Solar Autoclave for Rural Areas

Final Design Review and Project Proposal

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Team #6

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Presentation Overview

- Problem Statement
- Need Identification
- Concept Generation
- Engineering Analysis
- Cost Analysis
- Final Design
- Gantt Chart
- Conclusion
- References

Problem Statement

- NEED STATEMENT: Certain developing areas around the world have limited availability to sterilized medical equipment.

- OUR GOAL: To create a solar autoclave that can be easily used at remote clinics in rural areas.

Need Identification

- Objectives
  - Provide remote clinics in rural areas with the means to sterilize medical equipment
  - Create a flexible design from location to location
  - Parts can be repaired/replaced from local, readily available materials

- Constraints
  - Temperature must reach and hold 121°C for at least 15 minutes
  - Pressure must reach and hold 2.05 bar for at least 15 minutes

Concept Generation

Analytical Hierarchy Process

Table 1: Numerical rating

Judgment of Importance	Numerical Rating
Extremely more important	9
	8
Strongly more important	7
	6
Moderately more important	5
	4
Slightly more important	3
	2
Equally important	1

Table 2: Pairwise comparison matrix

Column1	Thermal Capture	Heat Transfer into Fluid	High Pressure Maintenance	Insulation	Thermal Storage
Thermal Capture	1	1	2	5.00	9.00
Heat Transfer into Fluid	1	1	2	4.00	9.00
High Pressure Maintenance	0.5	0.5	1	6.00	9.00
Insulation	0.2	0.25	0.17	1	5
Thermal Storage	0.11	0.11	0.11	0.2	1
Total	2.81	2.86	1.28	16.20	28.00

Table 3: Overall importance matrix

Column1	Thermal Capture	Heat Transfer into Fluid	High Pressure Maintenance	Insulation	Thermal Storage	Overall Importance
Thermal Capture	0.36	0.35	1.56	0.31	0.32	2.90
Heat Transfer into Fluid	0.36	0.35	1.56	0.25	0.32	2.84
High Pressure Maintenance	0.18	0.17	0.78	0.37	0.32	1.83
Insulation	0.07	0.09	0.13	0.06	0.18	0.53
Thermal Storage	0.04	0.04	0.09	0.01	0.04	0.21

Concept Generation

- Thermal Capture
  - Parabolic Trough, Dish and Fresnel Lens

Figure 1: Parabolic Trough
Courtesy of Tech Bells
http://techbells.blogspot.com/2012/07/working-of-csp-parabolic-trough.html

Figure 2: Parabolic Dish
Courtesy of Inhabitat
http://inhabitat.com/19-year-old-teenager-makes-homemade-solar-death-ray/solarray2/

Figure 3: Fresnel Lens
Courtesy of WN
http://article.wn.com/view/2008/01/16/Fresnel_lens_sheet_rear_projection_screen_and_rear_projectio/

Concept Generation

- Heat Transfer into Fluid
  - Fins
  - Boiler at focal point of parabolic trough

Figure 4: Fin Array

Courtesy of Pencom
http://www.hellotrade.com/peninsula-components/forged-fin-heat-sinks.html

Concept Generation

- Maintaining High Pressure
  - Wing Nuts
  - Clamp

Figure 5: Metal Clamp

Courtesy of ElectriDuct
http://www.electriduct.com/Arlington-Industries-Steel-and-Iron-Beam-Clamps.html

Figure 6: Pressure Cooker

Courtesy of Pressure Cookers Best
http://www.pressurecookersbest.com/all-american-15-12-quart-pressure-cooker.html

Concept Generation

- Lightweight Insulation
  - Thermablok® Aerogel Insulation
  - Styrofoam
  - Fiberglass
  - Mineral Wool
  - Clay-coated straw
  - Phenolic Foam
  - Liquid Cement
  - Cork

Figure 7: Mineral Wool

Courtesy of Unipro
http://www.alibaba.com/product-tp/12283858/FiberGlass_wool_Insulation

Table 4: Thermal conductivity of possible insulation materials

Insulation Material	k value $[\frac{W}{mK}]$
Thermablok Aerogel	0.014
Balsa wood	0.048
Cork	0.07
Cork, regranulated	0.044
Corkboard	0.043
Fibreglass	0.04
Mineral wool	0.04
Styrofoam	0.033

Concept Generation

- Dry Heat Sterilization
  - **Pros:**
    - Does not require water
    - Lower gauge pressure, meaning safer to use
  - **Cons:**
    - Takes 2 hours at 160°C to “sterilize” equipment
    - Does not kill all proteins associated with bacteria

- Saturated Steam Sterilization
    - Takes 15 minutes at 121°C to fully sterilize equipment

Engineering Analysis

- Thermal Capture
  - $q_{rad} = \alpha * \rho * G * A_{proj}$

Where:

α = absorptivity of pressure vessel
ρ = reflectivity of mirror
G = solar irradiance, $[\frac{W}{m^2}]$
A_{proj} = projected area, $[m^2]$

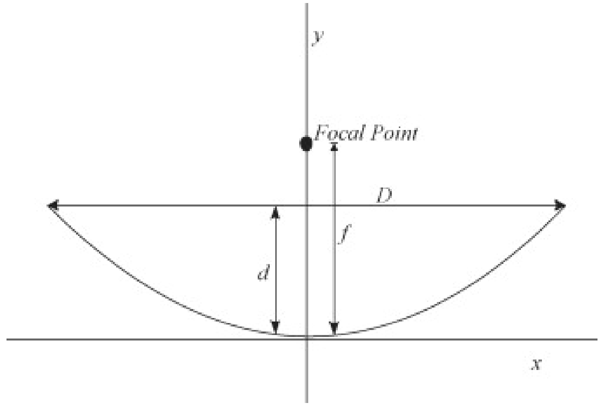


Figure 8: Parabolic Trough with Focal Point

Courtesy of Science Direct
http://www.sciencedirect.com/science/article/pii/S1364032110001206

Engineering Analysis

- Thermal Capture
  - $f = \frac{r}{2}$

Where:

f = focal length, [m]
r = radius of curvature, [m]

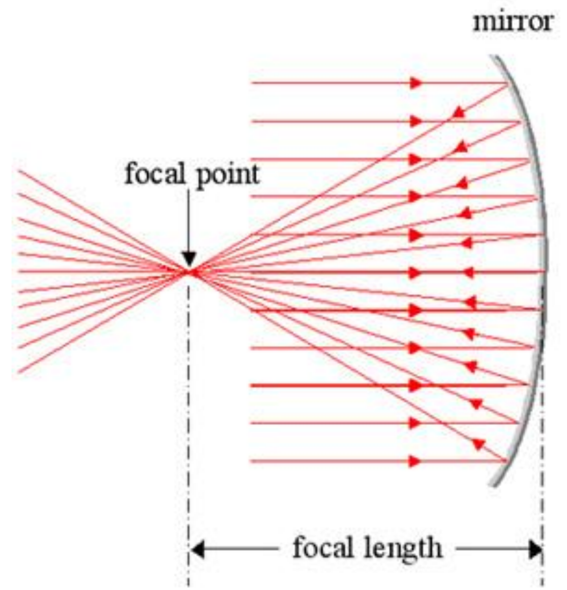


Figure 9: Focal Point
Courtesy of DiracDelta
http://www.diracdelta.co.uk/science/source/f/o/focal%20point/image002.jpg

Engineering Analysis

- Thermal Circuit

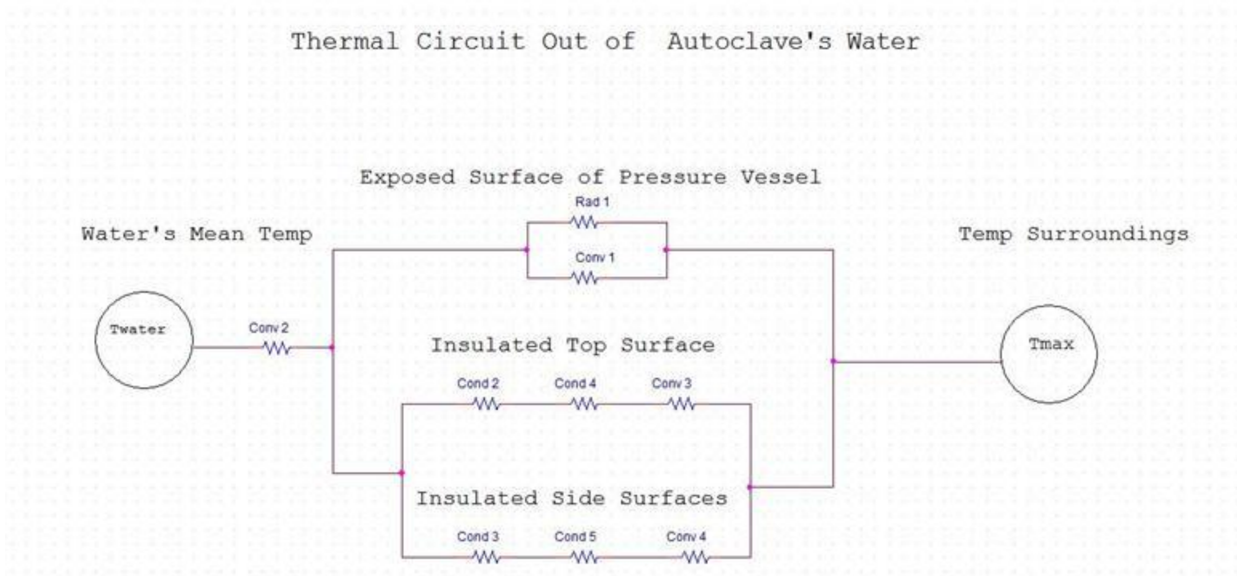


Figure 10: Thermal Circuit Out of Autoclave's Water

Governing Equations for Resistance:

$$R_{cond} = \frac{L}{kA}\ , [\frac{K}{W}] \qquad q = \frac{\Delta T}{R}\ , \text{[W]}$$

$$R_{conv} = \frac{1}{hA}\ , [\frac{K}{W}]$$

Engineering Analysis

- Thermodynamic Properties of Water

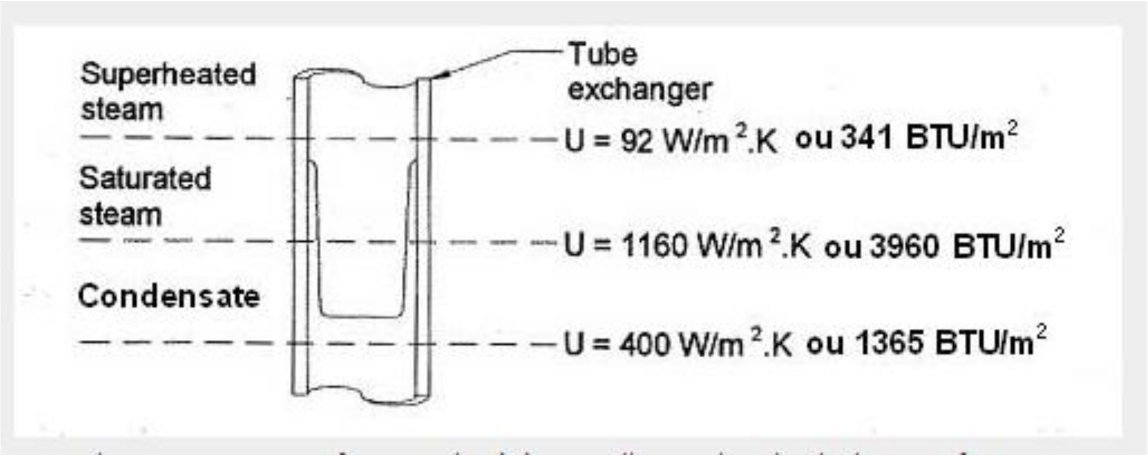


Figure 11: Saturated vs. Superheated Steam

Courtesy of Systhermique
(http://www.systhermique.com/steam-condensate/services/troubleshooting/superheated-steam/)

Engineering Analysis

- Thermodynamic Properties of Water

Table 6: Saturated vs. Superheated Steam

		Internal Energy, u [$\frac{kJ}{kg}$]
Temperature [°C]	Pressure [bar]	Saturated Liquid
20	0.02339	83.95
121	2.05050	507.752

$$Q = m \cdot (u_2 - u_1)$$

Where:

$Q =$ Heat transfer, [kJ]
$m =$ Mass, [kg]
$u =$ Internal energy, [$\frac{kJ}{kg}$]

Engineering Analysis

- Pressure Vessel

Maximum hoop stress:

$$(\sigma_h)_{max} = \frac{pr}{t}$$

Maximum longitudinal stress:

$$(\sigma_l)_{max} = \frac{pr}{2t}$$

Where:

p = pressure inside vessel, [Pa]
r = inner radius of vessel, [m]
t = wall thickness, [m]

Figure 12: Pressure Vessel

Engineering Analysis

- Pressure Vessel

The gage pressure creates stress in bolts, defined as:

$$\delta_b = \frac{F_b L}{A_b E_b}$$

F_b is the force applied at each bolt due to gage pressure, calculated as:

$$F_b = \frac{p(\pi r^2)}{N}$$

Where:

L = overall length of the cylinder, in m
A_b = area of each screw, in m
E_b = modulus of elasticity, in Pa
r = inner radius of the vessel, in m
N = number of bolts used

Cost Analysis

- List of materials and their costs

Table 7: Cost Analysis of Solar Autoclave

Material	Quantity	Cost
Schedule 40 Galvanized Pipe	1	$ 30.00
Mylar (Emergency Blanket)	3	$ 15.00
Steel Sheet (1.2192 X 2.4384[m])	1	$ 50.00
Hose (1.5 [m])	1	$ 10.00
Modified Pot	1	$ 50.00
Spring Apparatus	2	$ 20.00
Miscellaneous (Hose Clamps, O-rings, etc.)		$ 75.00
Stand for Trough	1	$ 50.00
Total		$ 300.00

Final Design

- For approximately 1 Liter of water:
  - m = 1 kg
  - $Q = m \cdot (u_2 - u_1) = 4.23 \times 10^5\ J$

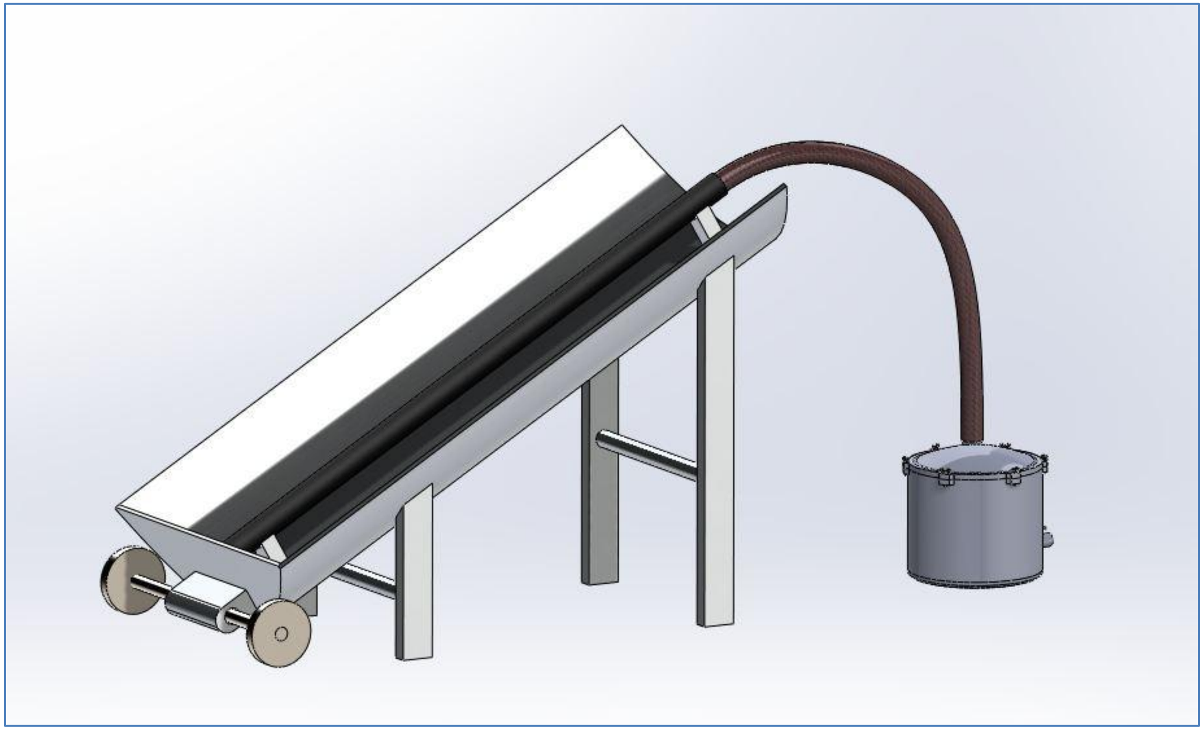


Figure 13: Final Design

Final Design

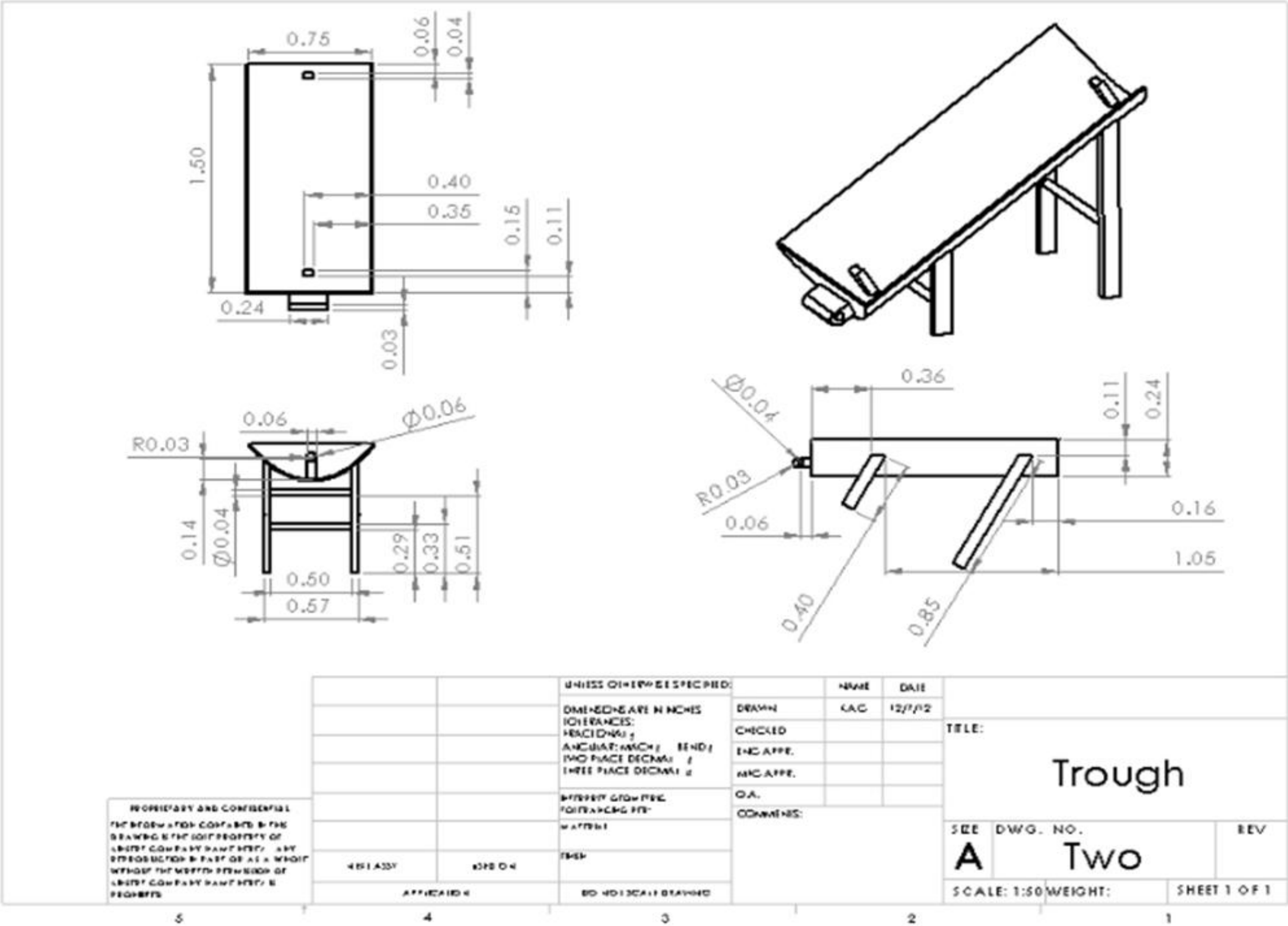
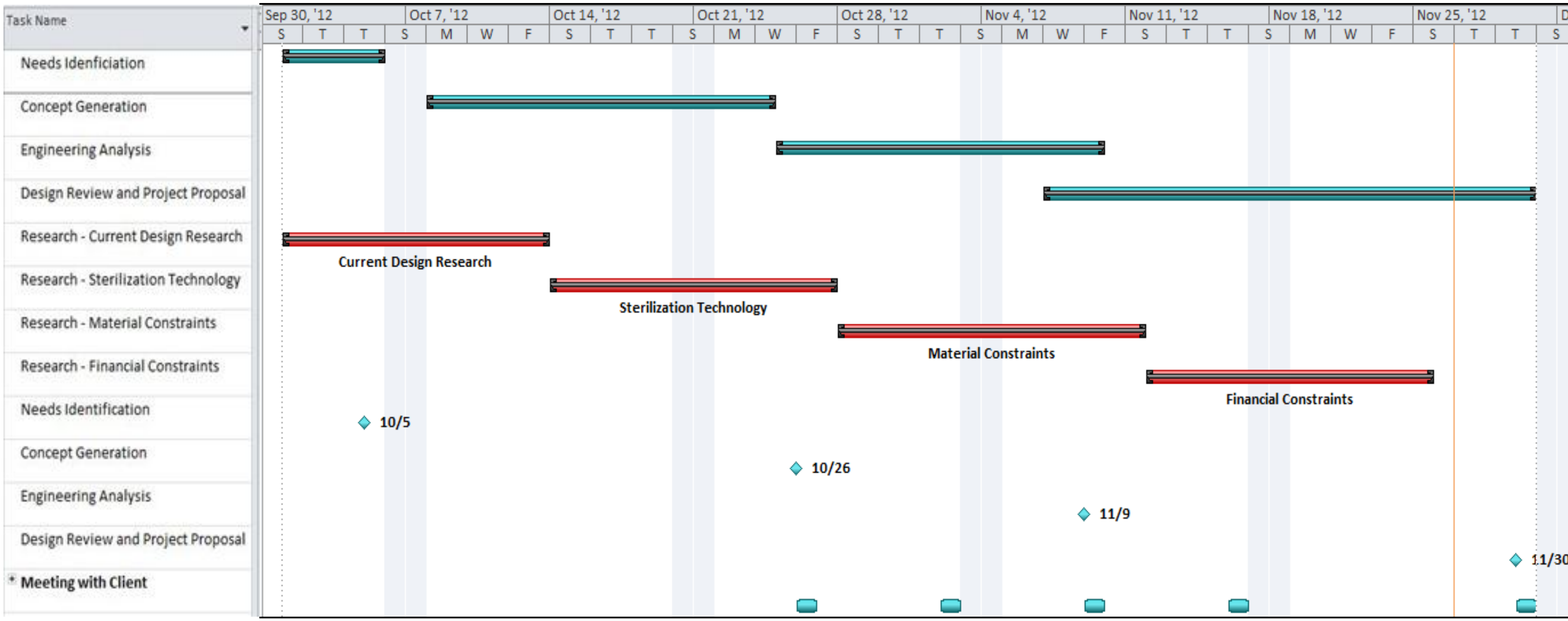


Figure 14: Dimensions for Trough

Gantt Chart


Task Name
Needs Idenficiation
Concept Generation
Engineering Analysis
Design Review and Project Proposal
Research - Current Design Research
Research - Sterilization Technology
Research - Material Constraints
Research - Financial Constraints
Needs Identification
Concept Generation
Engineering Analysis
Design Review and Project Proposal
Meeting with Client
Sep 30, '12
Oct 7, '12
Oct 14, '12
Oct 21, '12
Oct 28, '12
Nov 4, '12
Nov 11, '12
Nov 18, '12
Nov 25, '12
Current Design Research
Sterilization Technology
Material Constraints
Financial Constraints
10/5
10/26
11/9
11/30

Conclusion

- Concept Generation
  - Trough design
  - Boiler provides more efficient sterilization
  - Secondary pressure vessel with medical equipment
- Engineering Analysis
  - Thermal capture
  - Thermal circuit
  - Thermodynamic properties of water
  - Pressure vessel
- Cost Analysis
- Final Design

References

- **Sponsor**: Dr. Brent Nelson
  - brent.nelson@nau.edu

- **Text:**
  - Michael J. Moran and Howard N. Shapiro. Fundamentals of Engineering Thermodynamics 6th. 2008. Print.
  - Richard Budynas and Keith Nisbett. Shingley's Mechanical Engineering Design 9th. 2010. Print.

- **Project Website:**
  - http://www.cefns.nau.edu/interdisciplinary/d4p/EGR486/ME/13-Projects/SolarAutoclave/

- **Web Sources:**
  - Centers for Disease Control and Prevention:
    - http://www.cdc.gov/hicpac/Disinfection_Sterilization/13_0Sterilization.html
  - Global Challenge:
    - http://globalchallenge.mit.edu/teams/view/171
  - Solar Sterilisator:
    - http://www.solare-bruecke.org/projekte-Dateien/Solarsterilisator/summary%20english.html
  - TravelState.gov:
    - http://www.travel.state.gov/
  - Science Direct:
    - http://www.sciencedirect.com/science/article/pii/S1364032110001206

Questions?