Design for Manufacturing, Reliability, and Economics.

Solar Phase Change Compressor

Team 20

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A- Prototype design and components to be manufactured

A1) Manufacturing

We are designing a compressor that has compressing pressure of no greater than 150 Psi; we will be using steam to create a pressure of up to 150 Psi, which happens at 185.5 °C.

From our sponsor, we took the design with two chambers with a membrane in between. To close it we will use sealant and screws and nuts; the screws need to be smooth where they meet the membrane to prevent tearing.

To control the refrigerant flow, we included check valves on the top (refrigerant) chamber. The steam inlet is controlled by a globe valve. To control the steam (stop to increase pressure, let flow to release pressure), we originally had a two solenoid valves which we reduced to one attached to the steam outlet; the solenoid valve will be controlled with a microcontroller, which is connected to the valve through a circuit. For safety measures, in case anything goes wrong, we added a safety relief valve to limit how much pressure can build up.

After we received our valves, we found them to be female just like our compressor, we decided to get couplings. To make our check valves horizontal, we got elbows.

After we bought the a/c unit, which we will use to test compression, we saw how small the tubing was and to reduce the size from our valves to our tubes, we bought reducing adapters and extra tubing to weld the two systems together. To prevent leaks we use pipe thread tape.

For testing and data acquisition, we bought a gauge for quick observations, a transistor for accurate data displays, and adapters to attach them to our system.

A2) Selection Criteria

1) Compression Chamber (machined)
    a. Material — 1018 Mild Steel
    b. Yield Strength — 153.6 Kpsi
2) Membrane
    a. Material — Silicone Rubber
    b. Maximum Temperature — 273°C
3) Check valve for one directional flow
    a. Maximum Temperature — 407 °C
4) Solenoid Valve to control pressure
    a. Maximum Temperature — 178 °C
5) Relief valve for safety measures
    a. Minimum Pressure — 150 Psi
    b. Maximum Temperature — 207 °C
6) Screws & Nuts
    a. Length — > 1 in
    b. Thread clearance — 0.625 in

7) Air Conditioning unit
    a. Cooling capacity — 5000 BTU (lowest possible)
8) Extra tubing
    a. Material — Copper (same as AC)

A3) Machining

To reduce cost, all machining was made at the FSU COE machine shop

a. Changed machining from a steel billet to be machined, to a steel tube with caps and flanges welded on, and screw holes machined.

A4) Bill of Materials and Blueprints

Item	Vendor	Part#	Price	Process Selection
6"x6" Steel Cylinder	McMaster-Carr	7786T78	155.82	original
High Temperature Silicone Rubber, 3/8"	Rubber Sheet Roll		113.56	design
High-use check valves (x2)	McMaster-Carr	4894K47	105.24	valves
ASCO Solenoid Valve	Grainger	4NWZ8	312.5	for
Globe Valve	McMaster-Carr	47865K43	11.18	one-direction/stop-go/safety
Pressure releif valve, 1/2"MNPT	McMaster-Carr	4755K11	143.3	flow
Microcontroller: Arduino Uno R3	Radio Shack	276-128	29.99	
Solid State Relay	Mouser	653-G3A-210B-DC5	15.3	Solenoid
Modular IC Breadboard Socket	Radio Shack	276-003	9.99	Valve
Transistor 2N222	Radio Shack		1.49	controller
Resistor 5K Ohm	Radio Shack		1.49	and
Straight Blade Plug, 120V,15Amp-ac	Grainger	1PKF8	16.44	Accessories
M to F Jumpers and Headers	Radio Shack	276-156	6.99	
Elbow, 1/2"FNPT	Home Depot		1.64	For
Street Elbow, 1/2"MxFNPT (x3)	Home Depot		7.02	Redirecting
Coupling, 1/2"FNPT	Home Depot		1.97	and Extension
Window Unit AC, 5000btu	Quick Appliance		102.13	For Testing
Copper Tube, 3/8", 10'	Home Depot		13.48	For AC Coupling
Reducing Adapter, 1/2"MNPT x 3/8" Female C (x2)	McMaster-Carr	5520K502	5.4	
Reducing Adapter, 1/4"FNPT x 1/8" Female C	McMaster-Carr	5520K174	4.04	
Reducing Adapter, 1/2"MNPT x 1/4" Female C (x2)	McMaster-Carr	5520K493	4.12	Reduction
Reducing Coupling, 1/4"MNPT x 1/8"FNPT	McMaster-Carr	5520K221	1.01	From
Adapter, 1/8"Female C x 1/8"FNPT	Grainger	1VLR7	5.7	Valves
Reducing Bushing, 1/2"MNPT x 1/4"FNPT	McMaster-Carr	50785K65	2.54	to
Nipple, 4-1/2", 1/2"MNPT	Home Depot		1.87	AC
Nipple, 1-1/2", 1/2"MNPT (x2)	Home Depot		2.68	Tubing
Nipple, 2", 1/2"MNPT	Home Depot		1.34	
Nipple, 1-1/2", 3/4"MNPT	Home Depot		1.58	
PTFE pipe thread tape	McMaster-Carr	44945K12	6.12	Sealing to Prevent Leaks
Refrigerant service manifold	McMaster-Carr	1873K32	174.5	
Refrigerant Port-Quick Connect Adapter	Auto Zone		12.99	Testing
1/8" copper tee	McMaster-Carr	5520K833	3.89	and
Air Fill Valve, 1/4"MNPT	McMaster-Carr	8063K37	3.94	Data
Refrigerant clamp-on valve (x2)	McMaster-Carr	1809K28	14.54	Acquisition
Compound Gauge, 1/4" Ctr Back, 30"hg-0,200 Psi	McMaster-Carr	4004K72	12.07	Eqipment
Ashcroft Pressure Transducer	Grainger	5DEK4	175.5	
Low-pressure steam hose, 3/4" NPT	McMaster-Carr	5301K22	83.98	

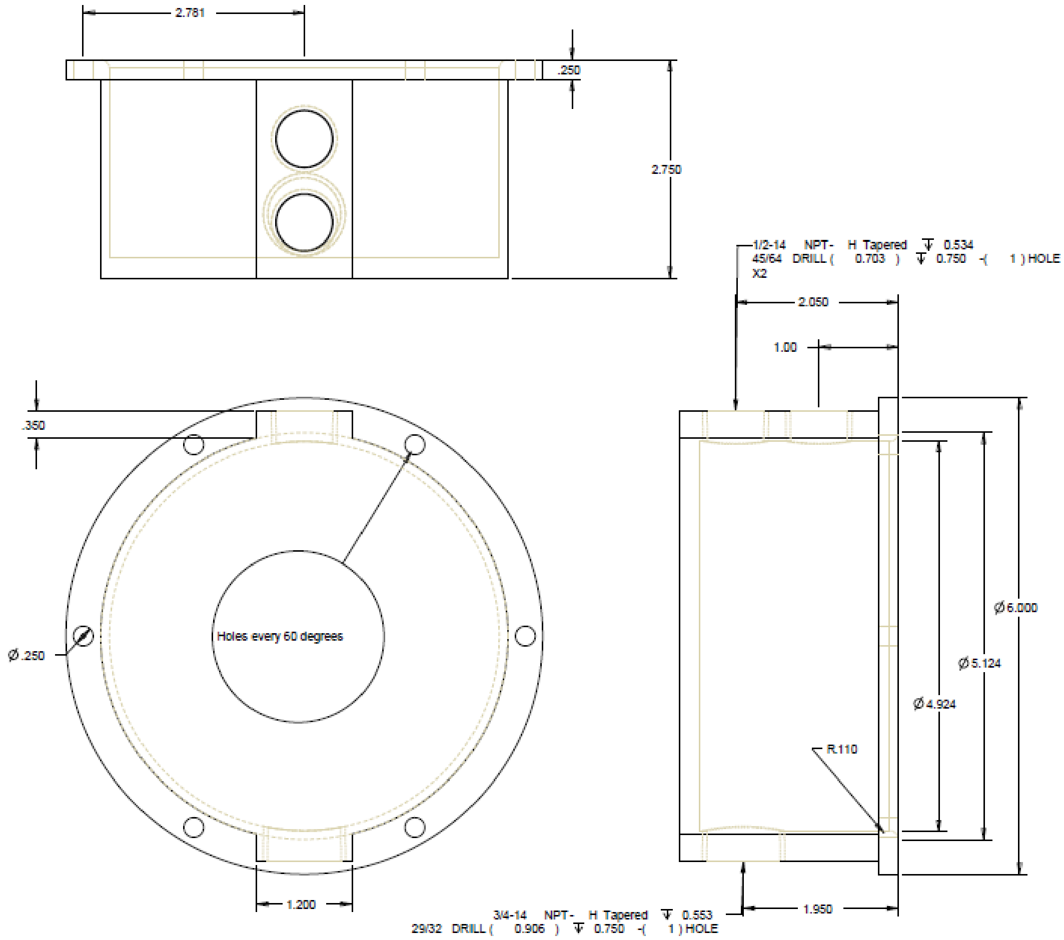

Figure 1 Compressor Steam Compartment

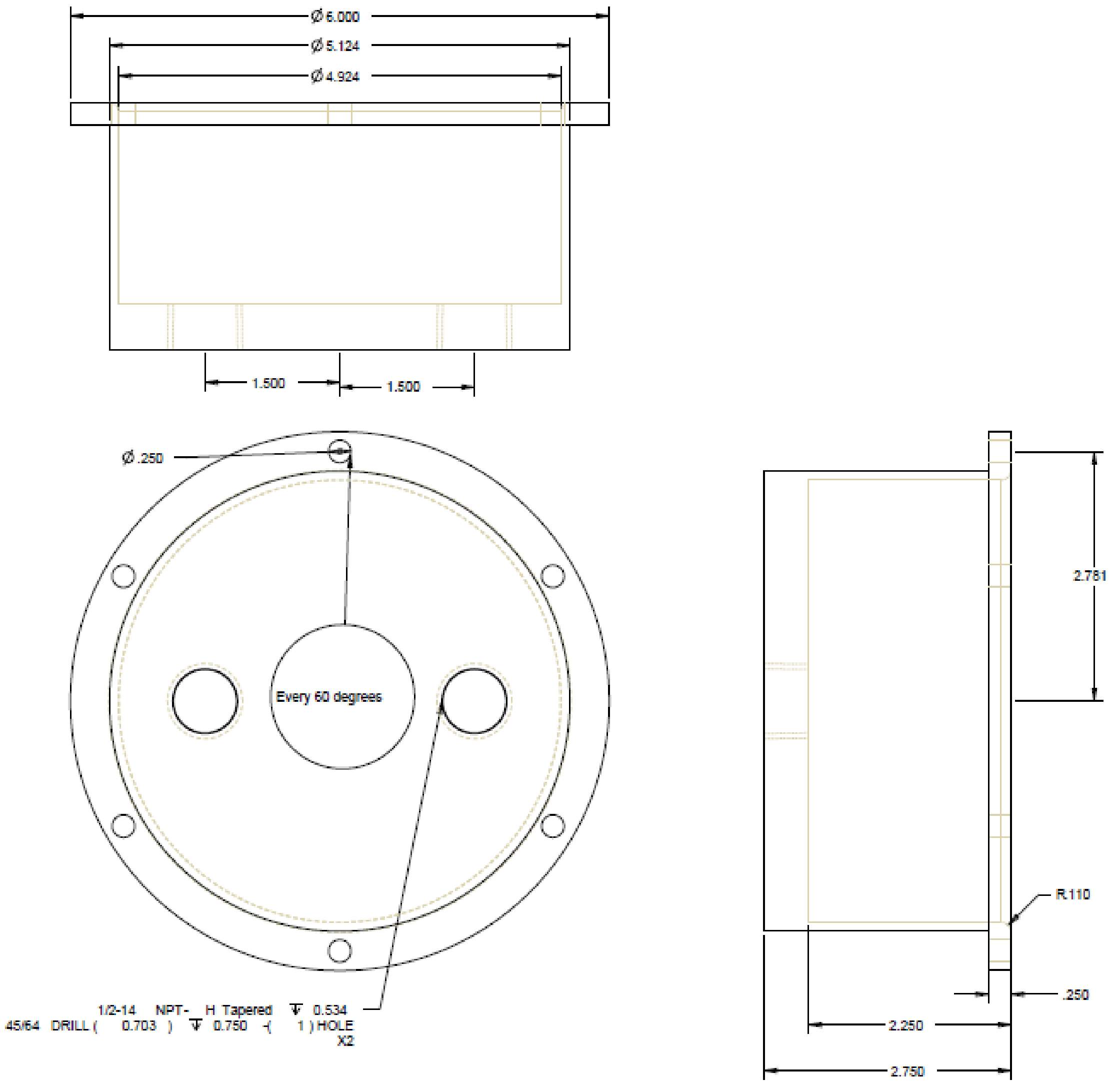

Figure 2 Compressor Refrigerant Compartment

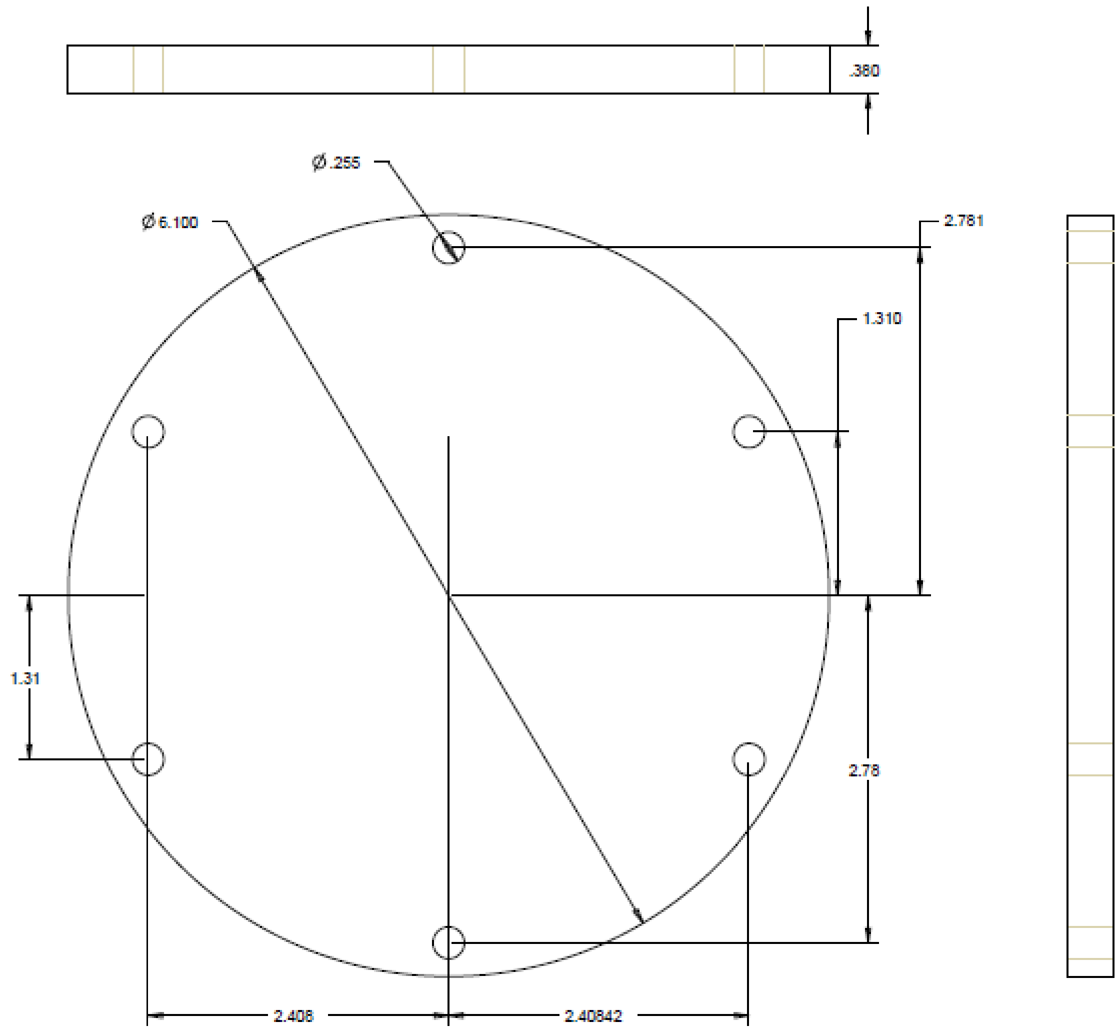

Figure 3 Membrane

A5) Assembly

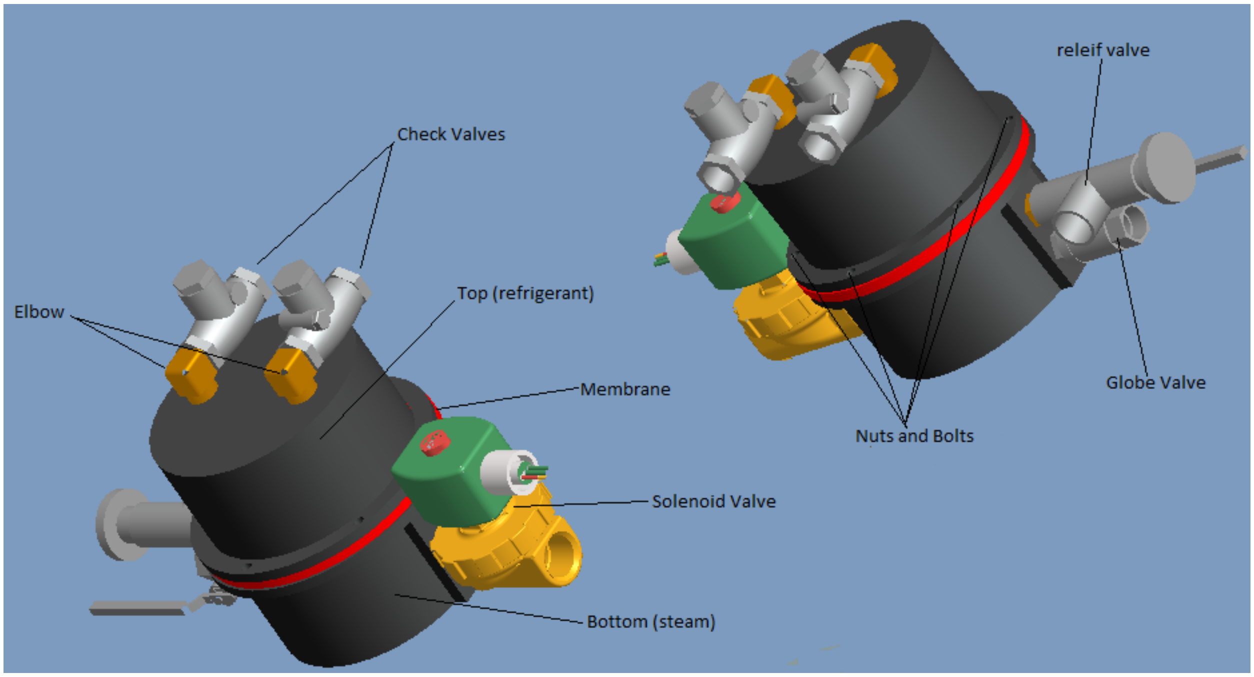

Figure 4 Completed Assembly

Instructions:

This compressor may be used with various appliances. These instructions will be to assemble the compressor, additional assembly with other systems (AC or otherwise) may vary.

1) Align the screw holes of the top compartment, membrane, and bottom compartment, so that the valve holes are all in one line as shown on above picture.
2) Put in bolts and tighten with nuts.
3) On all the male threads, wrap thread tape.
4) Screw in elbows onto top compartment, they should be facing perpendicular to steam compartment holes.
5) Screw in check valves to elbows.
6) The bottom compartment has ½-14 NPT(x2) and ¾-14 NPT holes; screw in the solenoid valve to the ¾-14 NPT hole.
7) In the top ½-14 NPT hole of the bottom compartment, screw in an elbow; this should be facing parallel to the check valves.
8) Screw in the relief valve to the elbow.
9) In the bottom ½-14 NPT hole of the bottom compartment, screw in a coupler.
10) Screw in globe valve to coupler
11) While in operation, the steam inflow will be attached to the globe valve while the outflow will be attached to the solenoid valve.
12) The check valves will need to be reduced to new system pipe size, and soldered for sealing.

B- Design for Reliability

The required pressure vessel thickness is determined by solving the equation for circumferential stress in a cylindrical pressure vessel for t:

$$t = \frac{Pr}{\sigma_\theta}$$

Applying the upper limit steam pressure, 800 kPa, and the yield strength of A36 Steel, 250MPa, the equation gives that a wall thickness of 0.2mm is required. The designed wall thickness of 5.1mm exceeds this value by a safety factor of 25.5. Clearly, as much material is not necessary, however this dimension was determined by available material.

The component that is most vulnerable to failure is the silicone-elastomer membrane. The design requires the membrane to oscillate through positive and negative displacement at a frequency near 1Hz. This material was selected due for its elastic modulus and high temperature tolerance (260°C). However, there is a lack of previous art for it being used in such an application. A primary area of research for future development should be the fatigue characteristics of this material. Generally, the yield strength of a material degrades as it undergoes cyclic loading. Testing should be carried out to determine when this reaches a critical point for the elastomer being used in such a way.

It is necessary to replace the membrane before failure occurs. Though the effects of R134a, our chosen refrigerant, are not as harmful with respect to ozone depletion potential as compared to other refrigerants, it should not be vented to the atmosphere. If it can be determined when the membrane is likely to fail, it can be replaced before the failure occurs.

A second vulnerable component is the solenoid valve, which opens and closes at 1Hz to regulate the steam flow. ASCO, the manufacturer of the valve used in our system manufactures solenoid valves rated for 20 million cycles. Assuming the compressor operates for 12 hours per day at 1 Hz, this threshold would be reached in 463 days. After this time the valve seal components would need to be replaced. This is a reasonable task to include in an annual maintenance schedule.

C- Design for Economics

The total cost for developing the prototype for the solar powered phase change compressor has totaled approximately $1,600. The overall cost of producing another compressor would drop significantly due to the fact that $600 has been invested in testing supplies, accounting for 37.5% of the total funds. The individual components of the system will be constructed from stainless steel and can be easily manufactured due to simplistic part drawings. The assembly of the pressure vessel would not be time consuming, since it is simply bolting the bottom and top half with the silicone diaphragm being clamped between the two shells. Overall, the parts will decrease as production volume increases once the manufacturer installs the necessary machine equipment for mass amount of units.

The components of the system will consist of stainless steel, which will be machined and finished in-house; and silicone rubber, mechanical valves, and connection units will all be purchased through external sources for mass production. The assembly of the vessel will be minimal, estimated assembly of one vessel every 20 minutes for each production tech. The approximated $600 of testing investments will be condensed into a cost of a single, one-way mechanical valve, which the pressure of the valve will be determined post testing. The valve will be responsible for releasing steam after a set pressure has been exceeded to allow the diaphragm to decompress. The elimination of the solenoid valve and components of the control circuit will greatly decrease the production cost of the phase change compressor.

The current design utilizes the reduction in assembly cost. All components are necessary for correct pumping of the refrigerant through the A/C unit. A visual document will be developed in order for properly maintaining, servicing, and when to replace individual components of the compressor, which will attribute to the life cost, but not the initial production of the unit. To reduce the assembly cost, or to ensure that time spent is efficiently, visual standards and centerlines will be established. This will decrease time spent on assembly and decrease likelihood of errors by the production techs. All of these implementations will greatly reduce the original cost of the system and create a permanent and sustainable solution for production of the phase change compressor.