SAAR

Solar Ammonia Absorption Refrigerator

Senior Design Project

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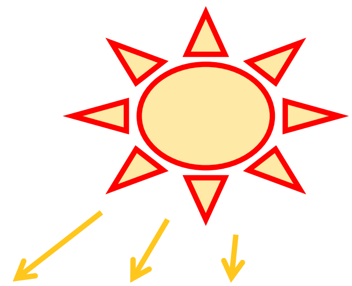

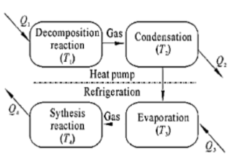

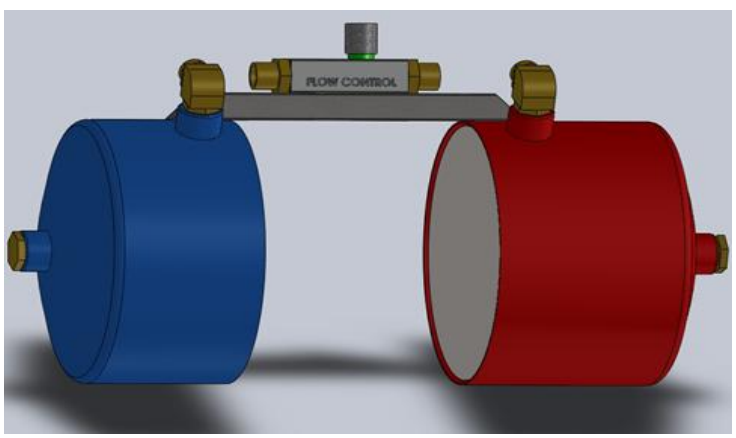

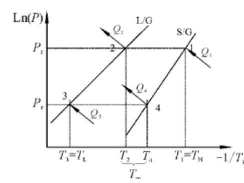

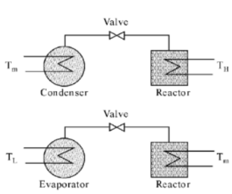

$$Q_g = \dot{m}_{ref}\left(h_1 - h_4\right)$$

$$COP = \frac{Q_e}{Q_g}$$

$$CaCl_2 \bullet nNH_3 + n_1\Delta H_r \leftrightarrow CaCl_2 \bullet (n - n_1)NH_3 + n_1NH_3$$

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Table of Contents

Project Justification & Intention

Nearly half of the vaccines in developing countries go to waste every year due to temperature spoilage, according to the World Health Organization. Current transportation and storage methods in remote regions still rely on ice packs that last just a few days causing a large need for sustainable refrigeration where electricity is not readably available. To solve this problem the SAAR student design team is in the process of developing an affordable refrigerator that is capable of operating on solar energy and/or alternative fuels such as small camp fires. The SAAR will be capable of maintaining the optimal temperature range of 2 to 8° C for temperature sensitive medicines and vaccine.

The SAAR design team will be utilizing the adsorption intermittent refrigeration cycle for simplicity as a focus for manufacturing, maintenance and daily use. It will consist of no moving parts and will be simple to reconstruct, and teach/learn how to operate. After the initial charge of each unit, the refrigerator is designed to work without any maintenance for three to five years, less it is ill-treated or improperly used.

In an effort to make this solar refrigeration technology available around the globe, the team's final deliverable is a set of manufacturing plans that will be distributed without patent on the internet. This open-source distribution will allow the refrigerator to be built by governments, local businesses and nonprofit organizations throughout the world's developing communities. The posting of the manufacturing instructions and technical reports on the internet will not only spread the technology and knowledge, but has the possibility to lead to significant improvements in the design from the global input on possible cost reductions and unique adaptations for each region.

We anticipate the SAAR refrigerator to prove its worth by reducing the volume of spoiled temperature sensitive medicines, vaccine and food. At a cost of approximately $300 per refrigerator unit, and is expected to be within reach of governments and nonprofits. However reducing the cost could increase its availability throughout third world countries.

Design Mission Statement

Design a compact refrigeration unit capable of operation in rural or harsh conditions (no service utilities). Capable of consistent refrigeration temperatures between 2°C and 8°C for a 24-36 hour period

Project Design Concepts

The development of an inexpensive, modular, small scale device based upon the absorption refrigeration process. It is anticipated that the SAAR to provide refrigeration using just solar energy or low grade heat sources such as camp fires or gas heaters, and will allow for refrigeration to occur in climates up to 35-50°C. Of grave concern is for safe operation at high pressures, attempting to design the SAAR at pressures of 10.5 Bar, similar to a household air compressor. Safety for pressure operations was designated the unit to have a minimum safety factor of 2:1, so the maximum operating pressure is set at 14 Bar, with hydrostatic testing of the system to be accomplished at pressures up to 28 Bar. Safely heating the unit is tied to pressure operations, so the highest safety for the heating processes will also be implemented.

The team's initial goal was to make 20 pounds of ice in one day, double the S.T.E.V.E.N system, one half of the ISSAC double intermittent system. However a more realistic goal is weight of ice per unit cost. Design parameters are now balanced with modularity and overall weight limits. The SAAR component weight was set to 20 Kg, a reasonable weight to have a person move around and load up on a truck for transportation. This size gives our system the best results to meet both refrigeration capacity and portability. Thermal chest size is estimated at $0.5m^3$; however final testing will determine optimum size for capability and modularity of design.

Project Parameters

- Design parameters were created to better define our Solar Refrigerator/Freezer:
- $0.5m^3$ Thermal Chest
- Maximum component weight 20 Kg
- Maximum operating pressure 14 Bar
- Operational on alternative fuels
- Adaptable to a range of heating sources
- Ambient cooling of components

Parameters where created to help differentiate the design from models that are currently in use today. Creating a system that is capable of operating off of alternative fuels and also adaptable to multiple heating sources is the team's secondary charter. Substantial cooling is an important parameter in maintain an operating system below 14 Bar, thus requiring a balance of energy used to charge the unit and the cooling capacity for condensing the refrigerant to a useful state.

Market Research

The ammonia absorption refrigeration process has been around for over a hundred years and many different types of design processes have been invented. There are three designs that our team has identified to research, the Crosley IcyBall, S.T.E.V.E.N. (Solar Ammonia Absorption Icemaker), and the ISAAC (Double Intermittent Solar Ammonia Absorption Cycle) Ice Maker.

The Crosley Icyball was first patented in 1927 by David Forbes Keith and then manufactured by Powel Crosley Jr., who purchased the rights. It has since been out of production although thousands of units were produced the 1930's. The Icyball is an intermittent heat absorption refrigerator using a water/ammonia mixture as the absorbent and refrigerant pair. At room temperature water and ammonia combine into a single solution. The Icyball consists of a hot and cold side, with the hot side being a ball of steel that holds the water/ammonia mixture. Heat is than added to the hot side boiling out the ammonia from the water and then condensing inside the cold ball that is in a water bath. After the hot side is heated for around 90 minutes most of the ammonia is condensed into a liquid and the cold ball is placed inside an insulated chest. After the hot ball cools down, the ammonia in the cold ball will start to evaporate and recombine with the water that is still in the hot ball causing the pressure to drop in the cold ball which allows for a refrigeration effect. These units were capable of cooling a 4cu ft. insulated chest for approximately 24 hours and operated at around 250 Psi [7].

In 1996 the S.T.E.V.E.N Foundations (Solar Technology and Energy for Vital Economic Needs) Solar Ammonia Absorption Icemaker, developed their design also using the intermittent absorption cycle but uses calcium chloride salt as the absorber and pure ammonia as the refrigerant. Utilizing calcium chloride as the absorber instead of water allows for some practical advantages, primarily no water is evaporated when heated which produces a non-diluted ammonia solution and allowing for a stronger absorption process. The S.T.E.V.E.N design consists of three main components: a generator for heating the calcium chloride ammonia mixture, a condenser coil in a water tank, and an evaporator tank that is placed inside of an insulated chest. The generator is a three-inch non-galvanized steel pipe that is at the focus of a parabolic trough solar collector that will heat the pipe when the sun in out. When the ammonia is boiled out of the generator it moves into the condenser coils that are immersed in a water bath and then turned into liquid ammonia inside the evaporator tank. This system is a stationary unit that operates on a two cycle process that consists of a day and night cycle. During the day cycle the sun produces the energy to boil the ammonia out of the generator, and the night cycle allows for ambient cooling of the generator to allow the ammonia to evaporate back into the calcium chloride causing the refrigeration effect capable of yielding around ten pounds of ice in a single process/day. Because of the simple design this unit is capable of operating without any human assistance. The total cost is $510 and is able to be constructed of materials that are readably available in most third world countries, the unit in about 10 feet in length and 6 feet in diameter [23].

The third system is not only the most advanced system, but also the most expensive unit. The ISAAC solar Ice maker is produced by the Energy Concepts Co. and is a double intermittent solar ammonia-water absorption cycle. This system also operates on the Day/Night cycle heating the generator with a parabolic trough solar collector, but instead of using a condenser in a water bath it uses air condenser coils that are capable of condensing the ammonia into a liquid form inside of the evaporator tank. The ISAAC design requires a human operator that is needed to switch valves from the day to night cycle to allow the ammonia to evaporate back to the water. The critical component in this system is the use of a thermo syphon that operates during the night cycle to remove the heat from the generator instead of using just the ambient temperature of the night. The ISAAC has a higher coefficient of performance system yielding around 35 pounds of ice per day in the 37 foot parabolic trough collector. Energy Concepts also offers larger models: a 63 foot collector, and 125 foot collector that are capable of yielding 70 pounds and 150 pounds of ice per day. The price for each unit varies for each size with the price being $11,000 for the 37 foot collector, $13,000 for the 63 foot collector, and $17,000 for the 125 foot collector [13].

Principles of Refrigeration

An understanding of the basics in refrigeration is helpful in determining system components, knowing that elements of each basic refrigeration phase are still required in order to make the cooling refrigeration environment take place. Basics of a refrigerant in heat transfer are:

- Liquids absorb heat changing from liquid to gas
- Gases emit heat changing from gas to liquid.

Four State Refrigeration Cycle

- High pressure gas/vapor (usually associated with heat or compressor unit)
- High Pressure Liquid (usually associated with a cooling processes condenser)
- Low Pressure Liquid (associative with a volume expansion)
- Low Pressure Liquid into a gas/vapor (associative with an evaporated)

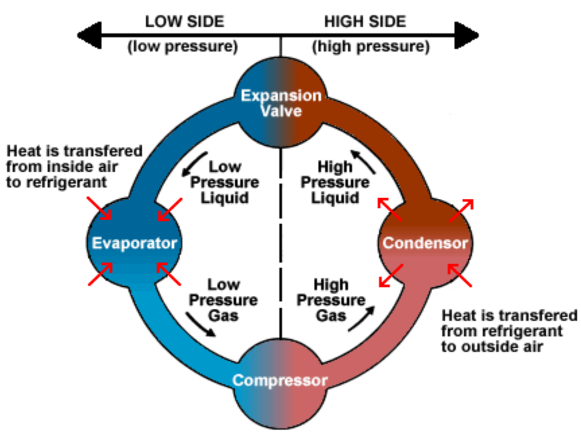


Figure: 1.1 Four State Cycle

Primary Refrigeration Processes

Vapor-Compression Systems: Are typical of most household, smaller scale industrial refrigeration units. These units require stable, continuous electrical current to maintain the refrigeration process. Larger units may be powered by a fossil fuel mechanical power source, such as an internal combustion engine.

Continuous Absorption Systems: Are typically used in recreational vehicles, and large industrial units. The driving force in this type of refrigeration process is heat, from fossil fuels such as heating oil, propane, or kerosene. Waste heat from steam generators or combustion exhaust gases can also be harnessed to produce the refrigerant process. Batteries are also used in small scale recreational vehicle application.

Intermittent Absorption Systems: Are mainly found in alternative refrigeration unit using solar energy or waste heat as a generating pressure source and ambient environmental cooling prior to the regenerating cooling/refrigeration phase. This requires a working pair of a refrigerant and an absorbent. High pressure or heat separates the two elements during the generating phase and cooling/refrigeration takes place through the absorption/adsorption of the pair. Ambient cooling is an intermediate phase which takes place to reduce high pressure gas/vapor into a refrigerant working liquid. Four examples this project design looked at are:

- Water & Ammonia
- Lithium Bromide & water
- Carbon & Methanol
- Calcium Chloride & Ammonia

Double Intermittent Absorption Systems: Are a refinement of the single/intermittent systems that works either in cascade, at a higher pressure, and/or has a greater condensing ability thereby producing refrigeration beyond the typical intermittent absorption process.

Refrigeration Process Decision Matrix

Vapor-Compression Systems: Units require stable, continuous electrical current or a fossil fueled mechanical power source to maintain the refrigeration process. The vapor-compression system is not a feasible process due to availability of an electrical grid or continuous fuel source.

Continuous Absorption Systems: Requires a continuous heat source and availability of waste heat in rural areas is normally limited. Batteries as a heating source are limited to an electrical charge; photovoltaic cells for recharging can be costly. Continuous absorption systems are also complex in nature and generally more moving parts (valves and float level devices).

Intermittent Absorption Systems: have the widest array of functional designs; some systems are complex in nature and many other designs very simple. Intermittent Absorption Systems are able to use waste heat and solar energy as the primary driving source. The intermittent process works ideal with the intermittency of the sun. At night the natural ambient cooling environment is a practical means to complete the refrigerant process.

Double Intermittent Absorption Systems: Able to use waste heat and solar energy as the primary driving source. Current example systems like the ISAAC are large, long and bulky. These units do not conform to a modular compact design and the operational size of the solar collector would most likely necessitate being fully constructed on user site.

Absorption vs. Adsorption

- Absorption is the incorporation of a substance in one state into another of a different state (e.g., liquids being absorbed by a solid or gases being absorbed by a liquid).
- Adsorption is the physical adherence or bonding of ions and molecules onto the surface of another phase (e.g., reagents adsorbed to solid catalyst surface). Classic stratification of absorbent layer can often be seen during saturation and 100% saturation of absorbent may be difficult to achieve give a specific time constraint [14].

Absorbent and Refrigerant Working Pairs

Water & Ammonia
- Most common working pair
- Water absorbent
- Ammonia refrigerant
- Continuous or intermittent absorption process
- Vaporized H_20 reduces refrigeration
- High side 10-13 Bar @ 90-100˚C
- Ideal refrigerant regeneration below boiling point of water

Lithium Bromide & Water
- Environmentally safer than R12, R21, R134
- Lithium Bromide absorbent (like salt extreme hygroscopic)26
- Water Refrigerant
- Absorption/adsorption process
- Continuous or intermittent process
- Refrigeration process requires a plumb/leveled working system
- Maximum high side temperature @ 552˚C (melting point of Lithium Bromide)

Carbon & Methanol

- Intermittent adsorption process
- Carbon absorbent
- Methanol refrigerant
- High side requires a vacuum condition prior to refrigeration regeneration
- High side 2-5 bar @ 90-110˚C

Calcium Chloride & Ammonia

- Intermittent adsorption process
- Calcium Chloride absorbent
- Ammonia refrigerant
- No vaporization of H_20 reducing refrigeration phase
- Does not require vacuum or level environment required
- Subject to heat crystallization
- Corrosive to aluminum brass and copper
- Target low side operation 20-30 ˚C
- Target high side operation 90-140˚C
- Target operating pressure 8-14 Bar

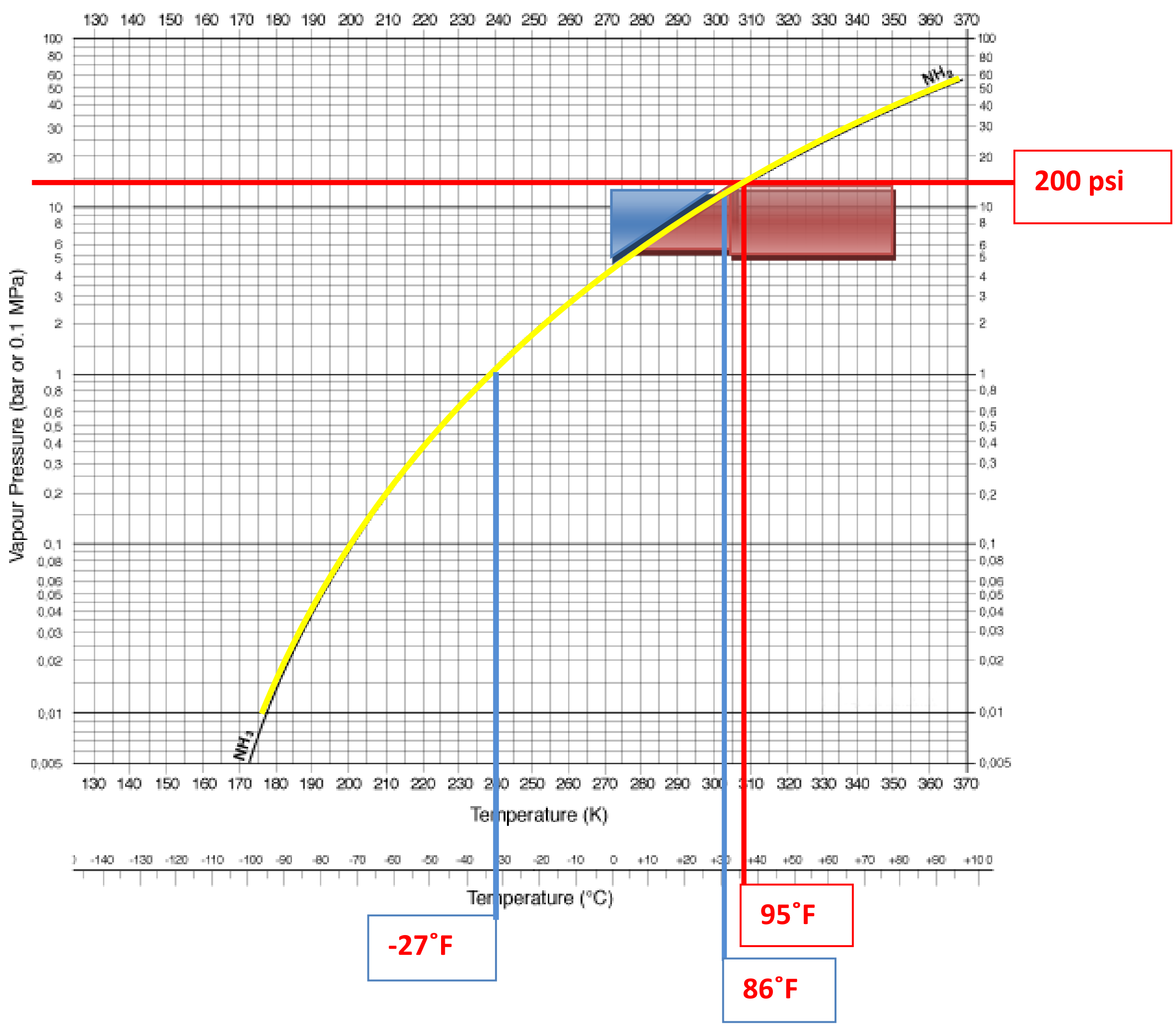
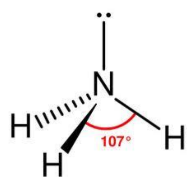


Figure 1.2: Temperature vs. Pressure graph of Ammonia

R-717 Ammonia NH_3 CAS Number: 7664-41-7 UN1005

Ammonia is a colorless gas possessing a characteristic pungent smell and a strongly alkaline reaction; it is lighter than air, its specific gravity being .589. It is easily liquefied and the liquid boils at -33.7° C, and solidifies at - 75° C. to a mass of white crystals. It is extremely soluble in water, one volume of water at 0° C. and normal pressure absorbs 1148 volumes of ammonia. All the ammonia contained in an aqueous solution of the gas may be expelled by boiling. It does not support combustion, thus making it an ideal refrigerant in sea vessels where accidental fire can be detrimental. Ammonia gas has the power of combining with many substances, particularly with metallic halides; thus with calcium chloride it forms the compound $CaCl_2$.& NH_3, and consequently calcium chloride compound cannot be used for drying ammonia gas [14].

The NH3 molecule has a large dipole moment, and this is consistent with its geometry, a triangular pyramid. The electronic arrangement in nitrogen obeys the octet rule. The four pairs of electrons (three bonding pairs and one non-bonding lone pair) repel each other, giving the molecule its non-planar geometry. The H–N–H bond angle of 107 degrees is close to the tetrahedral angle of 109.5 degrees. Because of this, the electronic arrangement of the valence electrons in nitrogen is described as sp^3 hybridization of atomic orbitals.



The polarity of NH_3 molecules and their ability to form hydrogen bonds explains to some extent the high solubility of ammonia in water. However, a chemical reaction also occurs when ammonia dissolves in water. In aqueous solution, ammonia acts as a base, acquiring hydrogen ions from H_2O to yield ammonium and hydroxide ions.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4 +(aq) + OHG(aq)$$

The production of hydroxide ions when ammonia dissolves in water gives aqueous solutions of ammonia their characteristic alkaline (basic) properties. The double arrow in the equation indicates that equilibrium is established between dissolved ammonia gas and ammonium ions. Not all of the dissolved ammonia reacts with water to form ammonium ions. A substantial fraction remains in the molecular form in solution. In other words, ammonia is a weak base. A quantitative indication of this strength is given by its base ionization constant:

$$K_b = [(NH_4^+)(OH^-)] / (NH_3) = 1.8 \times 10^{-5} \text{ @ } 25° C$$

In contrast, the ammonium ion acts as a weak acid in aqueous solution because it dissociates to form hydrogen ion and ammonia.

$NH_4^+(aq) \rightleftharpoons NH_3(aq) + H^+(aq)$

The ammonium ion is found in many common compounds, such as ammonium chloride, NH_4Cl. Typically, ammonium salts have properties similar to the corresponding compounds of the Group IA alkali metals.

The commercial production of ammonia by the direct combination of nitrogen and hydrogen is an example of equilibrium in the gaseous state. The equation for the reaction and its equilibrium constant expression are

$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g) \qquad K_C = (NH_3)^2 / [(N_2)(H_2)^3]$$

At 300°C, K_C has a value of 9.6, indicating that at this temperature, an appreciable amount of NH_3 forms from N_2 and H_2. Because the reaction gives off heat (ΔH°= –92.0 kJ for the equation above), increasing the temperature drives the reaction to the left. Thus, Kc decreases with increasing temperature. The equilibrium mixture at 500°C contains less NH_3 than at 300°C or at 100°C. If one is in the business of making ammonia (and money), the object is to make as much NH_3 as possible as quickly as possible. The temperature dependence of the equilibrium constant suggests that working at low temperatures is better because more ammonia is obtained at equilibrium. Alas, equilibrium isn't everything! All chemical reactions slow down as the temperature decreases. While a low temperature favors a high equilibrium yield of ammonia, it also dictates that a long time will be required to obtain the yield. The ideal method is a balance between yield and speed [14].

Molecular Weight: 17.03 g/mol

Solid phase

- Melting point : -78 °C
- Latent heat of fusion (1,013 bar, at triple point) : 331.37 kJ/kg

Critical point

- Critical temperature : 132.4 °C
- Critical pressure : 112.8 bar

Miscellaneous

- Solubility in water (1.013 bar / 0 °C (32 °F)) : 862 vol/vol
- Auto ignition temperature : 630 °C

Liquid phase

- Liquid density (1.013 bar at boiling point) : 682 kg/m3
- Liquid/gas equivalent (1.013 bar and 15 °C (59 °F)) : 947 vol/vol
- Boiling point (1.013 bar) : -33.5 °C
- Latent heat of vaporization (1.013 bar at boiling point) : 1371.2 kJ/kg
- Vapor pressure (at 21 °C or 70 °F) : 8.88 bar

Gaseous phase

- Gas density (1.013 bar at boiling point) : 0.86 kg/m3
  (1.013 bar and 15 °C (59 °F)) : 0.73 kg/m3
- Compressibility Factor (Z) (1.013 bar and 15 °C (59 °F)) : 0.9929
- Specific gravity (air = 1) (1.013 bar and 21 °C (70 °F)) : 0.597
- Specific volume (1.013 bar and 21 °C (70 °F)) : 1.411 m3/kg
- Heat capacity at constant pressure (Cp) 1.013 bar & 15°C (59°F):0.037 kJ/mol.K
- Heat capacity at constant volume (Cv) (1.013 bar & 15°C (59°F): 0.028 kJ/mol.K
- Ratio of specific heats (Gamma: Cp/Cv) (1.013 bar and 15°C (59°F)): 1.309623
- Viscosity (1.013 bar and 0 °C (32 °F)) : 0.000098 Poise
- Thermal conductivity (1.013 bar and 0 °C (32 °F)) : 22.19 mW/(m.K)

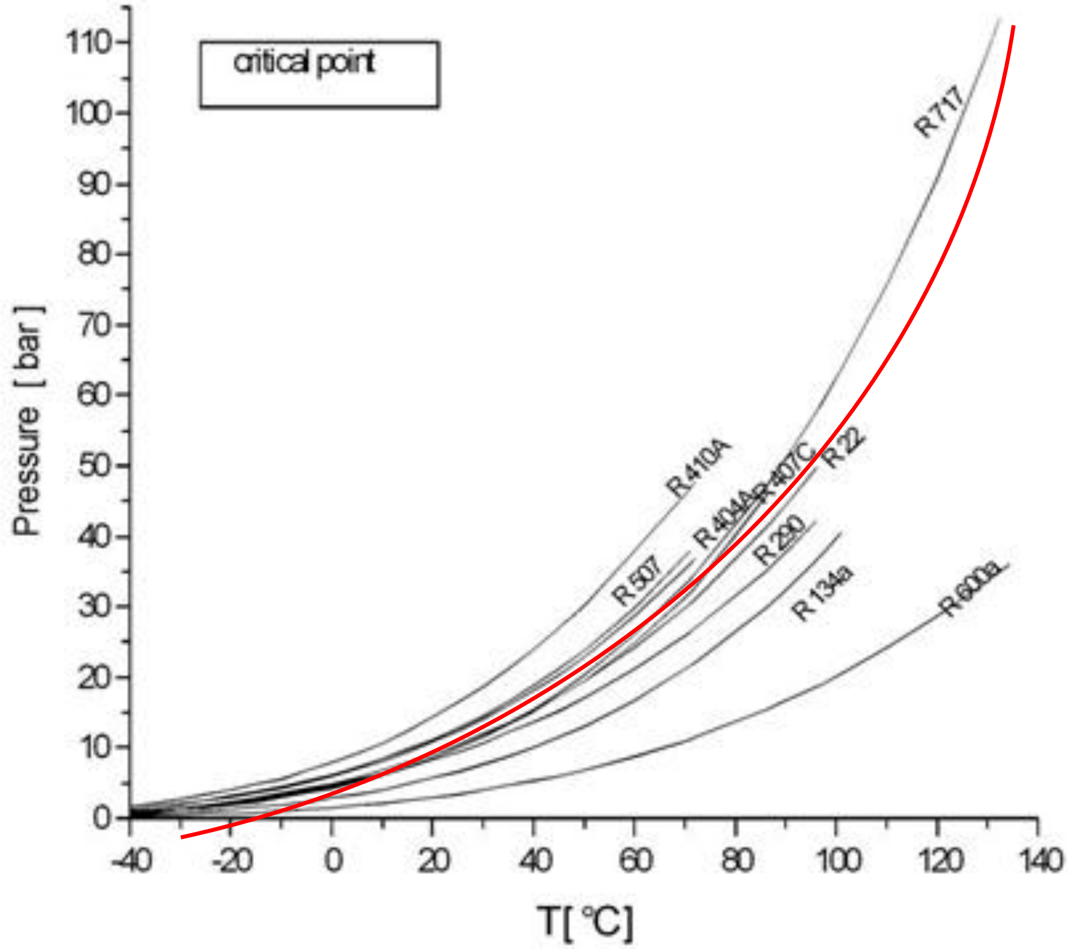


Figure 1.3: Pressure vs. Temperature graph of common refrigerants

Material compatibility

Air Liquide Corp has assembled data on the compatibility of gases with materials to assist in evaluating which products can use be used for the gas system. Although the information has been compiled from what Air Liquide believes are reliable sources (International Standards: Compatibility of cylinder and valve materials with gas content; Part 1: ISO 11114-1 (Jul 1998), Part 2: ISO 11114-2 (Mar 2001)), NH_3 it must be used with extreme caution.

No raw data can cover all conditions of concentration, temperature, humidity, impurities and aeration. It is therefore recommended that this table is used to choose possible materials and then more extensive investigation and testing is carried out under the specific conditions of use. The collected data mainly concern high pressure applications at ambient temperature and the safety aspect of material compatibility rather than the quality aspect.

Metals

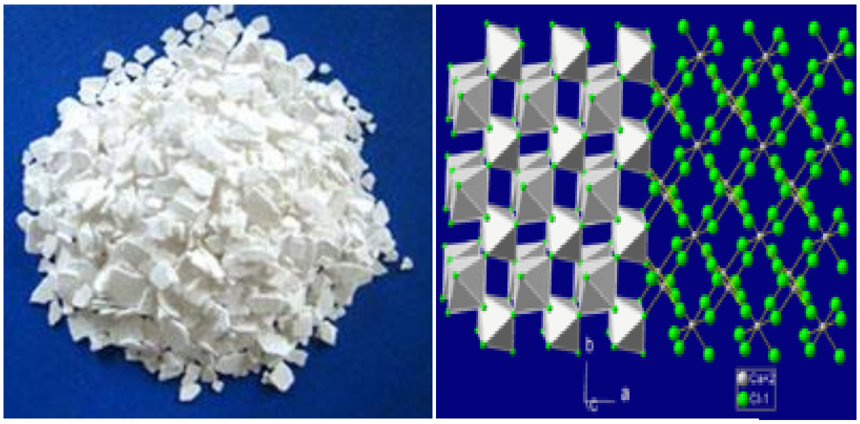
- Aluminium Satisfactory
- Brass Non recommended
- Copper Non recommended
- Ferritic Steels (e.g. Carbon steels) Satisfactory
- Stainless Steel Satisfactory

Plastics

- Polytetrafluoroethylene (PTFE) Satisfactory
- Polychlorotrifluoroethylene (PCTFE) Satisfactory
- Vinylidene polyfluoride (PVDF)(KYNAR™) Non recommended, notable acceleration
- process of ageing and significant loss of
- mass by extraction or chemical reaction.
- Polyamide (PA) (NYLON™) Satisfactory
- Polypropylene (PP) Satisfactory
- Elastomers Buthyl (isobutene - isoprene) rubber (IIR) Satisfactory
- Nitrile rubber (NBR) Acceptable but significant loss of mass by extraction or chemical reaction.
- Chlorofluorocarbons (FKM) (VITON™) Non recommended, significant loss of mass by extraction or chemical reaction.
- Silicon (Q) Non recommended, significant loss of mass by extraction or chemical reaction.
- Ethylene - Propylene (EPDM) Satisfactory

Calcium Chloride $CaCl_2$

$CaCl_2$ is a salt of calcium and chlorine which behaves as a typical ionic halide and is white solid at room temperature. Common applications include brine for refrigeration plants, ice and dust control on roads, and desiccation. Because of its hygroscopic nature, anhydrous calcium chloride must be kept in tightly-sealed air-tight containers [4].



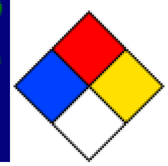


Figure 1.4: Calcium chloride in solid form (left), calcium chloride crystal structure (right)

Molar mass:	110.98 g/mol (anhydrous) 128.999 g/mol (monohydrate) 147.014 g/mol (dihydrate) 183.045 g/mol (tetrahydrate) 219.08 g/mol (hexahydrate)
Density:	2.15 g/cm^3 (anhydrous) 1.835 g/cm^3 (dihydrate) 1.83 g/cm^3 (tetrahydrate) 1.71 g/cm^3 (hexahydrate)
Melting point:	772 °C (anhydrous) 260 °C (monohydrate) 176 °C (dihydrate) 45.5 °C (tetrahydrate) 30 °C (hexahydrate)
Boiling point:	1935 °C (anhydrous)
Solubility:	In water 74.5 g/100mL (20 °C)

Ammonia	adsorbed 59.5 g/100 mL (0 °C)
Acidity (pK_a)	8-9 (anhydrous)
	6.5-8.0 (hexahydrate)

CaCl2 and NH3 Calculations

The calcium chloride cage which is located within the generator portion has a volume of 301.59in^3. The following values are used in the calculations:

- *Density of liquid NH_3: 681.9 kg/m^3*
- *Density of anhydrous $CaCl_2$: 2,150.0 kg/m^3*
- *Molar Mass of liquid NH_3: 17.031 kg/kmol*
- *Molar Mass of anhydrous $CaCl_2$: 110.98 kg/kmol*
- *Reaction Enthalpy: 78 kJ/mol*

Based upon research done on the reaction of calcium chloride and ammonia, it is assumed for this project that a total molar ratio of ammonia to calcium chloride is 8:1, while the working ratio is only 6:1 [14]. This means that after the SAAR system is charged with ammonia, only a percentage of the adsorbed ammonia will be available for use as the working refrigerant fluid. By using the values listed above, it is calculated that one mole of calcium chloride and eight moles of ammonia require a volume of 15.34in^3. Since the volume of the cylinder cage that will be holding the adsorbent is a fixed quantity, we can then determine the quantity of each compound that will be utilized .

The SAAR will use 4.404 lbs. of calcium chloride, when in the anhydrous form, and occupy a volume of 56.70in^3. For ammonia, the SAAR will require 5.41 lbs., which when in the liquid form will have a volume of 219.47 in^3. This provides a total volume of calcium chloride and ammonia of 276.17in^3. While this is slightly under the maximum cage volume of 301.59in^3, it will provide enough room for error to account for tolerances in the metal fabrication of the cage.

Using the sunlight for refrigeration generation, the intensity of the sun can vary for many different reasons and provide a range of generation time for driving the ammonia gas out of the calcium chloride. The following graph displays the generation time for several different sunlight intensities. In documented research and logged uses of the Icy Ball, it is recorded that several alternate methods of low-grade heat to decrease the generation time down to as low as an hour are obtained. However, when only using the sun, the following generation time is possible [5].

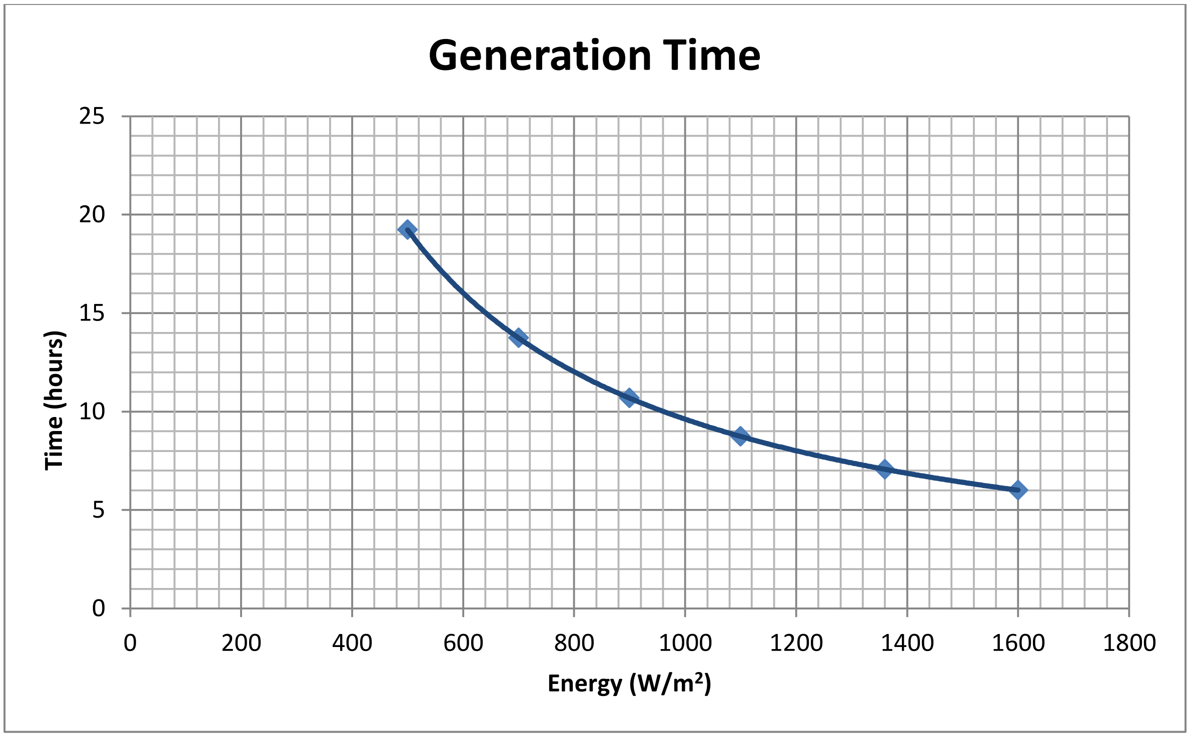


Figure 1.5: Generation time of SAAR (Energy vs. Time)

Adsorption/Generator Container

The Adsorption/Generator is a closed container pressure vessel that houses the calcium chloride ammonia (adsorbent/refrigerant) working pair, and is designed to hold gases/liquids at a pressure substantially greater than ambient pressure. The pressure vessel will be made of steel, manufactured into a cylindrical vessel and project team will attempt to follow pressure vessel design codes and application standards (ASME BPVC Section II, EN 13445-2 etc.).

The Adsorption/Generator container will also be hydrostatically pressure tested prior to use to insure vessel integrity will withstand the tensile forces due to gas pressure within the walls of the container. The normal (tensile) stress in the walls of the container is proportional to the pressure and radius of the vessel and inversely proportional to the thickness of the walls. Therefore the Adsorption/ Generator container will have a designed thickness proportional to the radius of tank and the pressure of the tank and inversely proportional to the maximum allowed normal stress of the particular material used in the walls of the container. In addition to adequate vessel strength, noncorrosive high impact valves will be used because calcium chloride and ammonia are an adsorption working pair process, perforated cylindrical tubes within the container will be used to minimize adsorption stratification. The perforated cylindrical tubes will allow for a maximum avenue for the vapor/gas to flow out of the container vessel into the evaporator cylinder. As the cycle reverses in the regeneration phase, again the perforated cylindrical tubes will provide a greater exposure avenue for the ammonia vapor to rebind with the calcium chloride.

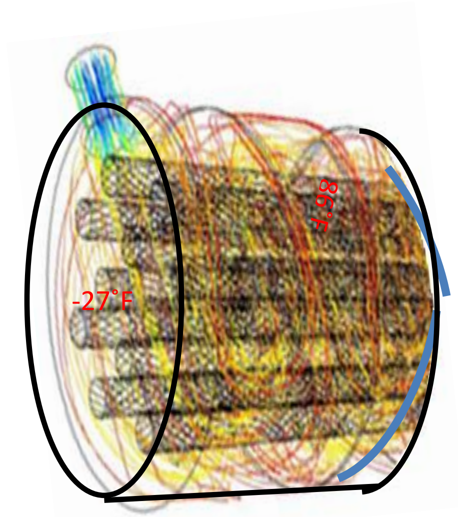


Figure 1.6: CaCl2 generator with diffuser tubes

Adsorption/Generator Container Calculations

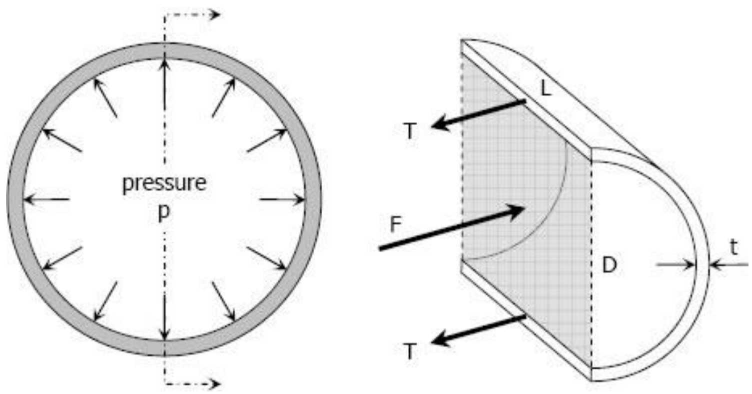
Pressure vessels, containers, or tanks can be analyzed by the use of shell theory because of their shell-like shape and symmetrical loading. To distinguish between thick and thin wall shells or cylinders, the relationship of the wall thickness (t) to the radius (r) must be considered:

- If 10t is <r, the thin wall theory applies.
- If 10t is >r, the thick wall theory applies.

In dealing with pressure vessels, only those vessels having internal pressure resulting in a tensile failure will be addressed. External pressure resulting in buckling failure is not covered here because it seldom occurs in practice. The equations are as follows:

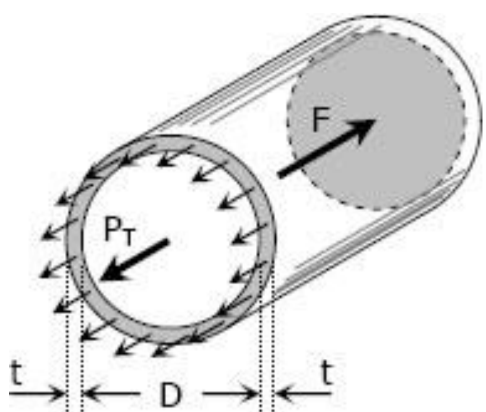
- For a sphere, the mass of a pressure vessel is $M = \frac{3}{2}PV\frac{\rho}{\sigma}$
- *M* is mass,
- *P* is the pressure difference from ambient (the gauge pressure),
- *V* is volume,
- ρ is the density of the pressure vessel material,
- σ is the maximum working stress that material can tolerate
- For a cylinder with hemispherical ends $M = 2\pi R^2(R+W)P\frac{\rho}{\sigma}$
- *M* is mass,
- *P* is the pressure difference from ambient (the gauge pressure),
- R is the radius
- W is the middle cylinder width only, and the overall width is W + 2R

- The forces acting are the total pressures caused by the internal pressure **P** and the total tension in the walls **T**.



  - $F = pA = pDL$
  - $T = \sigma_t A_{wall} = \sigma_t tL$
  - $\Sigma F_H = 0$
  - $F = 2T$
  - $pDL = 2(\sigma_t tL)$
  - $\sigma_t = \frac{pD}{2t}$

LONGITUDINAL STRESS, σL the free body diagram in the transverse section of the tank:



- The total force acting at the rear of the tank **F** must equal to the total longitudinal stress on the wall
- $P_T = \sigma_L A_{wall}$ Since **t** is so small compared to **D**, the area of the wall is close to πDt
- $F = pA + P\frac{\pi}{4}D2$
- $P_T = \sigma_L \pi Dt$
- $\Sigma FH = 0$
- $P_T = F$

- $\sigma_L \pi Dt = P \frac{\pi}{4} D2$
- $P_T = \sigma_L A_{wall}$
- $\sigma_t = \frac{pD}{4t}$
- $\sigma_t = 2\sigma_L$ (the tangential stress is twice that of the longitudinal stress)

Solar Adsorption/Generator Interaction

Scheffler reflective heating

- Alignment with the sun optimizes heat generation
- Reflective focal point concentrated on adsorbent/generator
- Requires solar tracking manual or automated

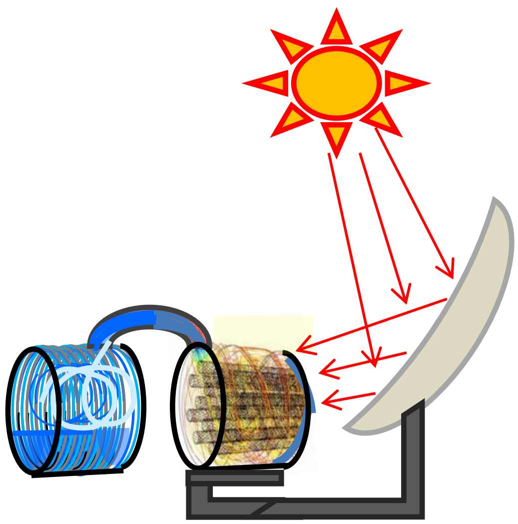


Figure 1.7: Scheffler reflector heating SAAR

Fresnel Solar concentrator

- Alignment with the sun optimizes heat generation
- Focal point concentrated on adsorbent/generator
- Requires solar tracking manual or automated

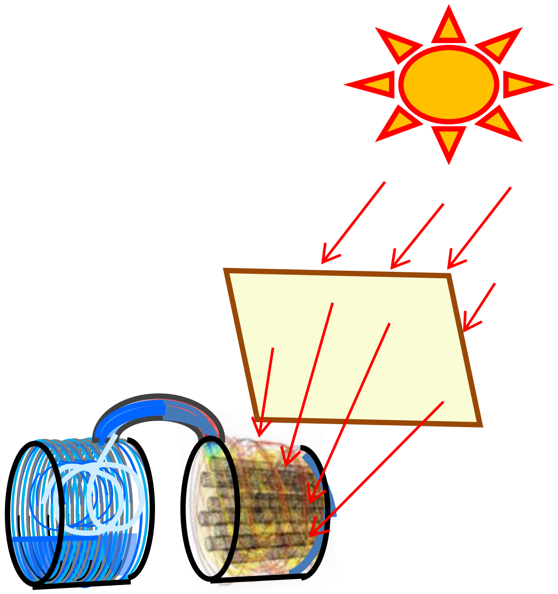


Figure 1.8: Fresnel Solar lens heating SARR

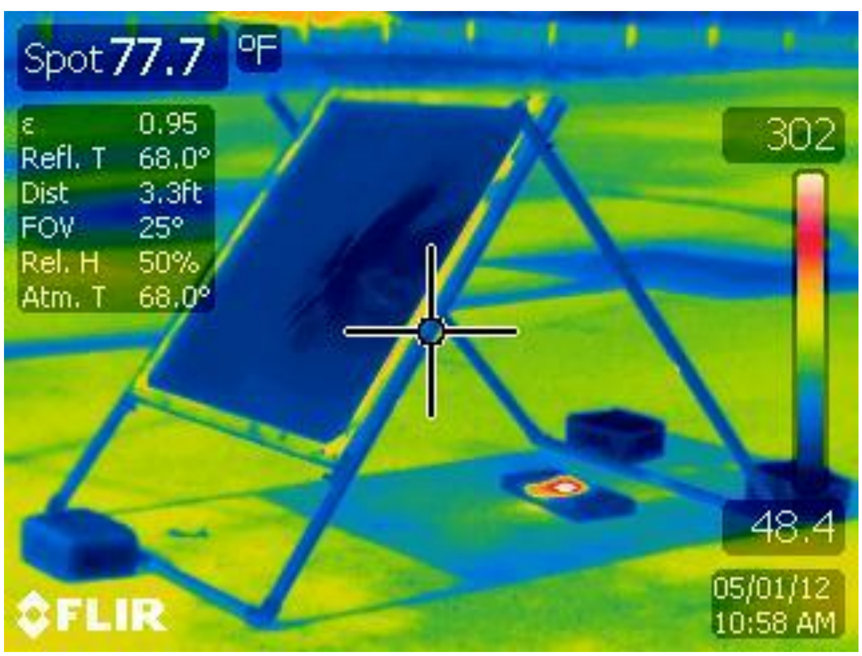


Figure 1.9: Thermal image of md60 fresnel lens with sun's focal heating brick

Alternative Heating

- Refrigeration process even on cloudy, rainy days
- Fossil Fuels (gasoline, diesel, kerosene, propane)
- Wood

Figure 1.10: Alternative heating of SAAR using a campfire

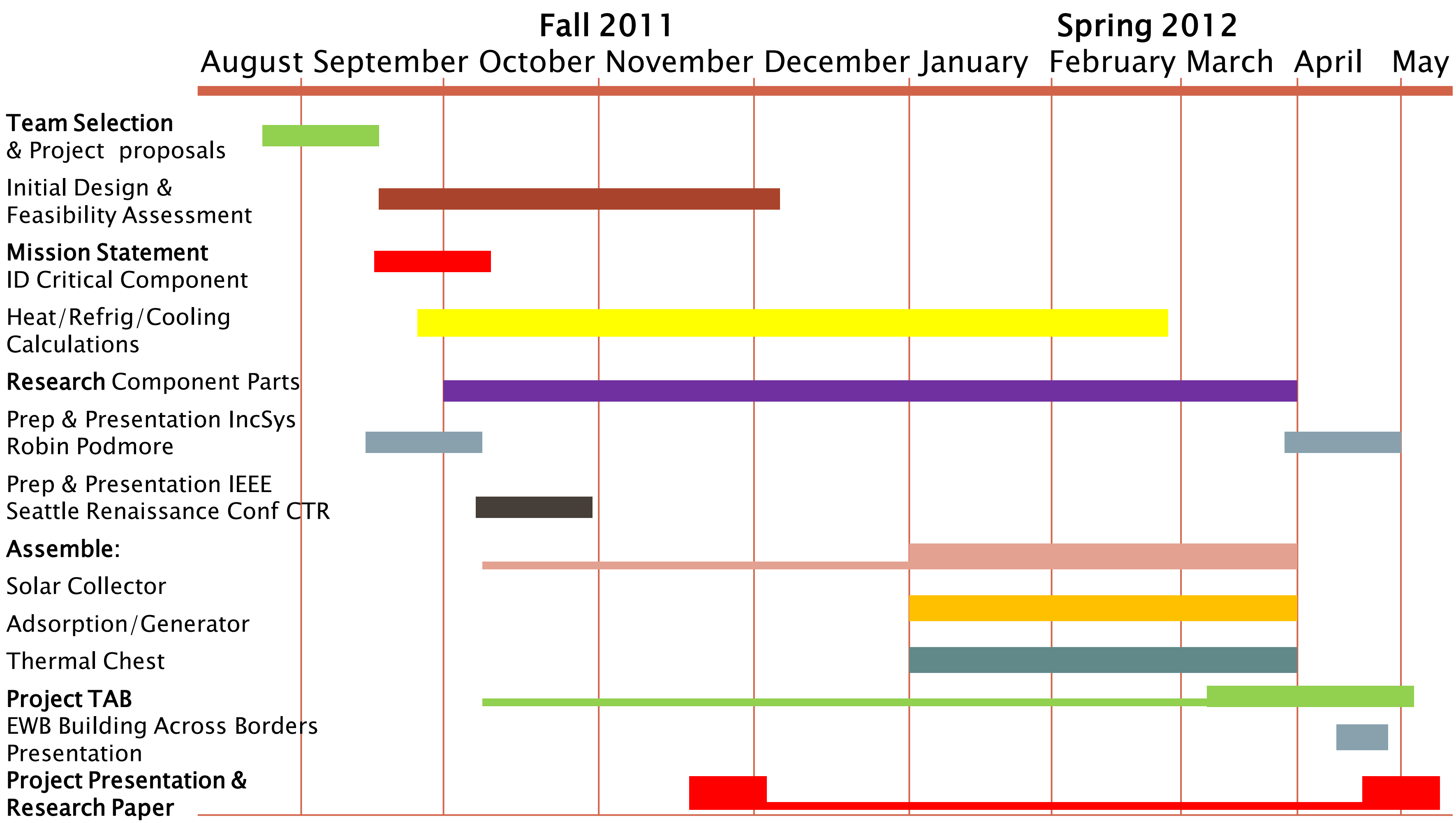
Natural Ambient Cool of Night

- Regeneration
- Liquid refrigerant evaporates to rebind with absorbent
- Evaporator continues to absorb heat until all refrigerant is depleted

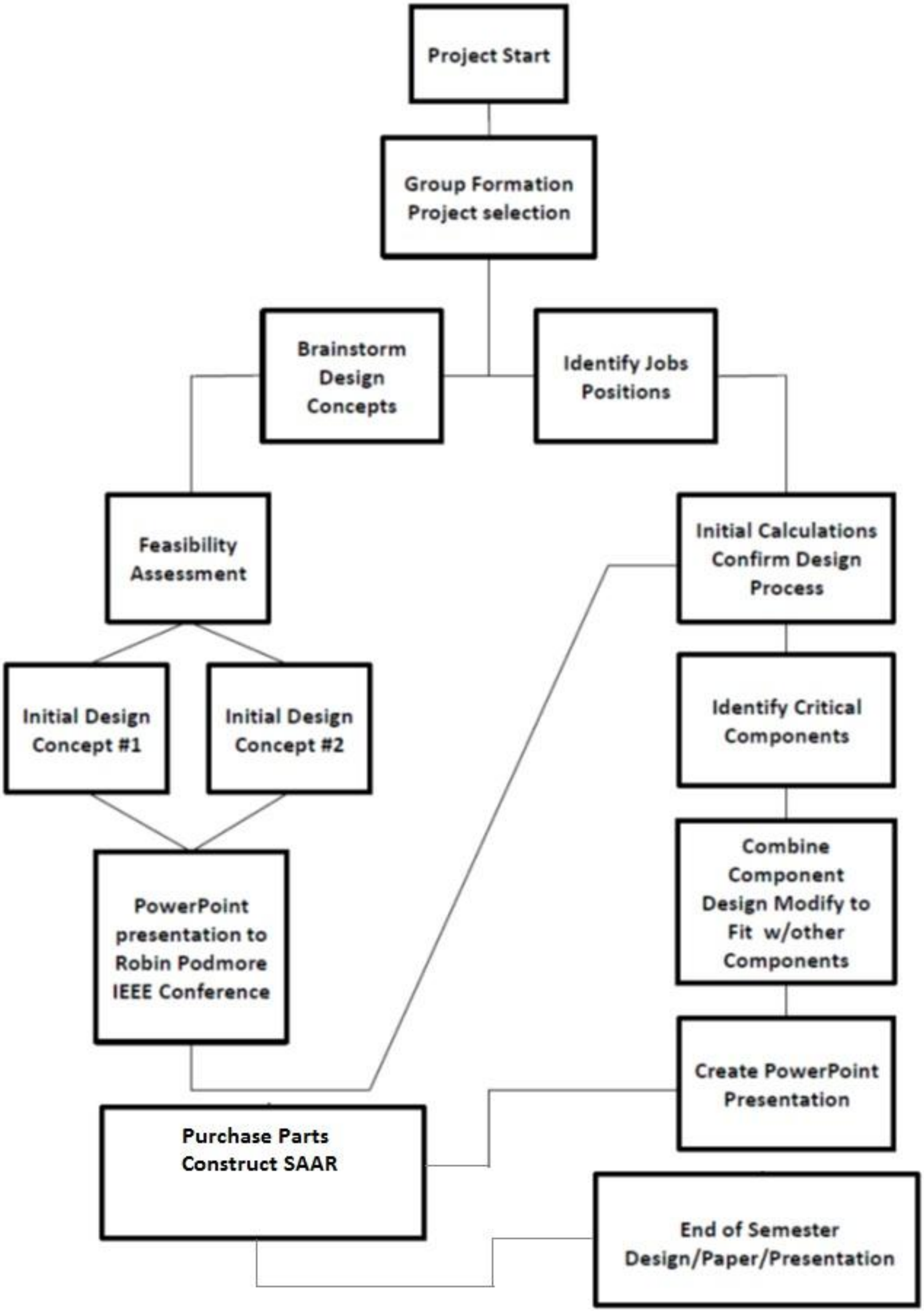
Material Cost Table

Part	Manufacturer	Description	Quantity	Price per Unit	Tax	Our Cost+Tax
Fresnel Lens	Green Power Science	Md60 42" Focal Length	1	$134.96	$21.59	Donation (no cost)
Parabolic Reflector	Self-Constructed	24" Satellite Dish with Mylar Reflector	1	Donated	N/A	Donation (no Cost)
r717	The Linde Group	R717	18	$1/lb	$5.73	$23.73
Ammonia	Ace Hardware	Janitorial Strength Ammonia, 10% ammonium hydroxide	2	$5.99	$0.99	$11.98
Calcium Chloride	Ace Hardware	Pool Calcium Plus HTH	1	$9.49	$0.79	$9.49
Calcium Chloride	WillPowder	WillPowder16-Ounce Jar	1	$15.08	N/A	$15.08
Generator and Evaporator	N/A (used from junk yard)	Semi-Truck air tank	1	Donated	N/A	Donation (no cost)
Crimp Fittings	Industrial Hydraulics Inc.	10643-8-8 Crimp Fitting	2	$8.41	$1.40	$16.82
Crimped Hose End	Industrial Hydraulics Inc.	Crimped hose end on hose assembly	2	$3.50	$0.58	$7.00
Male Pipe Elbow	Industrial Hydraulics Inc.	½ CR-S Male Pipe Elbow	1	$7.07	$0.59	$7.07
Hex Head Plug	Industrial Hydraulics Inc.	½ HP-S Hex Head Plug	3	$1.22	$0.30	$3.66
Hex Head Plug	Industrial Hydraulics Inc.	3/8 HP-S Hex Head Plug	1	$0.80	$0.07	$0.80
Pipe Connector	Industrial Hydraulics Inc.	¼ GG-S Pipe Connector	1	$2.16	$0.18	$2.16
Male Connector	Industrial Hydraulics Inc.	8-8 FTX-S Male Connector	1	$2.55	$0.21	$2.55
Male Elbow	Industrial Hydraulics Inc.	8-8 CTX-S Male Elbow	1	$7.71	$0.64	$7.71
Hydraulic Hose	Industrial Hydraulics Inc.	801-8-BLK Jiffy Hose Push-On, ½"	1	$1.84	$0.15	$1.84
Flow Control Valve	Industrial Hydraulics Inc.	F800S 3/8"	1	$55.54	$4.44	$59.98
Pressure Relief Valve	Capital Industrial Inc.	165 PSI Pressure Relief Valve	1	$11.39	$0.99	$11.39
Plastic model	Self-Constructed	Polyvinyl chloride Piping with Metal cage and Pressure Gauge	1	$19.57	N/A	$19.57
Ammonia CaCl2 Experiment	Self-Constructed	Constructed of Galvanized Steel piping purchased at Lowes	1	$46.68	$4.06	$50.74
					Total Cost	**$251.57**

Timeline



Fall 2011
Spring 2012
August September October November December January February March April May
Team Selection
& Project proposals
Initial Design &
Feasibility Assessment
Mission Statement
ID Critical Component
Heat/Refrig/Cooling
Calculations
Research Component Parts
Prep & Presentation IncSys
Robin Podmore
Prep & Presentation IEEE
Seattle Renaissance Conf CTR
Assemble:
Solar Collector
Adsorption/Generator
Thermal Chest
Project TAB
EWB Building Across Borders
Presentation
Project Presentation &
Research Paper


Project Start
Group Formation
Project selection
Brainstorm
Design
Concepts
Identify Jobs
Positions
Feasibility
Assessment
Initial Calculations
Confirm Design
Process
Initial Design
Concept #1
Initial Design
Concept #2
Identify Critical
Components
Combine
Component
Design Modify to
Fit w/other
Components
PowerPoint
presentation to
Robin Podmore
IEEE Conference
Create PowerPoint
Presentation
Purchase Parts
Construct SAAR
End of Semester
Design/Paper/Presentation

SAAR Team Activity

Jacob Buehn

- Project Manager:

  In charge of supervising team activity and keeping project on track to be completed in a timely manner, and also in charge of finalizing design decisions of SAAR and overseeing of testing and construction.

- Thermal and Systems Calculation:

  Primary concentration of producing accurate thermodynamic and heat transfer calculations directly related to SAAR, as well as calculating generation time of refrigerator and amount of calcium chloride and R717 needed to produce the amount of energy required to create a capable refrigeration process.

Adam Hudspeth

- Project Scheduler:

  In charge of scheduling weekly team meetings and scheduling presentations (IEEE conference and EWB Building Across Borders), and also keeping a written record of team activity of design, presentation, and construction of SAAR.

- Finance Manager:

  In charge of keeping financial records of funds as well as time spent with professional engineers and time put into construction. Also in charge of formulating strategic and long-term financial plans and managing the budget to make sure overspending does not occur.

- Component Research and Procurement:

  In charge of finding viable components that will not only be usable for the SAAR, but also will fit into the budget of the project, as well as completing market research for components that are already implemented in the world today.

Gary Villanueva

- Design & Research Manager:

  Main overseer of SAAR design and research also coordinated research of components chosen specifically for the project. In charge of keeping written records of old design concepts and newly updated drafts. Very important for keeping team on track with not only the newest advancements in technology but in keeping the scopes of the project in reach for the resources available.

- Technical Liaison to:

  Yauheni Martynau (SAAR process calculation assistance)

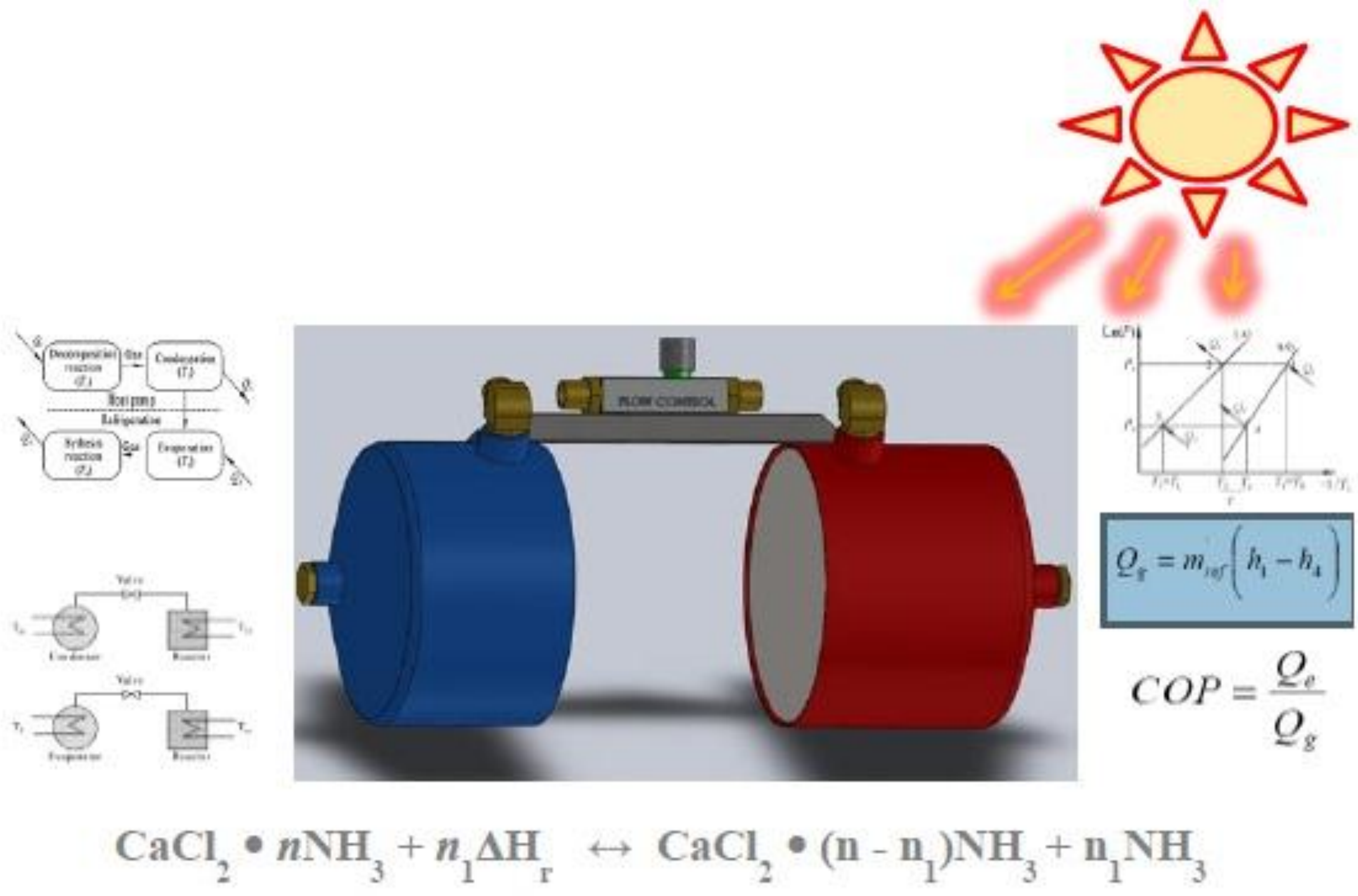
  Robin Podmore of IncSys (SAAR project initiator)

  Alfred Villanueva of DPW Pt. Mugu NAS CA (refrigeration process expertise)

  Will Howson of Bremerton AC & Mechanical (refrigeration process expertise)

SAAR Conclusion

- The SAAR is a nonproprietary concept design for use in developing countries where many do not have adequate access to electrical power.
- The SAAR is an intermittent two-step process of solar charging and evaporative cooling.
- The SAAR will primarily charge utilizing the sun or other low-grade heat sources to drive the Ammonia Absorption Refrigeration Cycle refrigeration cycle.
- The SAAR is a small scale, sustainable solar refrigerator system that can operate in tempered regions of the world and be duplicated using common materials found in developing communities



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Appendix 1: Ammonia R717 Table

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Ammonia R717

Temperature (°C)	Pressure (bar)	Liquid Density (kg/m³)	Vapor Density (kg/m³)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)
-70	0.10941	724.72	0.11101	32.343	1498.7	0.1622	7.3803
-69	0.11768	723.63	0.11886	36.591	1500.6	0.18306	7.3541
-68	0.12647	722.53	0.12715	40.846	1502.4	0.20384	7.3281
-67	0.13581	721.43	0.13593	45.106	1504.2	0.22455	7.3025
-66	0.14572	720.33	0.1452	49.372	1506.1	0.24519	7.2772
-65	0.15624	719.22	0.15499	53.645	1507.9	0.26576	7.2522
-64	0.16739	718.11	0.16532	57.922	1509.7	0.28625	7.2276
-63	0.17921	716.99	0.17621	62.206	1511.5	0.30668	7.2032
-62	0.19171	715.87	0.18769	66.496	1513.3	0.32703	7.1791
-61	0.20495	714.75	0.19978	70.792	1515.1	0.34732	7.1553
-60	0.21893	713.62	0.21251	75.093	1516.9	0.36754	7.1318
-59	0.23371	712.48	0.22589	79.4	1518.7	0.38769	7.1085
-58	0.24932	711.35	0.23997	83.714	1520.4	0.40778	7.0856
-57	0.26579	710.2	0.25475	88.033	1522.2	0.42779	7.0629
-56	0.28315	709.06	0.27028	92.357	1524	0.44774	7.0405
-55	0.30145	707.9	0.28657	96.688	1525.7	0.46763	7.0183
-54	0.32072	706.75	0.30366	101.02	1527.5	0.48745	6.9964
-53	0.34101	705.59	0.32157	105.37	1529.2	0.5072	6.9747
-52	0.36235	704.43	0.34034	109.71	1530.9	0.5269	6.9533
-51	0.38479	703.26	0.35999	114.07	1532.6	0.54652	6.9321
-50	0.40836	702.09	0.38055	118.43	1534.3	0.56609	6.9112
-49	0.43312	700.91	0.40207	122.79	1536	0.58559	6.8905
-48	0.45911	699.73	0.42456	127.16	1537.7	0.60503	6.87
-47	0.48637	698.55	0.44806	131.54	1539.4	0.6244	6.8498
-46	0.51495	697.36	0.47261	135.92	1541.1	0.64371	6.8298
-45	0.54489	696.17	0.49824	140.31	1542.7	0.66297	6.81
-44	0.57626	694.97	0.52498	144.7	1544.4	0.68216	6.7904
-43	0.60909	693.77	0.55287	149.1	1546	0.70129	6.771
-42	0.64345	692.57	0.58194	153.5	1547.7	0.72036	6.7518
-41	0.67937	691.36	0.61224	157.91	1549.3	0.73937	6.7329
-40	0.71692	690.15	0.6438	162.32	1550.9	0.75832	6.7141
-39	0.75615	688.94	0.67665	166.74	1552.5	0.77721	6.6955
-38	0.79711	687.72	0.71085	171.17	1554.1	0.79604	6.6772
-37	0.83986	686.49	0.74641	175.6	1555.7	0.81482	6.659
-36	0.88447	685.27	0.7834	180.03	1557.3	0.83353	6.641
-35	0.93098	684.04	0.82184	184.48	1558.8	0.85219	6.6232
-34	0.97946	682.8	0.86178	188.92	1560.4	0.87079	6.6055
-33	1.03	681.57	0.90326	193.37	1561.9	0.88933	6.588
-32	1.0826	680.32	0.94633	197.83	1563.4	0.90782	6.5708
-31	1.1373	679.08	0.99102	202.29	1565	0.92625	6.5536
-30	1.1943	677.83	1.0374	206.76	1566.5	0.94462	6.5367
-29	1.2535	676.58	1.0855	211.23	1568	0.96294	6.5199
-28	1.3151	675.32	1.1353	215.71	1569.4	0.9812	6.5033
-27	1.3792	674.06	1.187	220.19	1570.9	0.99941	6.4868
-26	1.4457	672.8	1.2405	224.68	1572.4	1.0176	6.4705
-25	1.5147	671.53	1.2959	229.17	1573.8	1.0357	6.4543
-24	1.5864	670.26	1.3533	233.66	1575.2	1.0537	6.4383
-23	1.6608	668.98	1.4126	238.17	1576.7	1.0717	6.4224
-22	1.7379	667.71	1.474	242.67	1578.1	1.0896	6.4067
-21	1.8179	666.42	1.5376	247.19	1579.5	1.1075	6.3911
-20	1.9008	665.14	1.6033	251.71	1580.8	1.1253	6.3757

Appendix 1: Ammonia R717 Table

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Ammonia R717

Temperature (°C)	Pressure (bar)	Liquid Density (kg/m³)	Vapor Density (kg/m³)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)
-19	1.9867	663.85	1.6711	256.23	1582.2	1.1431	6.3604
-18	2.0756	662.55	1.7413	260.76	1583.5	1.1609	6.3452
-17	2.1677	661.25	1.8138	265.29	1584.9	1.1785	6.3302
-16	2.263	659.95	1.8886	269.83	1586.2	1.1962	6.3153
-15	2.3617	658.65	1.9659	274.37	1587.5	1.2137	6.3005
-14	2.4637	657.34	2.0456	278.92	1588.8	1.2313	6.2859
-13	2.5691	656.02	2.1279	283.47	1590.1	1.2487	6.2713
-12	2.6782	654.7	2.2128	288.03	1591.4	1.2662	6.2569
-11	2.7908	653.38	2.3003	292.6	1592.6	1.2835	6.2426
-10	2.9071	652.06	2.3906	297.16	1593.9	1.3009	6.2285
-9	3.0273	650.73	2.4837	301.74	1595.1	1.3181	6.2144
-8	3.1513	649.39	2.5795	306.32	1596.3	1.3354	6.2004
-7	3.2793	648.06	2.6783	310.9	1597.5	1.3526	6.1866
-6	3.4114	646.71	2.7801	315.49	1598.7	1.3697	6.1729
-5	3.5476	645.37	2.8849	320.09	1599.8	1.3868	6.1592
-4	3.688	644.02	2.9928	324.69	1601	1.4038	6.1457
-3	3.8327	642.66	3.1038	329.3	1602.1	1.4209	6.1323
-2	3.9819	641.3	3.2181	333.91	1603.2	1.4378	6.119
-1	4.1356	639.94	3.3357	338.53	1604.3	1.4547	6.1058
0	4.2938	638.57	3.4567	343.15	1605.4	1.4716	6.0926
1	4.4568	637.2	3.5811	347.78	1606.5	1.4884	6.0796
2	4.6246	635.82	3.709	352.42	1607.5	1.5052	6.0667
3	4.7972	634.44	3.8405	357.06	1608.5	1.5219	6.0538
4	4.9748	633.06	3.9757	361.71	1609.6	1.5386	6.041
5	5.1575	631.66	4.1146	366.36	1610.5	1.5553	6.0284
6	5.3453	630.27	4.2573	371.02	1611.5	1.5719	6.0158
7	5.5385	628.87	4.4039	375.69	1612.5	1.5885	6.0033
8	5.737	627.46	4.5545	380.36	1613.4	1.605	5.9908
9	5.9409	626.05	4.7092	385.04	1614.4	1.6215	5.9785
10	6.1505	624.64	4.8679	389.72	1615.3	1.638	5.9662
11	6.3657	623.22	5.0309	394.41	1616.2	1.6544	5.954
12	6.5866	621.79	5.1983	399.11	1617	1.6708	5.9419
13	6.8135	620.36	5.37	403.81	1617.9	1.6871	5.9299
14	7.0463	618.93	5.5461	408.52	1618.7	1.7034	5.9179
15	7.2852	617.49	5.7269	413.24	1619.5	1.7197	5.906
16	7.5303	616.04	5.9123	417.97	1620.3	1.7359	5.8941
17	7.7817	614.59	6.1025	422.7	1621.1	1.7521	5.8824
18	8.0395	613.13	6.2975	427.44	1621.9	1.7682	5.8707
19	8.3038	611.67	6.4975	432.18	1622.6	1.7844	5.859
20	8.5748	610.2	6.7025	436.94	1623.3	1.8005	5.8475
21	8.8524	608.72	6.9127	441.7	1624	1.8165	5.8359
22	9.1369	607.24	7.1281	446.47	1624.7	1.8326	5.8245
23	9.4283	605.76	7.3488	451.24	1625.3	1.8485	5.8131
24	9.7268	604.26	7.5751	456.03	1626	1.8645	5.8017
25	10.032	602.76	7.8069	460.82	1626.6	1.8804	5.7904
26	10.345	601.26	8.0443	465.62	1627.2	1.8963	5.7792
27	10.666	599.75	8.2876	470.43	1627.7	1.9122	5.768
28	10.993	598.23	8.5368	475.25	1628.3	1.9281	5.7569
29	11.329	596.7	8.792	480.08	1628.8	1.9439	5.7458
30	11.672	595.17	9.0533	484.91	1629.3	1.9597	5.7347
31	12.023	593.63	9.3209	489.76	1629.8	1.9754	5.7237

Appendix 1: Ammonia R717 Table

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Ammonia R717

Temperature (°C)	Pressure (bar)	Liquid Density (kg/m³)	Vapor Density (kg/m³)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)
32	12.382	592.08	9.595	494.61	1630.3	1.9911	5.7128
33	12.749	590.53	9.8755	499.47	1630.7	2.0069	5.7019
34	13.124	588.97	10.163	504.34	1631.1	2.0225	5.691
35	13.508	587.4	10.457	509.23	1631.5	2.0382	5.6801
36	13.9	585.82	10.758	514.12	1631.9	2.0538	5.6693
37	14.3	584.24	11.066	519.02	1632.2	2.0694	5.6586
38	14.709	582.65	11.381	523.93	1632.5	2.085	5.6479
39	15.127	581.05	11.703	528.86	1632.8	2.1006	5.6372
40	15.554	579.44	12.034	533.79	1633.1	2.1161	5.6265
41	15.99	577.82	12.371	538.74	1633.3	2.1317	5.6159
42	16.435	576.2	12.717	543.69	1633.5	2.1472	5.6053
43	16.89	574.56	13.071	548.66	1633.7	2.1627	5.5947
44	17.353	572.92	13.432	553.64	1633.9	2.1781	5.5841
45	17.827	571.27	13.803	558.63	1634	2.1936	5.5736
46	18.31	569.61	14.181	563.63	1634.1	2.209	5.5631
47	18.802	567.94	14.569	568.65	1634.2	2.2244	5.5526
48	19.305	566.25	14.965	573.68	1634.2	2.2398	5.5422
49	19.818	564.56	15.371	578.72	1634.2	2.2552	5.5317
50	20.34	562.86	15.785	583.77	1634.2	2.2706	5.5213
51	20.873	561.15	16.209	588.84	1634.2	2.286	5.5109
52	21.417	559.43	16.643	593.92	1634.1	2.3013	5.5005
53	21.971	557.7	17.087	599.02	1634	2.3167	5.4901
54	22.536	555.95	17.541	604.13	1633.9	2.332	5.4797
55	23.111	554.2	18.006	609.26	1633.7	2.3473	5.4693
56	23.698	552.43	18.481	614.4	1633.5	2.3627	5.4589
57	24.295	550.65	18.967	619.56	1633.3	2.378	5.4486
58	24.904	548.86	19.464	624.73	1633	2.3933	5.4382
59	25.524	547.06	19.973	629.92	1632.7	2.4086	5.4278
60	26.156	545.24	20.493	635.12	1632.4	2.4239	5.4174
61	26.799	543.41	21.025	640.35	1632.1	2.4392	5.4071
62	27.454	541.57	21.57	645.59	1631.7	2.4545	5.3967
63	28.121	539.72	22.127	650.84	1631.2	2.4698	5.3863
64	28.8	537.85	22.697	656.12	1630.8	2.4851	5.3759
65	29.491	535.96	23.28	661.42	1630.2	2.5004	5.3655
66	30.195	534.06	23.877	666.73	1629.7	2.5157	5.355
67	30.911	532.15	24.488	672.07	1629.1	2.531	5.3446
68	31.639	530.22	25.113	677.42	1628.5	2.5463	5.3341
69	32.381	528.27	25.753	682.8	1627.8	2.5617	5.3236
70	33.135	526.31	26.407	688.2	1627.1	2.577	5.3131
71	33.902	524.33	27.078	693.62	1626.3	2.5923	5.3026
72	34.682	522.33	27.764	699.06	1625.5	2.6077	5.292
73	35.476	520.32	28.467	704.53	1624.7	2.6231	5.2814
74	36.284	518.28	29.186	710.02	1623.8	2.6385	5.2707
75	37.105	516.23	29.923	715.53	1622.9	2.6539	5.2601
76	37.939	514.16	30.678	721.07	1621.9	2.6693	5.2493
77	38.788	512.07	31.451	726.64	1620.9	2.6847	5.2386
78	39.651	509.96	32.244	732.23	1619.8	2.7002	5.2278
79	40.528	507.83	33.056	737.85	1618.6	2.7157	5.2169
80	41.42	505.67	33.888	743.5	1617.5	2.7312	5.206
81	42.326	503.49	34.741	749.18	1616.2	2.7468	5.195
82	43.247	501.29	35.615	754.88	1614.9	2.7623	5.184

Appendix 1: Ammonia R717 Table

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Ammonia R717

Temperature (°C)	Pressure (bar)	Liquid Density (kg/m^3)	Vapor Density (kg/m^3)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)
83	44.183	499.07	36.512	760.62	1613.6	2.778	5.1729
84	45.134	496.82	37.432	766.39	1612.2	2.7936	5.1617
85	46.1	494.54	38.376	772.2	1610.7	2.8093	5.1504
86	47.082	492.24	39.344	778.04	1609.1	2.825	5.1391
87	48.079	489.91	40.338	783.91	1607.5	2.8408	5.1277
88	49.093	487.56	41.359	789.82	1605.9	2.8566	5.1162
89	50.122	485.17	42.407	795.77	1604.1	2.8725	5.1046
90	51.167	482.75	43.484	801.76	1602.3	2.8884	5.0929
91	52.229	480.31	44.59	807.79	1600.5	2.9043	5.0811
92	53.307	477.82	45.728	813.86	1598.5	2.9204	5.0692
93	54.402	475.31	46.898	819.97	1596.5	2.9365	5.0572
94	55.514	472.76	48.101	826.13	1594.4	2.9526	5.045
95	56.643	470.17	49.34	832.34	1592.2	2.9689	5.0327
96	57.79	467.55	50.615	838.6	1589.9	2.9852	5.0203
97	58.954	464.88	51.928	844.91	1587.5	3.0016	5.0078
98	60.135	462.18	53.282	851.27	1585	3.018	4.995
99	61.335	459.43	54.677	857.68	1582.5	3.0346	4.9821
100	62.553	456.63	56.117	864.16	1579.8	3.0513	4.9691
101	63.789	453.79	57.603	870.69	1577	3.068	4.9558
102	65.044	450.9	59.138	877.29	1574.1	3.0849	4.9424
103	66.318	447.95	60.724	883.96	1571.1	3.1019	4.9287
104	67.61	444.95	62.365	890.7	1568	3.119	4.9148
105	68.923	441.9	64.063	897.51	1564.7	3.1363	4.9007
106	70.255	438.78	65.822	904.4	1561.3	3.1537	4.8863
107	71.606	435.59	67.646	911.37	1557.8	3.1712	4.8716
108	72.978	432.34	69.539	918.43	1554.1	3.1889	4.8567
109	74.37	429.01	71.505	925.58	1550.2	3.2068	4.8414
110	75.783	425.61	73.55	932.84	1546.2	3.2249	4.8258
111	77.217	422.12	75.679	940.2	1542	3.2432	4.8099
112	78.673	418.54	77.899	947.68	1537.6	3.2618	4.7935
113	80.15	414.86	80.217	955.28	1533	3.2805	4.7768
114	81.649	411.08	82.642	963.01	1528.2	3.2996	4.7595
115	83.17	407.18	85.182	970.89	1523.1	3.319	4.7418
116	84.714	403.15	87.849	978.93	1517.8	3.3387	4.7235
117	86.281	398.99	90.654	987.15	1512.2	3.3588	4.7046
118	87.872	394.67	93.614	995.56	1506.3	3.3793	4.685
119	89.486	390.18	96.745	1004.2	1500	3.4003	4.6647
120	91.125	385.49	100.07	1013.1	1493.4	3.4218	4.6435
121	92.789	380.57	103.61	1022.2	1486.3	3.444	4.6214
122	94.478	375.4	107.4	1031.7	1478.7	3.4669	4.5982
123	96.192	369.93	111.48	1041.6	1470.6	3.4907	4.5737
124	97.934	364.08	115.9	1051.9	1461.8	3.5156	4.5477
125	99.702	357.8	120.73	1062.8	1452.3	3.5417	4.5199
126	101.5	350.95	126.06	1074.4	1441.8	3.5696	4.4899
127	103.32	343.37	132.03	1087	1430.1	3.5996	4.457
128	105.18	334.79	138.85	1100.8	1416.8	3.6327	4.4205
129	107.06	324.74	146.87	1116.4	1401.3	3.6702	4.3787
130	108.98	312.29	156.77	1135.2	1382.5	3.7153	4.3287