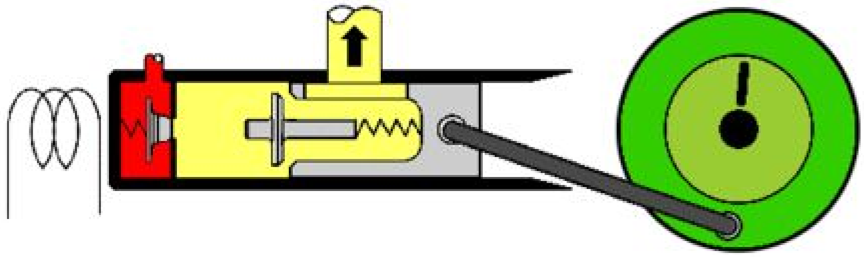


Image 2.3

Some initial calculations show that such a setup could be configured without the added complexity of the sprung exhaust valve, instead using a uniflow exhaust port. This would be accomplished by having a simple exhaust port which is uncovered by the piston, and then allowing the piston to re-compress some gas on the upstroke. This compressed gas would in turn open the inlet valve in place of a mechanical pin as in the image above.

Such a solution would open the option to create a low pressure volume over the exhaust port, reducing the energy needed to raid the piston back to top-dead-center. There are four options for such s system which are:

1. Using a chimney setup, allowing the updraft from the exhaust steam to create a vacuum to draw new exhaust out of the cylinder
2. Using an appropriately sized exhaust pipe, thereby using the momentum of the exhaust steam to create a low pressure at the exhaust port
3. A venturi system, which could utilize any flow of exhaust steam, or other gas to create a constant low pressure area
4. Creating a condenser system to cool the exhaust steam, thereby causing it to decrease in volume and creating a low pressure reservoir outside of the exhaust portauhast

4. Analysis of Valve Seals and Material

A brief discussion and explanation of pros/cons of each sealing material as they pertain to the GreenSteam project.

Note: Combinations of FPM and PTFE are seen in many steam rated valves though it seems (at least in most cases) these are used in different parts of a seal rather than collectively within a seal, contrary to what was previously mentioned in weekly reports.

3.1 FPM(Fluorinated propylene monomer aka fluorocarbon rubber)

Found in many high pressure valves, fluorocarbon rubber is valuable due to its incredible resilience to pressure and relatively high resistance to temperature and chemical degradation. It is found in many high pressure valves, and is extremely malleable, making it an easy solution for most sealing applications. Unfortunately it is not completely chemically inert and will eventually degrade after time in corrosive environments. (source below)

Advantages: Malleable, suitable for high pressure, chemically resilient
Disadvantages: Slowly chemically degrades in heat

3.2 PTFE(Polytetrafluoroethylene aka teflon)

Material of which is used to produce teflon. Unlike FPM, PTFE has a high hardness and is not incredibly well suited for high pressure environments. Despite this, it is essentially chemically inert while additionally having on of the lowest coefficients of friction

Advantages: Malleable, suitable for high pressure, chemically resilient
Disadvantages: Not malleable, poor longevity at high temperatures/pressures

3.3 EPDM(ethylene propylene diene monomer rubber)

Essentially a budget version of FPM. Degrades quicker and has less heat tolerance, but is much more replaceable cost-wise. A good option for running tests, or in situations where the possibility of compromising the seal may be higher.

Advantages: Malleable, somewhat resilient for small timescales, very cheap

Disadvantages: weaker in all regards to FPM

Final recommendations:

Of the options explored, piezoelectric valves seem to be the most reliable, efficient, and desirable option. They are however, an emerging technology coming with a high cost, and some availability issues. Cost allowing (or possibly charitable manufacturers allowing), a piezoelectric valve option would be ideal for all plausible scopes of this project .

From the off the shelf components explored, the valve of choice would be the Series 119W Beta Valve (see information below). This valve should meet the requirements of the project, for a reasonable price and allow for testing and tuning of a small engine. If, however, the steam used is cooler and at a lower pressure than initially expected, the DanFoss valve becomes a better option. These valves are designed to work under less than ideal conditions and should handle wet steam and poor operating conditions which are likely to appear in testing better than most other options. This decision would be best made once a clearer idea of the boiler performance and operating pressures has been formed.

Finally, looking beyond an initial prototype, and for an engine that is small enough, in house solutions such as the bash valve should be explored and tested more thoroughly. Alternatively, should the focus of the project solution be directed at larger, slower RPM engines, there are many more viable, more robust, valves to pull from.

In summary:

- Cost allowing, we recommend piezoelectric
- For testing we recommend an off the shelf valve: Series 119W Beta Valve
- For low quality steam at lower pressures: DanFoss Valves
- Moving forward to a functional generator, we recommend:
    - Test/Full scale: commercially available valves make sense
    - Further research: prototyping bash valves makes sense at a small scale.

Supplemental Reading list: :)

Super good doc to get familiarized with the types of off the shelf valves referenced:https://automationforum.co/different-types-of-servo-assisted-solenoid-valves/

Chart of performance characteristics of rubber seals: http://blucherpipe.com/Resources/Technical/Rubber_Seal_Properties

Sources

Piezoelectrics:

1. https://www.dynamic-structures.com/actuators
2. https://www.techbriefs.com/component/content/article/tb/techbriefs/mechanics-and-machinery/20303

Viable Commercial Valve Options:

1. http://www.siscon.nl/cms_img/danfoss_v_225_b_solenoid_valves.pdf
2. https://www.cedengineering.com/userfiles/Control%20Valves%20Basics%20-%20Sizing%20&%20Selection.pdf

Seal Material Info:

1. http://blucherpipe.com/Resources/Technical/Rubber_Seal_Properties
2. https://trp.co.uk/fkm-rubber-vs-ptfe/
3. https://www.ahpseals.com/
4. https://www.sspseals.com/fluorocarbon-rubber.html
5.

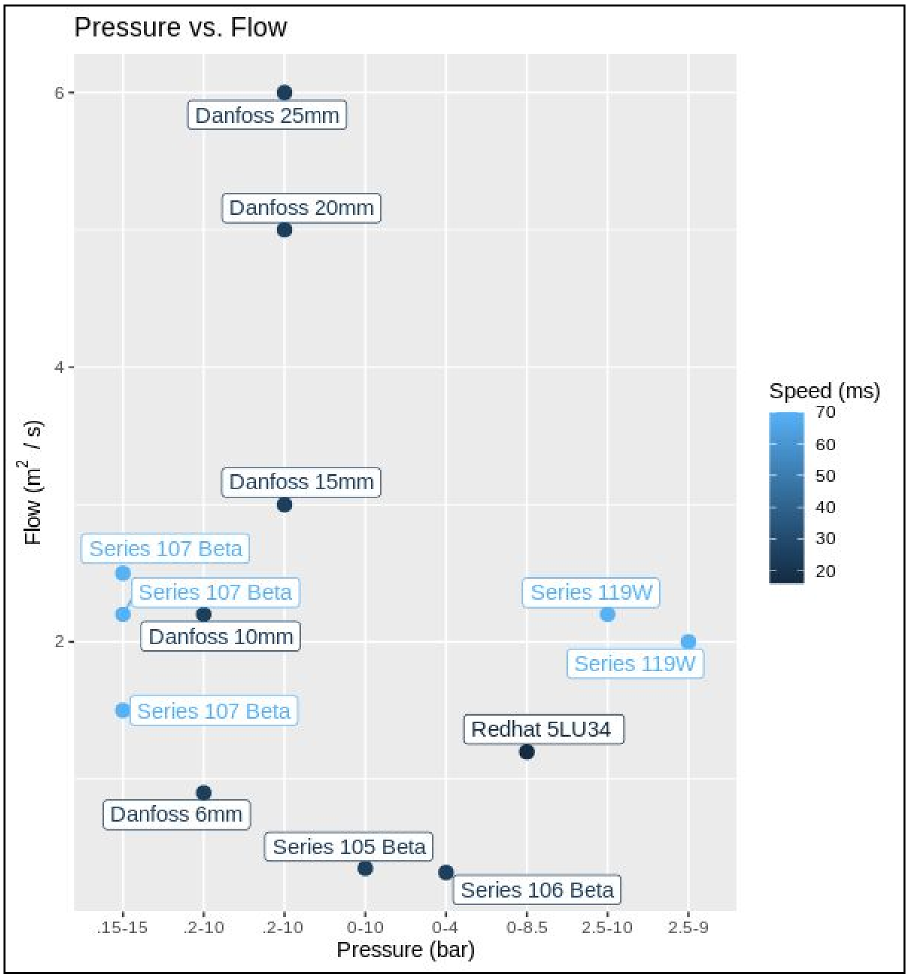
Image Citations:

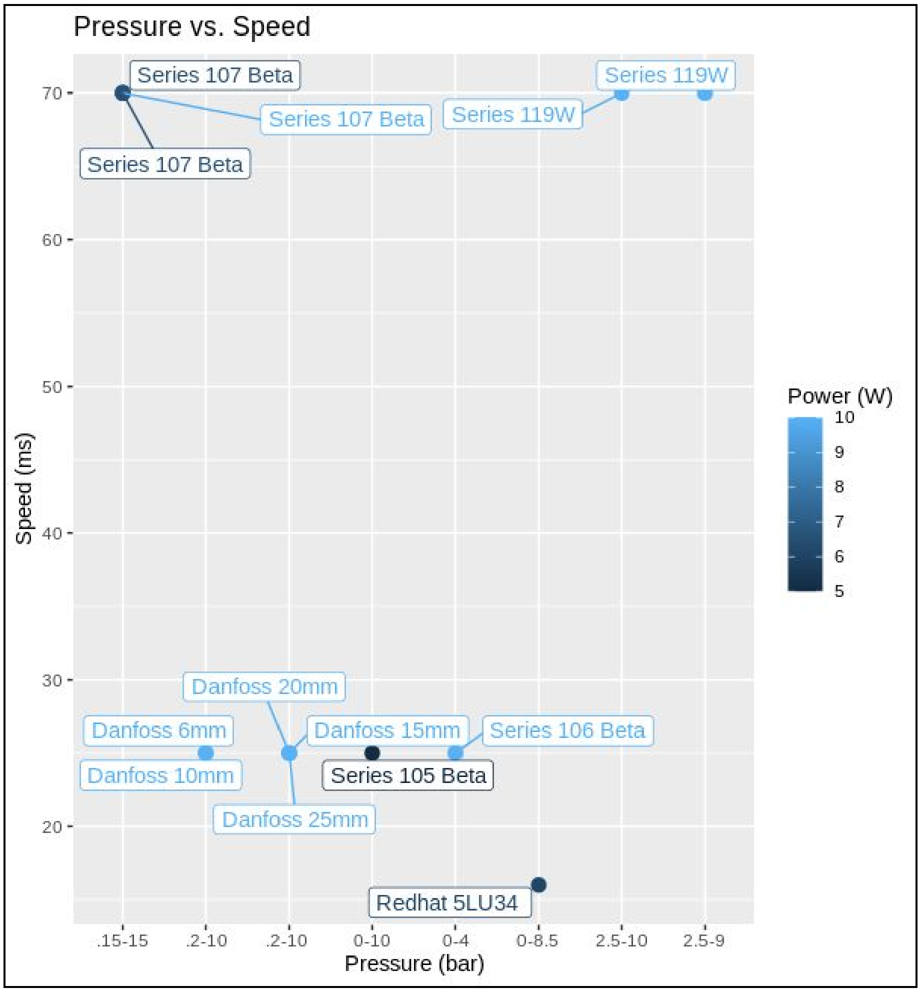
Image 2.2) https://automationforum.co/different-types-of-servo-assisted-solenoid-valves/

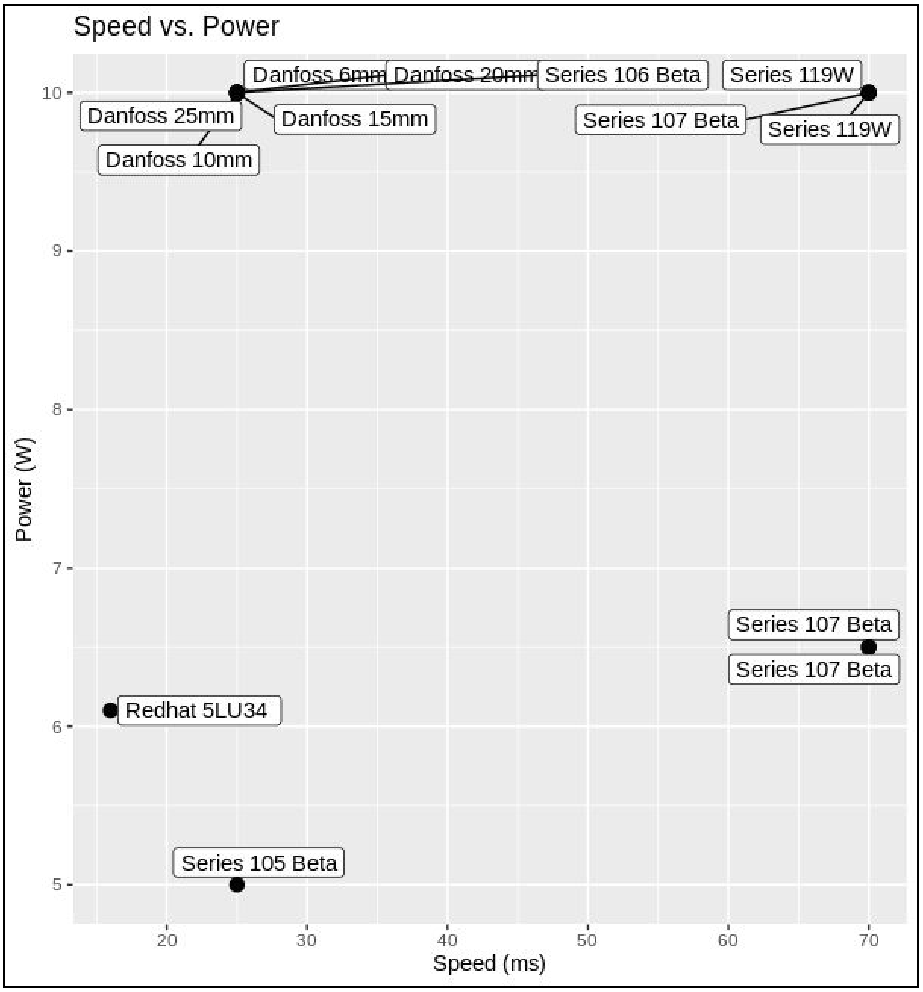
Image 2.3) https://www.wikiwand.com/en/Bash_valve

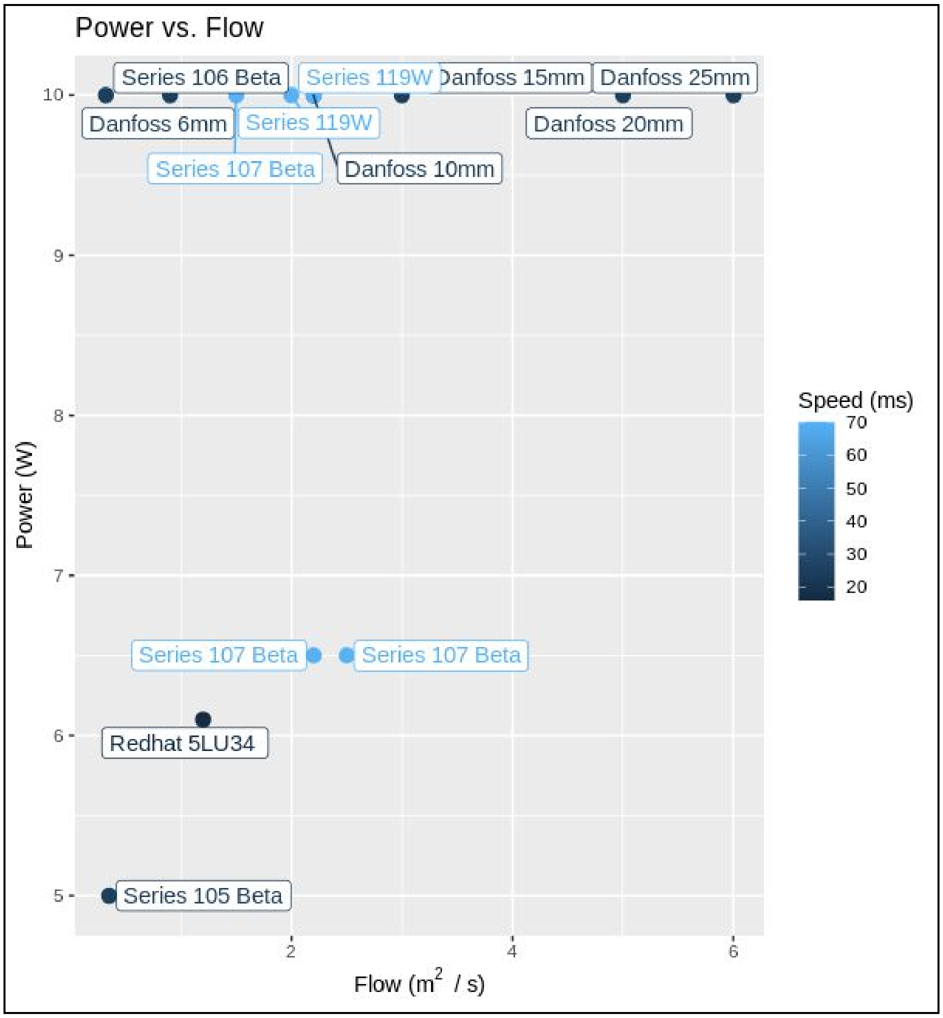
Appendix

A) Spreadsheet with valve information
   https://docs.google.com/spreadsheets/d/1PVQ4BDr1OaT7GQo2VtG4I6B3LQb9oPNj409jV5BNlWA/edit
B) Plots comparing off the shelf valves in various categories

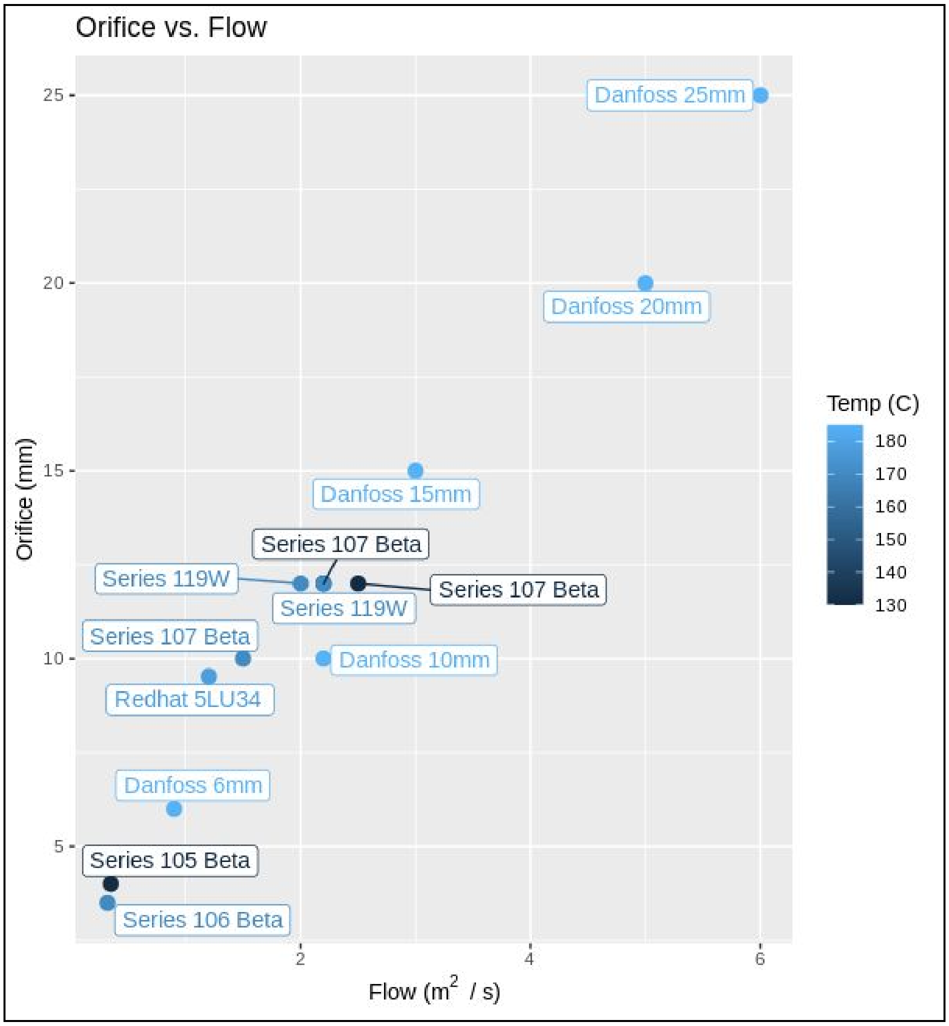



Pressure vs. Speed
Series 107 Beta
Series 107 Beta
Series 107 Beta
Series 119W
Series 119W
Danfoss 20mm
Danfoss 6mm
Danfoss 15mm
Series 106 Beta
Danfoss 10mm
Series 105 Beta
Danfoss 25mm
Redhat 5LU34
70
60
50
40
30
20
Speed (ms)
.15-15
.2-10
.2-10
0-10
0-4
0-8.5
2.5-10
2.5-9
Pressure (bar)
Power (W)
10
9
8
7
6
5


Speed vs. Power
Danfoss 6mm
Danfoss 20mm
Series 106 Beta
Series 119W
Danfoss 25mm
Danfoss 15mm
Series 107 Beta
Series 119W
Danfoss 10mm
Series 107 Beta
Series 107 Beta
Redhat 5LU34
Series 105 Beta
Power (W)
Speed (ms)
10
9
8
7
6
5
20
30
40
50
60
70



Power vs. Flow
Series 106 Beta
Series 119W
Danfoss 15mm
Danfoss 25mm
Danfoss 6mm
Series 119W
Danfoss 20mm
Series 107 Beta
Danfoss 10mm
Series 107 Beta
Series 107 Beta
Redhat 5LU34
Series 105 Beta
10
9
8
7
6
5
Power (W)
2
4
6
Flow (m2 / s)
Speed (ms)
70
60
50
40
30
20



Orifice vs. Flow
Danfoss 25mm
Danfoss 20mm
Danfoss 15mm
Series 107 Beta
Series 119W
Series 107 Beta
Series 119W
Series 107 Beta
Danfoss 10mm
Redhat 5LU34
Danfoss 6mm
Series 105 Beta
Series 106 Beta
Orifice (mm)
25
20
15
10
5
2
4
6
Flow (m2 / s)
Temp (C)
180
170
160
150
140
130