# MIDTERM 1 SPRING
# THERMAL STORAGE

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# VERDICORP

## Organic Rankine Cycle Power systems

- Builds Modular Vapor Power cycles
- Runs from waste or low temperature heat sources
- Uses environmentally friendly fluids (R245a)

Figure 1. Image of Verdicorp ORC System

# NEED

Depending on waste or renewable heat sources causes:

- unreliable power output
- Limits running time to that of the fuel source
- Decreases system efficiency

Solve by inclusion of Thermal Energy Storage

## Goal: To produce a commercially viable thermal storage solution for Verdicorp's Rankine Cycle utilizing environmentally friendly materials.

# SYSTEM OVERVIEW

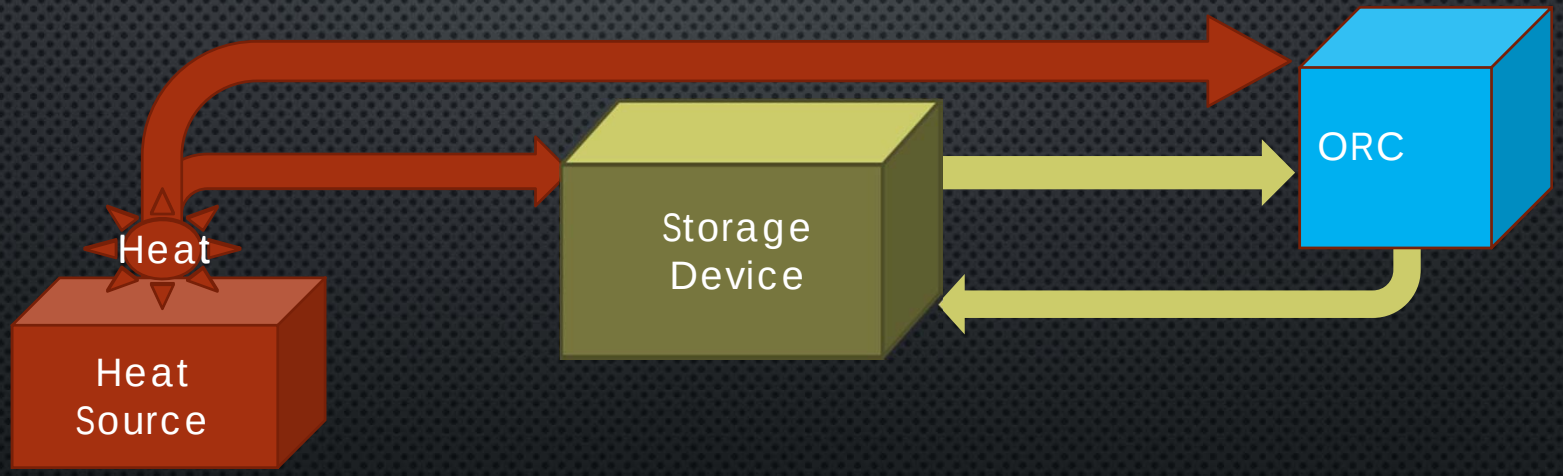



Figure 2. Overall System Diagram

# THERMAL ENERGY STORAGE

STORAGE OF ENERGY FOR LATER USE:

- STABILIZES THE SYSTEM OUTPUT
- EXTENDS THE OPERATION TIME
- RESPONDS TO DEMAND
- INCREASES EFFICIENCY; THUS DECREASING COST
- FORMS OF STORAGE: SENSIBLE OR LATENT

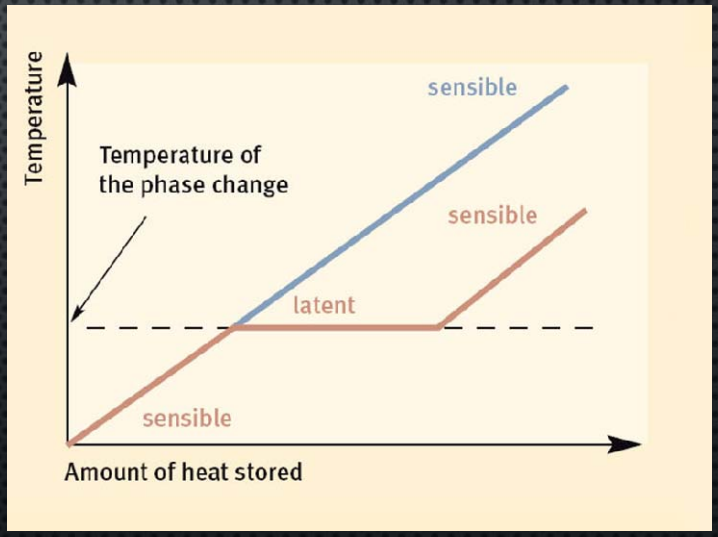



Figure 2. Heat Storage Forms

# LATENT HEAT STORAGE

- Based on Shell-and-tube heat exchanger
- Transfer fluid transfer heat to/from phase change materials
- Full size: 37.8GJ Model: 19.8kJ
- Scale: 1/1900$^{TH}$
- Capsule Scale: 1/20$^{TH}$

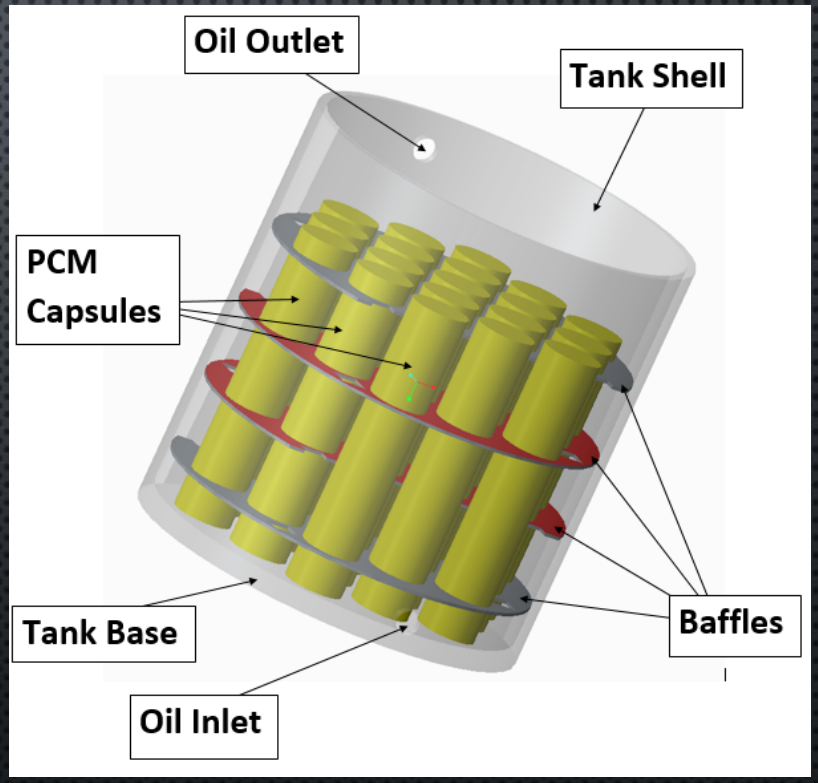



Figure 4. Model of Latent Heat Storage Device

# SYSTEM SCHEMATIC OF TESTING EQUIPMENT

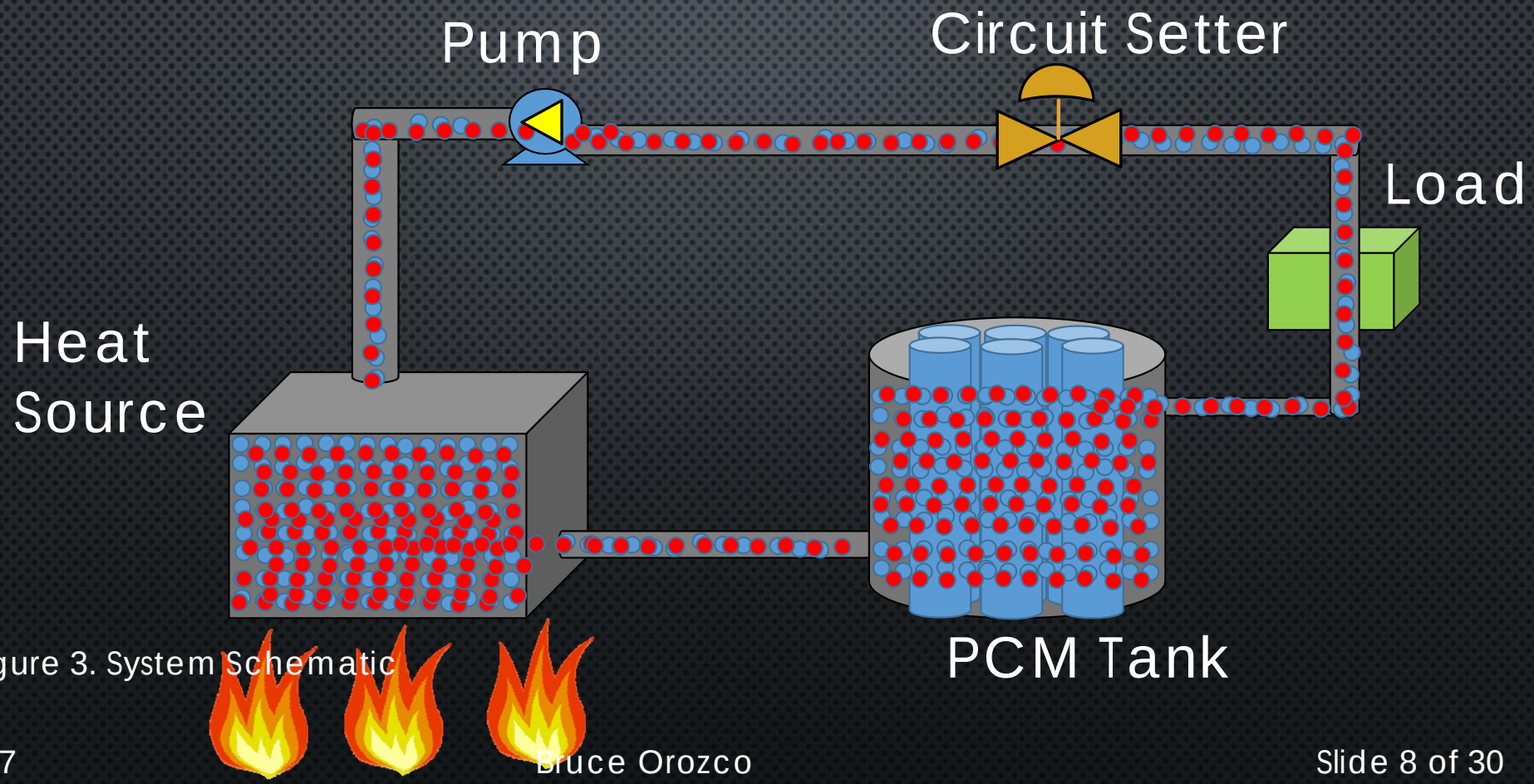



Figure 3. System Schematic

# CHARGE TIME

## ASSUMPTIONS:

- THERMOPHYSICAL PROPERTIES ARE INDEPENDENT OF TEMPERATURE.
- THE PCM IS HOMOGENEOUS AND ISENTROPIC AS BOTH LIQUID AND SOLID
- PCM TEMPERATURE IS UNIFORM ACROSS SHELL AREA
- PERFECTLY INSULATED

## METHOD:

1. AVERAGE FLUID VELOCITY
2. EFFECTIVE FLOW AREA
3. AVERAGE MASS FLOW
4. USE LMTD AND MASS FRACTION RELATION

$$\Delta T \cong 30\ mins$$

# HEAT LOSS

- Find Overall Convective Heat Transfer Coefficient for Entire Shell
- Find the total Resistance of the system.
- Use One Dimensional to Find Heat Flux out of shell
- Divide the total energy of the system by the Heat loss

$$\dot{Q}_{loss} \cong 210\ W$$

$$time \cong 7\ hrs$$

# SYSTEM SCHEMATIC OF TESTING EQUIPMENT

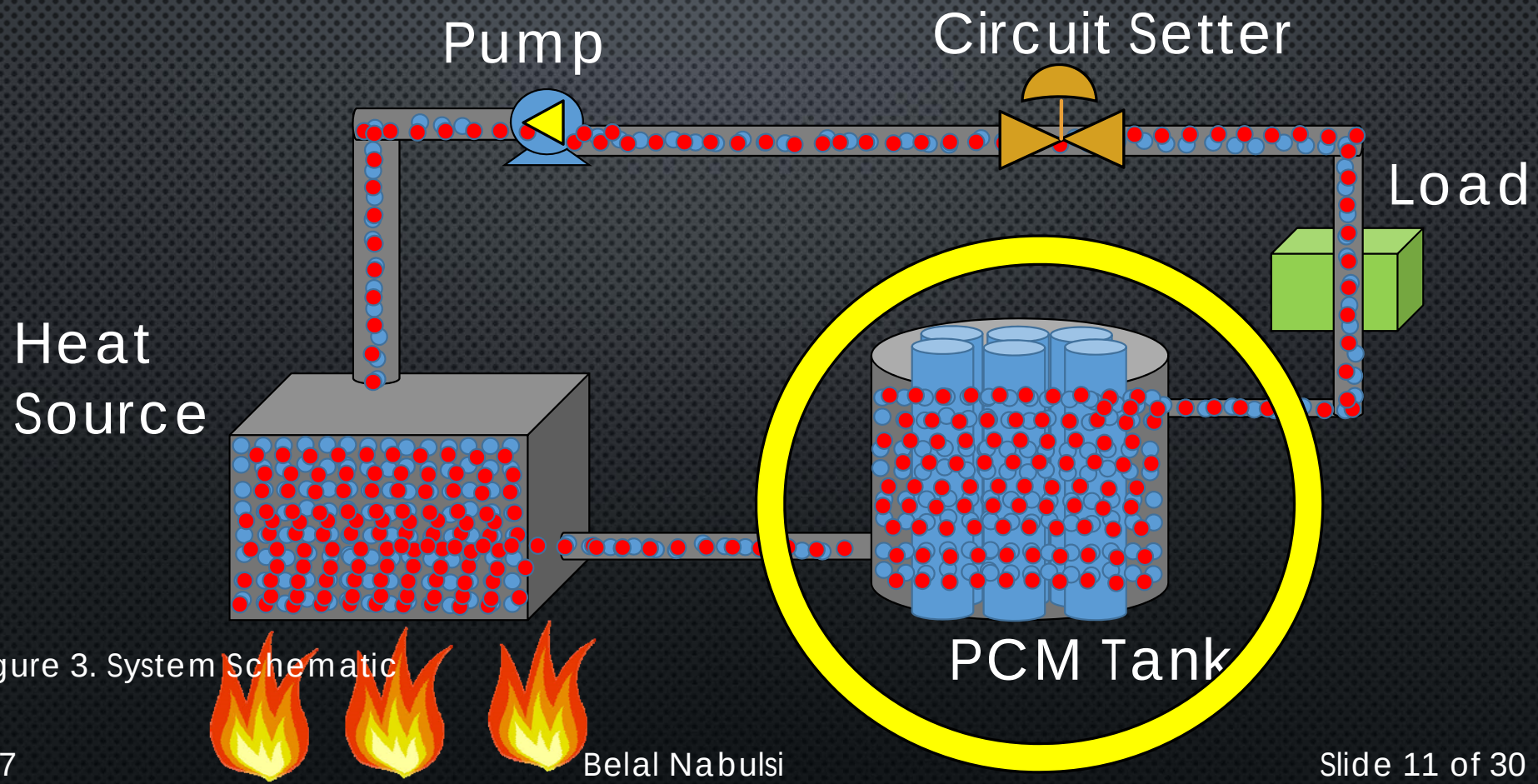



Figure 3. System Schematic

# FLUID FLOW: SINGLE SEGMENTAL

- Fluid flow is dictated by baffles
- Baffle cuts are 30% of tank inside diameter
- Spacing is 1/5 the tank inside diameter
  - 3.05 in apart
- Tube Pitch is the center-to-center distance of each tube
  - 1.25 times outside diameter of tube

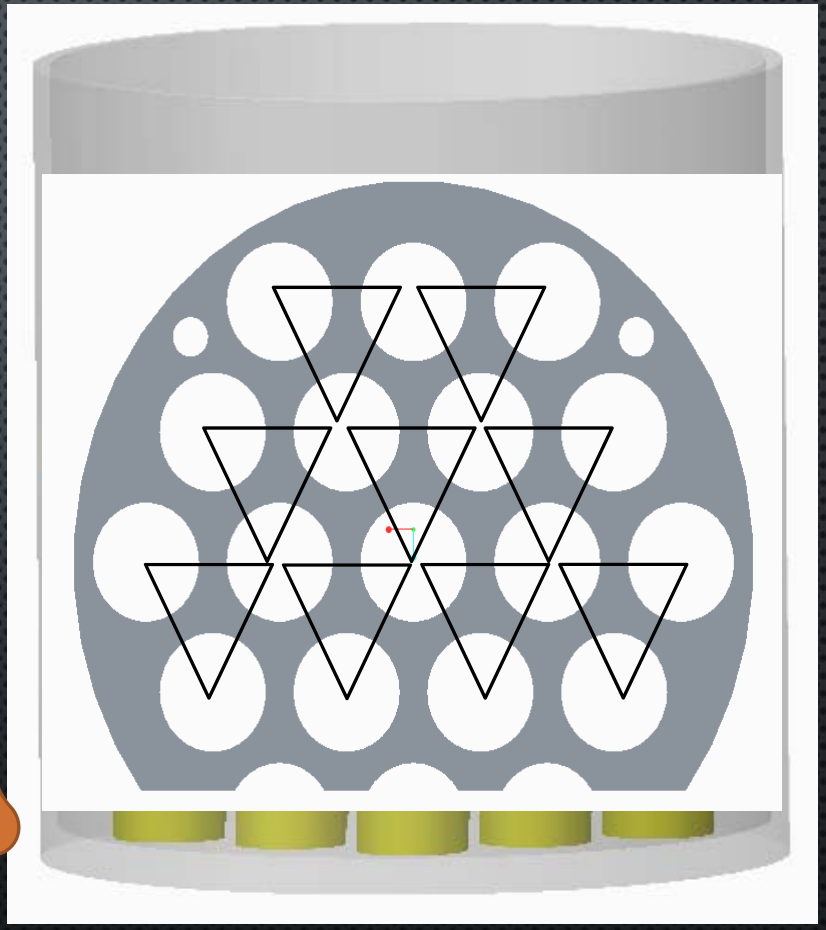
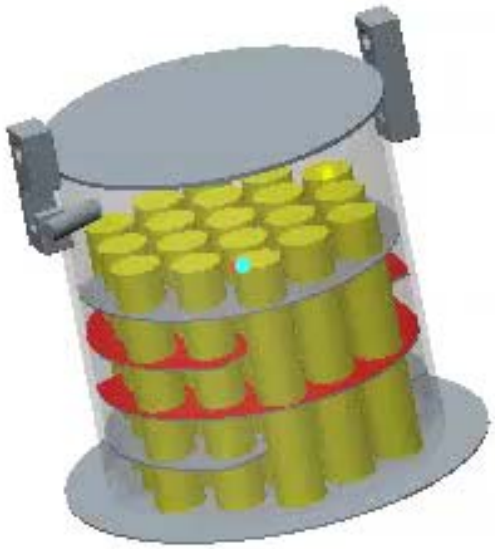


Figure 5. Animation of Fluid Flow in Shell

# SINGLE SEGMENTAL CONFIGURATION



# FLUID FLOW: DISK AND DOUGHNUT

- Annular area between disk and shell is same as area of ring
- Spacing is 1/5 the tank inside diameter
  - 3.05 in apart
- Tube Pitch is the center-to-center distance of each tube
  - 1.25 times outside diameter of tube

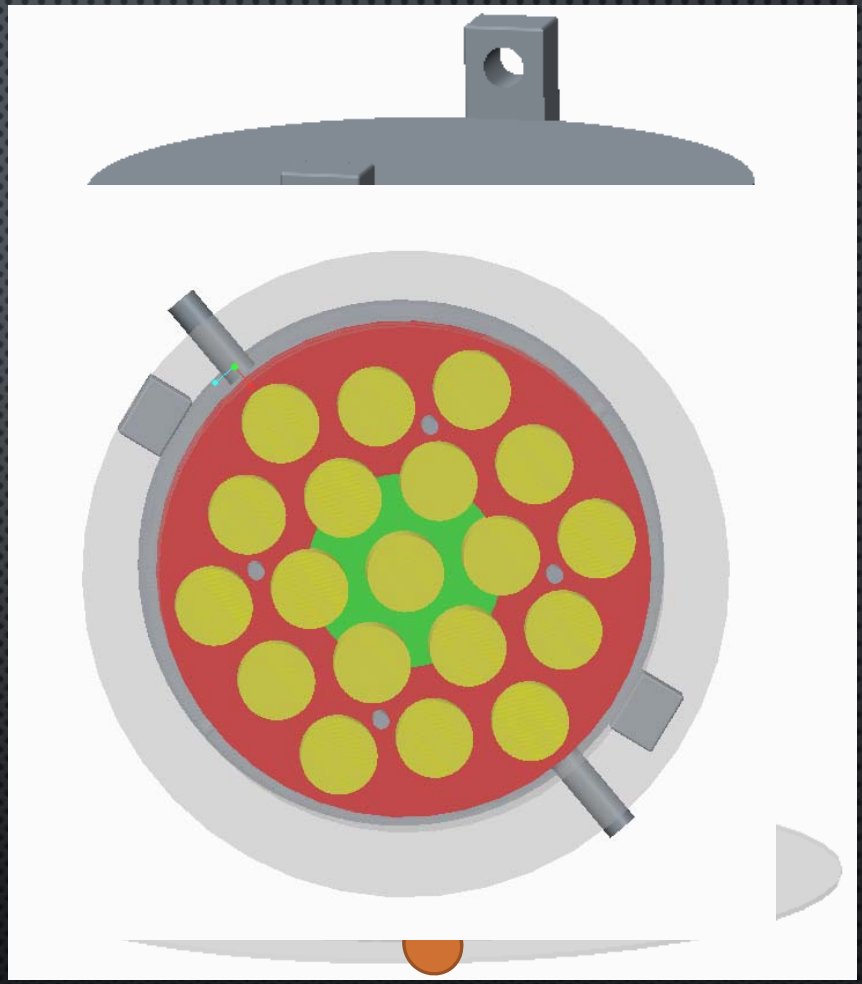


Figure 6. Animation of Fluid Flow in Shell

# DISK AND DOUGHNUT CONFIGURATION

# TWIST-ON LID DESIGN

- LATCH DESIGN ALLOWS FOR EASY REMOVAL OF LID
- WHEN LIFTED THE WELDED PEGS WILL LOCK INTO PLACE
- REDUCES MANUFACTURING TIME

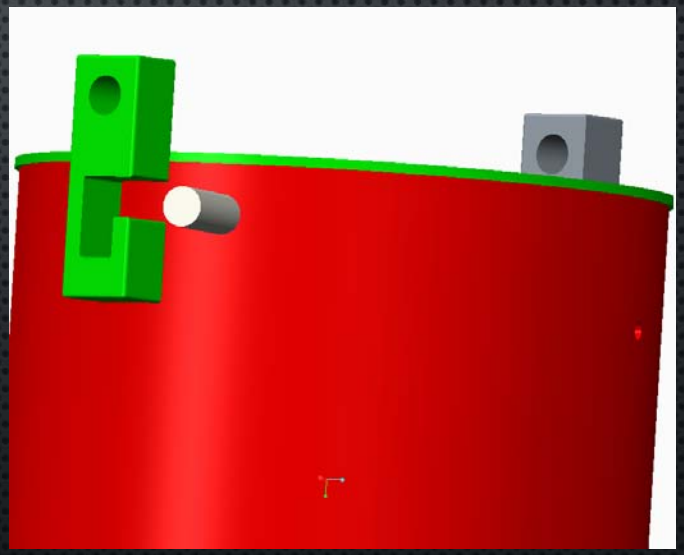


Figure 7. Proposed Lid Design

# LATCH STRESS ANALYSIS

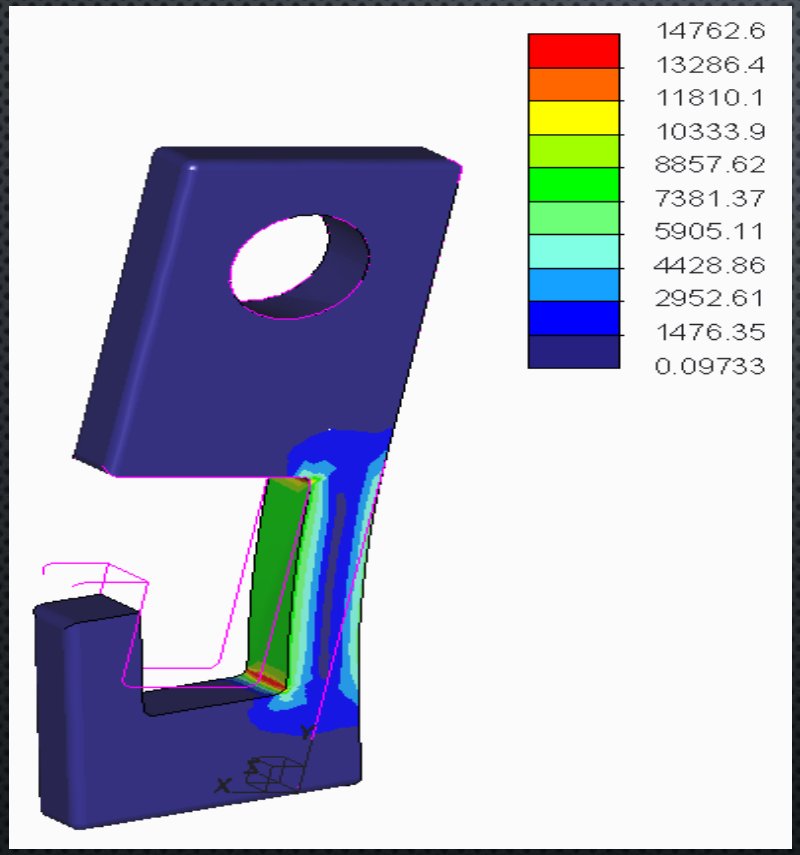



Figure 8. von Mises' Stress (psi)

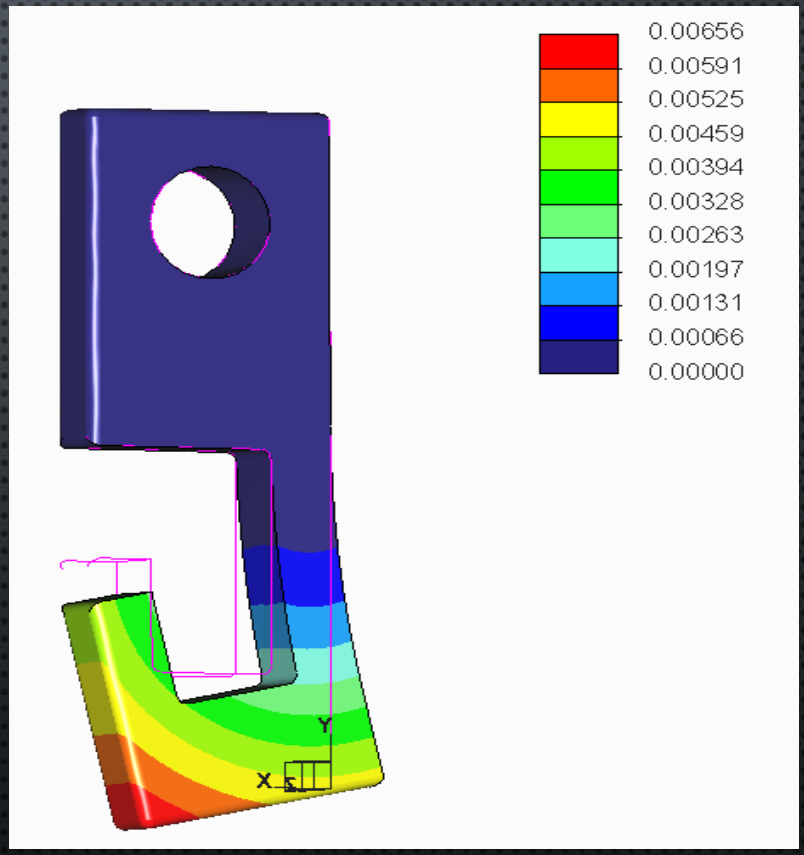



Figure 9. Displacement (in)

# SYSTEM SCHEMATIC OF TESTING EQUIPMENT

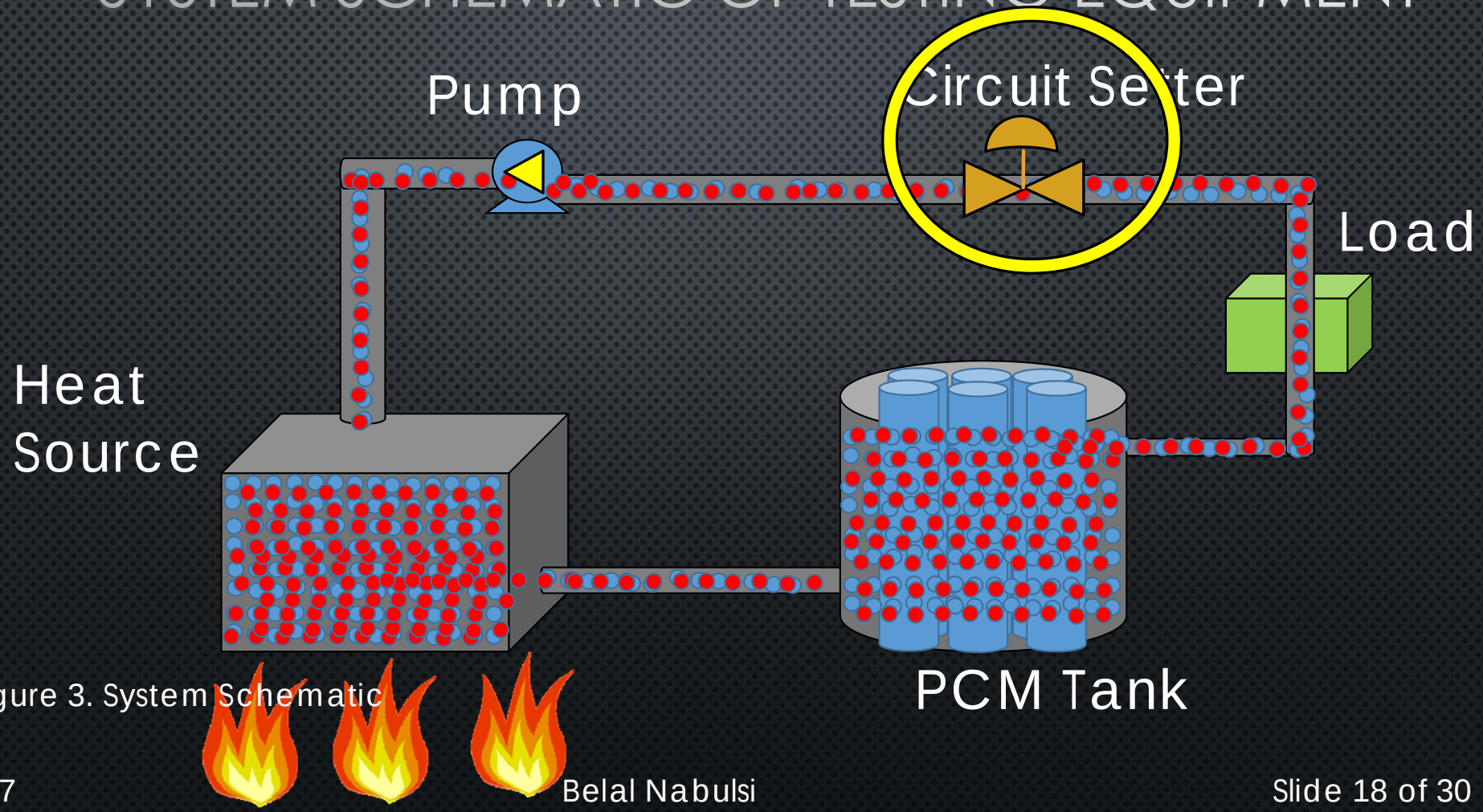



Figure 3. System Schematic

# Flow Meter vs. Circuit Setter

## Flow Meter

- Provide measurements of the flow rate
- But can not control and regulate that flow rate
- requires additional throttling valves to control flow

## Circuit Setter

- Provides accurate flow readings with minimal impedance
- Regulates flow rates
- Does not require additional valves

# CIRCUIT SETTER

- CAN BE SET TO AUTOMATICALLY REGULATE FLOW RATES
- BUILT IN BALANCE VALVE
- INCUR LOW HEAD LOSS RELATIVE TO TYPICAL VALVES

Figure 10. Bell & Gossett Circuit Setters

# SYSTEM SCHEMATIC OF TESTING EQUIPMENT

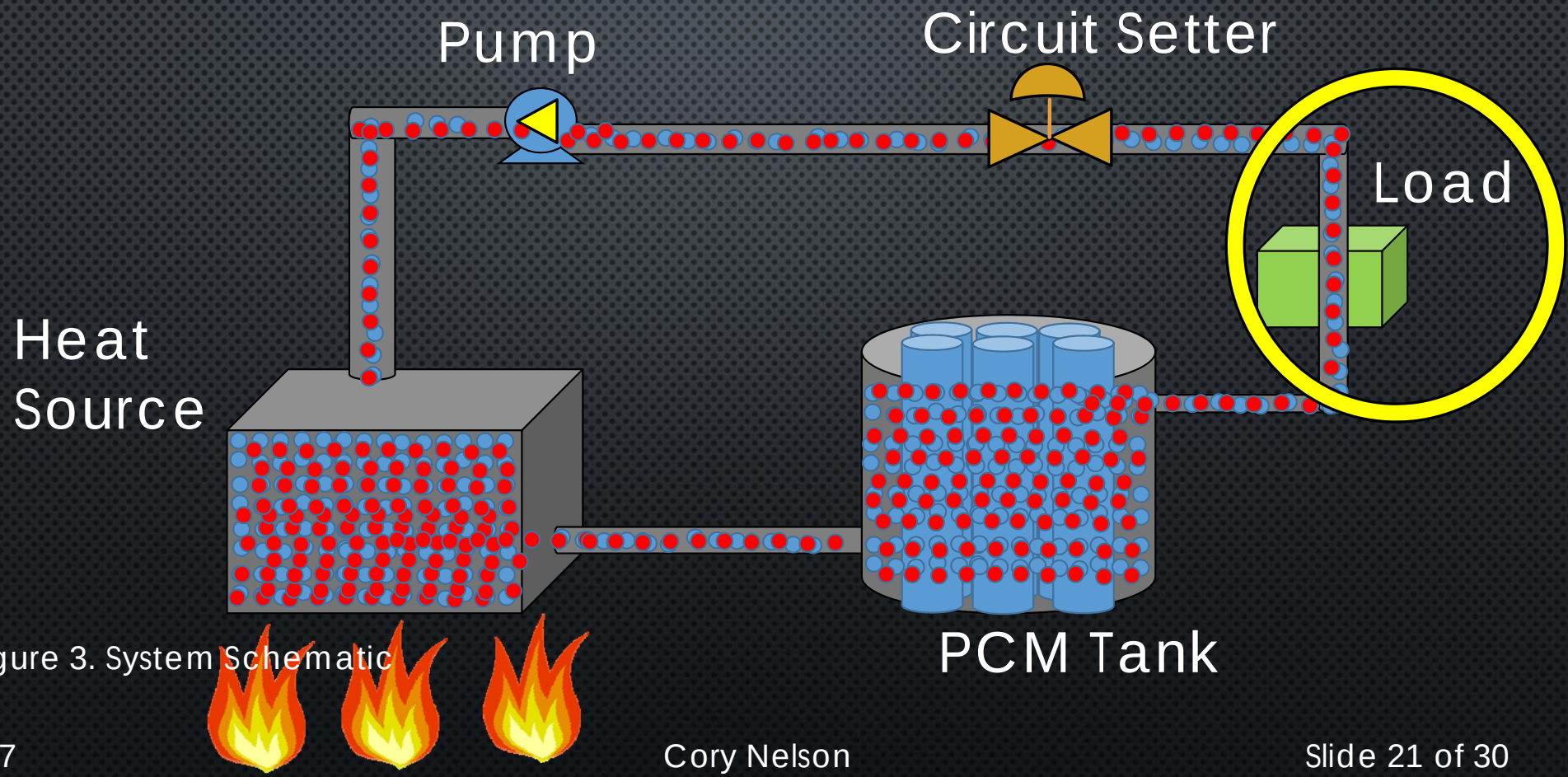



Figure 3. System Schematic

# HEAT EXCHANGER LOAD

## LYTRON LIQUID TO AIR HEAT EXCHANGER

- PROVIDED BY VERDICORP
- RATED AT 255W
- PRODUCES A TEMPERATURE DROP OF 10˚C


Figure 9. Lytron 6105G1SB-D9 Heat Exchanger

# SYSTEM SCHEMATIC OF TESTING EQUIPMENT

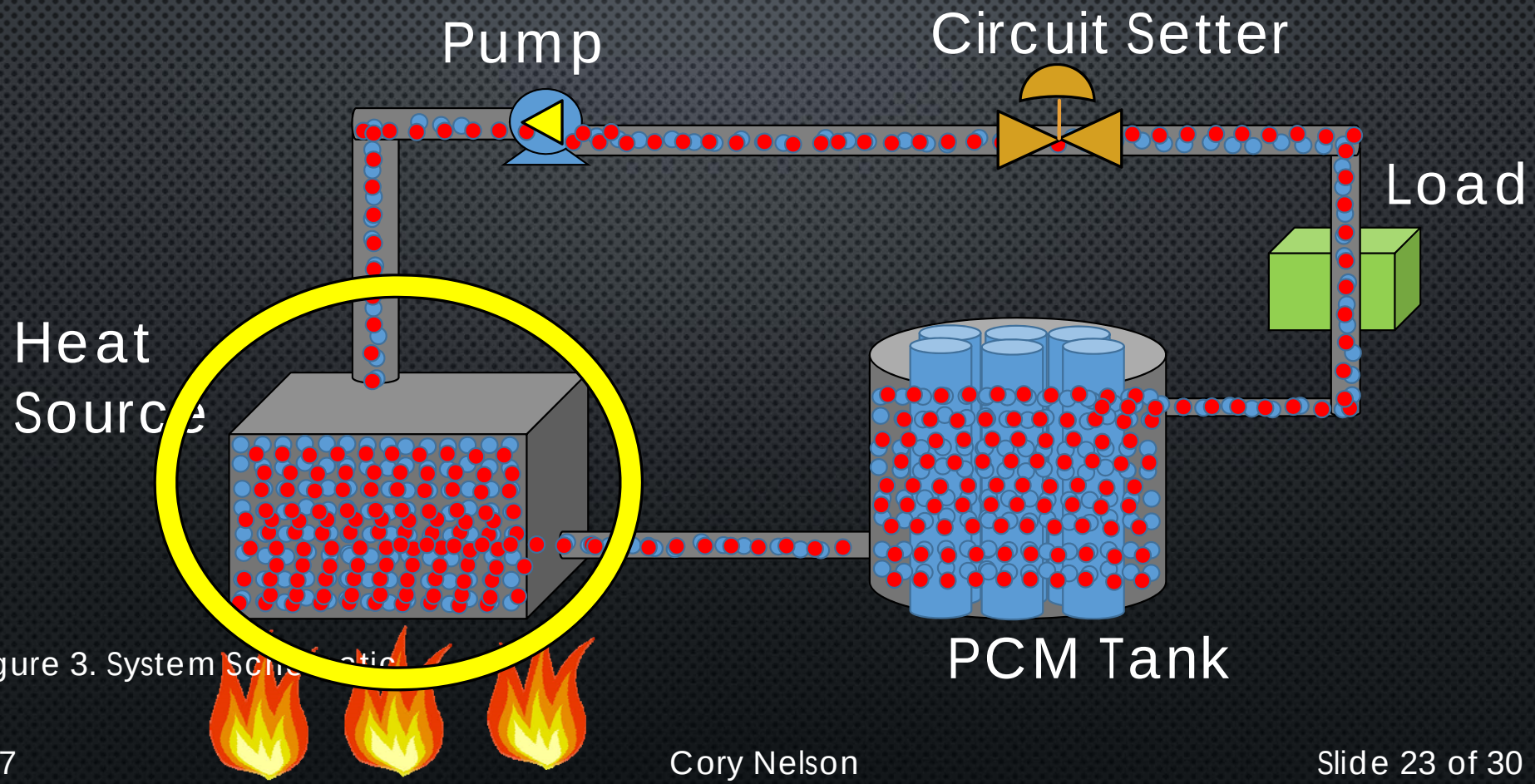



Figure 3. System Schematic

# HEAT SOURCE

## CARTRIDGE HEATER

- PROVIDED BY VERDICORP
- RATED AT 1000W EACH ONLY 1 IS NEEDED AT STEADY STATE
- USING Q = $\dot{m}C_p(230^{\circ}\text{C}) \approx 6{,}000W$
- NEED UP TO 6 CARTRIDGES TO HAVE SPEEDY START UP TIME


Figure 10. Generic Cartridge Heaters

# HEAT SOURCE

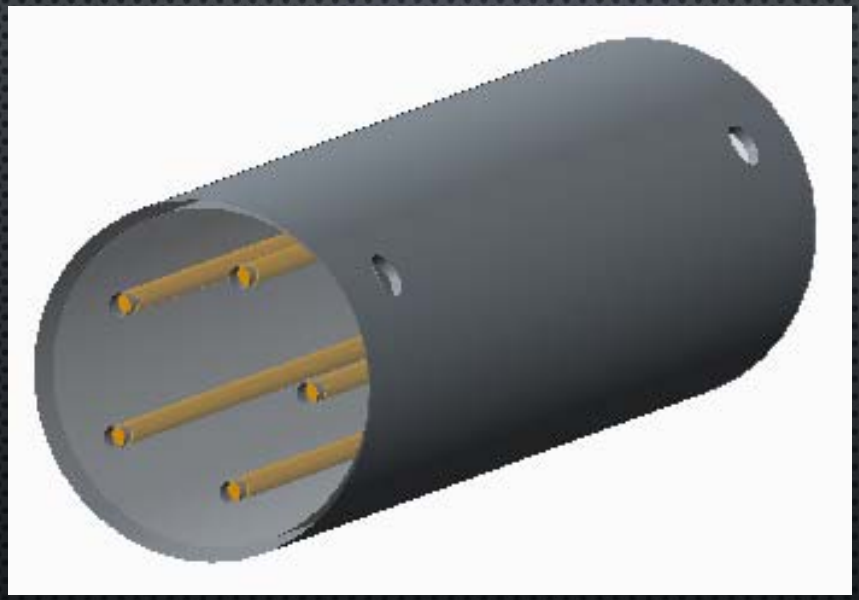


Figure 11. Generic Cartridge Heaters

# WHAT ABOUT THE MONEY?!?!

Verdicorp
Environmental Technologies

| Item/Product Number | Description | Quantity | Rate | Amount | Shipping | Total | Date of Purchase |
|---|---|---|---|---|---|---|---|
| 1.)Purchased | Dynalene MS-1<br>Molten Salt for thermal storage in Granular Solids (50lbs) | 50 | $ 6.00 | $ 300.00 | $ 180.00 | $ 480.00 | 1/6/2015 |
| 2.)Purchased | Duratherm HF - 5 gallon pail | 2 | $ 203.05 | $ 406.10 | $ 36.74 | $ 442.84 | 1/10/2015 |
| 4). Purchased | High-Temperature Mineral Wool Insulation, 24"x48" | 3 | $ 13.35 | $ 40.05 | $ 10.00 | $ 50.05 | 1/27/2015 |
| Yet to be purchased (supplier) | | | | | | | |
| 6.) 4548k177 (McMaste-Carr) | 5" Standard-wall Stainless Steel Threaded Pipe Type 316 | 6 | $ 8.56 | $ 51.36 | | | |
| 7.) 4452k414 (McMaste-Carr) | 90 Degree 1/2" Pipe Elbows Type 316 Steel | 2 | $ 8.16 | $ 16.32 | | | |
| 8.) (onlinemetals.com) | Hot Rolled steel Plate 1/8" Thick (36"x48") | 2 | $ 86.89 | $ 173.78 | $ 75.00 | | |
| 9.) (onlinemtals.com) | Hot Rolled steel Plate 1/4" Thick (24"x 48") | 1 | $ 147.72 | $ 147.72 | $ 75.00 | | |
| 10.) 93565A130 (McMaster-Carr) | 6 ft Stainless Steel Threaded Rod | 1 | $ 43.22 | $ 43.22 | | | |
| 11.) 4452k238 (McMaster-carr) | 1/2" Pipe Caps Type 316 Stainless Steel | 2 | $ 4.54 | $ 9.08 | | | |
| | | | | | | | |
| Projected Cost | | | | | $ 1,564.37 | | |
| Total Spent | | | | | | $ 972.89 | |
| Total Remaining | | | | | | $ 1,027.11 | |

# WHAT'S NEXT

- COMPLETE SIMULATION IN MATLAB
- FINALIZE PURCHASES
- START BUILDING
- START TESTING

| Task Name | Duration | Start | Finish |
|---|---|---|---|
| **Purchases** | **20 days** | **Mon 1/5/15** | **Fri 1/30/15** |
| 50LB Ms-1 | 3 days | Mon 1/5/15 | Wed 1/7/15 |
| Duratherm HF 10GAL | 3 days | Mon 1/5/15 | Wed 1/7/15 |
| Exterior tank | 15 days | Mon 1/5/15 | Fri 1/23/15 |
| Piping Insulation | 15 days | Mon 1/5/15 | Fri 1/23/15 |
| Inlet/outlet Piping | 15 days | Mon 1/5/15 | Fri 1/23/15 |
| Flow meter | 15 days | Mon 1/5/15 | Fri 1/23/15 |
| Baffle Material | 20 days | Mon 1/5/15 | Fri 1/30/15 |
| Threded rods | 15 days | Mon 1/5/15 | Fri 1/23/15 |
| Nuts and washers | 15 days | Mon 1/5/15 | Fri 1/23/15 |
| **Simulation & Modeling** | **26 days** | **Mon 1/5/15** | **Mon 2/9/15** |
| Vertical Configuration | 1 day | Sun 2/8/15 | Sun 2/8/15 |
| Horizontal Configuration | 1 day | Sat 2/7/15 | Sat 2/7/15 |
| CAD Modeling | 25 days | Mon 1/5/15 | Fri 2/6/15 |
| Submit Drawings to Sponsor | 1 day | Fri 2/6/15 | Fri 2/6/15 |
| **Building** | **14 days** | **Mon 2/16/15** | **Thu 3/5/15** |
| **Testing** | **21 days** | **Mon 3/9/15** | **Mon 4/6/15** |
| **Evaluation on tests** | **7 days** | **Wed 4/1/15** | **Thu 4/9/15** |
| **Future Suggestions** | **7 days** | **Sat 4/11/15** | **Mon 4/20/15** |
| **Presentation Prep** | **5 days** | **Mon 4/20/15** | **Fri 4/24/15** |

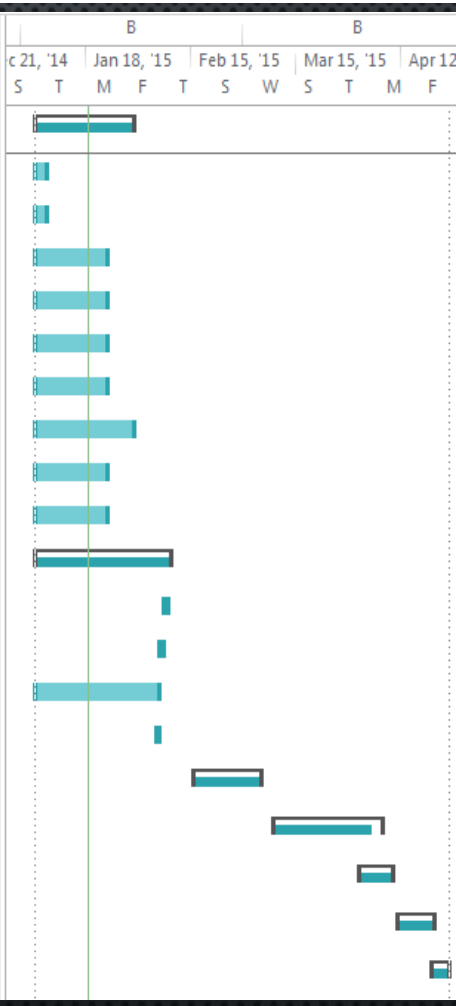



Figure 12. Team Scheduling

# RESOURCES


- Hasnain, S.M., "Review on Sustainable Thermal Energy Storage Technologies, Part 1: Heat Storage Materials And Techniques," Energy Conversion Mgmt., Vol. 39 No. 11 pp1127-1138, 1997.
- Sharma, Atul, Tyagi, V.V., Chen, C.R., Buddhi, D., "Review on Thermal Energy Storage with Phase Change materials and applications," Renewable and Sustainable Energy Reviews 13, pp318-345, 2009.
- Cengel, Yunus, and Cimbala, John M., and Turner, Robert, *Fundamentals of Thermal Fluid Sciences*, 4TH ed., New York, New York, 2011
- Mukherjee, R , (2014, December 20) *Effectively Design Shell-and-Tube Heat Exchangers. (1st ed.)* [Online] Available: http://www.mie.uth.gr/ekp_yliko/CEP_Shell_and_Tube_HX.pdf

**Group 17**
**Jhamal Holliday**
**Cory Nelson**
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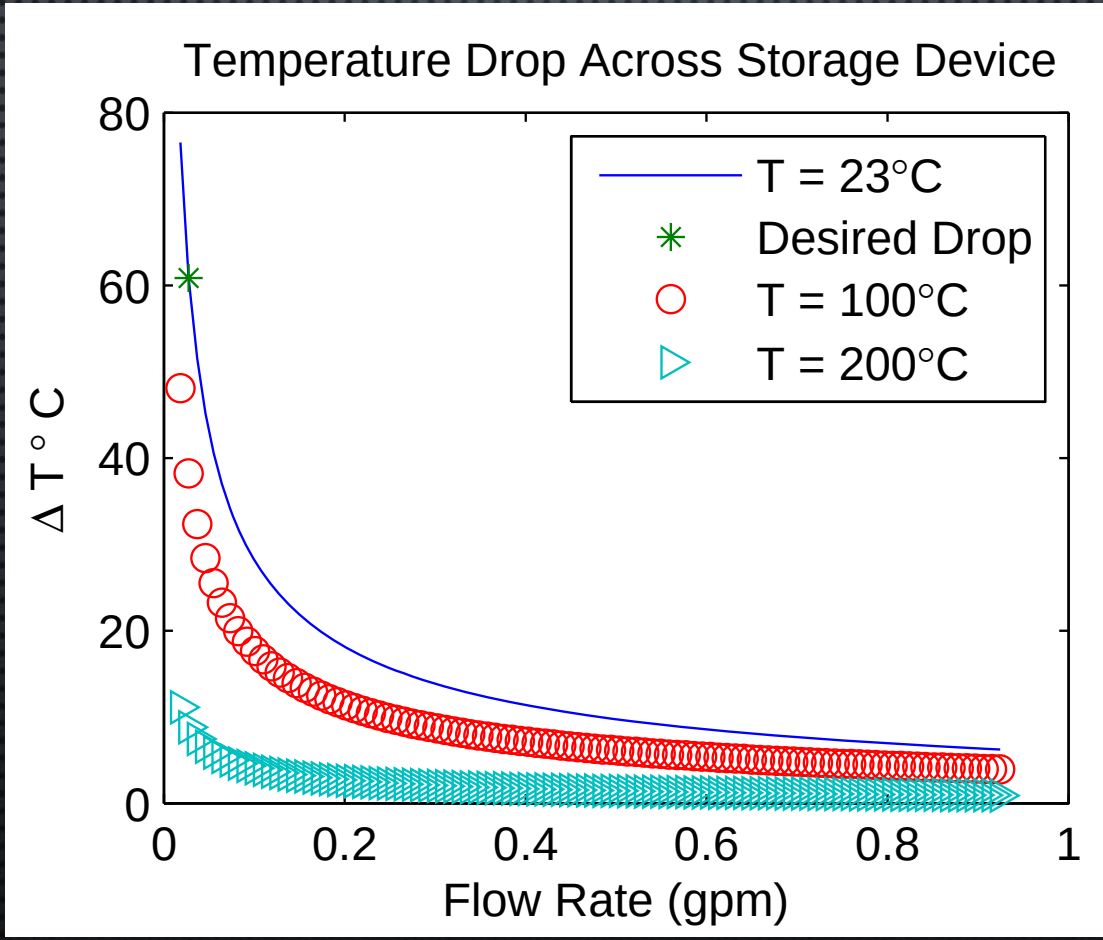
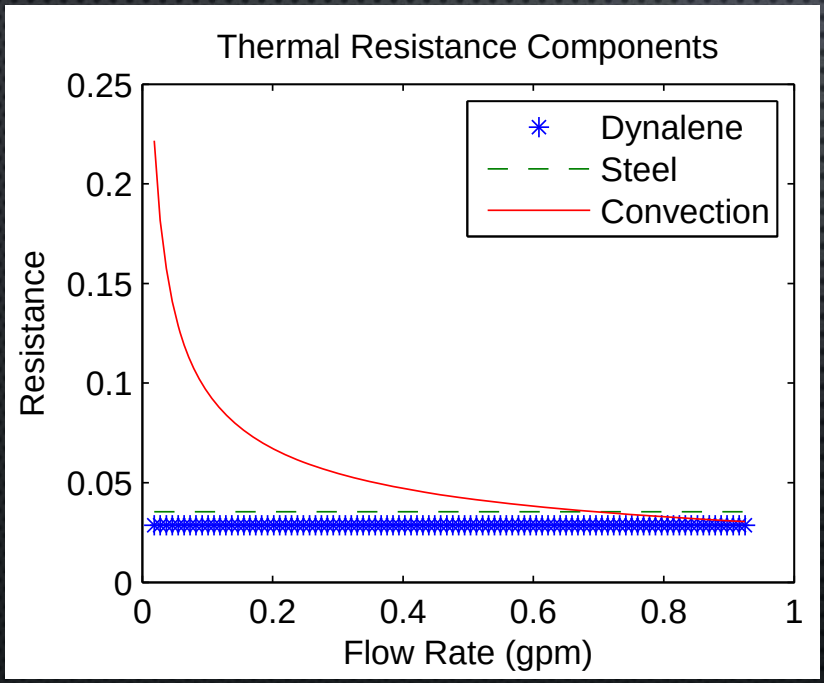
**Belal Nabulsi**

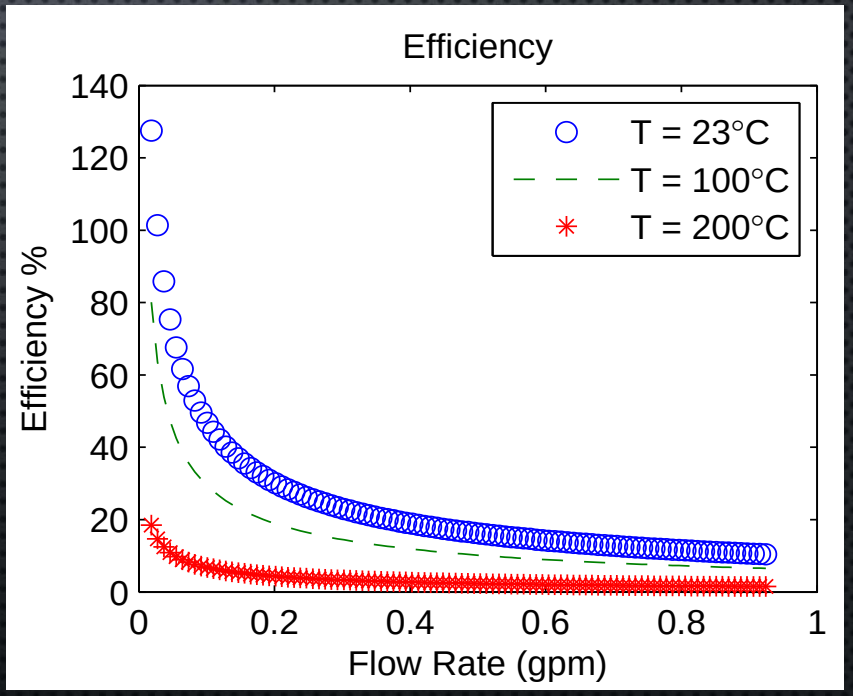
**Appendix Follows**

# OPERATION POINT



# INNOVATION


Thermal Resistance Components
Resistance
Flow Rate (gpm)
Dynalene
Steel
Convection
0.25
0.2
0.15
0.1
0.05
0
0
0.2
0.4
0.6
0.8
1


Efficiency
Efficiency %
Flow Rate (gpm)
T = 23°C
T = 100°C
T = 200°C
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1

# STORAGE MEDIUM & TRANSFER FLUID

## DYNALENE MS-1

- MOLTEN SALT WITH MINIMAL CORROSION TO STAINLESS STEEL
- STABLE THERMAL PROPERTIES THROUGHOUT OPERATION TEMPERATURE RANGE
- 3% EXPANSION ALLOWS FOR HIGHER POWER DENSITY PER CAPSULE

## DURATHERM HF

- PETROLEUM BASED
- HIGH OXIDATION RESISTANCE
- LOW VISCOSITY
- AVAILABLE AT THE PRICE OF SYNTHETIC CAR OIL
- FLASH POINT OF 275°C