SYSTEM DESIGN AND DESCRIPTION OF A MOLTEN SALT LOOP

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Submitted in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

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[May 2021]
Submitted March 2021

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ABSTRACT

Molten salt reactors (MSRs) use molten salts (instead of water or other fluids) to remove nuclear fission power from the reactor core. A molten salt loop system can be used to test materials and components for MSRs. In this thesis, the molten salt loop system design was described and analyzed. For an 8 feet by 3 feet molten salt loop with a 1.25 inch inner diameter pipe operating at 800°C, the required drain tank heater power needed to heat up the 11.6 kilograms of FLiNaK molten salt in 60 minutes was found to be approximately 12 kW. The power of the band heaters needed to maintain the operating temperature as the molten salt flows around the loop was calculated to be approximately 0.79 kW for pipes insulated with a 2 inch thick ceramic fiber insulation sheet. The pump used to circulate the molten salt through the piping was found to have a minimum required horsepower of 0.154 horsepower. The drive shaft needs to be approximately 1 meter long in order to dissipate the heat going from the 800°C molten salt to the ambient temperature pump motor. Commonly available components containing materials such as zinc, plastics, glues, or resins cannot be used in the molten salt loop design due to the extremely high operating temperature of the molten salt loop. Thermal expansion of the molten salt loop has to be taken into account when designing and constructing it. Extremely high operating temperatures and the corrosivity of the molten salt are some of the design challenges that need to be considered when designing molten salt loops in a laboratory.

1. Introduction

In some nuclear reactor designs (such as the one used in the 1960s Molten Salt Reactor Experiment at Oak Ridge National Laboratory), molten salt (instead of water) is used to remove heat from the reactor core. A molten salt loop system can be constructed to confirm aspects of existing molten salt nuclear reactor designs and/or test new materials and components. The purpose of this thesis is to provide a system description, design, and analysis of a potential molten salt loop system that can be constructed in a thermal-fluids laboratory at a university.

The main advantage of molten salt reactor designs over traditional light water reactor designs is the lower operating pressure. Molten salt reactors operate close to atmospheric pressure and at very high temperatures, while light water reactors operate at high pressures and lower temperatures. In a molten salt reactor, the energy from the reactor core is absorbed by the molten salt, which increases in temperature but does not become pressurized. However, in a light water reactor, the water (steam) absorbs the energy and becomes hot and highly pressurized. Disadvantages of molten salt reactors include the high operating temperatures and high corrosivity of the molten salt, making material research and selection extremely important.

1.1 Background

The 1960s Molten Salt Reactor Experiment at Oak Ridge National Laboratory in Oak Ridge, Tennessee involved the use of materials and techniques that had never been used before as part of a nuclear reactor. The reactor used the molten salt "FLiBe" (a mixture of lithium fluoride and beryllium fluoride) for the secondary loop and "FLiNaK" (a mixture of lithium fluoride, sodium fluoride, and potassium fluoride) for the primary loop (Molten Salt Reactor Experiment). The primary molten salt loop was in direct contact with the reactor core and the secondary loop transported heat away from the primary loop. In addition, the alloy "Hastelloy-N" (Nickel 71%, Molybdenum 16%, Chromium 7%, Iron 4% by weight) was used for the piping through which the molten salts flowed (Molten Salt Reactor Experiment).

More recently, the Idaho National Laboratory is leading the development of the Next Generation Nuclear Plant (NGNP) which uses molten salt in the design (Sabharwall). The characteristics that make the liquid salts good for process heat transfer applications are high boiling point, low vapor pressure, large specific heat and thermal conductivity, and high density at low pressures (Sabharwall). Idaho National Laboratory has used the test data from the University of Wisconsin's molten salt loop in order to identify issues with current designs and offer a path forward for future work. For example, it was found that using a graphite crucible increases the corrosiveness of KCl-$MgCl_2$ and FLiNaK molten salts compared to using a crucible made out of a metallic alloy (Sabharwall). In addition, Sabharwall et al. stated that "Chromium in the alloy is a concern in a FLiNaK heat transfer system because of its propensity to readily dissolve in molten fluoride salts" (Sabharwall). They also identified heat transfer and instrumentation issues that occur at the high operating temperatures. Their recommendations for future work and experiments include: working on the corrosion models for different molten salts such as carbonate salts, determining the effects of contaminants in the molten salts, and determining the effects of molten salts on the heat-affected zones of the weld regions in the welded area of tubes, among many other recommendations (Sabharwall).

1.2 Objective

The objective of this thesis is to demonstrate a small molten salt loop system design that is capable of testing new materials and components for molten salt nuclear reactors, and confirm materials and components used in existing molten salt reactor designs. The types of testing that can be performed include temperature testing, material compatibility testing, corrosion testing, and endurance testing. For example, different molten salts (such as FLiNaK or FLiBe) can be tested with different piping materials (such as Hastelloy-N, Inconel 600, or Nickel-201) to determine the rate of corrosion that the piping experiences. Different operating temperatures ranging from 700 to 1200°C can be tested to see the effect that different operating temperatures have on the system. Lastly, the pump performance can be analyzed across a range of different operating parameters.

2. Molten Salt Loop System Design & Description

The figures below outline a basic system schematic of the planned 8 feet by 3 feet by 4 feet molten salt loop and the associated system components.

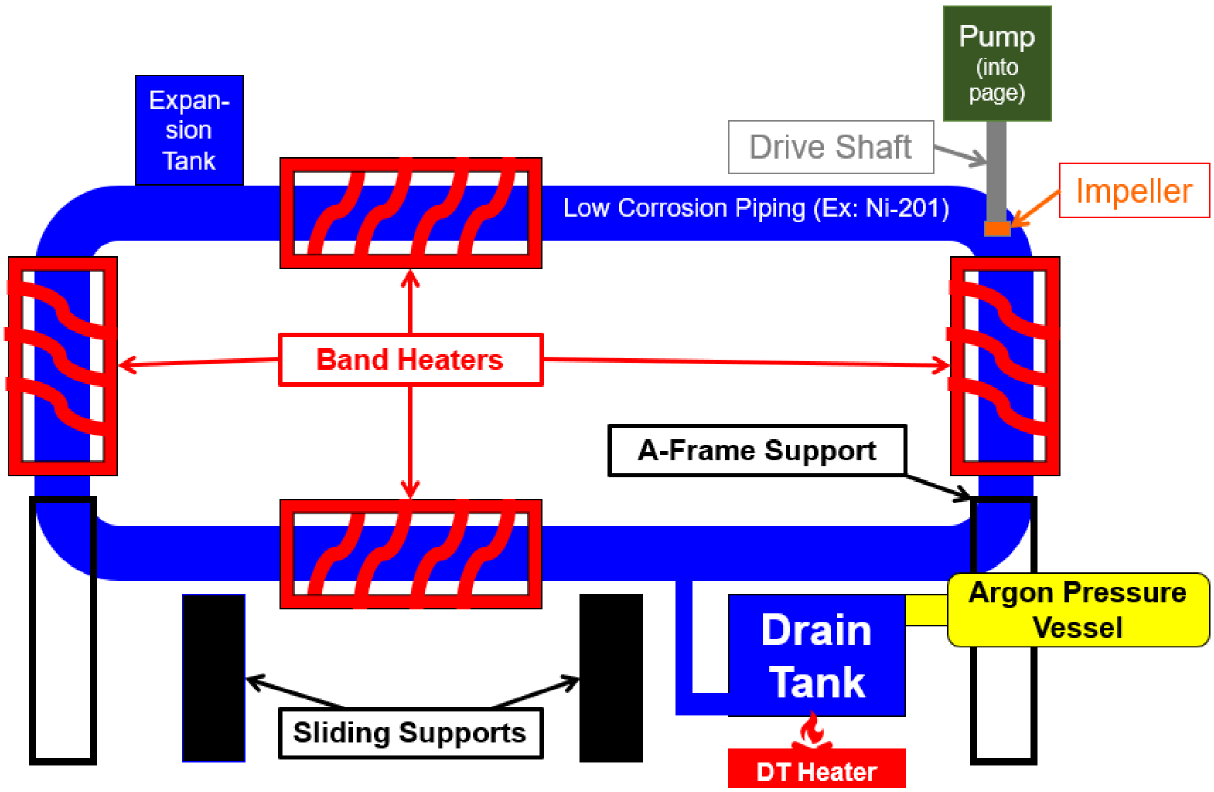

Figure 2.1: Molten Salt Loop Basic System Schematic

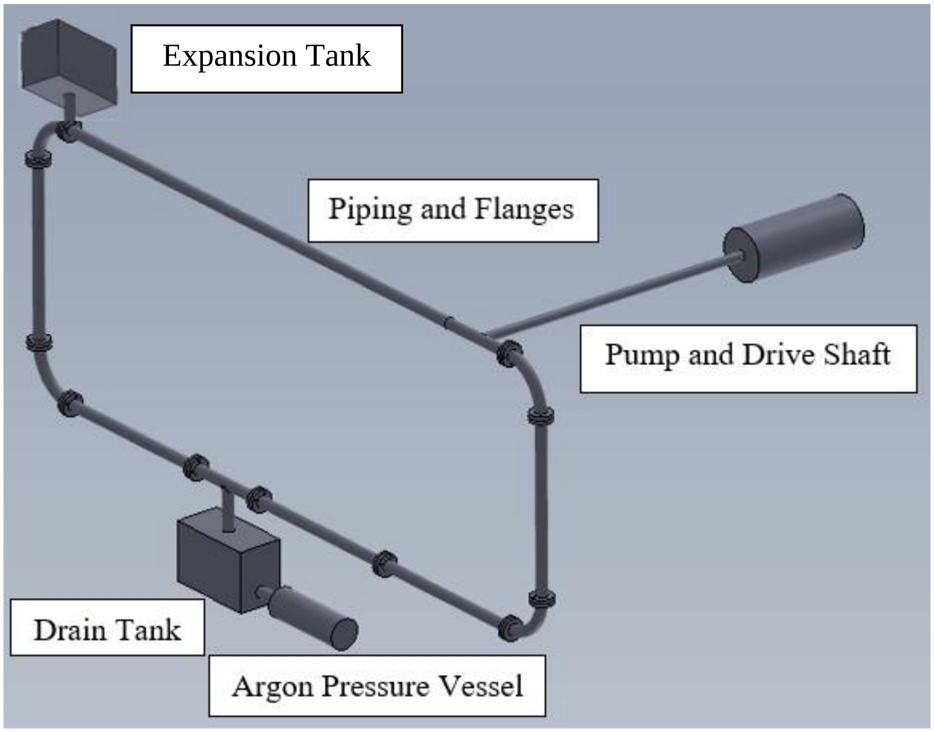

Figure 2.2: Molten Salt Loop Basic CAD Model

The molten salt circulates through the 8 feet by 3 feet low corrosion piping. The band heaters maintain the molten salt at the required operating temperature. The pump, drive shaft, and impeller circulate the molten salt through the piping. The drain tank holds the frozen salt while the system is not in operation, and contains the frozen and molten salt while it is being heated up to the operating temperature. The drain tank heater heats up the molten salt from room temperature to the required operating temperature. The argon pressure vessel pressurizes the drank tank so that the molten salt can flow into the loop. The A-frame and 1 meter tall sliding supports hold up the molten salt loop structure but are not directly attached to it. This is to allow flexibility for when the molten salt loop experiences thermal expansion and to avoid any cracking or warping of the piping and the supports. The sliding support should be 1 meter tall so that the heat does not conduct all the way to the floor. There should be a Nickel-201 platform with small walls (similar to a bathtub) under the platform in case there is a molten salt leak.

The loop will be divided into sections. There will be three pipe elbows for the corners of the loop and at least four straight pipes for the straight sections of the loop. (A fourth pipe elbow is not needed because the enclosure of the pump impeller will serve as one of the pipe elbows.) Each section of pipe will have flanges in order to connect them to the other sections. In order to prevent leakage of molten salt from the pipe flanges, there needs to be a gasket in between the pipe flanges (such as a Kammprofile Gasket). The gasket must withstand the operating temperature and must be of a material compatible with the molten salt, which the Kammprofile gasket does.

The nuts and bolts holding the flanges together must have coefficient of thermal expansions that are close to each other, so that they are still compatible after the large temperature change from room temperature to the operating temperature. Zinc-plated bolts cannot be used because the melting point of zinc is only 415°C ("Max Temperature for Zinc Fasteners"). Special high service temperature fasteners, such as 310 stainless steel bolts and nuts ("High-Temperature Fasteners") must be used to withstand the operating temperatures. In addition, for safety reasons (to prevent disassembly and leakage of the molten salt loop), the nuts and bolts must be secured with safety wire. Thread-locking compounds and locknuts containing polymers cannot be used because the effectiveness of the locking is reduced or becomes non-existent at the operating temperature. The safety wire should also be inspected to ensure that it does not loosen, yield, or fracture as a result of the temperature changes.

2.1 Heaters

Two heaters will be used. One heater will be located near the drain tank and one heater will be wrapped around the loop piping. The drain tank heater will heat the salt until it melts and reaches the operating temperature, while the pipe heater will maintain the temperature of the circulating molten salt.

2.1.1 Drain Tank Heater

The molten salt loop system should be able to change the temperature of the salt from room temperature (20°C) to the operating temperature (e.g. 800°C) in a reasonable amount of time (e.g. approximately 60 minutes) so that the desired experiments can be conducted in one workday and the molten salt loop system can be shut down at the end of the day.

The main equation used was:

$$Q = mc_S\Delta T_S + mh_f + mc_L\Delta T_L \tag{1}$$

where Q is the required heat input, m is the mass of the salt, c_S is the specific heat of the solid salt, ΔT_S is the temperature difference between the room temperature and the melting point, h_f is the latent heat of fusion, c_L is the specific heat of the molten salt, and ΔT_L is the temperature difference between the melting point and the operating temperature. The required power was found using the equation:

$$P = Q / t \tag{2}$$

where P is the required power, Q is the required heat input, and t is the desired heating time. The following table summarizes the variables and equations used to arrive at the required drain tank heater output.

Table 2.1: Drain Tank Heater Calculation Table

Variable	Description	Value	References/Notes
t	Desired heating time (minutes)	60	
m	Mass of FLiNaK to be heated (kg)	11.628	Volume of molten salt loop inside the piping. This is the maximum volume of molten salt that can flow through the pipe.
c_L	Specific heat capacity of molten FLiNaK (J/g C)	1.88	An et al. (2019). Constant at all operating temperatures.
c_S	Specific heat capacity of solid FLiNaK (J/g C)	1.3	Yin et al. (2015). Average specific heat capacity.
h_f	Latent heat of fusion of FLiNaK (cal/g)	380	Williams (2016).
t_i	Initial Temperature (°C)	20	
t_m	Melting temperature of FliNaK (°C)	450	Williams (2016).
t_f	Final Temperature (Operating Temperature) (°C)	800	
Q	Energy required to bring FLiNaK to operating temperature (J)	$3.264 * 10^7$	$Q = mc_S\Delta T_S + mh_f + mc_L\Delta T_L$
$P_{no\ losses}$	Power required to heat FLiNaK to operating temperature in desired time (kW), neglecting heat losses	9.066	$P = Q / t$ Does not take into account the rate of heat loss
P	Power required to heat FLiNaK to operating temperature in desired time (kW), considering heat losses	12.228	See Table 2.2. This is a conservative estimate because we are assuming that the heat loss at 800°C is the same as the heat loss at lower temperatures, even though the actual rate of heat loss at lower temperatures is lower.

2.1.2 Band Heaters

The pipe heaters / band heaters should keep the circulating molten salt at the same temperature throughout the loop. There should be a closed-loop control system to control the heaters to maintain the operating temperature and change the operating temperature if desired. The main equation used to find the rate of heat loss across the entire loop was:

$$q = (T_m - T_\infty) / R_{tot} \tag{3}$$

$$R_{tot} = 1/(2\pi r_1 \Delta x\, h_1) + \ln(r_2/r_1) / (2\pi k_1 \Delta x) + \ln(r_3/r_2) / (2\pi k_2 \Delta x) + 1/(2\pi r_3 \Delta x\, h_\infty) \tag{4}$$

where T_m is the temperature of the molten salt, T_∞ is the ambient temperature, r_1 is the inner pipe radius, r_2 is the outer pipe radius, r_3 is the outer radius of the insulation, Δx is the length of the pipe section, h_1 is the heat transfer coefficient of the molten salt, k_1 is the thermal conductivity of the pipe, k_2 is the thermal conductivity of the insulation, and h_∞ is the heat transfer coefficient of the air (Bergman).

The following table shows the calculation of the resulting band heater required power, which was found to be approximately 0.79 kW per band heater. It is recommended for the band heater power to be variable so that different operating temperatures can be achieved.

Table 2.2: Band Heater Calculation Table

Variable	Description	Value	Reference
T_m	Temperature of the FliNaK molten salt (°C)	800	
T_∞	Temperature of the ambient air (°C)	25	
r_1	Pipe inner radius (meters)	0.0183	1.25-inch nominal pipe
r_2	Pipe outer radius (meters)	0.0211	1.25-inch nominal pipe
r_3	Insulation outer radius (meters)	0.123	4-inch thick ceramic fiber insulation
Δx	Pipe section length (m)	6.71	Perimeter of molten salt loop. An 8 feet by 3 feet loop has a perimeter of approximately 22 feet, or 6.71 meters.
Re	Reynolds Number	13600	Re = ρvD/μ, where ρ is the molten salt density, v is the velocity, D is the diameter of the pipe, and μ is the dynamic viscosity of the molten salt. Values for ρ, v, D, μ obtained from Vriesema (1979), design, and An, Cheng, Su, and Zhang (2017). This is a turbulent flow.
h_1	Heat transfer coefficient of molten FLiNaK (W/m^2K)	1800	Zhang & Sun (2020) Extrapolated from Figure 10 in the paper. See Figure 2.4 below for the extrapolation.
k_1	Thermal conductivity of Nickel 201 alloy (W/mK)	79.3	("Nickel 201 Alloy")
k_2	Thermal conductivity of ceramic fiber insulation (W/mK)	0.18	("RSBL Alumina Silica Blanket")
h_∞	Heat transfer coefficient of air (W/m^2 K)	15	(Bergman)
R_{tot}	Thermal resistance (K/W)	0.246	From calculation of equation (4)
q	Heat loss rate for whole loop (W)	3174	From calculation of equation (3)
P_{heater}	Power needed for each heater (W)	794	Heat loss rate divided by number of heaters

2.2 Pump Selection and Design

The parameters affecting the pump selection include the pipe length, pipe diameter, desired fluid velocity, and Darcy friction factor, as well as losses due to bends in the pipe. First, the head loss due to pipe friction was found using the Darcy-Weisbach equation shown below:

$$h_f = f\,(L/D)\,(v^2/(2g)) \qquad (5)$$

where h_f is the head loss due to friction, f is the Darcy friction factor, v is the fluid velocity (approximately 5 feet per second), L is the length of the pipe, and D is the pipe diameter. It was assumed that the piping material friction factor is equal to 0.10. This is a conservative estimate because badly corroded carbon steel had the highest surface roughness out of all the materials listed in the reference.

The total head loss was found by adding the head loss due to the pipe friction and the head loss due to the height of the loop (3 feet or approximately 1 meter). The equation below was used to find the required power needed to overcome the head loss in the pipe:

$$P = Q\rho g H \qquad (6)$$

where Q is the volumetric flow rate of the molten salt, ρ is the density of the molten salt, g is the acceleration due to gravity, and H is the total head loss needed to be overcome.

The following table summarizes the variables and equations used to arrive at the required pump power:

Table 2.3: Pump Power Calculation Table

Variable	Description	Value	References/Notes
H	Total head loss (m)	3.61	Total Head Loss = Head Loss due to height difference + Head Loss due to pipe friction + Head Loss due to pipe elbows
h	Height of molten salt loop (m)	0.914	
H_{elbows}	Head Loss due to pipe elbows (m)	0.10	$H_{elbows} = 4K\ v^2/2g$ where K = 0.2. (Ratzlaff)
g	Gravitational constant (m/s^2)	9.81	
ρ	Highest Fluid Density (kg/m^3)	2,201.5	ρ = 2530-0.73T(°C) (kg/m^3) for T = 500 to 800°C Extrapolated to 450°C. (Vriesema)
Q	Flow Rate (m^3/s)	0.00123	0.00123 m^3/s of flow means that the salt travels through approximately 5 feet of pipe per second. Design flow rate.
P	Required power (kW)	0.0959	P = QρgH / 1000
P + 20%	Required power (hp)	0.154	Unit conversion

The next table summarizes the head loss calculation using the Darcy-Weisbach equation:

Table 2.4: Head Loss Calculation Table

h_f	Head loss due to pipe friction (m)	2.60	Darcy-Weisbach equation, $h_f = f\ (L/D)\ (v^2/2g)$, where f is the Darcy friction factor
f	Darcy Friction Factor	0.10	Worst case scenario - badly corroded carbon steel. The assumption is that the piping material friction factor will be similar to the carbon steel friction factor. ("Absolute Roughness") (Shipway)
v	Fluid velocity (m/s)	1.55	v = Q / A, where Q is volumetric flow rate and A is inside cross-sectional area. Design velocity.
L	Total pipe length (perimeter) (m)	6.71	8 feet by 3 feet molten salt loop for university laboratory. Design pipe length.
D	Pipe Diameter (m)	0.0318	1.25 inch pipe inner diameter. Design pipe diameter.

The design values for pipe length, and pipe diameter were chosen because the pipe length and pipe diameters were commonly available and are the appropriate size for a small university laboratory molten salt loop. The design value for the fluid velocity was chosen because it seemed to be a reasonable number and the molten salt would circulate completely around the loop within a few seconds. If different values were chosen for the pipe length, pipe diameter, and fluid velocity, they would have a major effect on the required pump power and the required heater powers. For example, if a 1-inch diameter pipe was used, holding all other values constant, the required pump power would increase (due to increased pipe friction and faster flow velocities) and the required drain tank heater power would go down to approximately 6.96 kW (due to a decrease in the mass of the molten salt to be heated).

Using smaller pipe sizes would require larger pump power (assuming the same volume flow rate), and it is best to minimize the pump power. The ideal design would be a smaller molten salt loop with a relatively large pipe size to minimize the pump power needed. It would be advantageous for a small modular molten salt reactor to use larger pipe sizes to carry the molten salt due to the lower pump power required to circulate it.

A basic search reveals that most of the molten salt pumps available on the market are relatively very large in size and used commercially in the chemical and solar power industries, rather than for research purposes in university laboratories. For example, the molten salt pump made by Sulzer was designed for use in large commercial solar applications and has a head of up to 1150 feet ("Molten Salt Circulation Pumps"). In addition, it is not clear if the remaining pumps can be integrated into the molten salt loop in accordance with the basic system schematic shown earlier. The Wenesco High-Temperature Pumps were designed to pump smaller amounts of molten salts or other very hot liquids, but the discharge piping has to be significantly modified in order to successfully incorporate it into this molten salt loop design ("Wenesco High-Temperature Pumps"). Alternatively, the Tobee High Temperature Molten Salt Pump may be integrated into the molten salt loop, but the discharge piping also has to be significantly modified ("High Temperature Molten Salt Pump"). Therefore, it may be best to design a pump assembly for this specific molten salt loop application.

In addition, in order to produce a range of flow velocities, it is recommended to vary the pump power, either by using a built-in power setting or by varying the current that goes to the motor. Another consideration that needs to be taken into account is the potential heating of the drive shaft and motor by the molten salt. The drive shaft material, length, and motor must be carefully selected in order to prevent overheating of the pump motor.

2.2.1 Drive Shaft

The drive shaft needs to be relatively long, at least 1 meter (3.28 feet), so that the heat from the molten salt loop does not heat up the motor of the pump. Most motors can only operate at an ambient temperature of 40°C in order to avoid damage to the motor windings. In addition, there needs to be a fan to increase the convection heat transfer from the drive shaft to the air.

A thermal analysis was done on the drive shaft in order to show that the heat from the 800°C molten salt does not conduct all the way to the motor. The temperature 1 meter from the hot end of the drive shaft was determined to be approximately 25.68°C, which is less than the maximum allowable temperature of 40°C (Bergman). The formula used was:

$$\theta / \theta(0) = \cosh m(L-x) / \cosh mL \quad (5)$$

where cosh is hyberolic cosine, θ is $T(x) - T_\infty$, (temperature difference between the rod at distance x from the hot end and the surrounding temperature), θ(0) is the temperature of the rod at the hot end, and m^2 is hP/kA_c, where h is the heat transfer coefficient of air, P is the perimeter of the rod, k is the thermal conductivity of the rod, and A_c is the cross sectional area of the rod (Bergman). A graph showing the shaft temperature at various lengths from the hot end is shown in the next figure. The table below shows the values used for the drive shaft temperature analysis.

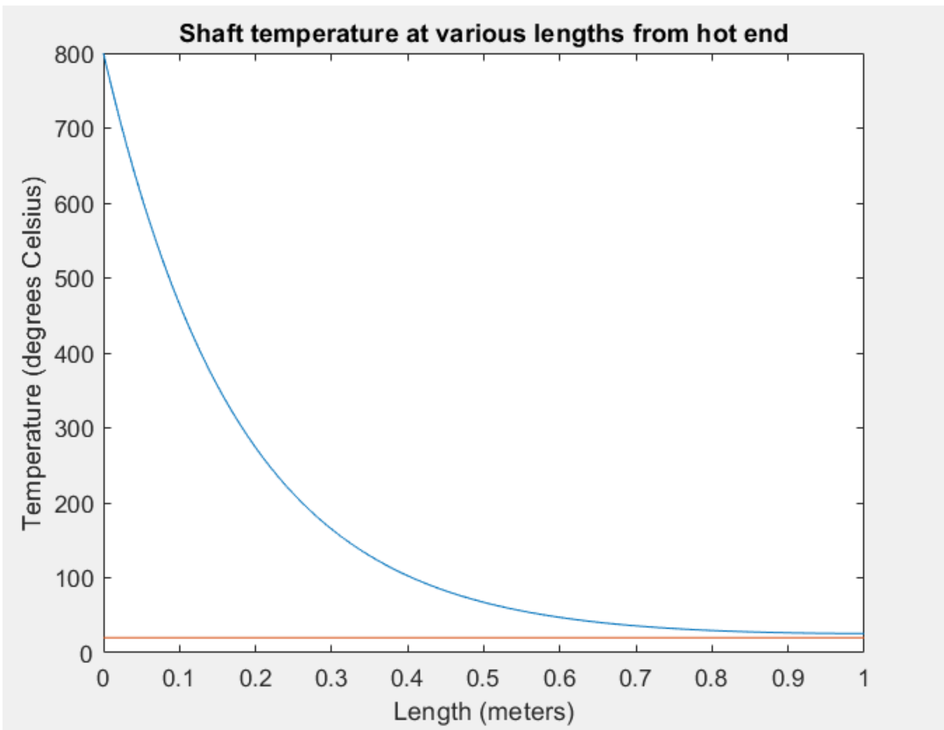

Figure 2.3: Drive Shaft Temperature Analysis

Table 2.5: Values Used for Drive Shaft Temperature Analysis

Variable	Description	Value	References/Notes
h	Heat transfer coefficient of air (W/m^2K)	25	Forced convection of air using fan
P	Perimeter of rod (m)	0.126	2 centimeter radius solid drive shaft
k	Thermal conductivity of nickel 201 rod (W/mK)	79.3	(Rosenberg)
A_c	Cross sectional area of rod (m^2)	0.0013	2 centimeter radius solid drive shaft

2.2.2 Impeller and Seal

The impeller and seal assembly must be assembled in such a way so that the molten salt does not flow outside of the molten salt loop. One possible way to do this is to use "a John Crane–type 2800 rotating shaft seal" (Robb). The impeller must be custom-made for this specific application due to the high operating temperatures and corrosivity of the molten salt. The impeller can be made out of Nickel-201 or Inconel 600, which both offer excellent corrosion resistance under the operating temperatures (Robb).

2.3 Summary of Nominal Operating Parameters

The table below shows the approximate nominal operating parameters of the molten salt loop:

Table 2.6: Nominal Operating Parameters

Variable	Description	Value	References/Notes
t	System Start up Time (minutes)	60	Design value. This value was chosen so that any experiments can be performed in one work day.
P	Drain Tank Heater required power (kW)	10.88	From Calculation Table
P_{pump}	Pump required power (hp)	0.154	From Calculation Table
d	Pipe diameter (in)	1.25	Design value. This value was chosen because the piping must be able to fit inside of a small laboratory space.
v	Flow velocity of molten salt (ft/s)	5	Design value.
P_{heater}	Required power for each band heater (kW)	0.79	From Calculation Tables, assuming ceramic fiber insulation is used
T	Operating temperature (°C)	800	Design value.

3. Instrumentation

Instrumentation is required for the molten salt loop, especially because of the high temperatures involved. Thermocouples and the associated displays are needed to at least provide a visual representation of the temperature. Ideally, the thermocouples should be connected to a control system to provide control over the temperature and to maintain the safe operation of the molten salt loop. The control system also allows the operating temperature of 800°C to be changed to another value if desired.

There should be thermocouples located throughout all pipe sections where the molten salt would flow, and the thermocouples should be rated for the operating temperature. For example, there needs to be at least two (2) thermocouples located at the drain tank. In addition, there needs to be at least four (4) thermocouples for the loop, with at least one on each side of the loop. One example of a thermocouple rated for high temperatures is the "High Temperature Platinum Thermocouple" from Omega which is designed to be immersed in the molten salt and is rated for up to 1650°C ("High Temp Thermocouples").

Lastly, there needs to be pressure gages located somewhere in the molten salt loop, in addition to the pressure gage that comes with the Argon Pressure Vessel. The purpose of the pressure gage is to ensure the successful operation of the loop and to prevent dangerous overpressure conditions. One example of a pressure gage that could be used is the ThermIQ pressure sensor, which works up to a temperature of 850°C ("ThermIQ Sensors").

4. Operating Procedure

The operation of the molten salt loop system is described. First, the molten salt (FLiNaK) starts out in the Drain Tank at room temperature. The Drain Tank Heater heats the molten salt from room temperature to the loop operating temperature (typically 800°C). The valve from the Argon Pressure Vessel is then opened so that the loop is pressurized and molten salt occupies all parts of the loop. (The air from the molten salt loop would have been previously removed using a vacuum pump, and the argon is an inert gas that does not cause any corrosion.) The piping material should be a low-corrosion material that is compatible with the molten salt, such as Nickel-201 (Diaz). (It is possible to use Hastelloy-N similar to what was done in the Oak Ridge Molten Salt Experiment, but the piping would corrode at a higher rate, and a filter would be required to filter out the corrosion byproducts. Eventually all of the piping would have to be replaced.) A centrifugal pump pumps the molten salt through the loop at a predetermined constant velocity. The pump impeller and drive shaft materials would also have to be compatible with the molten salt.

A band heater is placed at each side of the loop around the piping in order to maintain the operating temperature of the system and prevent the molten salt from freezing. A control system with the associated temperature and pressure instrumentation should be present in order to have full control over the system and improve safety. The loop structure is held up using two A-frame supports and two sliding supports designed to accommodate the thermal expansion of the piping as it heats up to the operating temperature.

In order to shut down the system, the valve to the Argon Pressure Vessel is closed so that the system loses pressure and the molten salt flows back down into the drain tank. The other system components that take in power (the pump and band heaters) can then be powered off. Once all of the molten salt is in the drain tank, the drain tank heater can be turned off. Four hours should be allowed to elapse to allow the molten salt to transition from the liquid state back to the solid state. The molten salt can then be removed and analyzed for any changes in chemical or physical composition due to corrosion or erosion of the piping.

5. Components

The table below gives a list of the main components required to construct the molten salt loop.

Table 5.1: Main Components Required to Construct Molten Salt Loop

Component	**Qty**	**Example Supplier**	**Approximate Cost**
1.25" Nickel 201 Straight Pipe (2 feet)	5	U.S. Metals	$258.50
1.25" Nickel 201 Straight Pipe (7 feet)	1	U.S. Metals	Not available
1.25" Nickel 201 Pipe Elbow (6 inch radius)	3	U.S. Metals	Not available
1.25" Nickel 201 Tee (1 foot)	1	U.S. Metals	Not available
Drain Tank, Nickel 201	1	Custom-made	$905.58
Bathtub	1	Custom-made	$265.92
Argon Pressure Vessel	1	Cyberweld	$164.00
Drain Tank Heater propane torch	1	Harbor Freight	$24.99
Drain Tank Heater propane tank	1	Flame King	$246.24
Molten Salt Pump and Impeller	1	Tobee	$1200
Supports	4	Custom-made	Not available
Thermocouples	6	Omega	$564.54 x 6 = $3387.24
Pressure Sensors	2	ThermIQ	Not available
Band Heaters	4	Big Chief Inc.	$137.70 x 4 = $550.80
Alumina-Silica Insulation Sheets	1	Grainger/Unitherm	$120.60
		Minimum Cost:	**$7124.87**

6. Conclusion

The molten salt loop system description and basic design described in this report is a good starting point for any person or group who wishes to construct a molten salt loop in a thermal hydraulics laboratory. This design was selected because the dimensions (8 feet by 3 feet by 4 feet) are small enough to fit inside a small laboratory space. A small pipe size (1.25" inner diameter) was selected because of space constraints and because a larger pipe size does not necessarily yield more useful information. The Tobee pump was selected because it has more horsepower than the required horsepower, although other custom-made pump/shaft/impeller combinations can be used.

Although the design may look simple at first, there are many details (especially details related to the heater powers, structural thermal expansion and assembly tolerances) that need to be analyzed before a full design can be completed and a reliable molten salt loop can be constructed. Ultimately, this molten salt loop can be used to verify the effectiveness of materials used in existing molten salt reactor designs, and test new materials and components that are planned for use in future nuclear reactor designs.

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