Optimization of a Pipeline Table-Top Educational Model

Sponsored by Pembina

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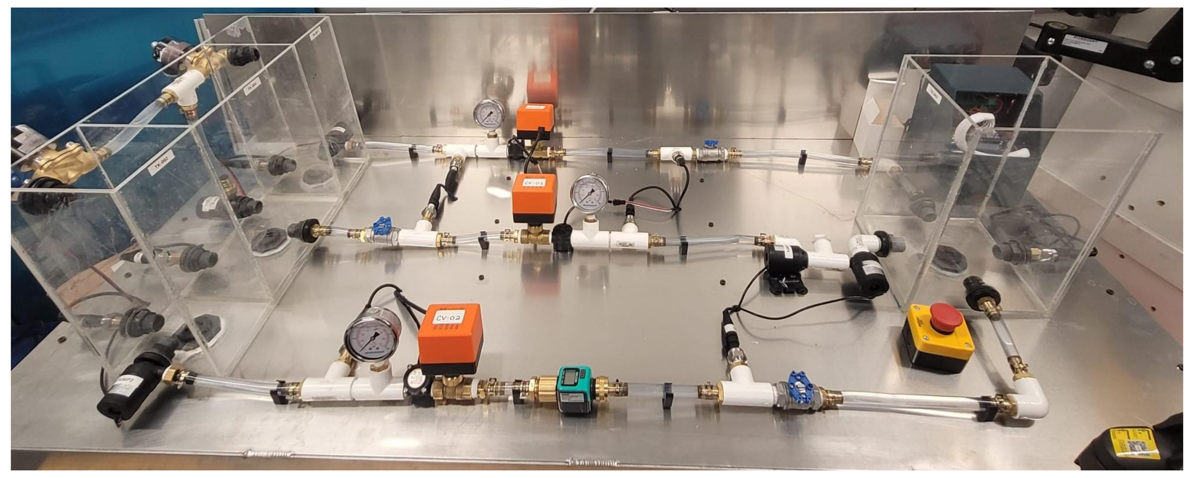


Project Scope of Work

Problem Statement:

- "The goal of this project is to create a table-top apparatus that demonstrates key concepts in pipeline system operations and control, […]"
- "By building a physical model, […] it provides an opportunity to convey these ideas to a broader audience in the industry"

Constraints

- Each segment of the model should have an effective length-to-diameter ratio no less than 10,000.
- Working fluid is water.
- Pumps are to be centrifugal.
- Tank level and valves to be actuated.
- The system can be controlled and monitored from an interactive display.
- System to run on open platform communications (OPC) protocol.
- The design should be compact, simple to setup and can be easily transported.

Engineering and Optimization Theory

This project required theory about fluid mechanics and turbomachinery to demonstrate the concepts of optimization. From fluid mechanics, the system curve must be found, for as the flow increases, so does the pressure loss. The flow rate for a desired length-to-diameter ratio can be found by combining the major and minor pressure losses.

$$h_L = \frac{\Delta P_L}{\rho g} = f\frac{L}{D}\frac{V_{avg}^2}{2g}$$

Major Losses Equation

$$h_L = K_L\frac{V^2}{2g} = f\frac{L_{equiv}}{D}\frac{V^2}{2g}$$

Minor Losses Equation

$$h_{L,total} = \left(f\frac{L}{D} + \sum K_L\right)\frac{V^2}{2g}$$

Total Loss Equation

$$\eta = \frac{Power\ Output}{Power\ Input} = \frac{\Delta P \times \dot{Q}}{V \times I}$$

Efficiency Equation

The above equations show major and minor losses, with major losses being attributed to straight sections of piping and minor being attributed to elbows, valves and other fittings. These two equations can be combined to formulate the system's total losses and pressure differential. This rate for this total pressure loss can be plotted against the flow rate to create a positive parabolic curve, showing that as the flow rate increases, the pressure losses increase exponentially.

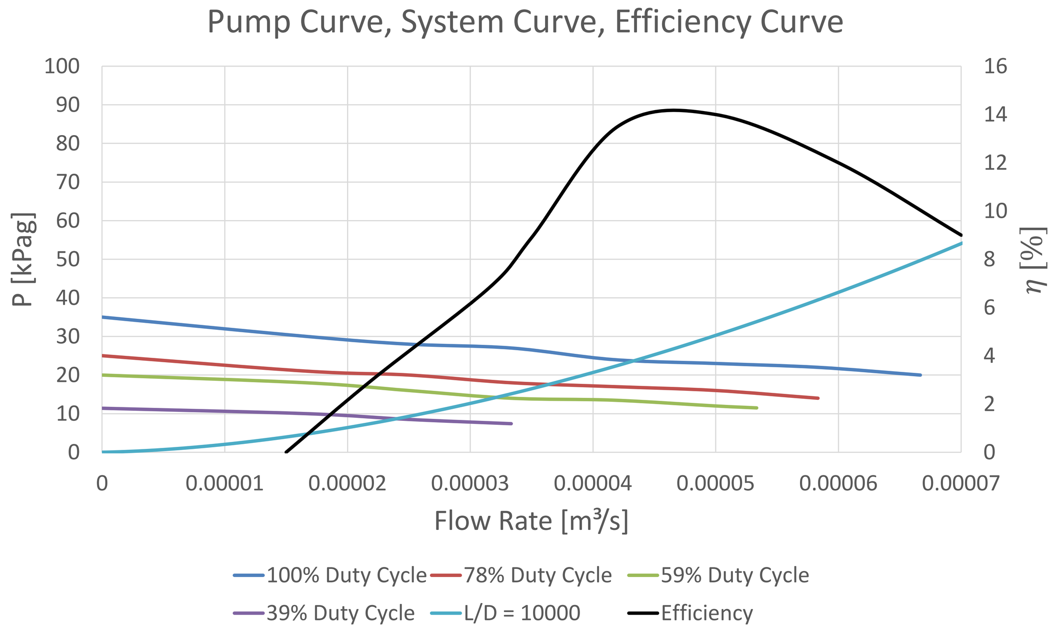
Theory of turbomachinery is applied to generate pump curves for the individual pumps used in the model. As the pumps did not come with operating curves, the team needed to generate pump curves by testing each pump. Matching a pump to the system curve required testing to quantify and measure the flow rate and pressure from the outlet of the pump. The flow rate is restricted downstream of the pump. Plotting these pressures against the corresponding flow rate created a negative power curve, showing the pressure the pump can generate decreases as the flow rate increases.

The optimization theory is based on the pump's power consumption efficiency which is derived from the pump and system curves. The model simulates head losses through the pipe by trying to run along the line where the pump curve and system curve intersect. These intersection points along are called operating points. Each operating point has a corresponding system efficiency. From the origin, as flow rate increases, the system efficiency increases until it reaches the maximum. After which, an increase in flow rate results to greater losses, ultimately decreasing the system efficiency.

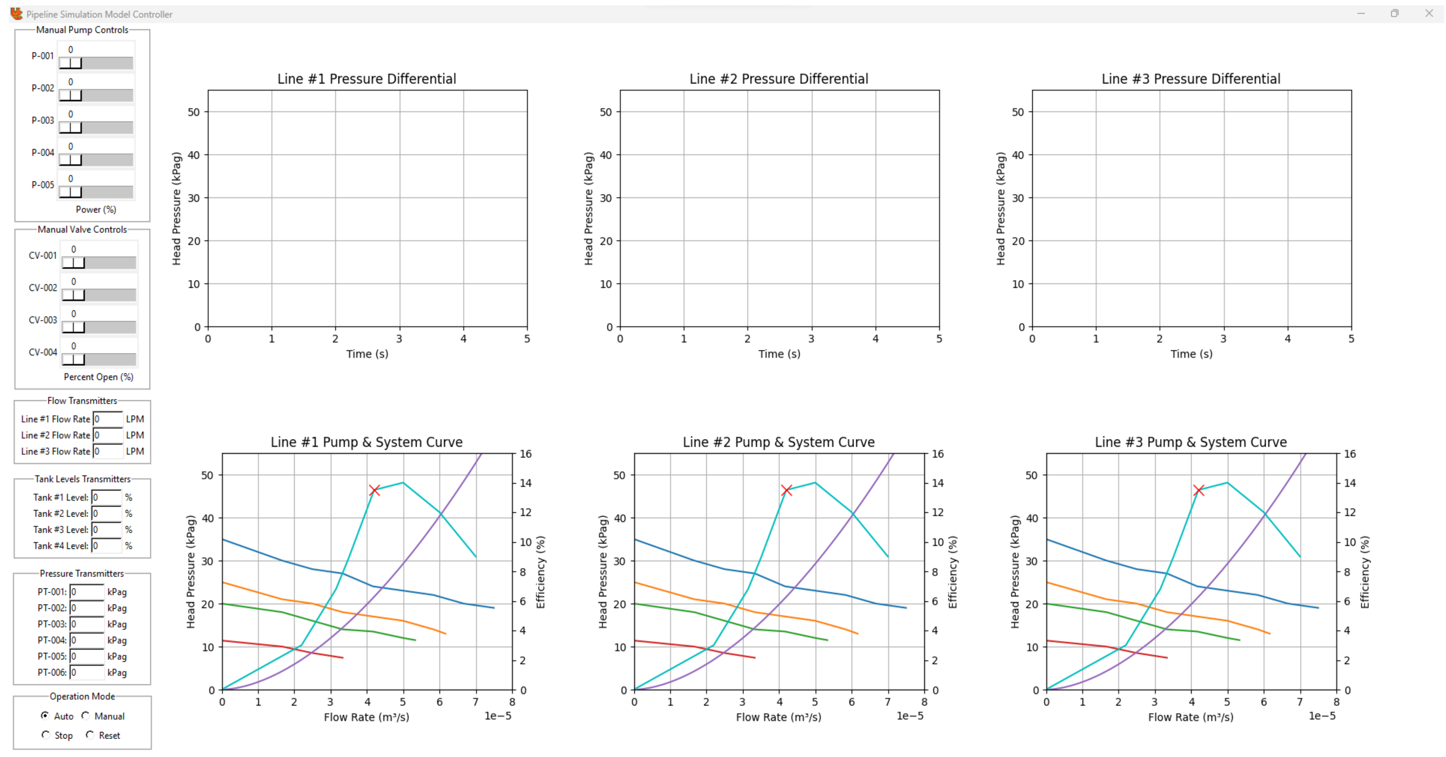
$$\eta = \frac{Power\ Output}{Power\ Input} = \frac{\Delta P \times \dot{Q}}{V \times I}$$

Results

In the chart below, the teams' results from testing the pumps and calculating the system curve for an L/D ratio of 10,000 have been plotted. The efficiency curve shows an inflection point, where the energy consumption by the pumps is providing the largest return on work.



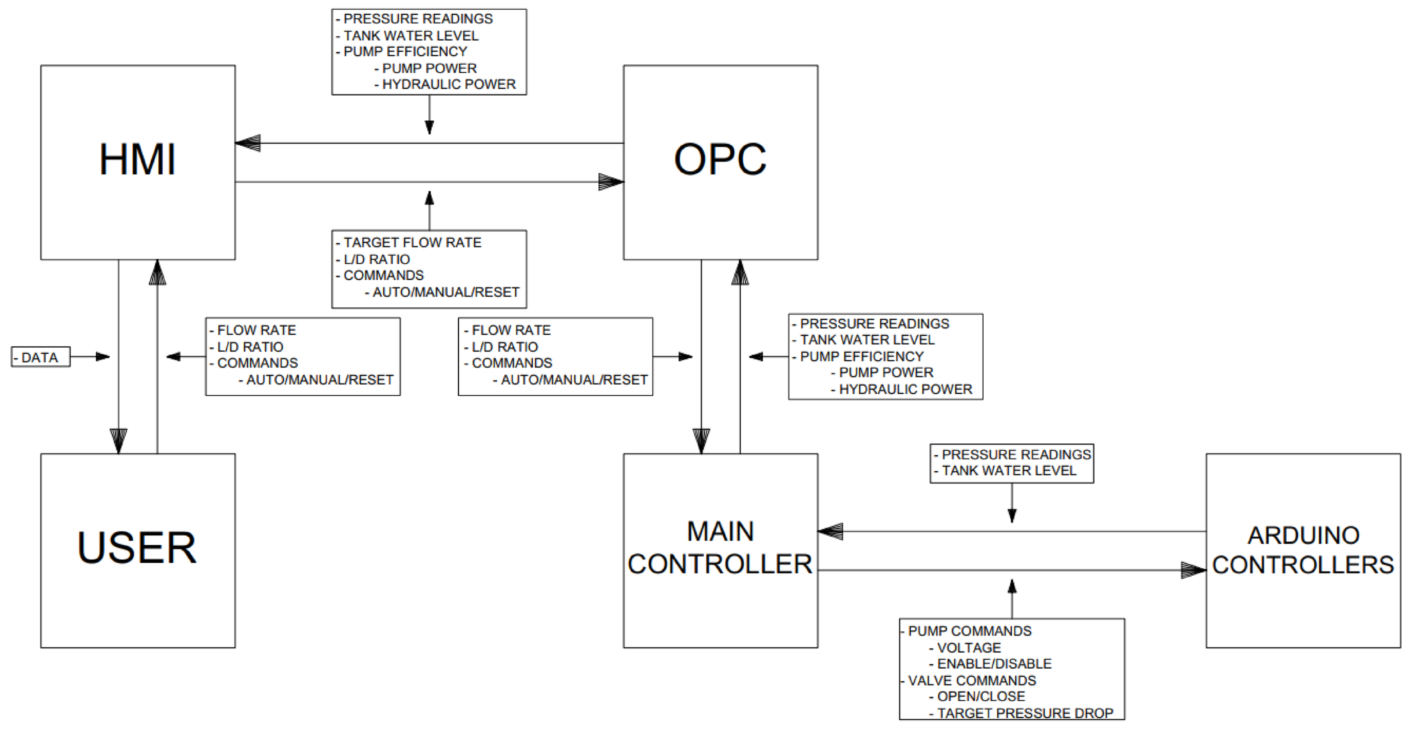
Methods and Materials



To convey the learning outcomes, the team has created a human-machine interface (HMI) that allows a user to run the model showing the most energy-efficient mode, or to change parameters in the manual mode to demonstrate what adjusting specific parameters does to the system. This will all be displayed for each line via plots on the screen that can show the pressure differential and the model's current L/D ratio being achieved.

The team has incorporated the use of an Open Platform Communication Unified Architecture (OPCUA) server that has two clients: the HMI and the main controller. This allows for remote control and communication of the model.

The main controller is the desktop PC, which controls the four Arduino Nano boards that transform the digital signals from the main controllers into 12V electrical signals.



Conclusions

This project is applying principles of fluid mechanics that can be used to optimize the energy consumption of the whole model. These concepts are then applied using Python Programming, in addition to controlling the fluid flow throughout the model.

References

[1]WikiTechy, "Motor Control Robots with Voltage Regulator Using Arduino Serial Port," WikiTechy, [Online]. Available: https://www.wikitechy.com/final-year-project/dotnet/motor-control-robots-with-voltage-regulator/arduino-serial-port. [Accessed: Feb. 11, 2024].
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