PORTABLE REFRIGERATOR

A final year project report

Presented to

SCHOOL OF MECHANICAL AND MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment

of the Requirements for the Degree of

Bachelors of Mechanical Engineering

By

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(June 2017)

EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by: Faiq Munir – 05821, Humayun Asif – 06159 and Tayyab Ijaz – 05825. Titled: "Portable Refrigerator" be accepted in partial fulfillment of the requirements for the award of BE Mechanical Engineering degree.

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ABSTRACT

Design and fabrication of portable and chargeable refrigerator based on absorption refrigeration cycle containing ammonia water mixture as working fluid. We developed a new schematics of absorption refrigeration according to the need of our project. Our refrigerator contains two chambers connected with a solenoid valve that is controlled with a temperature sensor. In the charging cycle chamber **A** that contains ammonia water mixture will be heated. This will allow ammonia vapors to leave the mixture and go into chamber **B** where they will be condensed into liquid due to high pressure. After charging, valve will be closed and the whole system is allowed to cool. During cooling phase valve opens when the temperature of chamber **B** reaches above 3°C, this will allow ammonia to evaporate which will cause cooling effect. While the ammonia vapors will go to chamber **A** and dissolve in water. We made the whole system out of Stainless steel to avoid corrosion due to ammonia. Stress analysis and flow simulations were conducted on ANSYS. We have calculated vapor fractions by running simulations on ASPEN HYSYS. Our refrigerator will generate cooling equivalent to 288 kJ per charge, which will last for about 20hrs.

PREFACE

Most vaccines require 2-8°C temperature to maintain potency. Studies conducted by Path (Non-Profit Organization) found that 77% of countries don't achieve WHO 80% targets. Great advances have been made in temperature control as far as medical centers but last mile systems are ad hoc and unreliable. What is needed is a portable device that can maintain 2-8°C reliably. We have developed a mobile refrigerator that can be carried like a bag on shoulders. It is designed to provide cooling for 24 hours and require 1 hour for charging. Charging does not require electricity but can be done by any heat source. It is a completely innovative project and the schematics of this refrigeration cycle is solely developed by ourselves. The device uses Ammonia-Water absorption refrigeration to provide a controlled cooling effect in a portable container. Ammonia-Water evaporative cooling effect is one of the strongest known long term chemical cooling processes in nature. It requires no mechanically moving parts and can be renewably regenerated for reuse over the course of decades without degradation or loss of performance.

ACKNOWLEDGEMENT

In this project everyone we have come across was extremely helping and encouraging. In particular we really want to thank Dr. Sarah Farrukh from SCME, for her exceptional cooperation and support. She has helped us at every single step of our project. Without her guidance and constructive criticism we were never have been able to complete this project. We are genuinely appreciative to her for sharing her honest and lighting up perspectives.

We would also like to express my special gratitude to Mr. Sohail (Lab Technician SCME) for helping us in carrying out high pressure leak test. He always go extra mile for us whenever we are in need of any help.

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We like to thank HOD SCME – Dr. Arshad Hussain for allowing us to use labs in SCME and for providing us the gasses we needed.

We'd like to thank Hafiz Abdur Rehman, for his constant support during this whole project.

We are also very thankful to the whole staff of MRC, who helped us during the fabrication of our project.

Our special thanks to LASANI TECHNO IMPEX, they helped us with the high pressure testing of our valves without any charges.

In the end a very special gratitude to our supervisor AP Jamal Saeed who has guided us at every single step. We are highly indebted for his constant supervision and for his support in completing the project. We have not only learnt the technical and theoretical aspects of the project under his supervision but also the way of handling pressure situation.

Faiq Munir

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ABBREVIATIONS

WHO	World Health Organization
PATH	Program for Appropriate Technology in Health
DS	Dilute Solution
CS	Concentrated solution
DAR	Diffusion absorption refrigeration
VCR	Vapor compression refrigeration
VAR	Vapor absorption refrigeration
ASME	American society of mechanical engineering
BPG	Bubble pump generator
COP	Coefficient of performance

NOMENCLATURE

R134a	1,1,1,2-tetrafluoroethane
ξ^L	Liquid phase mass fraction
ξ^V	Vapor phase mass fraction
H_{fg}	Enthalpy of vaporization
Q	Cooling load
h	Enthalpy
m_a	Mass of ammonia
m_w	Mass of water
m_s	Mass of solution
h_{va}	Enthalpy of vaporization of ammonia
h_{vs}	Enthalpy of vaporization of solution
E	Efficiency of appropriate joints in cylindrical or spherical shells
P	Pressure
R	Inside radius of the shell under consideration
S	Maximum allowable stress value
D	Inside diameter of the head skirt
D_0	Outside diameter of the head skirt
K	Conductivity of Styrofoam
T_1	Cooling temperature
T_2	Ambient temperature

CHAPTER 1

INTRODUCTION

Most Vaccine require 2-8°C Temperature to maintain potency. Studies conducted by PATH, an international non-profit organization, found that 77% of countries don't achieve WHO 80% targets.

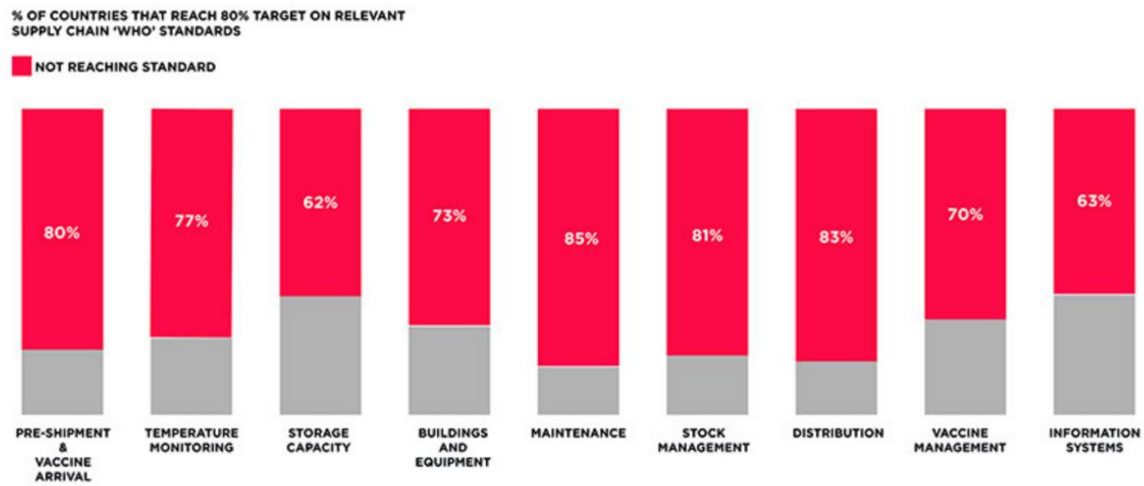


Figure 1. Analysis of WHO Targets

Great advances have been made in temperature control but they are limited to medical centers. When it comes to transportation of vaccines to remote areas, most of the systems are unreliable. Mostly dry ice with iceboxes are used which can cause two major issues

- If put at low temperatures, for long journeys, it can Freeze the vaccines as a result they will lose their potency.
- When transported to remote areas where electricity is not available. It becomes impossible to maintain the required temperature for its storage.

Motivation

Keeping in mind the difficulties that we are facing in transportation of vaccines, we concluded that a portable device is needed that can maintain 2-8°C reliably. So we decided to design and fabricate a portable and chargeable refrigeration unit. The unit will be capable of sustaining the desirable temperature and will be free of any active components. It won't need any electricity for the operation and can be charged just by using a small burner. Once fully charged the unit will operate for an approximate of 20 hrs. (Under optimum conditions).

Working Principle:

Our refrigeration unit consists of two chambers which are connected together with a pipe and a valve.

First (hot) chamber contains ammonia water mixture which is heated in the **first stage**. Ammonia evaporates and vapors will go into the other chamber through the pipe. Second (cold) Chamber is kept cool during this time in a water bath. Where ammonia vapors will condense. Then valve is closed and first chamber is left to cool at room temperature.

In **second stage** the valve is again opened and ammonia vapors will start to evaporate. Due to pressure difference vapors will travel to first chamber through the pipe where they will dissolve into the water. As a result the second chamber will generate cooling effect, which will be placed in the insulation box.

Organization of the Report:

Our report is divided into four main chapters. In this chapter an overview about our project and our motivation for doing this project is explained. The working mechanism of our refrigerator is also explained briefly in this chapter.

In second chapter literature review and background information of the process is given. Moreover the background information about the designs are also explained from materials point of view.

Third chapter gives the detailed explanation of the processes, materials and chemicals used in our product and their calculations. Calculation and analysis are divided into two sections. First contains calculations and analysis of Heat and mass transfer and second part contains analysis from mechanics point of view.

Fourth chapter consists of results obtained after doing all the calculations and analysis. It further contains conclusion and recommendations of our project.

CHAPTER 2

LITERATURE REVIEW:

Vapor Compression Refrigeration System (VCR)

The purpose of refrigeration is to remove heat from one area and transfer it to another location. A typical vapor compression cycle consists of a compressor, condenser, expansion valve and an evaporator. It works by absorbing heat from the evaporator at low pressure and then exits at high temperature, then it further exchanges heat with a warn environment and condenses to vapor with is then passed from expansion valve to decrease its temperature. The most common use of this cycle is for cooling purpose in household refrigerators and freezers. Most common used refrigerant in this cycle are Ferron 22 (R22) or R134.

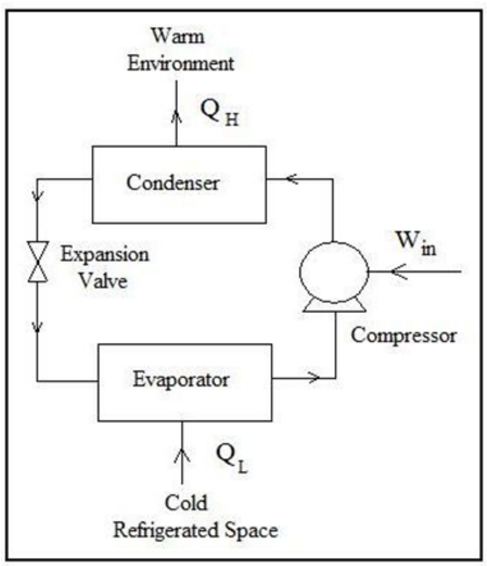


Figure 2. Schematic of VCR

Vapor Absorption Refrigeration System (VAR)

Vapor Absorption Refrigeration Systems (VARS) belong to the class of vapor cycles similar to vapor compression refrigeration systems. However, unlike vapor compression refrigeration systems, the required input to absorption systems is in the form of heat. Hence these systems are also called as heat operated or thermal energy driven systems. Since conventional absorption systems use liquids for absorption of refrigerant, these are also sometimes called as wet absorption systems. Similar to vapor compression refrigeration systems, vapor absorption refrigeration systems have also been commercialized and are widely used in various refrigeration and air conditioning applications. Since these systems run on low-grade thermal energy, they are preferred when low-grade energy such as waste heat or solar energy is available.

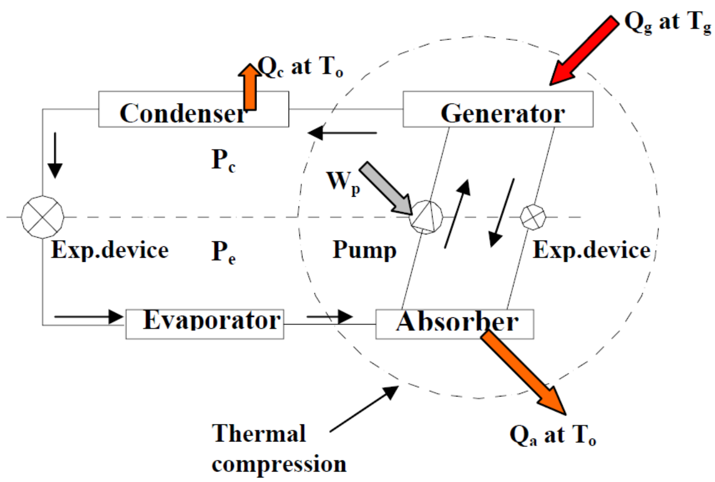


Figure 3. Schematic of VAR

Diffusion Absorption Refrigeration System (DAR)

This refrigeration system is totally heat operated and there is no need of electrical or mechanical energy. DAR cycle utilizes triple fluids namely ammonia, water and an auxiliary inert gas usually hydrogen, where ammonia is used as refrigerant and water as absorbent. The unique feature of this cycle, as compared to a conventional ammonia-water absorption cycle, is that introduction of the auxiliary inert gas plays its role to reduce the partial pressure of the refrigerant in the evaporator and allows the refrigerant to evaporate at low temperatures producing the cooling effect

In the basic DAR cycle implementation, the following processes takes place:

1. Absorbent dilute (refrigerant-rich) solution (DS) flows from the reservoir to the generator (1), where it is heated to desorb refrigerant vapor.

2. The refrigerant vapor and solution flow up through the bubble-pump generator (BPG) , and are lifted by the buoyancy of the vapor bubbles.

3. Refrigerant vapor separates from the solution flow at the BPG outlet, and continues to the condenser

4. The refrigerant rejects heat to the surroundings as it flows through the condenser and exits as subcooled liquid.

5. The liquid refrigerant partially flashes in the presence of the refrigerant-poor auxiliary gas mixture at the evaporator inlet. The two-phase mixture continues to evaporate and cools the conditioned space as it flows through the evaporator toward the absorber vapor inlet.

6. Absorbent-concentrated (refrigerant poor) solution (CS) from the BPG flows into the absorber solution inlet, and contacts the gas stream from the evaporator in a counter-

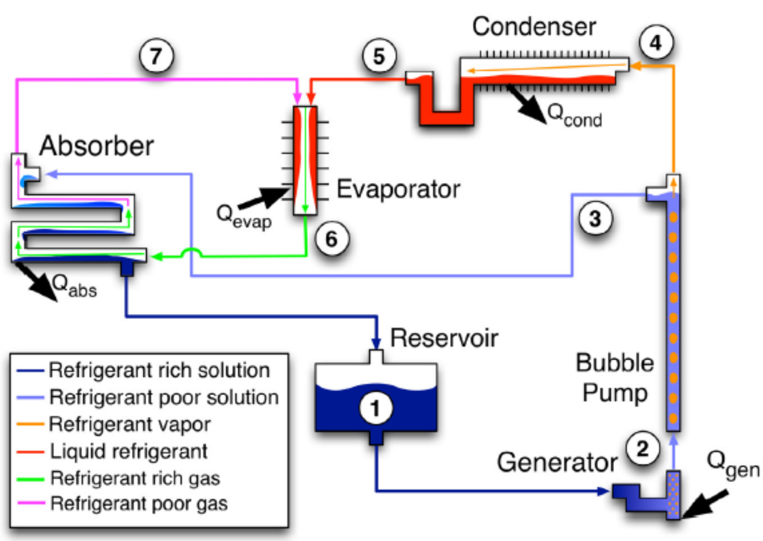


Figure 4. Schematic of DAR [9]

flow fashion (3 → 1). Refrigerant is absorbed from the gas mixture into the solution, rejecting heat to the surroundings and regenerating both the DS and auxiliary gas streams.

7. The DS returns to the reservoir, and the refrigerant-poor gas rises to the evaporator inlet, completing the cycle.

Composition Study of Ammonia-Water Vapors

Experimental results show that vapor composition of ammonia-water mixture varies from the one that is obtained using ideal mixture equation. Various charts have been developed based on the concentration of Ammonia in the solution with respect to pressure, temperature, enthalpy etc. Since both liquid and vapor phase exist in the solution subscript L and V will be used to distinguish between liquid and vapor states respectively. Liquid phase mass fraction ξ^L and vapor phase mass fraction ξ^V can be calculated using the following steps in order to get the concentration of ammonia vapors and liquid at a specific temperature.

Suppose that initially (state 1) your mixture is placed at normal temperature and is in the subcooled solution region of the graph. The system is heated and its temperature increases steadily. Further heating increases the temperature and the system achieves another state (state 2) as shown in graph. If heating in kept increase it will cause the solution to evaporate after some time and mixture will enter a superheat vapor state (State 3). If the process is repeated by using different initial concentration of ammonia ranging from 0 (pure water) to 1(pure ammonia) at same pressure, different values of bubble point and dew point temperature are achieved. Now if all the bubble point is joined by one curve and all dew points by another we get an equilibrium Temperature vs concentration curve at that pressure.

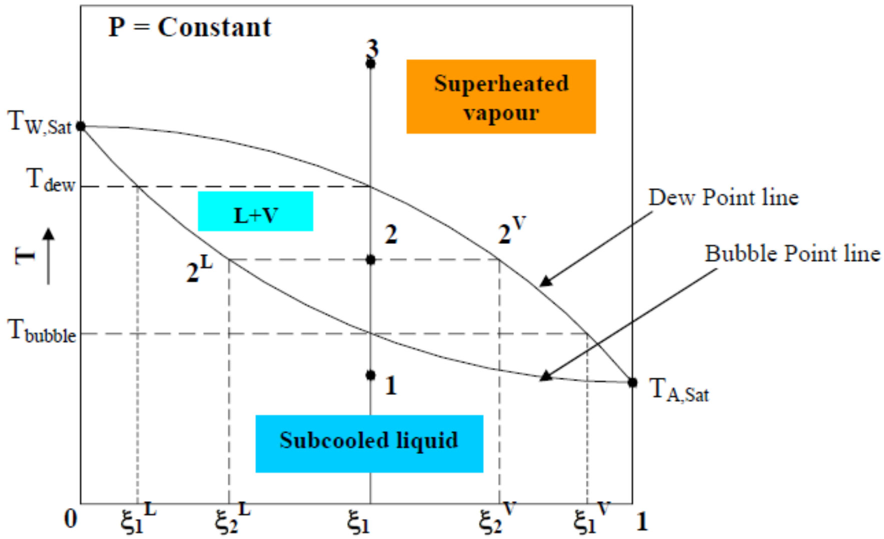


Figure 5. Ammonia-Water Constant Pressure Graph

When a process is carried out in a controlled volume, total mass and mole fraction of ammonia and water will remain the same. However, during the 2-phase region (state 2) some of the mixture will exist in vapors and some will remain as solution. So, in order to find concentration of vapors or liquid at a specific state in the process, an intersection of constant temperature line with bubble point line will yield the concentration of liquid ξ^L while a similar intersection with dew point line show the concentration of vapor ξ^V at that state. By making various iterations of same process by changing pressure the following graph is achieved with shows the change in the value of bubble point and dew point with change in pressure.

If the solution is heated in closed chamber then mixture's temperature and pressure both increases, when it is subjected to heat. Thus, the system never goes above the bubbling temperature of the corresponding pressure.

Type of Pressure Vessel Heads:

There are 3 main types of pressure vessel heads per ASME standards. These are classified based on their application, shape and dimensional features. Each head offers extra features apart from other but varies in manufacturing cost with each other. These are:

Ellipsoidal Head:

These are also termed as elliptical head and are the economical, as height of the head is a fraction of its diameter. For a same value of design pressure, temperature and material the head thickness will be very close to the thickness of the shell.

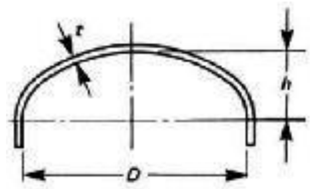


Figure 6. Ellipsoidal head

Hemispherical Head:

An ideal shape for a head, as it divides the vessel's pressure equally across the surface of the head thus ensuring that there are no concentrated spots that can cause extra fatigue on the head. One of the main issue with this is that fabrication cost of the head is high. For a same value of design pressure, temperature and material the head thickness will be approximately half of the shell thickness.

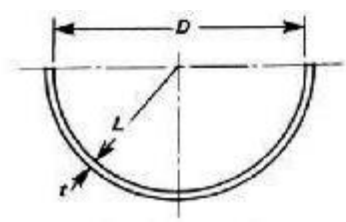


Figure 7. Hemispherical head

Torispherical Head:

These heads have dish with fixed radius and for similar conditions used as for shell thickness calculations the thickness of the head is calculated to be approximately 1.77 times the shell thickness.

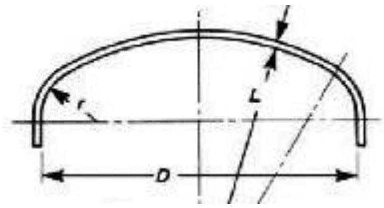


Figure 8. Torispherical head

CHAPTER 3

METHODOLOGY:

Why DAR system?

Following are some of the reasons for selecting diffusion absorption cycle.

Method of compression of refrigerant:

In other refrigeration system, the compression of the refrigerant is done using a compressor (VCR) or pump (VAR) that either be reciprocating, rotating etc. Whereas in DAR, only heat is needed for increasing pressure of refrigerant. Moreover mechanical components are one of the heaviest part of the cycle. Therefore DAR solves the issue of weight and constant supply of energy to the compressor.

Amount of energy required:

In our system the cooling load would be very low as we just need to maintain the temperature of the vaccines to the required temperature, therefore there isn’t a strong need of cycle which has high coefficient of performance. Instead portability and working without energy sources are required.

While compressor and pump in VCR and VAR requires large quantities of power for its operation and it is the major power consuming device in the cycle. Moreover they also requires continuous supply of energy to operate. Whereas in our cycle will only require initial charging and can run very efficiently on it. Thus, reducing the running cost of the cycle as compared to vapor compression cycle.

Type of refrigerants used and their cost:

In ammonia-water absorption refrigeration system, ammonia is used as the refrigerant, which is easily and cheaply available. In lithium bromide system, water is used as the refrigerant, which is also available cheaply and easily. In case of the vapor compression refrigeration system halocarbons are used as the refrigerants, which are very expensive.

Acoustic Effect:

As vapor compression cycle uses a compressor that operates at a high speed and thus makes a lot of vibration and noise. Therefore, for larger units based on this cycle requires strong foundations to be made to endure the vibrations and high pressure of refrigerant. On the other hand, vapor absorption cycle has no major moving part hence they don't require any special features to setup.

Maintenance:

Major component of the vapor compression cycle is the compressor and it, itself has a lot of moving parts. It is required to keep them properly lubricated and checked upon after regular intervals to ensure nothing is wrong with them as failure in compressor can be very expensive at time. Our system will have no moving part so maintaining it will be less difficult.

Selection Criteria for Refrigerant

The desirable properties that the refrigerant-absorbent mixture should have for diffusion absorption refrigeration system are:

- The refrigerant should be more volatile than the absorbent i.e. the boiling point of the refrigerant should be lower than the absorbent.
- The heat provided in the generator should be close to the temperature required to boil of the refrigerant only. This ensures that only refrigerant is removed from the mixture and maximum cooling can be achieved.
- The refrigerant should have high solubility with solution in absorber.
- Operating pressures should be kept low in order to have minimum thickness of walls and connecting pipes.
- The mixture should be safe, chemically stable, noncorrosive, and inexpensive and should be readily available.
- The refrigerant should have a high heat of vaporization.

Following are some of the mixtures that were either tested in labs or are being used in industrial applications:

- Hydrocarbon working fluid mixture (C4H10-C9H20) has been used. Since C4H10 evaporates at -1°C therefore it will give relatively high delivery temperature.
- H2O-LiBr has also been considered, but may not be suitable for refrigeration-grade cooling due to the relatively high freezing point of water (0 °C).
- R124-DMAC refrigerant-absorbent pair could be used but its COP is very low as compared to ammonia absorbent pairs as H_{fg} of NH_3 is very large.
- NH_3-H_2O working fluid is considered.

Based on the above criteria most applicable mixture was found out to be Ammonia-Water system (NH3-H2O). Since ammonia has boiling point of -33°C therefore low temperature refrigeration can be achieved easily. It has Hfg = 1200kJ/mol at 0°C therefore we will need small amount of ammonia for producing the required cooling.

Material Selection:

We know that the material that will be used to make the vessel will be exposed to the corrosive nature of ammonia and will tend to corrode with the passage of time. Moreover to ensure portability of the system we should also consider the relative weight of the material. In order to avoid these problems, the best material chosen for the vessel is Aluminum.

But due to unavailability of the welding facilities for Aluminum metal. We selected Stainless steel SA-204 for the sake of our prototype.

Some of its properties are stated below:

Table 1. SA-204 Properties

Specification No.	SA-240
Type/Grade	304
Nominal Composition	18Cr-8Ni
Min. Tensile Strength [MPa]	515
Min. Yield Strength [MPa]	205

The properties stated above were taken from ASME Section II, Part D, Table 1A, metric.

What makes this material a feasible option for our project is has a good corrosion resistance, high ductility. It also has low carbon content so it means much cleaner welding and low susceptibility to intergranular corrosion. Moreover its low cost, high yield strength and easily available machining processes in market.

Concept model:

It consists of two chambers which are connected together with a pipe and a valve. One chamber contains ammonia water mixture which is heated in the *first stage*, ammonia evaporates and vapors will go into the other chamber through pipe. Second Chamber is kept cool during this time in a water bath. Where ammonia vapors will condense. Then valve is closed and first chamber is left to cool at room temperature. In *second stage* the valve is again opened and ammonia vapors will start to evaporate. Due to pressure difference vapors will travel to first chamber through the pipe, where they will dissolve into water. As a result the second chamber will generate cooling effect, which will be placed in the insulation box.

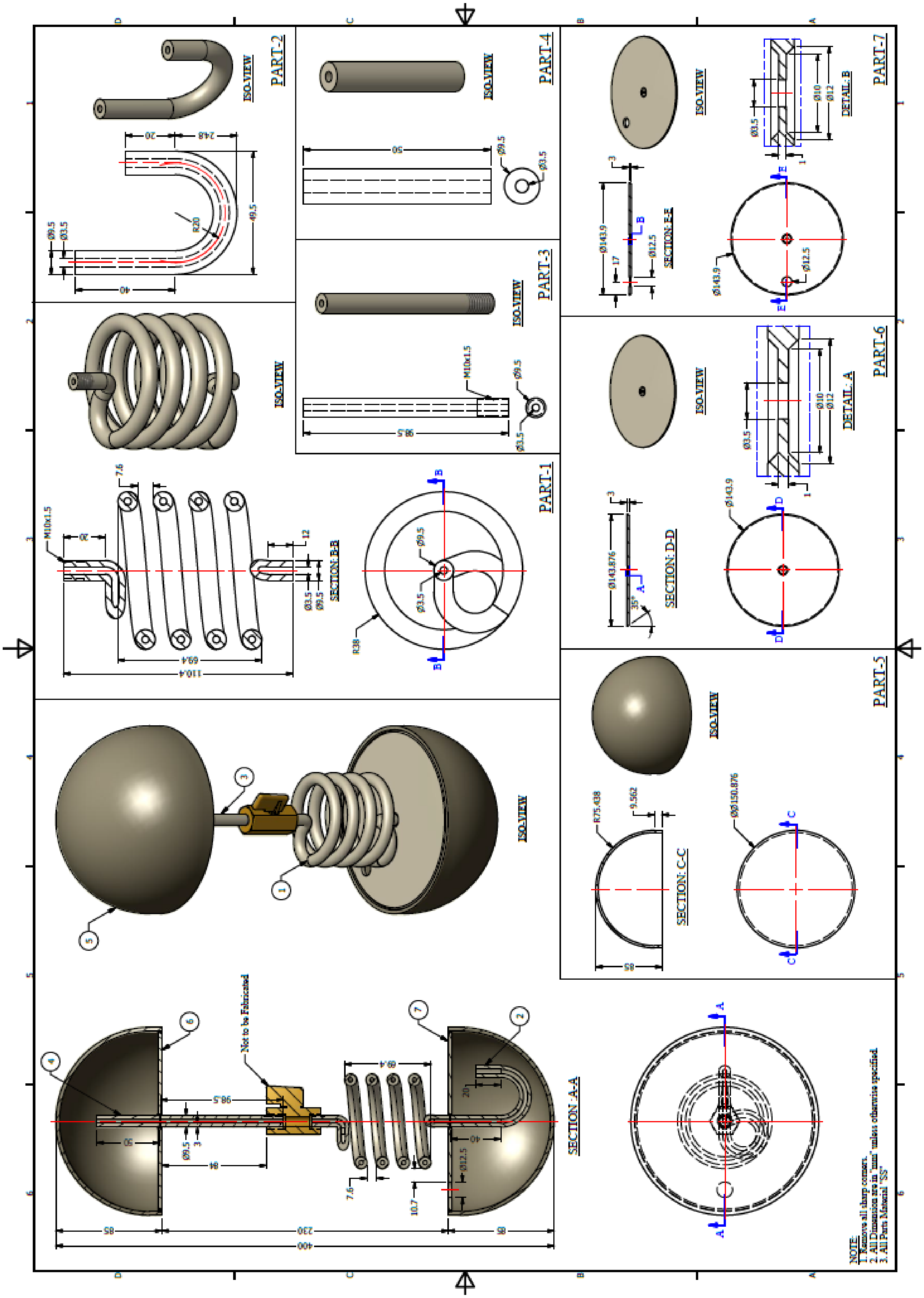


Figure 9 CAD Model

THERMAL ANALYSIS

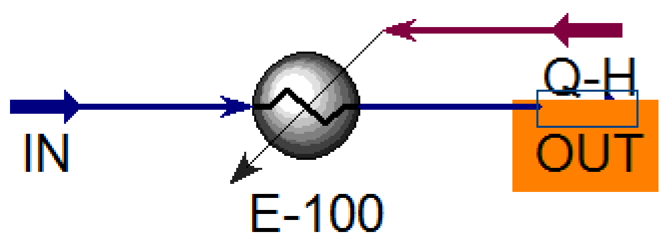
Ammonia-Water Solution analysis:

To ensure the distillation of ammonia and water a complex study of heat and mass transfer is required. Therefore we have used a comprehensive process modeling tool for process simulation of ammonia and water solution at our required conditions.

The software used is ASPEN HYSYS 8.4.

In the following analysis we have given thermodynamic states to 0.40 Molar solution in liquid phase. And then heat is added till it reaches 120°C and 15 bar.

The design model for heating this shown:



Boundary conditions:

Table 2. ASPEN HYSYS Boundary Conditions

Property	Before	After
Total Mole Fraction	0.4 (Ammonia)	0.4 (Ammonia)
Static Temperature	35°C	120°C
Static Pressure	1 bar	15 bar

Initial conditions:

Table 3. ASPEN HYSYS Initial Conditions

Aqueous Phase Mole Fraction	0.4 (Ammonia)

Results Obtained:

Table 4. ASPEN HYSYS Results

Vapor Phase Mole Fraction	0.9220
Aqueous Phase Mole Fraction	0.1829

The results obtained prove that the maximum amount of ammonia is separated from the solution at our operating condition without using any heat exchanger in the system.

MATERIAL SELECTION AND DESIGN ANALYSIS

Thickness Calculation:

Based on the values stated above the thickness of the cylinder is calculated using ASME (Boiler and Pressure Vessel Code) Section VIII division 1.

For a vessel to be able to sustain the required pressure, the value of the minimum thickness of the shell under internal pressure should not be less than the calculated values.

The symbols defined below are used in the formulas of this paragraph.

E= joint efficiency, or efficiency of appropriate joints in cylindrical or spherical shells

P = internal design pressure

R = inside radius of the shell under consideration

S = maximum allowable stress value

t = minimum thickness of the shell

Table 5. Initial Condition for Stress

E	0.3
P	30 bar
S	515 N/mm^2
R	152 mm

Circumferential Stress:

When the thickness does not exceed one-half of the inside radius, or P does not exceed 0.385S E, the following formulas shall apply:

$$t = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$E = 0.3$$

$$P = 3$$

$$S = 515$$

$$R = 152$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

E = 0.3	P = 3	R = 152
S = 515	t = 2.986	

No unit problems were detected.

Longitudinal Stress:

When the thickness does not exceed one-half of the inside radius, or P does not exceed 1.25SE, the following formulas shall apply:

$$t = \frac{P \cdot R}{2 \cdot S \cdot E + 0.4 \cdot P}$$

$$E = 0.3$$

$$P = 3$$

$$S = 515$$

$$R = 152$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

E = 0.3	P = 3	R = 152
S = 515	t = 1.47	

No unit problems were detected.

Using the initial conditions

The minimum thickness calculated are:

- Circumferential Stress thickness = 2.986 mm
- Longitudinal Stress thickness = 1.47mm

Vessel Head Calculation:

The type of head of the vessel is selected to be elliptical as it is most economical and easy to manufacture. So, calculation for the minimum thickness of the head per ASME standard section viii is given by following formulas.

$$t = \frac{PDK}{2SE - 0.2P} \qquad\qquad t = \frac{PD_oK}{2SE + 2P(K - 0.1)}$$

Where

$$K = \frac{1}{6}[2 + \frac{D}{2h}^{2}]$$

t = minimum required thickness of head after forming

P = internal design pressure

D = inside diameter of the head skirt

D_0 = outside diameter of the head skirt

S = maximum allowable working stress

E = weld joint efficiency

h = height

Taking initial conditions as

Table 6. Initial condition for Vessel Head

P	40 bar
D	152 mm
S	515
E	0.3
H	37 mm

Both formulas calculate the wall thickness to be 2.0448 mm and 2.0698mm respectively. Which is very close to the actual calculated thickness of the shell.

Stress analysis of the Chamber:

The purpose of conducting a simulation test for our product is to ensure and reconfirm that the results obtained theoretically are accurate.

Since our project involves high pressure of up to 17 bars a simulation of the vessel was done to get insight on stress that it will endure (mainly hoop and axial stress), percentage of deformation in the shell (if any). Another simulation was conducted for the container which must contain the cooling side will be placed. It was done to account for the amount heat that will be required to remove for cooling the box in an extreme weather condition.

Both simulations were conducted using ANSYS R15.0. Detailed mechanical report of the analysis is given in **Appendix (VI)**.

Material:

As it was stated earlier that the material selected for the vessels is Stainless steel SA-304

Pressure Simulation:

Since both chambers in the product will be similar to each other apart from performing different roles. Simulation was carried out using a single shell. Some of the parameters that were used in the simulation are:

- Pressure: 30 bars / 3 MPa
- Temperature: 200^{o}C
- Time = 4 sec

Units used for the simulation are:

Table 7. Units for Stress Analysis

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model:

The initial model was made using SolidWorks and was later imported in ANSYS. The dimensions of the shell are given below:

Table 8. Model for Stress Analysis

Internal Diameter	152.4 mm
Thickness	2 mm
Height	76.2 mm

Contours of Analysis obtained:

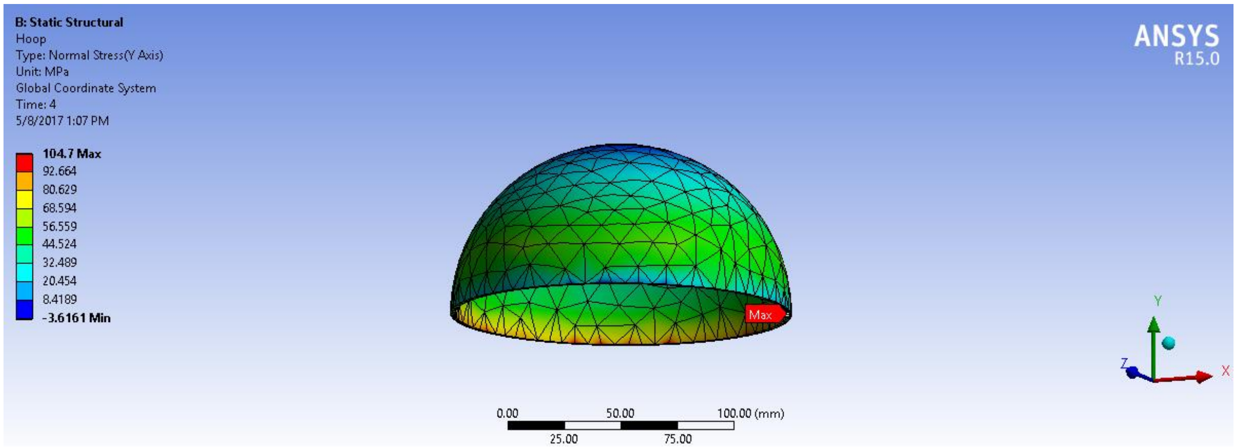


Figure 10. Hoop Stress Contour

Theoretical Result:

Solving using hoop stress formula we get:

$$h = \frac{p \cdot d}{2 \cdot t}$$

$$p = 3 \times 10^{6}$$

$$d = 0.152$$

$$t = 0.002$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

d = 0.152
p = 3.000E+06

h = 1.140E+08
t = 0.002

No unit problems were detected.

H (hoop stress) = 114 MPa

Percentage Error:

The percentage error between the simulation result and the calculated result is follows:

$$error = \frac{h_{theo} - h_{ansys}}{h_{theo}}$$

$$percentage_{error} = error \cdot 100$$

$$h_{theo} = 1.14 \times 10^{8}$$

$$h_{ansys} = 1.04 \times 10^{8}$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

error = 0.08772

h_{theo} = 1.140E+08

h_{ansys} = 1.040E+08

$percentage_{error}$ = 8.772

No unit problems were detected.

CHAPTER 4

RESULTS

Cooling Load:

Our Cooling will depend mainly on three factors:

1. Conduction
2. Sunlight Radiations
3. Infiltration

For calculating the cooling load through conduction we have considered an icebox which is available in the market. The size of icebox approximated to be 0.75 x 0.75 x 0.75 feet, insulated using polystyrene and having a thickness of 3 cm. Using

$$\dot{Q} = \frac{A_{surface} \cdot k \cdot [T_2 - T_1]}{d}$$

$d = 0.03$

$A_{surface} = 0.052$

$T_2 = 35$

$T_1 = 3$

$k = 0.03$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$A_{surface} = 0.052$	$d = 0.03$
$k = 0.03$	$\dot{Q} = 1.664$
$T_1 = 3$	$T_2 = 35$

No unit problems were detected.

By solving we get the value of load to be about 1.664 W.

Our system will work in a manner to maintain this cooling load for a time period of 20 hours.

So energy that will be required is given as

$$Q = \frac{\dot{Q} \cdot t}{1000}$$

$$\dot{Q} = 4$$

$$t = 72000$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$Q = 288$ $\dot{Q} = 4$ $t = 72000$

No unit problems were detected.

The value of energy required is 288 kJ.

Mass of ammonia required:

Using table in appendix (V) in order to calculate the latent heat of vaporization of ammonia.

$$mass_{Ammonia} = \frac{Q}{h_{fg@35}}$$

$$Q = 288000$$

$$h_{fg@35} = 1.1283 \times 10^{6}$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$h_{fg@35} = 1.128E+06$ $mass_{Ammonia} = 0.2553$

$Q = 288000$

No unit problems were detected.

Mass of ammonia (kg) = 0.255 kg

Concentration of Ammonia in mixture:

Using the graph in appendix (I) it is noted that ammonia at 0.4 concentration at 1 atm pressure will start to bubble at 10.27^{o}C. Therefore, we will inject cooled ammonia mixture into our system. The concentration of ammonia that we have used in the mixture is about 0.4 by mass. As handling ammonia in near pure form is very difficult to handle as it will start bubbling at very low temperatures at 1 atm pressure. Low concentration of ammonia was not used as large volume of ammonia vapors will be required to produce the desired cooling effect.

Now we have to determine what will be the operating pressure of our system. Using appendix (V) at ambient temperature value of 35^{o}C we calculated the vapor pressure of ammonia to be about 13.5 bar.

Above 13.5 bar the boiling of the mixture will start thus increasing the concentration of water vapors.

One of the major issue that we faced is to find the concentration of vapors above ammonia-water mixture. As explained earlier, Roults Law will give us the concentration of vapors in liquid when the pressure of the system remains constant.

But in our case we have a closed chamber in which pressure and temperature will be increasing simultaneously. A detailed study of temperature-concentration graph reveals that if our chamber is closed then the graph is moving from one pressure line to another at its bubbling point. As a result temperature obtained from the graph at 13.5 bar is 110.28^{o}C which is our maximum temperature.

Initial amount of ammonia-water mixture:

The mass of liquid ammonia calculated above is about 0.25 kg. Keeping in mind the factor of safety and the unidentified heat loss, the amount of ammonia take is estimated to be about 0.3 kg.

Density of liquid ammonia at 35^{o}C = 600 kg/m^{3}

Volume of liquid ammonia required (ml) = 500

Using

$$E = \frac{m_A}{m_A + m_W}$$

$$E = 0.4$$

$$m_A = 0.3$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$E = 0.4$ $m_A = 0.3$ $m_W = 0.45$

No unit problems were detected.

M_W required to make 0.4 concentration of ammonia-water mixture is calculated to be 0.45 kg and volume to be 450 ml. Thus the total volume of the whole mixture will be equal to 950 ml (450 water & 500 ammonia)

Coefficient of Performance (COP):

The coefficient of performance of our refrigerator is calculated as:

$$h_{va} = 1128$$

$$h_{vs} = 649.7$$

$$m_a = 0.255$$

$$m_s = 0.6375$$

$$row_{ammonia,30oC} = 3558$$

$$h_{ammonia,30oC} = 1313.28$$

$$n = \frac{m_a \cdot h_{va}}{m_s \cdot h_{vs}}$$

$$mass = \frac{row_{ammonia,30oC} \cdot h_{ammonia,30oC}}{1000000}$$

$$coolingload = mass \cdot 6$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

coolingload = 0.02804

h_{va} = 1128

mass = 4.673

m_s = 0.6375

$row_{ammonia,30oC}$ = 3558

$h_{ammonia,30oC}$ = 1313

h_{vs} = 649.7

m_a = 0.255

n = 0.6945

No unit problems were detected.

CONCLUSION

Our project is designed on the basis of calculations stated above. We tested our system using small amount of ammonia. As a result required cooling effect is produced for a short period of time.

RECOMMENDATION

Based on the results and the fabrication limitation of the time, here are some of the recommendations for improving the overall model:

1. Whole structure should be fabricated using Aluminum as it is very light weight and has higher coefficient of heat transfer as compared to stainless steel.
2. More precise discharge valve should be used in order to achieve maximum efficiency of the system with only the specific amount of ammonia being discharged into the other chamber.
3. A carry-on heating system can be added that could charge the system whenever it is needed.
4. The size of the chambers and the distance between them can be reduced to enhance the portability of the product.
5. Typical level sensors don’t work in case of ammonia so a miniature ammonia sensor can be used to notify the level of liquid ammonia in the upper chamber.

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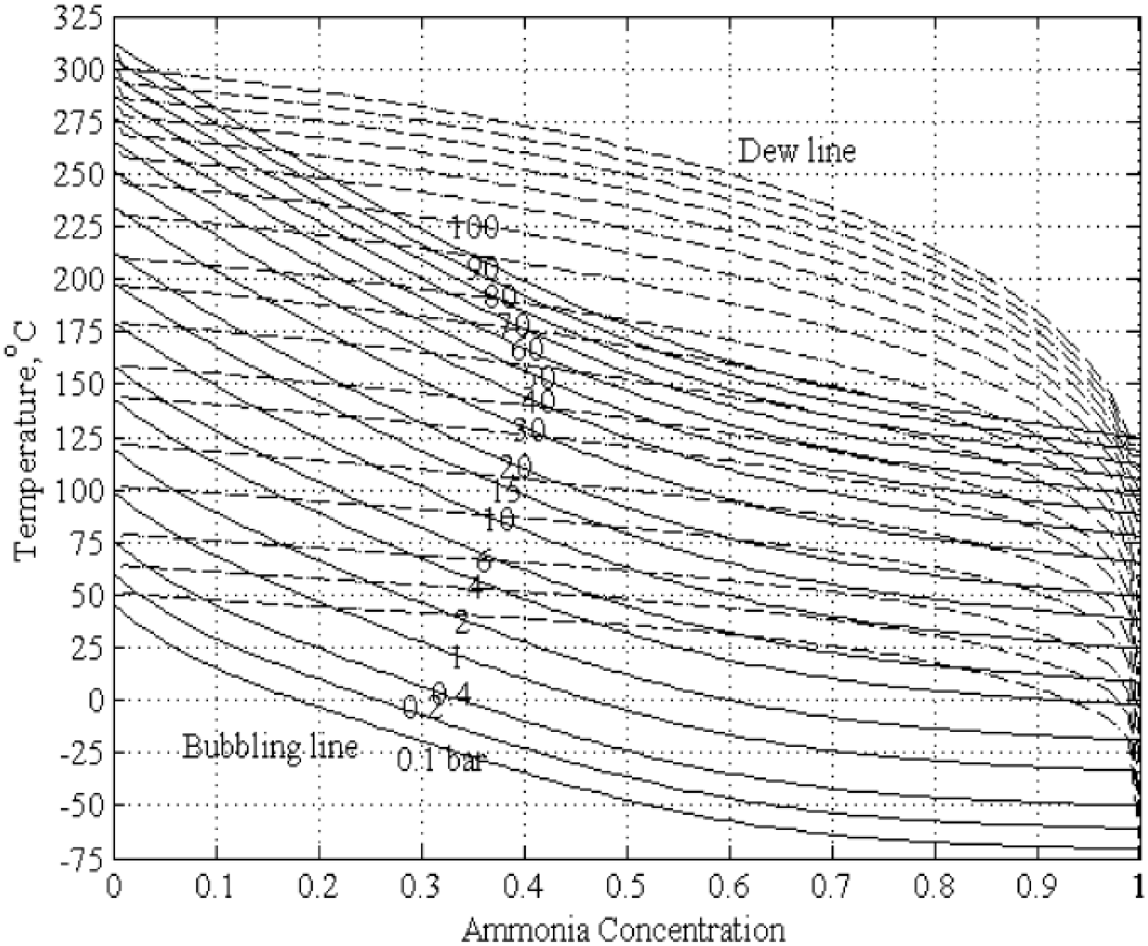
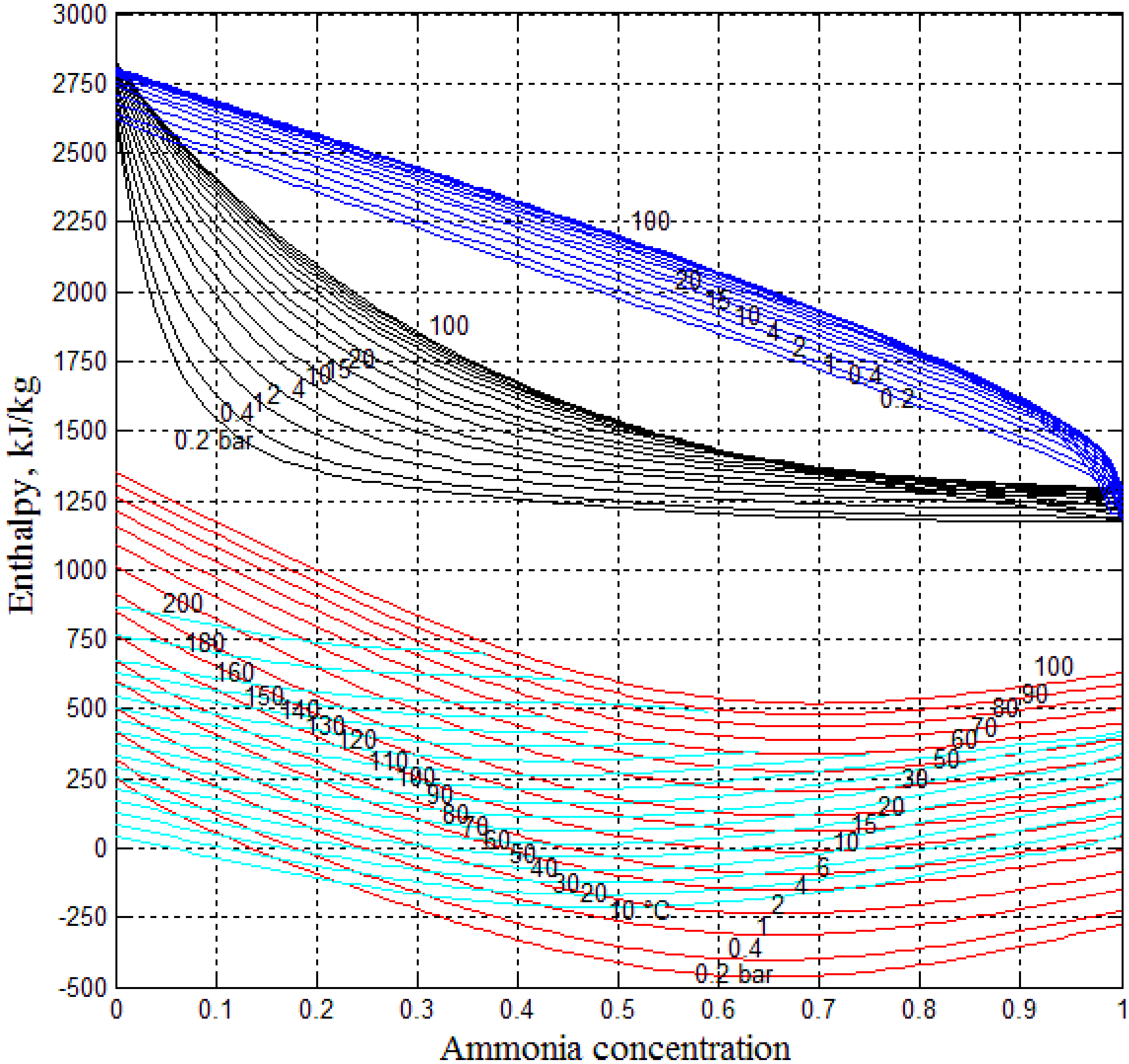
APPENDIX (I)



Dew line
100
90
80
70
60
50
40
30
20
15
10
6
4
2
1
0.4
0.2
Bubbling line
0.1 bar
Temperature, °C
Ammonia Concentration
325
300
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

APPENDIX (II)



Enthalpy, kJ/kg
Ammonia concentration
0.2 bar
0.4
1
2
4
10
15
20
100
0.2
10 °C
0.2 bar

APPENDIX (III)

Bubble point temperature of ammonia water mixture

x	Pressure, bar																			
	0.2	0.4	0.6	0.8	1.0	2.0	4.0	6.0	8.0	10	15	20	30	40	50	60	70	80	90	100
0	60.50	76.10	86.02	93.48	99.53	120.00	143.47	158.85	170.59	180.06	198.96	213.14	234.96	251.68	265.39	277.10	287.38	296.57	304.90	312.53
0.1	29.59	45.25	55.22	62.71	68.78	89.31	112.81	128.18	139.90	149.32	168.17	182.26	203.95	220.55	234.15	245.77	255.96	265.06	273.31	280.87
0.2	10.25	24.94	34.34	41.42	47.17	66.70	89.15	103.87	115.13	124.16	142.32	155.87	176.80	192.83	205.98	217.21	227.07	235.89	243.87	251.20
0.3	-6.71	7.00	15.83	22.50	27.94	46.44	67.82	81.89	92.66	101.30	118.74	131.76	151.90	167.35	180.04	190.89	200.42	208.93	216.66	223.74
0.4	-22.51	-9.54	-1.17	5.17	10.34	28.01	48.49	62.00	72.36	80.67	97.49	110.04	129.51	144.45	156.73	167.24	176.47	184.72	192.22	199.09
0.5	-36.09	-23.70	-15.68	-9.59	-4.63	12.35	32.08	45.13	55.14	63.17	79.45	91.61	110.48	124.98	136.90	147.11	156.07	164.10	171.38	178.06
0.6	-46.43	-34.49	-26.75	-20.88	-16.08	0.32	19.41	32.04	41.74	49.53	65.31	77.12	95.45	109.54	121.14	131.07	139.80	147.61	154.70	161.21
0.7	-53.26	-41.67	-34.17	-28.48	-23.84	-7.93	10.56	22.80	32.21	39.78	55.10	66.58	84.40	98.11	109.40	119.06	127.56	135.17	142.08	148.42
0.8	-57.14	-45.86	-38.57	-33.04	-28.53	-13.10	4.83	16.71	25.84	33.19	48.07	59.23	76.55	89.89	100.88	110.29	118.57	125.99	132.72	138.90
0.9	-59.25	-48.22	-41.12	-35.74	-31.35	-16.37	1.03	12.55	21.41	28.54	42.99	53.82	70.67	83.64	94.33	103.50	111.56	118.78	125.34	131.37
1	-60.78	-49.96	-43.03	-37.79	-33.52	-18.96	-2.08	9.09	17.68	24.60	38.62	49.14	65.50	78.11	88.51	97.43	105.28	112.32	118.71	124.58

APPENDIX (IV)

Dew point temperature of ammonia water mixture

x	Pressure, bar																			
	0.2	0.4	0.6	0.8	1.0	2.0	4.0	6.0	8.0	10	15	20	30	40	50	60	70	80	90	100
0	60.50	76.10	86.02	93.48	99.53	120.00	143.47	158.85	170.59	180.06	198.96	213.14	234.96	251.68	265.39	277.10	287.38	296.57	304.90	312.53
0.1	60.99	75.79	85.26	92.41	98.22	117.93	140.48	155.17	166.31	175.40	192.95	206.24	226.25	241.38	253.68	265.10	273.19	281.26	288.53	295.17
0.2	57.77	72.39	81.75	88.81	94.54	114.00	136.25	150.75	161.76	170.73	188.06	201.19	220.96	235.91	248.07	258.37	267.35	275.33	282.53	289.09
0.3	54.69	69.01	78.16	85.07	90.69	109.74	131.55	145.77	156.57	165.38	182.40	195.30	214.74	229.45	241.41	251.55	260.39	268.24	275.33	281.80
0.4	51.53	65.47	74.38	81.10	86.56	105.09	126.32	140.18	150.70	159.29	175.90	188.50	207.48	221.86	233.56	243.48	252.13	259.82	266.76	273.09
0.5	48.01	61.57	70.21	76.72	82.01	99.94	120.47	133.86	144.04	152.35	168.42	180.63	199.02	212.96	224.30	233.92	242.32	249.78	256.52	262.67
0.6	43.76	57.03	65.43	71.74	76.84	94.11	113.82	126.65	136.41	144.36	159.75	171.43	189.05	202.40	213.27	222.50	230.54	237.70	244.16	250.06
0.7	38.27	51.44	59.65	65.77	70.71	87.27	106.02	118.17	127.39	134.90	149.41	160.41	177.00	189.57	199.80	208.48	216.06	222.80	228.88	234.44
0.8	30.74	44.03	52.14	58.10	62.87	78.65	96.22	107.51	116.03	122.96	136.29	146.39	161.58	173.08	182.43	190.37	197.29	203.45	209.01	214.09
0.9	19.26	32.75	40.72	46.46	50.99	65.66	81.57	91.62	99.14	105.23	116.90	125.69	131.87	148.84	156.93	163.80	169.78	175.11	179.91	184.30
1	-60.78	-49.96	-43.03	-37.79	-33.52	-18.96	-2.08	9.09	17.68	24.60	38.62	49.14	65.50	78.11	88.51	97.43	105.28	112.32	118.71	124.58

APPENDIX (V)

Thermodynamic table of anhydrous ammonia

Temp. °C	Pressure kPa	spec. Density kg/m³		spec. Volume m³/kg		spec. Enthalpy kJ/kg			spec. Entropy kJ/kg K	
		liquid	gas	liquid	gas	liquid	latent	gas	liquid	gas
30	1167,2	595,17	9,0533	0,0016802	0,11046	484,91	1144,39	1629,3	1,9597	5,7347
31	1202,3	593,63	9,3209	0,0016846	0,10729	489,76	1140,04	1629,8	1,9754	5,7237
32	1238,2	592,08	9,595	0,001689	0,10422	494,61	1135,69	1630,3	1,9911	5,7128
33	1274,9	590,53	9,8755	0,0016934	0,10126	499,47	1131,23	1630,7	2,0069	5,7019
34	1312,4	588,97	10,163	0,0016979	0,098399	504,34	1126,76	1631,1	2,0225	5,691
35	1350,8	587,40	10,457	0,0017024	0,095632	509,23	1122,27	1631,5	2,0382	5,6801
36	1390,0	585,82	10,758	0,001707	0,092957	514,12	1117,78	1631,9	2,0538	5,6693
37	1430,0	584,24	11,066	0,0017116	0,09037	519,02	1113,18	1632,2	2,0694	5,6586
38	1470,9	582,65	11,381	0,0017163	0,087867	523,93	1108,57	1632,5	2,085	5,6479
39	1512,7	581,05	11,703	0,001721	0,085445	528,86	1103,94	1632,8	2,1006	5,6372
40	1555,4	579,44	12,034	0,0017258	0,083101	533,79	1099,31	1633,1	2,1161	5,6265
41	1599,0	577,82	12,371	0,0017306	0,080832	538,74	1094,56	1633,3	2,1317	5,6159
42	1643,5	576,20	12,717	0,0017355	0,078635	543,69	1089,81	1633,5	2,1472	5,6053
43	1689,0	574,56	13,071	0,0017405	0,076507	548,66	1085,04	1633,7	2,1627	5,5947
44	1735,3	572,92	13,432	0,0017454	0,074446	553,64	1080,26	1633,9	2,1781	5,5841
45	1782,7	571,27	13,803	0,0017505	0,07245	558,63	1075,37	1634,0	2,1936	5,5736
46	1831,0	569,61	14,181	0,0017556	0,070515	563,63	1070,47	1634,1	2,209	5,5631
47	1880,2	567,94	14,569	0,0017608	0,06864	568,65	1065,55	1634,2	2,2244	5,5526
48	1930,5	566,25	14,965	0,001766	0,066822	573,68	1060,52	1634,2	2,2398	5,5422
49	1981,8	564,56	15,371	0,0017713	0,06506	578,72	1055,48	1634,2	2,2552	5,5317
50	2034,0	562,86	15,785	0,0017766	0,06335	583,77	1050,43	1634,2	2,2706	5,5213
51	2087,3	561,15	16,209	0,001782	0,061692	588,84	1045,36	1634,2	2,286	5,5109
52	2141,7	559,43	16,643	0,0017875	0,060084	593,92	1040,18	1634,1	2,3013	5,5005
53	2197,1	557,70	17,087	0,0017931	0,058523	599,02	1034,98	1634,0	2,3167	5,4901
54	2253,6	555,95	17,541	0,0017987	0,057008	604,13	1029,77	1633,9	2,332	5,4797
55	2311,1	554,20	18,006	0,0018044	0,055537	609,26	1024,44	1633,7	2,3473	5,4693
56	2369,8	552,43	18,481	0,0018102	0,05411	614,40	1019,10	1633,5	2,3627	5,4589
57	2429,5	550,65	18,967	0,001816	0,052723	619,56	1013,74	1633,3	2,378	5,4486

APPENDIX (VI)

First Saved	Wednesday, March 29, 2017
Last Saved	Sunday, April 2, 2017
Product Version	15.0.7 Release
Save Project Before Solution	No
Save Project After Solution	No

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (B4)

Geometry

Length X	150.8 mm
Length Y	75.435 mm
Length Z	150.83 mm
Properties	
Volume	70090 mm³
Mass	0.5432 kg
Scale Factor Value	1.
Statistics	

Bodies	1
Active Bodies	1
Nodes	3406
Elements	1595
Mesh Metric	None

TABLE 3

Model (B4) > Geometry > Parts

Object Name	*lol*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	Stainless Steel
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	150.8 mm
Length Y	75.435 mm
Length Z	150.83 mm
Properties	
Volume	70090 mm^3

Mass	0.5432 kg
Centroid X	1.6425e-006 mm
Centroid Y	49.844 mm
Centroid Z	-6.9162e-007 mm
Moment of Inertia Ip1	1249.6 kg·mm²
Moment of Inertia Ip2	1998.2 kg·mm²
Moment of Inertia Ip3	1249.6 kg·mm²
Statistics	
Nodes	3406
Elements	1595
Mesh Metric	None

Mesh

TABLE 5

Model (B4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast

Span Angle Center	Coarse
Minimum Edge Length	461.410 mm
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On

Defeaturing Tolerance	Default
Statistics	
Nodes	3406
Elements	1595
Mesh Metric	None

Static Structural (B5)

TABLE 6

Model (B4) > Analysis

Object Name	*Static Structural (B5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	200. °C
Generate Input Only	No

TABLE 8

Model (B4) > Static Structural (B5) > Loads

Object Name	*Pressure*	*Fixed Support*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	1 Face	
Definition		

Type	Pressure	Fixed Support
Define By	Normal To	
Magnitude	3. MPa (ramped)	
Suppressed	No	

Solution (B6)

TABLE 9

Model (B4) > Static Structural (B5) > Solution

Object Name	*Solution (B6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done

TABLE 10

Model (B4) > Static Structural (B5) > Solution (B6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes

Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 11

Model (B4) > Static Structural (B5) > Solution (B6) > Results

Object Name	*Total Deformation*	*Axial*	*Hoop*	*Radial*
State	Solved			
Scope				
Scoping Method	Geometry Selection			
Geometry	All Bodies			
Definition				
Type	Total Deformation	Normal Stress		
By	Time			
Display Time	Last			
Calculate Time History	Yes			
Identifier				
Suppressed	No			
Orientation		Z Axis	Y Axis	X Axis
Coordinate System		Global Coordinate System		
Results				
Minimum	0. mm	-16.948 MPa	-3.6161 MPa	-16.11 MPa
Maximum	1.7871e-002 mm	57.324 MPa	104.7 MPa	58.253 MPa
Minimum Value Over Time				
Minimum	0. mm	-16.948 MPa	-3.6161 MPa	-16.11 MPa

Maximum	0. mm	-16.948 MPa	-3.6161 MPa	-16.11 MPa
Maximum Value Over Time				
Minimum	1.7871e-002 mm	57.324 MPa	104.7 MPa	58.253 MPa
Maximum	1.7871e-002 mm	57.324 MPa	104.7 MPa	58.253 MPa
Information				
Time	4. s			
Load Step	1			
Substep	1			
Iteration Number	1			
Integration Point Results				
Display Option		Averaged		
Average Across Bodies		No		

TABLE 12

Model (B4) > Static Structural (B5) > Solution (B6) > Probes

Object Name	*Stress Probe*
State	Solved
Definition	
Type	Stress
Location Method	Geometry Selection
Geometry	1 Face
Orientation	Global Coordinate System
Suppressed	No
Options	
Result Selection	Normal - Y Axis
Display Time	End Time
Spatial Resolution	Use Maximum
Results	

Normal - Y Axis	60.043 MPa
Maximum Value Over Time	
Normal - Y Axis	60.043 MPa
Minimum Value Over Time	
Normal - Y Axis	60.043 MPa
Information	
Time	4. s
Load Step	1
Substep	1
Iteration Number	1

TABLE 13

Model (B4) > Static Structural (B5) > Solution (B6) > Stress Probe

Time [s]	Stress Probe (NormY) [MPa]
4.	60.043

Material Data

Stainless Steel

TABLE 14

Stainless Steel > Constants

Density	7.75e-006 kg mm^-3
Coefficient of Thermal Expansion	1.7e-005 C^-1
Specific Heat	4.8e+005 mJ kg^-1 C^-1
Thermal Conductivity	1.51e-002 W mm^-1 C^-1
Resistivity	7.7e-004 ohm mm

TABLE 15

Stainless Steel > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
0

TABLE 16

Stainless Steel > Compressive Yield Strength

Compressive Yield Strength MPa
207

TABLE 17

Stainless Steel > Tensile Yield Strength

Tensile Yield Strength MPa
207

TABLE 18

Stainless Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
586

TABLE 19

Stainless Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 20

Stainless Steel > Isotropic Elasticity

Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	1.93e+005	0.31	1.693e+005	73664

TABLE 21

Stainless Steel > Isotropic Relative Permeability

Relative Permeability
1