2015

Molten Metal Loop Driven by Electromagnetic Pump

Dominic Espiritu
Virginia Commonwealth University

Dor Granek
Virginia Commonwealth University

Jerald Moore
Virginia Commonwealth University

Scott Torres
Virginia Commonwealth University

Team Members: Dominic Espiritu, Dor Granek, Jerald Moore, Scott Torres

Faculty Advisor: Supathorn Phongikaroon

Sponsor: Department of Energy – Nuclear Energy University Program (NU-12-VA-VCU-0203-01)

MECHANICAL AND NUCLEAR

Molten Metal Loop

Driven by Electromagnetic Pump

CAPSTONE DESIGN EXPO 2015

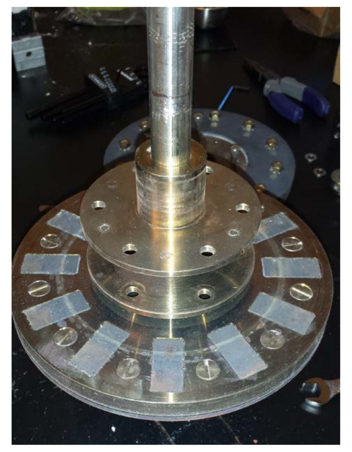
Abstract

Liquid Metal Fast Reactor (LMFR) utilizing liquid metal as a coolant is still being considered for future nuclear energy. In this concept, transporting liquid metal still poses many challenges in engineering design and material detection and accountability. In this senior design project, the team is exploring a design using the electromagnetic pump. Geometric configurations and pressure drop of the molten metal loop will be studied.

The electromagnetic pump used in this experiment differs from the standard electromagnetic motors by using rare earth magnets set into opposing steel plates that rotate simultaneously. Accurate data from the velocity and pressure gauges are necessary so the EM pump's functions and the flux created by it can be calculated. This design may provide advantages to industries using metal transportation, by saving both money and time. Model development and previous design work from the Nuclear Fuel Cycle project performed at the Center for Advanced Energy Studies have been utilized to accomplish the assigned tasks.

SolidWorks flow and heat transfer simulations will be used to develop the ideal models of the molten metal loop to be built. Based on this data, the design will be manufactured and tested to ensure it can accurately gather information. If this is achieved, then the possible incorporation of a Laser Induced Breakdown Spectroscopy system will be incorporated to analyze the different compositions (contaminations) of the molten metal in the loop completing material safeguarding concept. A new port will be added to the loop for implementation of the quartz window in anticipation of future use of the system.

Approach & Challenges



Approach:

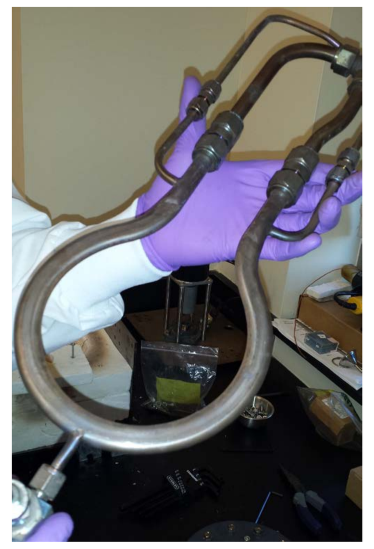
The initial design of this project was supported by the Department of Energy-Nuclear Energy University Program (DOE-NEUP) to investigate the usage of electromagnetic loop for the molten salt system. The current design will transform this original structure for the molten metal. Tin was the metal selected for this study because its thermal and electrical properties. The team has incorporated SAE 316 stainless steel into every part of the loop due to its resistance to deterioration.

Challenges with the design:

•Lack of measurement tools to accurately determine velocity;

•Low differential pressure caused problems calculating velocity;

•Accident during a trial caused tin to go into the differential pressure gauge and splash onto the heating tape.



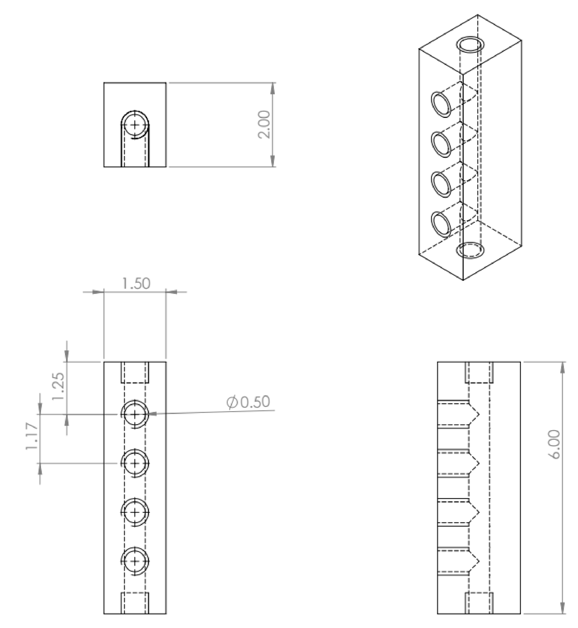
Solutions

The current design improves on the previous design by compensating for the previous design's inefficiencies. The way to address these challenges was by:

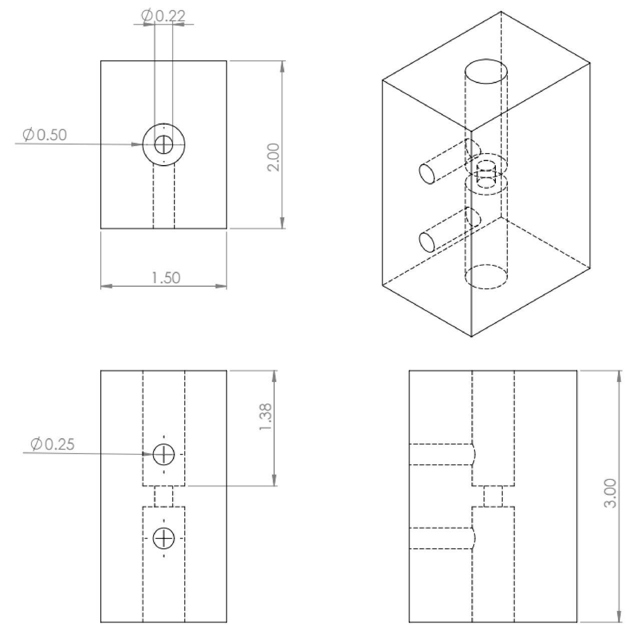
- Making the loop longer to create more of a pressure differential;
- Putting in an orifice meter to measure flow velocity;
- Creating a manifold with 4 ports to allow for more instruments to be used; and
- Making all risers tall enough that tin should not be able to enter the gauges

All drawing designs are shown below.

Manifold Design



Orifice Meter Design



Theoretical Comparison
(Preliminary study)

To see the difference in flow between the new design and the old design, a comparison of previous experimental data with calculated data for the new loop is shown below. Values were calculated using Bernoulli's equation with consideration of losses due to tube changes and friction. As can be seen, in the new design, when the Reynolds number is greater than 2000, it increases at a much faster rate than the value from previous experiments. This is because the formula used for the Reynolds number only applies for the laminar region (Re < 2000).

Old Design

ΔP (Pa)	Re
8	902
9	1015
10	1127
17	1916
20	2255
23	2593
25	2818
26	2931
35	3945
40	4509

New Design

ΔP (Pa)	Re
8	734
9	838
10	946
17	1797
20	2227
23	2705
25	3055
26	3240
35	5311
40	6905

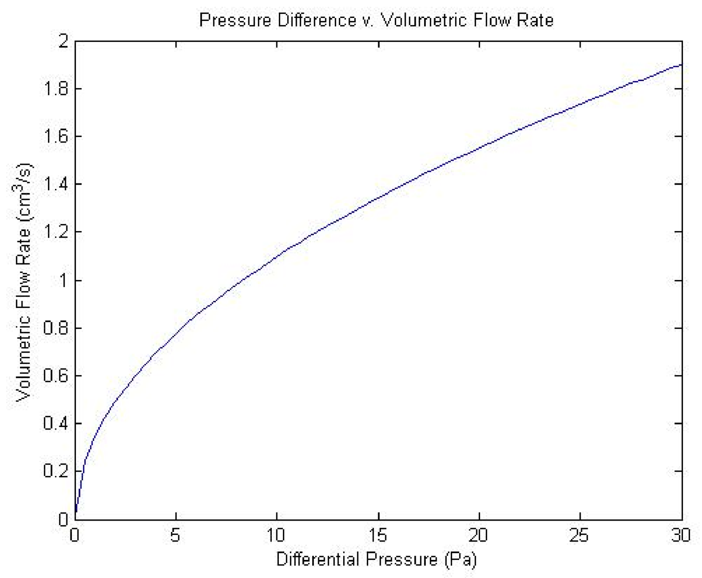
Theoretical Predictions
(Preliminary study)

To calculated the volumetric flow rate, an equation was derived from the Bernoulli Equation. The equation below is what was used to for the calculation.

$$Volume\ Flow\ Rate = C_d A_O \sqrt{\frac{2 * (P_{In} - P_{Out})}{Density * (1 - (D_O/D_T)^4)}}$$

Where D_O = Orifice Diameter
D_T = Diameter of the Tube
C_d = Coefficient of Discharge
A_O = Cross Sectional Area of Orifice

With this equation, several different scenarios of different differential pressures were calculated. The graph presented shows the correlation between differential pressure and the volumetric flow rate. This will allow for comparison to the actual relationship between pressure and volumetric flow rate. From this data, a more refined model of the flow can be generated. Also, a correlation from RPM of the rotating magnet to pressure difference can be made. If the experimental data differs from this prediction, the team will be able to determine and correct any erroneous variables.



Future Considerations

After the data has been analyzed and the behavior of the electromagnetic pump has been characterized, there are several ways that the design can progress forward. One of the ways would be to study how the pump behaves when it is moving different molten metals that have significant electrical conductivity. This, combined with varied densities, would affect the driving force of the pump and the equations derived from the use of tin could be verified.

Another possible consideration would be scaling of the pump. For the past two designs, while the size of the loop changed, the size of the pump did not. Testing whether the driving force of the pump scales linearly or otherwise with the number of magnets, strength of the magnets, and the radius of the pump. These factors, depending on how they scale, would affect the commercial viability of the design.

Additionally, a type of sampling system could be incorporated into the loop for commercial purposes, possibly making use of one of the extra ports. This type of loop could be attached to other systems that already have a flowing fluid, sampling a representative portion of the fluid. This would allow for measurements of flowing molten metal used in a reactor to be extracted and tested for impurities or other tests, all with a no contact pump.

Currently, in the design, the temperature of the fluid is assumed to be functionally the same as the temperature measured by the thermocouples attached to the heating tape. Another thermocouple could be inserted through one of the ports to confirm what the temperature of the molten metal is. This is important because all of the properties of tin used in calculations were based on a certain temperature.