



Utilization of absorption cycles for Nesfiskur and Skinnfiskur

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UTILIZATION OF ABSORPTION CYCLES FOR NESFISKUR AND SKINNFISKUR

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30 ECTS thesis submitted in partial fulfillment of a
Magister Scientiarum degree in Mechanical Engineering

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Abstract

Refrigeration systems are well known in industry and households. The purpose of such system may include a variety of tasks. In our daily lives we use refrigerators and freezers to keep food cold or frozen. Large fisheries in Iceland use mainly compressor systems to freeze fish for conservation, although this technology may not be the most cost effective. This thesis emphasizes on how to utilize absorption refrigeration technologies in Iceland and use optimization to investigate specific cases which are dealt with. This is done to find out whether companies can save equity by using unused heat from geothermal power plants or other heat source.

The main conclusion from the thesis is that absorption systems are not economical for the companies Skinnfiskur and Nesfiskur when compared to compressor system in terms of three cases that are discussed. The initial cost for the absorption system is too high. In case A the pipeline is too long and the pressure drop high, therefore the cost is too high. In case B the pipeline is not as long as in case A but the flow in the pipes is high which means larger diameter of the pipe and the cost increases dramatically which means that the case is not profitable. Case C is the most favorable of the three cases but not as profitable as current system.

Útdráttur

Kælikerfi eru vel þekkt í iðnaði og í heimilum. Tilgangur kælingar getur verið margskonar. Í daglegu lífi notum við ísskápa og frysta til að viðhalda mat köldum eða frystum. Stór útgerðarfyrirtæki á Íslandi nota aðallega þjöppur til að frysta fisk sem er síðan fluttur í frystigeymslur. Þessi tækni þarf ekki endilega að vera hagkvæmust.

Í þessari ritgerð er athugað hvernig skal nýta ísogs tækni á Íslandi til þess notuð bestun fyrir hvert tilfelli sem er fjallað um. Þetta er gert til að finna hvort fyrirtæki geta sparað fé með því að nota ónýttan hita frá jarðvarmavirkjunum eða öðrum varmagjöfum.

Helsta niðurstaða ritgerðarinnar er sú að ísogskerfi eru ekki hagkvæm fyrir fyrirtækin Skinnfisk og Nesfisk þegar þau eru borin saman við þjöppunarkerfi í þeim tilvikum sem fjallað erum, fjárfestingarkostnaðurinn er of hárr. Í tilfelli A er pípulögnin of löng og þrýstingstapið mikið á leiðinni, þar af leiðandi er kostnaðurinn of hárr. Í tilfelli B er pípulögnin ekki eins löng og í tilfelli A en flæðið í pípunni er mikið sem þýðir að þvermál pípunnar er meira og eykst þá pípu kostnaðurinn verulega, sem þýðir að verkefnið er ekki arðbært. Tilfelli C er hagstæðast af öllum þrem tilfellunum en ekki eins hagstætt og núverandi kerfi.

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Abbreviations

Symbols and units of parameters

Symbol	Dimension	Description
A	m^2	Area
ϵ	m	Roughness
d	kg/m^2	Density
h	kJ/kg	Enthalpy
G	l/s	Flow
L	m	Length
m	kg	Mass
\dot{m}	kg/s	Massflow
η	...	Efficiency
p	Pa	Pressure
p_f	Pa	Pressure loss
Δp_f	Pa/m	Pressure loss per meter
ρ	kg/m^3	Density
Q	kJ	Energy
\dot{Q}	kW	Heat
q	...	Quality
s	kJ/K	Entropy
T	$^\circ\text{C}$	Temperature
U	$\text{W}/(\text{m}^2 \cdot {}^\circ\text{C})$	Overall heat transfer coefficient
v	m^3/kg	Specific volume
\dot{W}	kW	Work
x	...	$\text{NH}_3 : \text{H}_2\text{O}$ ratio in liquid phase
y	...	$\text{NH}_3 : \text{H}_2\text{O}$ ratio in vapor phase

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1. Introduction

Refrigeration systems are widely used in homes and in industrial applications. They are of various type, with various efficiencies and of different sizes. In all cases there is a need to examine different options when designing a refrigeration system. In homes, refrigeration systems are mainly used to preserve food, cooled or frozen, and also for air conditioning. In industry, refrigeration systems are used in larger applications such as air conditioning systems for hospitals and warehouses, refrigeration for large storage rooms with food products and some fisheries need to quickly freeze fish to a low temperature.

When the temperature is slightly above the freezing point the process is often referred to as cooling, which can be useful when there is need to elongate the storage life of fresh perishable food. Freezing can be useful when there is need to store food over a longer period of time.

In Iceland geothermal energy has been used to produce electricity and for house heating. While the absorption technology is not yet used by the industry in corporations, the usage of electricity to cool or freeze products is common. Some fisheries in Iceland invest much of their revenues in freezing equipment which can be quite expensive, where there is need for heat exchangers, compressors, evaporators e.t.c. The energy cost can also be quite high. By using geothermal waste water in refrigeration systems, a better utilization of geothermal energy and lower cost for energy usage can possibly be obtained.

The background of this thesis comes from several sources, in particular a masters thesis (Ólafsson, P., 1999) refrigeration types are described for Icelandic conditions. Another masters thesis (Björnsdóttir, U., 2004) deals with absorption chillers and the use of lithium bromide and water mixture as working fluids.

The refrigeration systems addressed in this thesis involve compression of vapor. Conventional compression systems use electricity to run a compressor in a refrigeration cycle but absorption system can also be used, where heat is used in combination with a solution of a refrigerant and an absorbent. In order to find what system is more favorable we consider if we can reduce electricity cost by utilizing nearby heat sources (P. Srikrin, S. Aphornratana, 2001).

We address the refrigeration systems on a large scale. Examples of such systems are data centers that require powerful cooling systems, buildings with large air conditioning systems and the food plants that freeze food for storage. In Iceland, the fish industry represents a typical example of large freezing systems.

We will study a few cases for companies in the Reykjanes peninsula that use large amounts of electricity to freeze and examine if any of the cases are economical enough to replace the current system. Icelandic conditions for geothermal heat are assumed for this project. The purpose of this project is to design a freezing system that is economical in operation

and is based on the absorption method which uses heat direct and does not use electricity on the same scale as compressor systems. We will describe briefly the refrigeration systems and the theory behind them. We will look at several cases for implementations of absorption systems for Nesfiskur and Skinnfiskur and finally discuss the results.

2. Theory of refrigeration systems

Refrigeration systems discussed in this thesis are compression and absorption systems and this chapter will address a few of them and their process will be described in details. Coefficient Of Performance (COP) will be explained and issues associated with working fluids are taken into consideration. Finally the absorption model is explained in details.

2.1. Working cycles

Refrigeration systems discussed in this section are compressor system (CS) and absorption system (AS).

2.1.1. Compressor system

CS are a well known among refrigeration systems. Those systems are used in refrigerators and freezers both in homes and industry, they are the most common way to cool or freeze products. This technology uses electricity to compress the working fluid and the cycle has relatively good performance.

Coefficient of performance is a ratio that is used in refrigeration applications like compressor systems to indicate how well the system utilizes energy.

For CS the COP is calculated as:

$$COP_c = \frac{\text{Cooling capacity}}{\text{required input}} = \frac{\dot{Q}_e}{W_c} \quad (2.1)$$

where W_c is the work put into the compressor (Ólafsson, P., 1999).

Figure 2.1 shows in few steps how compressor systems work. The process from 1 – 2 is when the compressor increases the pressure of the evaporated refrigerant vapor to raise its temperature. On the suction side the compressor keeps the pressure of the liquid refrigerant low, causing the refrigerant to operate at lower temperatures.

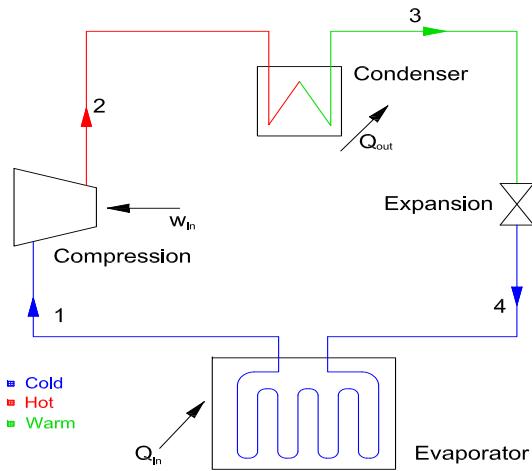
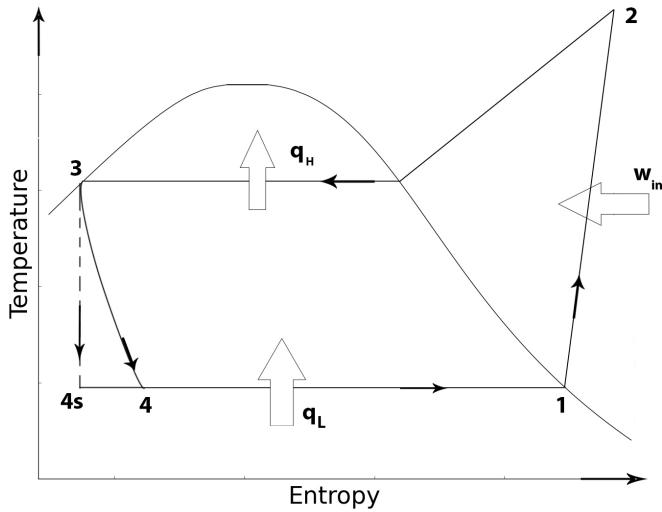


Figure 2.1: Component diagram of a compressor system



In the next step from 2 – 3 the fluid enters the condenser and heat is rejected while the pressure stays constant.

From 3 – 4 an expansion occurs under a throttling process where the enthalpy is constant. The pressure drops down as well as the temperature of the refrigerant.

The final step from 4 – 1 is when the cold liquid enters the evaporator, heat is added and the liquid evaporates. This is the part where the cooling takes place (Wulffinghoff, 1999). In figure 2.2 the relation between temperature and entropy is shown in different positions in the compression cycle where the curve shows saturation for the working fluid.

2.1.2. Single stage absorption systems

The COP for absorption systems is calculated with equation 2.2 (Ólafsson, P., 1999):

$$COP_a = \frac{\text{Cooling capacity}}{\text{required input}} = \frac{\dot{Q}_E}{\dot{Q}_g + W_p} \quad (2.2)$$

Where \dot{Q}_E is the heat taken out of the evaporator, \dot{Q}_g is the heat that is added into the system, W_p is the work put into the pump.

In absorption cycles the compressor is replaced with a generator, throttle valve, absorber and a pump as shown in figure 2.3.

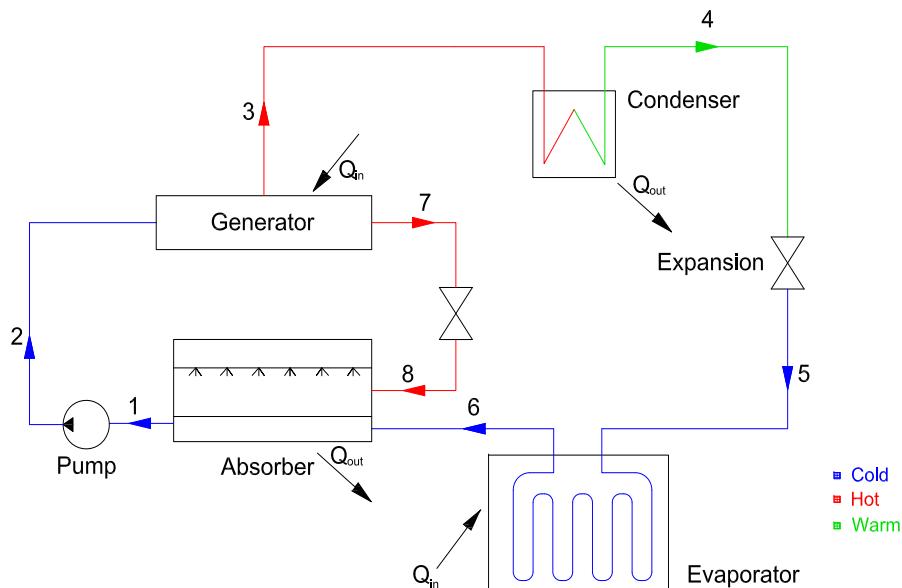


Figure 2.3: Basic absorption system

Figure 2.3 shows a schematic diagram of an absorbent cycle. A solution of a refrigerant and an absorbent is pumped into the generator at high pressure. Next, the refrigerant vapor is produced in the generator by boiling, using an external heat source. The absorbent requires higher temperature to evaporate so the refrigerant distillates for the most part. Next a strong refrigerant solution is cooled in the condenser and the vapor becomes liquid. The cool solution passes through a throttle valve where the pressure is reduced and the temperature decreases as well. Next, the refrigerant enters the evaporator and absorbs heat from the evaporator. Finally, the low pressure refrigerant is sprayed into the absorber where it mixes with the absorbent. The solution is condensed to liquid phase at the absorber output (J. C. B. Jaramillo, L. F. Pellegrini, 2010).

2.1.3. Two stage absorption system

One of the benefits of using a two stage absorption system is that it can take advantage of the higher availability of a higher temperature heat sources and achieve higher COP.

Two stage absorption chillers are usually installed in a large capacity refrigeration applications. A schematic diagram of two stage absorption is shown in figure 2.4

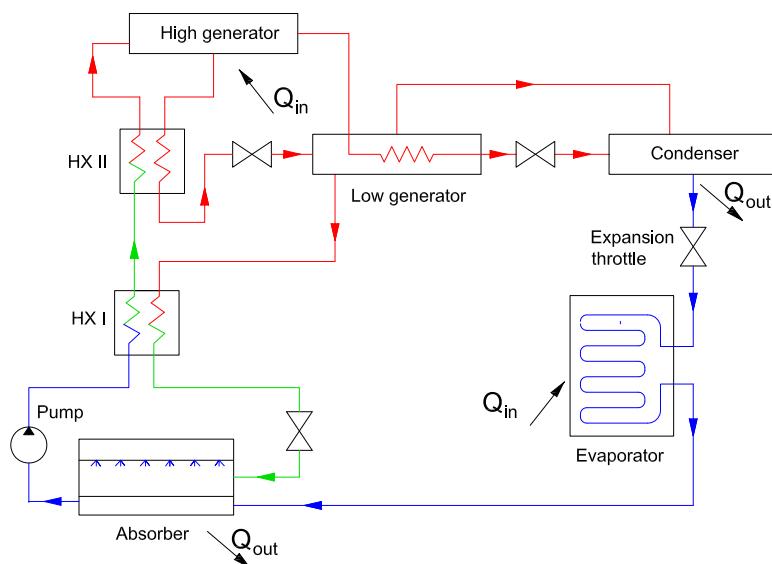


Figure 2.4: Double effect absorption system

In the two stage cycle there are three different pressure steps. First the heat is generated in the "high generator" where the pressure is the highest. The liquid from this generation is used in the "low generator" to generate heat at a lower pressure. The low pressure generator works as a rectifier for the high pressure solution. Next the high pressure solution is flashed in a throttle valve and the refrigerant vapor is mixed with the refrigerant from the low pressure generation. Next the refrigerant is condensed and throttled to the evaporation temperature. The refrigerant evaporates in the evaporator and flows into the absorber. To improve the efficiency of the cycle, heat exchangers are added between the absorber and lower generator and also between the lower and higher generator.

The two stage cycle has about 40% higher performance than single stage absorption but requires a thermal input with higher temperature (P. Srikrarin, S. Aphornratana, 2001, p. 351).

2.1.4. Comparison between compressor and absorption system

Table 2.1: Absorption system compared to compression system

Absorption system	Compression system
Uses low grade energy like heat.	Uses high-grade energy like mechanical work
Pump is the only mechanical part in the cycle, therefore the system is static and rarely needs to be serviced and maintained.	Is a dynamic system with moving parts, which means more tear and noise and needs maintenance and servicing periodically.
The system can operate on lower evaporation pressure without affecting the COP	The COP decreases with decreased evaporation pressure.
Liquid traces of refrigerant present in piping at the exit of evaporator constitute no danger	Liquid traces in suction line may damage the compressor
Automatic operation for controlling the capacity is easy	Automatic operation for controlling the capacity is difficult
Cost more and the COP is lower	Cost less and the COP is higher
Longer lifetime	Shorter lifetime

In the beginning of the twentieth century, absorption cycles with water/ammonia solution were very common and widely used. When the vapor compression technology emerged, and overtook the absorption systems. The reason was that the compression systems had a higher COP (Prof. U.S.P Shet & Mallikarjuna, 2012). Recent studies of absorption refrigeration system have demonstrated increasing importance. These systems can also be practical not only because of efficient usage of energy which would otherwise be rejected to the environment but also to consumption of electrical energy. Today, absorption systems are mainly used where fuel for heating is available but electricity is not. It is also used in industrial environments where plentiful waste heat overcomes its inefficiency.

2.2. Working fluids

The performance of the cycle depends mainly on the chemical and thermodynamic properties of the working fluid. The following elements have influence on the performance of the working fluid:

1. The liquid phase must have a margin of miscibility within the operating temperature range of the cycle.

2. It's recommended that the fluid is chemically stable, non-toxic and non-explosive.
3. The difference in boiling temperature between the pure refrigerant and the mixture at the same pressure should be as large as possible.
4. Refrigerant should have high heat of vaporization and high concentration within the absorbent in order to maintain low circulation rate between the generator and the absorber per unit of cooling capacity
5. Properties such as viscosity, thermal conductivity, and diffusion coefficient should be considered
6. Refrigerant and absorbent should be non-corrosive, environmental friendly and low cost.

There are about 40 refrigerant compounds and 200 absorbent compounds available, but $\text{H}_2\text{O}/\text{NH}_3$ and $\text{LiBr}/\text{H}_2\text{O}$ are most common ones. $\text{LiBr}/\text{H}_2\text{O}$ is used for space cooling applications where the temperature goes as low as 0°C , LiBr is then used as the absorbent and H_2O as a refrigerant (T. Ratlamwala, I. Dincer, 2012).

In the $\text{H}_2\text{O}/\text{NH}_3$ solution NH_3 is the refrigerant in the mixture. It has a freezing point of -77°C and has high latent heat of vaporization. In this thesis the $\text{H}_2\text{O}/\text{NH}_3$ mixture is used for absorption cycle applications because it has a low freezing point, and is low cost (P. Srikrarin, S. Aphornratana, 2001, p. 346).

2.3. COP found from fish muscle

One way to calculate the COP for the compression cycle, is to estimate the energy absorbed from the fish in the freezer. To compute the energy loss in the fish, the enthalpy difference has to be discovered and it depends on the initial and final temperature of the fish. Figure 2.5 (Figure found in (Rha, 1975)) shows the enthalpy difference in a fish muscle.

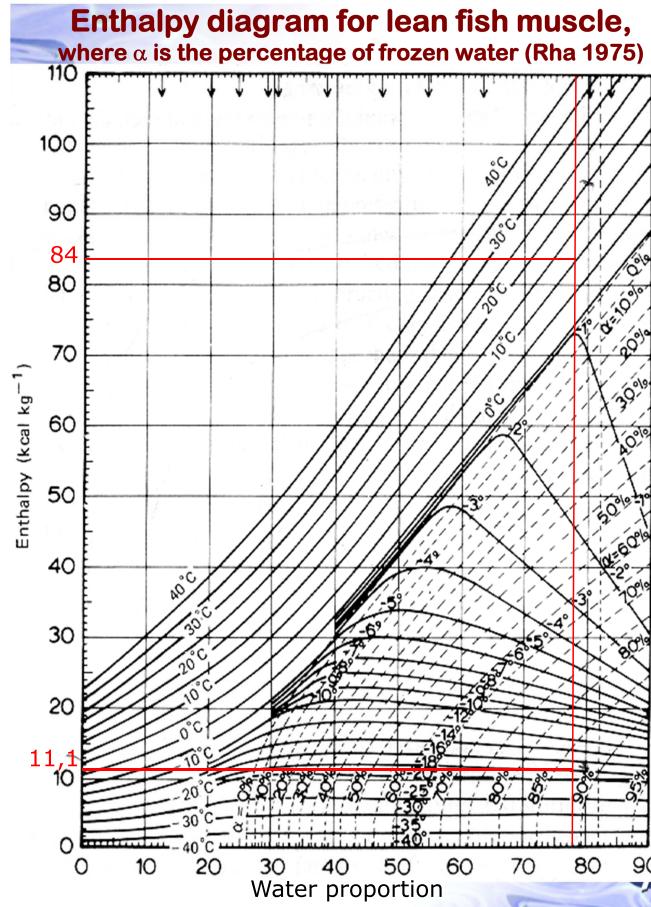


Figure 2.5: Enthalpy difference in a fish muscle from 10 – (–18)°C.

The energy needed to freeze the fish is found from equations 2.3 and 2.4:

$$Q = \dot{m} \cdot \Delta h \quad (2.3)$$

h is found in figure 2.5 and Δh is calculated from equation 2.4.

$$\Delta h = h_0 - h_{end} \quad (2.4)$$

2.4. Methodology for the calculations in the problem

This section addresses the calculations for the flow inside pipes and the pressure drop per meter. The equations for the area of the heat exchangers are discussed and equations related to the cost estimation.

The flow inside the pipe can be determined from equation 2.5:

$$G = \frac{\dot{Q}}{\rho \cdot \Delta h} \quad (2.5)$$

Where :	G	l/s	Flow
	\dot{Q}	kW	Power consumption
	ρ	kg/dm ³	Density
	Δh	kJ/kg	Enthalpy difference at inlet and outlet

The pressure drop per meter was calculated with following equations:

$$V = \frac{4Q}{\pi d_i^2} \quad (2.6)$$

$$Re = \frac{Vd_i}{v} \quad (2.7)$$

$$\frac{1}{\sqrt{(f)}} = -4.0 \log_{10} \left[\frac{\epsilon/D}{3,7} + \frac{1,26}{Re\sqrt{f}} \right] \quad (2.8)$$

$$\Delta p_f = \frac{f \rho L}{D} \frac{V^2}{2} \quad (2.9)$$

The equations listed in 2.6 and 2.9 are found in (Crowe, 2005). The equation for friction (f) is derived from the Colebrooks White equation and the pressure drop Δp_f is given by the Darcy-Weisbach equation.

The area for each heat exchanger is calculated with following equation:

$$A = Q / (\Delta T_m \times U) \quad (2.10)$$

The Logarithmic-mean temperature difference (T_m) can be calculated for counterflow heat exchanger with equation 2.11:

$$\Delta T_m = \frac{((T'_1 - T''_2) - (T'_2 - T''_1))}{\ln(\frac{T'_1 - T''_2}{T'_2 - T''_1})} \quad (2.11)$$

Where : T'_1 = Input temperature of the hot fluid[°C]
 T'_2 = Output temperature of the hot fluid[°C]
 T''_1 = Input temperature of the cold fluid[°C]
 T''_2 = Output temperature of the cold fluid[°C]

In this thesis the heat exchangers are assumed to be counterflow, where the colder fluid can then reach a higher temperature than in cocurrent flow systems.

The cost of the equipment used in the absorption system can be calculated from equation 2.12.

$$C_{PE,Y} = C_{PE,W} \left(\frac{X_Y}{X_W} \right)^\alpha \quad (2.12)$$

Where $C_{PE,Y}$ is the cost of an equipment item at a given capacity or size(X_Y), $C_{PE,W}$ is the purchase cost of the same item at a different capacity or size(X_W) and is a known parameter. α is an exponent which is found in table 2.2 (A. Bejan, G. Tsatsaronis, 1996).

To calculate the profitability we find the present value of an annuity (PVOAA), which is calculated from the present value (PV) of the annuity from the maintenance and electricity cost with addition to the initial cost (see equation 2.13) (Broverman, 1996).

$$C_t = C_c + \frac{C_e}{i} \left(1 - \frac{1}{1 + i^T} \right) \quad (2.13)$$

where : C_t = PVOAA
 C_c = Initial cost
 C_e = Annual cost
 T = Expected life time
 i = Interest rate

The annual electricity cost is calculated with equation 2.14. The time t is counted in months and the interest rate (i) is 10 %.

Table 2.2: Determination of factor α

Equipment	Variable X	Size Range	Exponent α
Pump (centrifugal;including motor)	Power	0.02 – 0.3 kW	0.23
		0.3 – 20 kW	0.37
		20 – 200 kW	0.48
Pump(vertical;including motor)	Circulating capacity	0.06 – 20 m ³ /s	0.76
Evaporator	Surface Area	10 – 1000 m ²	0.54
Flat plate heat exchanger	Surface Area	15 – 1500 m ²	0.4
Shell & tube heat exchanger	Surface Area	15 – 400 m ²	0.4
Separator(centrifugal)	Capacity	1.4 – 7 m ³	0.49

$$C_e = \sum_{t=1}^{12} \frac{C_{elect}}{(1+i)^{t/12}} \quad (2.14)$$

2.5. Absorption model

This section addresses the absorption cycles which are used in this thesis. The models which the project is based on are single stage and two stage absorption cycles. The single stage model is not as thermally efficient as the two stage model but the latter is more complex and requires a higher temperature of heat input. Additionally, the initial cost is greater (Gregory Zdaniuk & Blackwell, 2012, p. 346). To solve each case an optimization is made for chosen variables. The optimization method used is described in the end of the chapter.

2.5.1. Model of a single stage absorption cycle

A single stage absorption cycle with water/ammonia solution as a working fluid consists of a condenser, throttle valve, evaporator, absorber, rectifier, pump, generator and heat exchangers. In figure 2.6 a typical absorption cycle is shown (S.A. Adewusi, 2004,

p. 2358). The input and the output of the model are denoted by arrows, pointing to and away from the component, respectively.

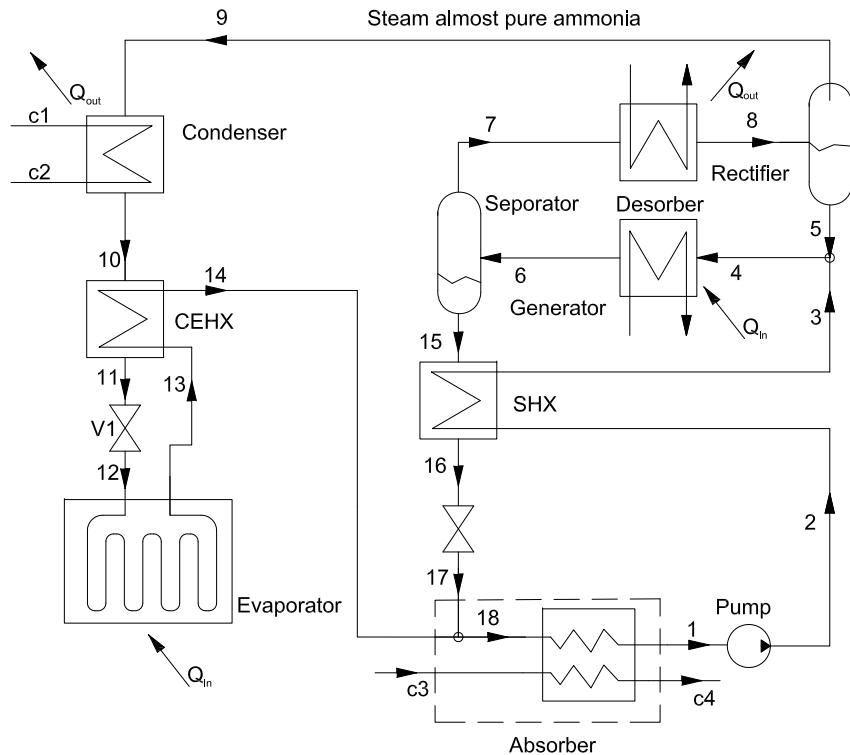


Figure 2.6: Absorption cycle

The function for each component in the cycle are as follows:

- Pump: The $\text{H}_2\text{O}/\text{NH}_3$ solution is pumped and the pressure increases. First the process is assumed to be isentropic. The ideal enthalpy (h_{2s}) is calculated where the entropy remains constant and the higher pressure is given. Then the efficiency of the pump (η_p) is given and the nonisentropic enthalpy (h_2) calculated from following equation:

$$h_2 = h_1 + \frac{h_{2s} - h_1}{\eta_p} \quad (2.15)$$

Eq. 2.16 models the work of the pump (\dot{W}_p):

$$\dot{W}_p = \frac{\dot{m}_1 \cdot v_1 (P_2 - P_1)}{\eta_p} \quad (2.16)$$

- Solution heat exchanger (SHX): The solution flows into a heat exchanger and heats

the solution with fluid from the generator. To find the heat difference in a heat exchanger the conservation of the energy is used, but it is described with following equation:

$$\dot{m}_2(h_3 - h_2) = \dot{m}_{15}(h_{15} - h_{16}) \quad (2.17)$$

- Mixing fluids: When two fluids are mixed together, energy conservation is assumed:

$$\dot{m}_4h_4 = \dot{m}_3h_3 + \dot{m}_5h_5 \quad (2.18)$$

And the mass flow balance is:

$$\dot{m}_4 = \dot{m}_3 + \dot{m}_5 \quad (2.19)$$

- Generator: An external source, heats up the solution in a heat exchanger, thus a part of the solution turns into vapor. Greater proportion of the vapor is ammonia, the reason being that the ammonia has a lower temperature for evaporation. The two phase flow separates in the separator and the liquid part flows into the SHX but the steam continues to the rectifier. Mass flow of each phase in the separator is found from the quality of the two phase flow after the heat exchanger as equations 2.20 and 2.21 describe.

$$\dot{m}_7 = q_6 \cdot \dot{m}_6 \quad (2.20)$$

$$\dot{m}_{15} = (1 - q_6) \cdot \dot{m}_6 \quad (2.21)$$

- Rectifier: The role of the rectifier is to distil the ammonia in the $\text{H}_2\text{O}/\text{NH}_3$ solution from the generator. That is done by humidifying the vapor slightly, thus the solution is hydrated. Surplus lean solution goes back to the circulation at point 5 in figure 2.6. There are two rectifiers used, reflux coolers and distillation columns.(Ólafsson, P., 1999)
- Condenser: The condenser cools down the ammonia vapor with a heat exchange process. Cold medium, flows into the condenser and condenses the vapor. Thus the ammonia becomes liquid. This is a heat exchanger process.
- Throttle Valve: The pressure of the refrigerant is reduced significantly so the temperature decreases to the value which is maintained in the evaporator.
- Evaporator: Is a heat exchanger on the suction side of the absorption cycle. This

is where the ammonia evaporates for refrigeration. The ammonia vapor enters the evaporator and the heat is transferred from the refrigerated space with a heat exchange process. If the system is designed to cool air directly, the evaporator is a air conditioner. If the role of the evaporator is to cool liquid, the refrigerant is sprayed over tubes containing the fluid to be cooled. Typically tube and shell heat exchangers are used for such processes. Another kind of an evaporator is a plate freezer but they are common when freezing food products quickly.

Where the ammonia has very low temperature at a low pressure, the designer has to choose the right type of evaporator for it to function correctly in low pressure.

- Absorber: The evaporated refrigerant (ammonia) passes into the absorber where it is mixed with an absorbent/refrigerant solution which has very low refrigerant content. This solution absorbs the vapor from the evaporator section.

Figure 2.7 (Figure taken from (Conde-Petit, 2004, p. 34)) shows an Othmer diagram (PTX) of $\text{H}_2\text{O}/\text{NH}_3$ solution. It describes the changes of temperature, pressure and the NH_3 ratio after each component in a single stage absorption cycle which is shown in figure 2.6.

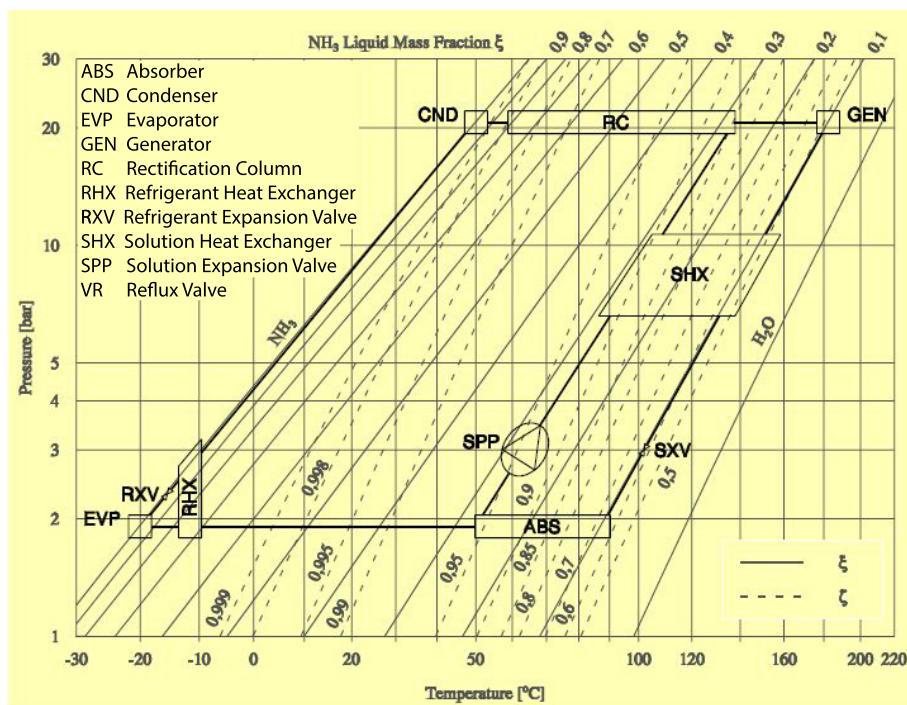


Figure 2.7: Descriptive diagram of a $\text{H}_2\text{O}/\text{NH}_3$, single stage absorption system

In figure 2.7, denotes ξ the liquid phase of the solution and ζ denotes the vapor phase.

2.5.2. Optimization

The optimization method used for this project is called CMA-ES and stands for Covariance Matrix Adaptation Evolution Strategy. CMA-ES searches for a minimal solution in a continuous domain:

$$f : \chi \subseteq \mathbb{R}^n \rightarrow \mathbb{R}, \mathbf{x} \mapsto f(\mathbf{x}) \quad (2.22)$$

CMA-ES is an evolutionary algorithm for difficult non-linear non-convex optimization problems in a continuous domain. The advantage of the evolution strategy is that gradient calculations are not necessary, only the object function values are needed, that means that the object function doesn't need to be linear. The CMA-ES method samples a number of new candidate solutions from a multivariate normal distribution and then updates the sampling distribution exclusively using the better solutions. This method resembles the principle of biological evolution where some better individuals are selected for the next generation.

The update consists of two mechanisms, the step-size control where the length of the path of the most recent iteration step are analyzed and the covariance matrix adaptation(CMA) which increases the likelihood of successful steps. This method has been used successfully in real-world problems (Guillaume Collange, 2010).

The reason for using an evolutionary algorithm for the optimization is that the function involves iteration for solution properties which can give a discontinuous solution. Therefore the gradient cannot be used.

3. Case studies and results

This chapter addresses the case studies and results. Among the issues discussed are the geothermal provider, the energy available, the electricity cost, etc. The consumers which are assumed to use the service are two companies in the fish industry, Nesfiskur and Skinnfiskur. The location of both companies is the Reykjanes peninsula (RP) in Iceland.

We will consider three cases of refrigeration system setups and calculate the profitability for each to determine if they are feasible. In the cases we use modified models of the single stage and two stage absorption systems that were mentioned in chapter 2. All the model codes are written in the python programming language, the optimizations were done with CMA-ES code (see section 2.5.2) and the drawings are generated in AutoCad.

3.1. HS veitur

HS veitur is one of the largest energy companies in Iceland and over the years the company has supplied and distributed hot water, fresh water, electricity and dispose sewage in several areas in RP and Vestmanneyjar. The energy source for the hot water and the electricity comes from a geothermal source, since RP is located in a high temperature geothermal area. The idea is to use one of the geothermal sources to produce refrigeration with absorption technology for companies nearby that consume large amounts of electric energy for refrigeration systems.

The plant studied in this thesis is a single flash geothermal power plant and is located in Reykjanes, Reykjanes Power Plant (RPP). The reason for studying this plant is that some amount of hot water is not used and discarded into the sea. The temperature of the waste water is 211 °C and the mass flow is 200 kg/s. The geothermal energy that is unused is high and there is a potential to utilize that energy. [Geir Þórólfsson Engineer at HS veitur (2012)].

The price for electricity for the general public utilities is 5.18 kr/kWh but for large power consumers (> 3000 kWh/yr) the price drops down to 3.5 kr/kWh [Jóhann Sigurbergsson at HS-veitur (2012)].

3.2. Description of the companies involved

There are few companies, mainly in the fish industry in RP that consume enough electricity for freezing to be interesting case studies for whether it's profitable to change refrigeration systems. Two companies are studied in this thesis, Nesfiskur ehf and Skinnfiskur ehf. They use compressors as described in section 2.1 which uses more electricity than absorption cycles. We will consider whether absorption systems are cheaper and a more convenient choice.

3.2.1. Nesfiskur ehf

Nesfiskur ehf is a large fishery located in Garður, RP. The distance between Nesfiskur and RPP is approximately 30.5 km.

Nesfiskur uses two kinds of freezers. One is a deep freezer where the temperature reaches a very low value, about -40°C and freezes the product in a short time. The second freezer is used to store the fish at low temperature which is about -24°C to -25°C but consumes only 18 kW so we will not consider it.

The usage of the deep freezer varies from day to day and depends on when the trawlers come ashore with the fish. When a trawler has delivered fish, it is prepared on conveyors and part goes into the deep freezer while the rest goes directly to sale. The temperature inside the deep freezer in October 2012 is shown in figure 3.1. [Friðbjörn Júlíusson at Nesfiskur(2012)].

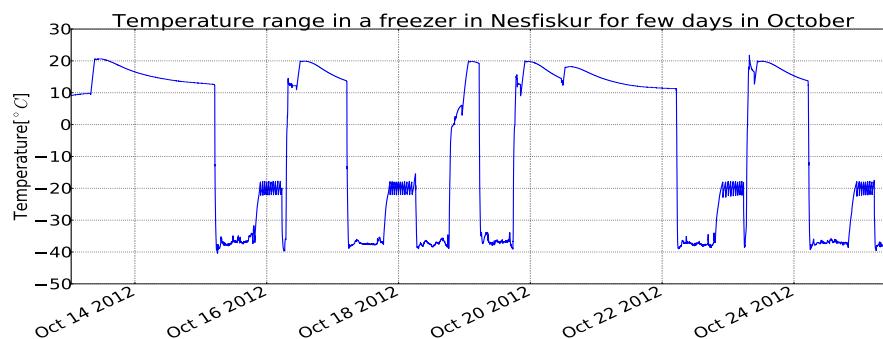


Figure 3.1: Temperature range in a deep freezer at Nesfiskur ehf.

The temperature in the evaporator varies from -40°C to -35°C until the freezing is finished. The time span of the freezing varies but from figure 3.1 it can be detected that the duration of one period is approximately 12 hours.

The medium to condense the refrigerant is seawater. The seawater is 7°C throughout the year [Friðbjörn Júlíusson at Nesfiskur(2012)]. A lot of electricity is used to maintain the low temperature in the freezer at a high refrigeration power output. The COP of the compression cycles varies from 1.44 to 2.01. The current use is 950 A and the electric

power consumption goes up to 890 kW when everything is running. The total refrigeration power output is ≈ 1700 kW. See figure 3.2

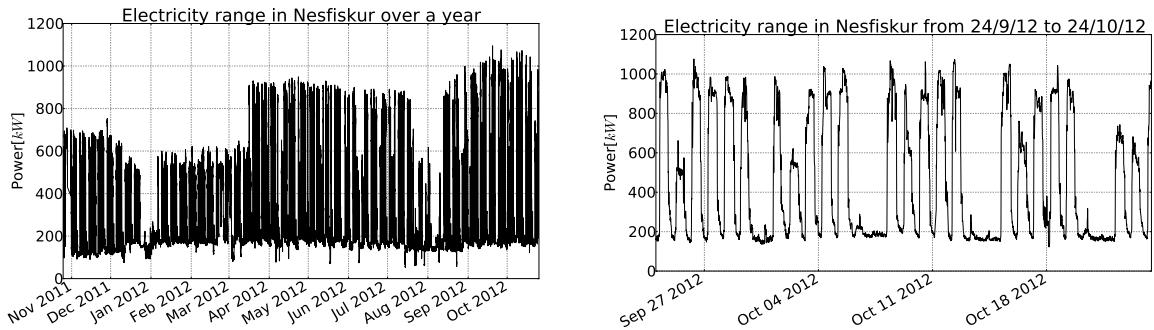


Figure 3.2: Power usage in Nesfiskur for different time periods.

The majority of energy consumed is used by the compressor but other usage includes conveyors, refrigerators and other equipment. Figure 3.2 depicts that spikes increases from October 2011 to October 2012 which means that freeze use increased in that year. In the calculations, late September and October 2012 are considered since those months included the most recent data at the time of writing. To calculate the electricity usage for the compression part, the electrical power spikes in figure 3.2 are integrated over time interval (in hours) and the other activity is subtracted from the integration, see equation 3.1.

$$I = \sum_{t_0=0}^{t_{end}} (P(t)_{Compressors} - P_{Other}) \quad (3.1)$$

In eq. 3.1 I is electricity consumption in kWh, t_0 and t_{end} define the time span and P_{Other} is approximated as 150 kW. The power consumption for the compressors from sept. to okt. is 227.000 kWh, the electricity cost for the freeze is listed in table 3.1¹

¹Electricity price list obtained from HS-Orka and HS-Veita

Table 3.1: Electricity cost at Nesfiskur

HS-Orka	Used Elect.(kWh)	Price rate(kr/kWh)	Price(kr)
Energy tax	227, 240.90	0, 12	27, 268.9
Energy rate	227, 240.90	3.51	797, 615.6
25, 5% VAT			210, 345.5
Total			1, 035, 230
HS-Veita			
Distribution price	227, 240.90	1.98	449, 937
Transportation price	227, 240.90	0, 83	188, 609.9
25, 5% VAT			162, 829.5
Total			801, 376.4
Total			1, 836, 606

More detailed information about the freezers can be found in table 3.2.

Table 3.2: Power used by the freezers in Nesfiskur.

Type	Evap. temp.(°C)	Power in.(kWh)	Evap. out.(kW)	COP
Blast freezer 1	-40	260	375	
Blast freezer 2	-40	310.13	511.72	
Screw Compressor 1	-35	214	387	
Screw Compressor 2	-40	167	336	
freezers 3x	-40	60	86.4	1.44
Total		1011.13	1696.1	1.67

Table 3.3: Other refrigeration systems that are not taken into consideration but could be replaced with an absorption system.

Type	Evap. temp.(°C)	Power in.(kW)
Raw food cooler	2	18
Storage freezer	-22	25
Bacalao cooler	5	15
Fillet cooler	2	15
Total		133

The unit for capital in the calculation is Million Icelandic krona(MISK). The annual cost for maintaining the compression system is 2.4 (MISK) [Friðbjörn Júlíusson at Nesfiskur].

3.2.2. Skinnfiskur ehf

Skinnfiskur ehf is located in Sandgerði which is about 27.4 km from RPP. Their product is frozen fish offal for animal consumption for external and internal markets. To freeze their

product they use similar technology as Nesfiskur. The freezer has two steps, lower step compression and higher step compression. The lower step runs on lower temperature, around -3°C to -8°C but for the higher step the temperature ranges from -32°C to -37°C on the suction side of the compressor. Table 3.4 shows data for compressors running at the date Nov 11. 2012, describing a typical day at Skinnfiskur. The temperature drops from the evaporator to the compressor due to pressure difference. The ideal temperature to be contained in the evaporator is -40°C [Sigurður Jónas Bergsson technologist at Frosti hf].

Table 3.4: Power use of the compressors at Skinnfiskur.

Type	Compressor Temp.(suction side)($^{\circ}\text{C}$)	Power in(kW)
High step compressor 1	-37	142.7
High step compressor 2	-32	150.34
Low step compressor 1	-5.8	119.9
Low step compressor 2	-3.5	122.6
Total		535.54

Table 3.5 shows how one compressor would function instead of all four compressors, this is done to simplify the calculations.

Table 3.5: Ideal Compressor

Type	Evaporator Temp.($^{\circ}\text{C}$)	Power in(kW)	Evap. out.(kW)	COP
Ideal compressor	-40	535.54	1017.53	1.9

It is hard to determine the COP for the system but it is approximated to be 1.9 for each compressor assembly [Sigurður Bergsson at Frosti].

The freezer is a plate freezer but the fish is planted in trays and placed in the freezer. Next the fish is cooled from 10°C to -18°C . The freezer can ingest about 13.3 tons at a time, and the duration of each replacement is 100 min. [Skúli Guðmundsson at Skinnfiskur ehf].

If the COP is calculated from the fish muscle, which is described in section 2.3 from the given condition, the real COP of the present system should be 1.264. Here we assume that all the refrigerating energy goes directly into the fish with no losses of energy out of the system. However in reality the energy loss in the freezer is unavoidable.

The electricity cost for October 2012 is 1.057 MISK for electric power consumption and 0.933 MISK for the electric distribution fee. A total of 1.990 MISK [Electric cost at Skinnfiskur for October 2012].

By using a two step compression systems the efficiency increases at the expense of capital cost. The electricity cost at Skinnfiskur varies from month to month but depends on how much of the material is imported from other fisheries.

The annual cost for maintaining the compression system is 1.6 MISK [Bárður Bragason at Skinnfiskur]

3.3. Case A - Pipeline from Reykjanes to Skinnfiskur and Nesfiskur

In case A we consider hot water from a geothermal source to heat the working fluid in an absorption cycle, the geothermal source being RPP. The main expense comes from pipe construction for transporting the geothermal water, where it is used in an absorption cycle. A problem can occur if the water from the geothermal borehole is transferred over long distances. Silica particles can form scaling along the way when the temperature of the liquid decreases. Therefore a groundwater source is used as a mediate and heated up in a heat exchanger and then sent to the refrigeration plant. Suggestion to changes on RPP is shown in figure 3.3

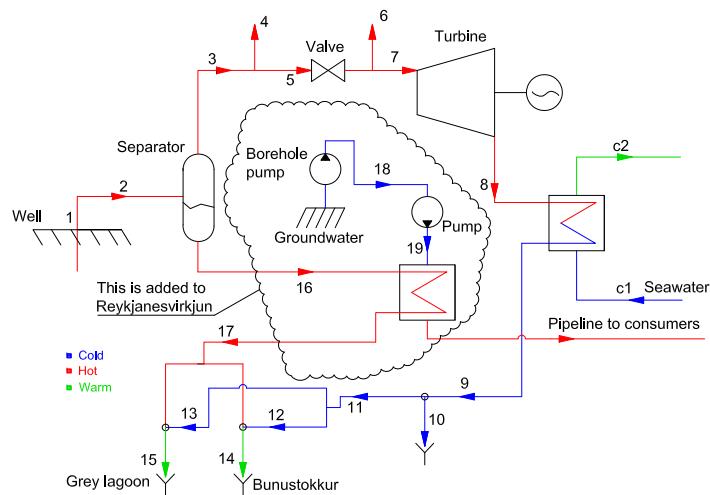


Figure 3.3: Reykjanes power plant after possible changes

The mass flow at point 16 in figure 3.3 is 244 kg/s (Benediktsson, D. Ö., 2010, p. 8) at 211 °C with pressure at 19,8 bar (Jóhannesson, P., 2011).

The surplus water in RPP would be transported through pipelines specially constructed for this project. The distance is quite long, from Reykjanes to Sandgerði and Garður as shown in figure 3.4. In the scenario, the water to Skinnfiskur and Nesfiskur has a shared pipeline, large part of the route. This means they can share expenses for the pipeline. Skinnfiskur would pay weighted proportion of the fee for the first 26,3 km of pipeline along with Nesfiskur and then pay the last 2,0 km exclusively while Nesfiskur would pay for 6,0 km of the pipeline for themselves. The cost of the pipeline depends on the diameter of the pipe, which can be determined from the water consumption.



Figure 3.4: Pipeline from RPP to Skinnfiskur and Nesfiskur [Map taken from www.ja.is].

3.3.1. Nesfiskur

In this section we address how the absorption system for Nesfiskur would function for case A. We determine the flow from RPP, choice of heat exchangers, pressure drop in the pipelines from RPP and more related.

To compute the mass flow and temperature required for the absorption cycle, we have to optimize and modify the single stage model which is shown in figure 2.6. After the modification the SHX and CEHX are removed from the model. Modified model for this case is shown in figure 3.5

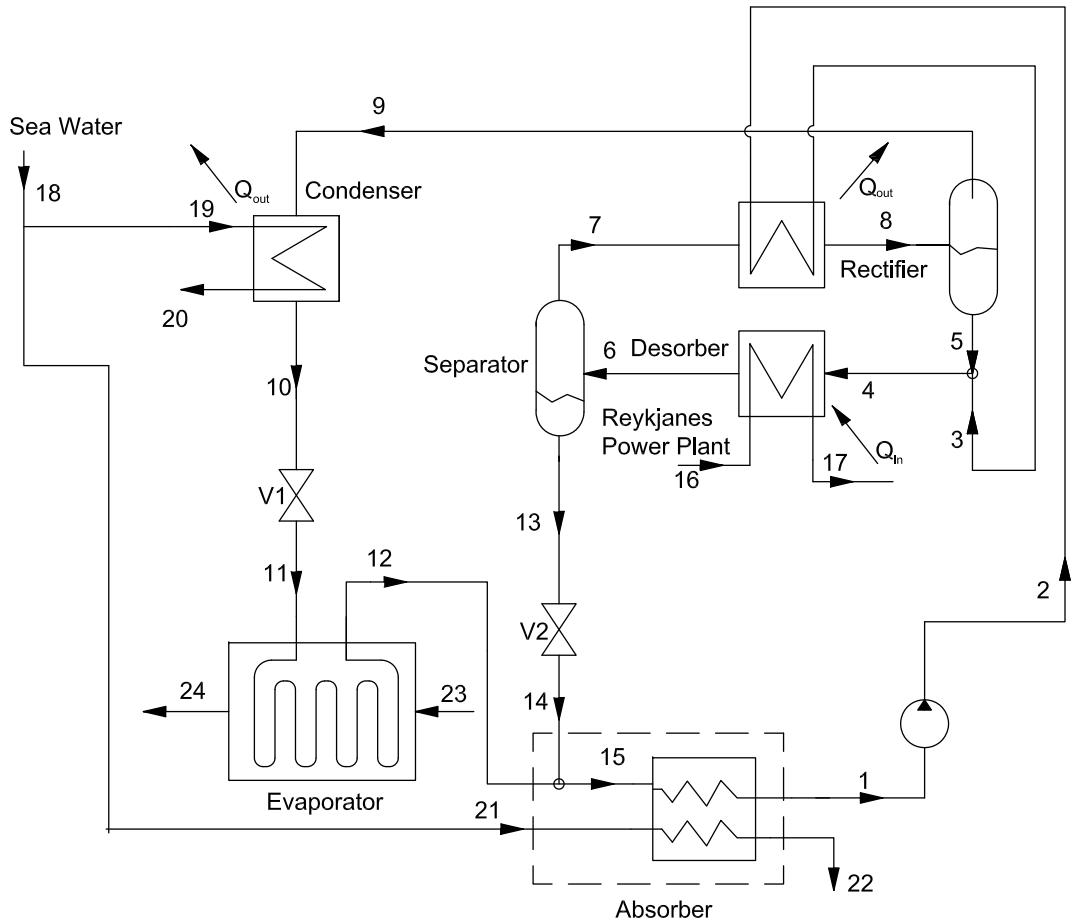


Figure 3.5: Modified single stage absorption cycle for case A

Since the thermal energy of the source water from RPP is very high we can remove SHX and CEHX from figure 2.6 and utilize the source in the desorber. This lowers the COP but it does not affect the power output of the evaporator. This is done to lower the expense of the model.

Optimizing the mass flow is a problem with several constraints:

- Mass flow of water from RPP can be up to 200 kg/s and the temperature can be maximum 206 °C at 18, 6bara.
- Steam from the rectifier is almost pure ammonia thus the evaporator can run on low temperature.
- The coolant in the condenser is the seawater which has the temperature 7 °C, which means that it can't cool lower than 12 °C since it is assumed that the pitch in the heat exchanger is 5 °C.
- Heat output from the evaporator is approximated 1700 kW at temperature of –40 °C
- The mass flow must be conserved and be equal at points 15 and 1 in figure 3.5.
- The fluid from the absorber must be in liquid phase and the temperature above 12 °C.
- Temperature of the water in the pipelines from RPP can reach up to 160 °C but that is the design temperature for the pipelines from SET (Set, 2012).

The optimization involves minimizing the mass flow from RPP provided that the evaporator heat output should be 1700 kW. the mass flow is minimized for the provided evaporator output. Next the constraints for certain variables are created within reasonable limits. Now the mass flow from Reykjaness power plant is optimized with respect to:

1. The high pressure that the pump produces (p_{high})
2. $\text{NH}_3 : \text{H}_2\text{O}$ ratio at point 1
3. Mass flow of the working fluid at point 1 (\dot{m}_1)
4. Temperature of the working fluid at the desorber output (T_6)

Results from the optimization are shown in table 3.6.

Table 3.6: Optimization for the mass flow from RPP, case A - Nesfiskur

\dot{m}_1 [kg/s]	p_{high} [kPa]	$x[\text{NH}_3, \text{H}_2\text{O}]$	T_6 [°C]	\dot{m}_{16} [kg/s]	Q_{evap} [kW]	COP
11.98	700.47	[0.3393, 0.6607]	99.87	13.384	1700.0	0.252

The COP for the optimization is 0.626 which would generally not be considered efficient. The power of the circulation pump in the cycle is 9.44 kW with 90 % efficiency. There is a clear interaction in the optimization between the $\text{NH}_3 : \text{H}_2\text{O}$ ratio and the high pressure. Fig. 3.6 depicts how the power in the evaporator changes with aforementioned variables.

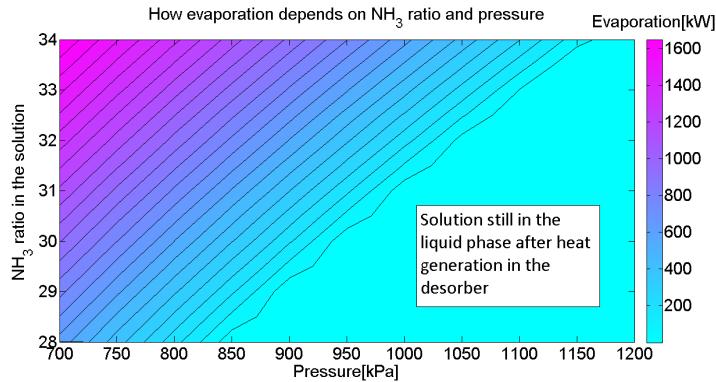


Figure 3.6: How evaporation power depends on pressure and the NH₃ : H₂O ratio.

Results for the properties at each point in the diagram (fig. 3.5) is found in section A.1 under Appendix A.

That is because the cost of the pipe depends on the pipe diameter. The temperature of the water should also be considered where the temperature tolerance limit of the pipe is restrictive and the lifetime of the pipe decreases with higher temperature where the isolation of the pipe has limited tolerance. The temperature of the district heating pipes purchased from Set hf are designed for a maximum at 160 °C. If the temperature is higher another type of pipe has to be chosen and the pipe cost will increase significantly [Örn Einarsson, Engineer at Set hf (2012)].

The necessary flow in the pipes from Reykjanes can be calculated from equation 2.5:

$$\begin{aligned} \text{Where : } G &= 14.745 \text{ l/s} \\ \dot{Q} &= 6,791.0 \text{ kW} \\ \rho &= 0.9077 \text{ kg/dm}^3 \\ \Delta h &= 675.8 - 168.3 \text{ kJ/kg} \end{aligned}$$

Available pipe diameters are given at Set hf with the cost per meter (Set, 2012). The Pressure drop (Δp_f) and the velocity (V) of the flow is calculated in table 3.7 for the design.

Table 3.7: Flow in different pipe diameters

d _i [mm]	Q[m ³ /s]	V[m/s]	Re	f	Δp _f [Pa/m]	C _p [kr/m]
125	0.014745	1.202	799, 941	0.0123	64.21	5080
150	0.014745	0.8344	666, 617	0.0126	26.55	6300
200	0.014745	0.469	499, 963	0.0132	6.61	9580

The pressure drop per meter was calculated with equations from 2.6 to 2.9. In the standards

in (Set, 2012) it's recommended that the pressure drop does not exceeds 100 Pa/m, therefore the 125 mm pipe should be chosen for Nesfiskur.

Choosing the right heat exchanger can be difficult. There are many types available but those who are mostly used are plate and shell & tube heat exchangers. Low cost is very important in the design and the shell and tube type are rather chosen where the plate heat exchangers are more expensive.

Table 3.8 lists all the detailed information for each heat exchanger.

Table 3.8: Overall heat coefficient, area and energy consumption for heat exchangers - Case A, Nesfiskur

Comp.\Var.	Type	U[kW/m ² K]	Q[kW]	A[m ²]
Desorber	Shell&Tube	0.71	6791.0	934.4
Rectifier	Shell&Tube	0.71	1141.5	31.3
Condenser	Shell&Tube	0.71	1973.3	479.3
Evaporator	Plate freezers	1.65	1700.1	32.1
Absorber	Shell&Tube	0.71	6530.3	1783.8

Value for U can vary, it's related to the individual film heat transfer coefficients, fouling and wall resistances, massflow and the outside surface area. U in table 3.8 is calculated from U values are for Evaporator found in (Granryd, 2009), other U values found in (Spang, 2012)). The evaporator is assumed to be a plate freezer which are designed to quick freeze food products like fish. The evaporator is not taken into account in the cost estimation since it is possible to use the existing one at Nesfiskur.

The temperature profiles for each heat exchanger can be found in figure A.1. The constraints for counterflow heat exchangers is that the temperature of each liquid can not cross the pitch which we use as 5 °C. The pitch is the minimum temperature difference between the fluids. In figure 3.7(a) and 3.7(b) we observe that the lines are parallel at 5 °C distance from each other which means that the model is successfully optimized.

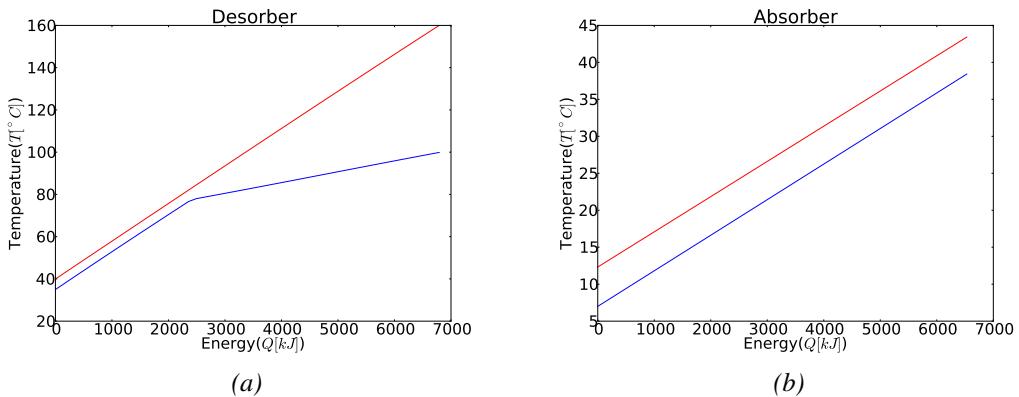


Figure 3.7: Heat exchange process for the desorber and absorber

3.3.2. Skinnfiskur

In this section we address the calculations for Skinnfiskur. The methodology is the same as in section 3.3.1, but the conditions are not the same. The model is the same but the evaporation power output is less.

For Skinnfiskur the optimization conditions change. The Evaporator output is now 1020 kW. The optimization is executed in CMA-ES for high pressure (p_{high}), $\text{NH}_3 : \text{H}_2\text{O}$ ratio and the mass flow of the working fluid at point 1 and T_6 (see figure 3.5). Results for this optimization is shown in table 3.9

Table 3.9: Optimization for the mass flow from RPP - case A, Skinnfiskur

\dot{m}_1 [kg/s]	P_{high} [kPa]	$x[\text{NH}_3, \text{H}_2\text{O}]$	T_6 [°C]	\dot{m}_{16} [kg/s]	Q_{evap} [kW]	COP
9.00	700.0	[0.34, 0.66]	94.84	8.46	1020	0.222

Properties for each point in the cycle along with the temperature profile for each heat exchanger can be found in section A.2 under the Appendix A. The COP of the cycle is 0.222 which is similar to the COP at Nesfiskur and the work of the circulation pump is 7.1 kW.

To determine the pipeline diameter, the pressure drop per meter is found from equations 2.5, 2.6, 2.9, 2.8 and 2.7. Results are shown in table 3.10

Table 3.10: Flow in different pipe diameters - Skinnfiskur

d_i [mm]	Q [m^3/s]	V m/s	Re	f	Δp_f [Pa/m]	C_p [kr/m]
125	0.00932	0.759	505.626	0.01325	27.73	5080
150	0.00932	0.527	421.355	0.0137	11.49	6300
200	0.00932	0.297	316.016	0.01438	2.87	9580

The most sensible choice for Skinnfiskur is the 125 mm diameter, It's cheapest and the pressure drop is within limits.

The result for heat exchanger characteristic is shown in table 3.11. The methodology is the same here as in section 3.3.1.

Table 3.11: Overall heat coefficient, area and energy consumption of heat exchangers - Case A, Skinnfiskur

Comp.\Var.	Type	U [kW/ m^2K]	Q [kW]	A [m^2]
Desorber	Shell&Tube	0.71	4597.7	455.4
Rectifier	Shell&Tube	0.71	524.7	14.1
Condenser	Shell&Tube	0.71	1184.1	266.0
Evaporator	Plate freezer	1.65	1020.0	19.23
Absorber	Shell&Tube	0.71	4442.4	1228.3

The pipeline is a little longer than the 26,3 km straight line from RPP to the pipe junction shown in fig. 3.4. A few more kilometers are added due to extra loops on the way to reduce the thermal expansion and also because the pipeline is not in straight line due to landscape. This doesn't affect the calculation much. The diameter for the pipe is found out with the flow from Skinnfiskur and Nesfiskur which is $\dot{m} = 24.065 \text{ dm}^3/\text{s}$. Now we deduce the diameter like before (see table 3.12).

Table 3.12: Pipe diameters - Skinnfiskur and Nesfiskur

$d_i[\text{mm}]$	$Q[\text{m}^3/\text{s}]$	$V[\text{m/s}]$	Re	f	$\Delta p_f[\text{Pa/m}]$	$C_p[\text{kr/m}]$
125	0.024065	1.961	1,305,566	0.0113	158,2	5080
150	0.024065	1.362	1,087,972	0.0116	65.2	6300
200	0.024065	0.7660	8,159,79	0.0121	16.2	9580
250	0.024065	0.4902	652,783	0.0126	5.4	14,085

In table 3.12 the cost per meter is quite high, the diameter ranges from 150 mm to 200 mm, the economical choice being 150 mm. The pressure drop is within limits. The table only shows the flow if both systems are running at the same time at Nesfiskur and Skinnfiskur. Storage tank near the pipeline junction would work as a buffer so the flow from RPP doesn't need to be as much and can be controlled in a better manner. Then the water could be dispensed to the companies when required. The benefits from this is that the pressure drop in the pipelines decreases.

The pressure drop due to the length of the pipe is:

$$\Delta p_{Nes,Skinn} = 1,714.8 \text{ kPa} \quad (3.2)$$

The pressure drop from the separation of pipeline to Nesfiskur is $\Delta p_{Nes} = 385.26 \text{ kPa}$ and to Skinnfiskur $\Delta p_{Skinn} = 55.46 \text{ kPa}$. This means that the pump or pumps have to increase the pressure up to 4475 kPa to reach 1100 kPa at the end.

3.3.3. Cost estimation

In this section we address the cost for each case and examine whether it's feasible for the companies to choose one of the cases.

It is assumed that both companies will agree choosing the same case, the cost is divided where there is need to determine the cost for the pipes and the pumps.

The cost analysis for case A divides into two parts, initial cost and annual cost. The initial cost factors for the setup of the system are:

- The pumps: Borehole pump to supply ground water which is heated up in RPP. Stage pump to increase the pressure from RPP to Garður and Sandgerði and a circulation pump that is used in the cycle.
- The pipelines: Pipeline from RPP to Garður and Sandgerði.
- Heat exchangers: In the absorption cycle
- Construction cost
- Other devices: Expansion valves, control valve, electrical control & monitor system.
- Civil structural and architectural work
- Design and supervision

Annual cost is low for this project, since the system mainly has mechanical components which rarely fail, but the cost can increase if the electricity usage for the pumps becomes an issue, mainly the stage pumps.

The weighted cost ratio between Nesfiskur and Skinnfiskur depends on the mass flow needed for each company. The share ratio for Nesfiskur is 0.6127, calculated from mass flow(m_{16}) in tables 3.6 and 3.9. The pipe is the largest cost factor. The total piping cost for Nesfiskur is $C_{p,n} = 132$ MISK. Equation 2.12 is used to calculate the cost of the equipment used in the absorption system.

Cost analysis for heat exchangers and pumps are listed in table 3.13

Table 3.13: Estimate cost for components in case A - Nesfiskur

Comp.\Var.	C_{PE,W}[MISK]	X_W	X_Y	α	C_{PE,Y}[MISK]	Total[MISK]
Borehole pump	1.01	31.9 kW	19.9 kW	0.48	0.806	0.49
Stage pump	2.080	40.3 kW	123.0 kW	0.48	3.554	2.18
Circulation pump	0.890	18.93 kW	9.4 kW	0.37	0.688	0.69
Pumps total						3.36
Desorber	111.104	850 m ²	934.4 m ²	0.4	115.39	115.39
Rectifier	111.104	850 m ²	31.3 m ²	0.4	29.661	29.66
Absorber	111.104	850 m ²	1783.8 m ²	0.4	149.452	149.45
Hx.Total - Hx						294.5

The Stage pump and the borehole pump are located in RPP and are bought for Nesfiskur and Skinnfiskur which divide the cost. The condenser and evaporator are already in use at Nesfiskur and they can be used in this case as well.

It is assumed that the expansion valves, control valve, electrical control & monitor system cost 5 % of the pump and heat exchangers, which is 14.8 MISK. The source for the cost of the heat exchanger wished to remain undisclosed.

The cost analysis for Skinnfiskur is calculated in the same manner as for Nesfiskur. The pipe cost for Skinnfiskur is 74.3 MISK. The costs for pumps and heat exchangers are listed in table 3.14, the reference price is the same as in table 3.13.

Table 3.14: Estimate cost for components in case A - Skinnfiskur

Comp.\Var.	X_Y	Total[MISK]
Borehole pump	19.9 kW	0.31
Stage pump	123 kW	1.38
Circulation pump	123 kW	0.62
Total - Pumps		2.31
Desorber	455.4 m ²	86.56
Rectifier	14.1 m ²	21.56
Absorber	1228.3 m ²	128.73
Total - Hx		236.85

The cost for expansion valves, control valve, electrical control & monitor system is 11.87 MISK

If the companies agree on choosing case A a rough estimation on the investment cost would be as listed in table 3.15 (Ólafsson, P., 1999, p. 55).

Table 3.15: Breakdown of total capital investment, Case A

Direct Cost (DC)		Nesfiskur	Skinnfiskur
	Onsite cost (ONSC)	(MISK)	(MISK)
Pipes	132.0	74.3	
pumps	3.4	2.3	
Heat Exchangers	295.5	236.9	
Electrical control& monitor system	14.8	11.9	
Total ONSC	445.7	325.4	
Offsite cost (OFSC)			
Civil, structural and architectural work 15% of ONSC	66.8	48.8	
Total DC	512.5	374.2	
Indirect Cost (IDC)			
Engineering and Supervision (10% of DC)	51.3	37.4	
Construction cost (15% of DC)	76.9	56.1	
Total IDC	128.2	93.5	
Total Capital Investment (TCI)	640.6	467.7	

The investment cost is very high compared to the other cases and it is likely that table 3.15 is an underestimation as the cost will increase due to components and other charges that are not mentioned.

The annual cost is the annual maintenance cost(C_m) of the absorption system and the electricity cost (C_{elect}) of the pumps. The usage from the freezers are approximately 70% per month(seen from figure 3.2) and the electricity price per kWh is calculated with the reference to table 3.1. To calculate the annual electricity cost equation 2.14 is used and PVOAA is calculated from equation 2.13.

For the present value of an PVOAA, the time span is 30 years with the interest rate of 10 %. In table 3.16 the unchanged compressor system (UC) is compared to case A (CA) version.

Table 3.16: present value of an annuity for case A and current mechanism

	Nes UC [MISK]	Sk UC [MISK]	Nes CA [MISK]	Sk CA [MISK]
Electricity	20.98	22.69	6.16	6.48
Maintenance	2.40	1.67	0.30	0.30
Annual Cost(C_e)	23.38	24.36	6.46	5.78
Initial cost	105	80	640.0	467.7
PVOAA	338.0	347.8	700.9	522.19

The PVOAA shows that case A is not feasible and is not recommended for either company. The electricity cost is calculated with the index rate of 10% on year basis. The operating cost is much higher with the CS.

3.4. Case B - Use of a district heating system

Another approach is evaluated to find an economical solution for Nesfiskur and Skinnfiskur. That is to use the district heating system from HS-veitur. The capacity of the district heating system at Vellir in Keflavik is approximately 150 l/s in addition to the hot water that is in use and the temperature of the water is 90 °C. It's possible to use this heat in an absorption cycle and return the water into the district heating system at a temperature above 70 °C, which is the normal temperature of the hot water for general use (See figure 3.8).

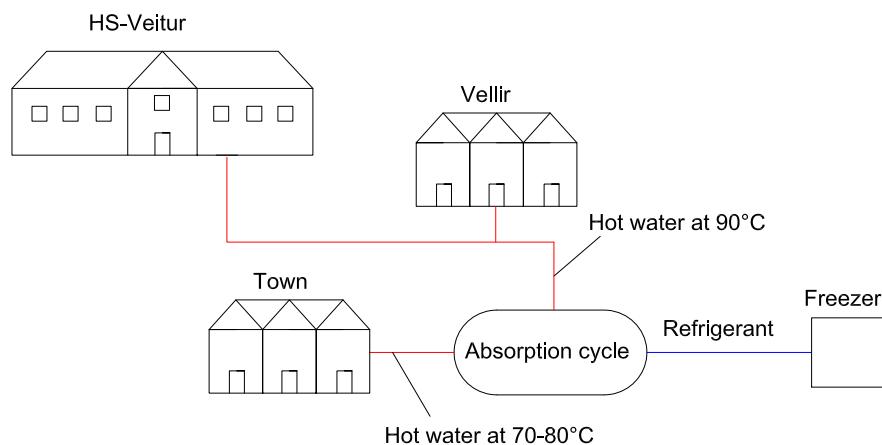


Figure 3.8: Modified District heating system

The map of the pipeline from Vellir is shown in figure 3.9 (Map is taken from www.map.is).



Figure 3.9: Pipeline from Vellir to Skinnfiskur and Nesfiskur

Case B addresses the optimization for the absorption cycle with challenging constraints where the temperature of the source is low and the flow is limited. We will consider

whether the system is feasible with the limited flow.

The problem changes, now the efficiency is more important and it is necessary to use heat exchangers to increase the COP.

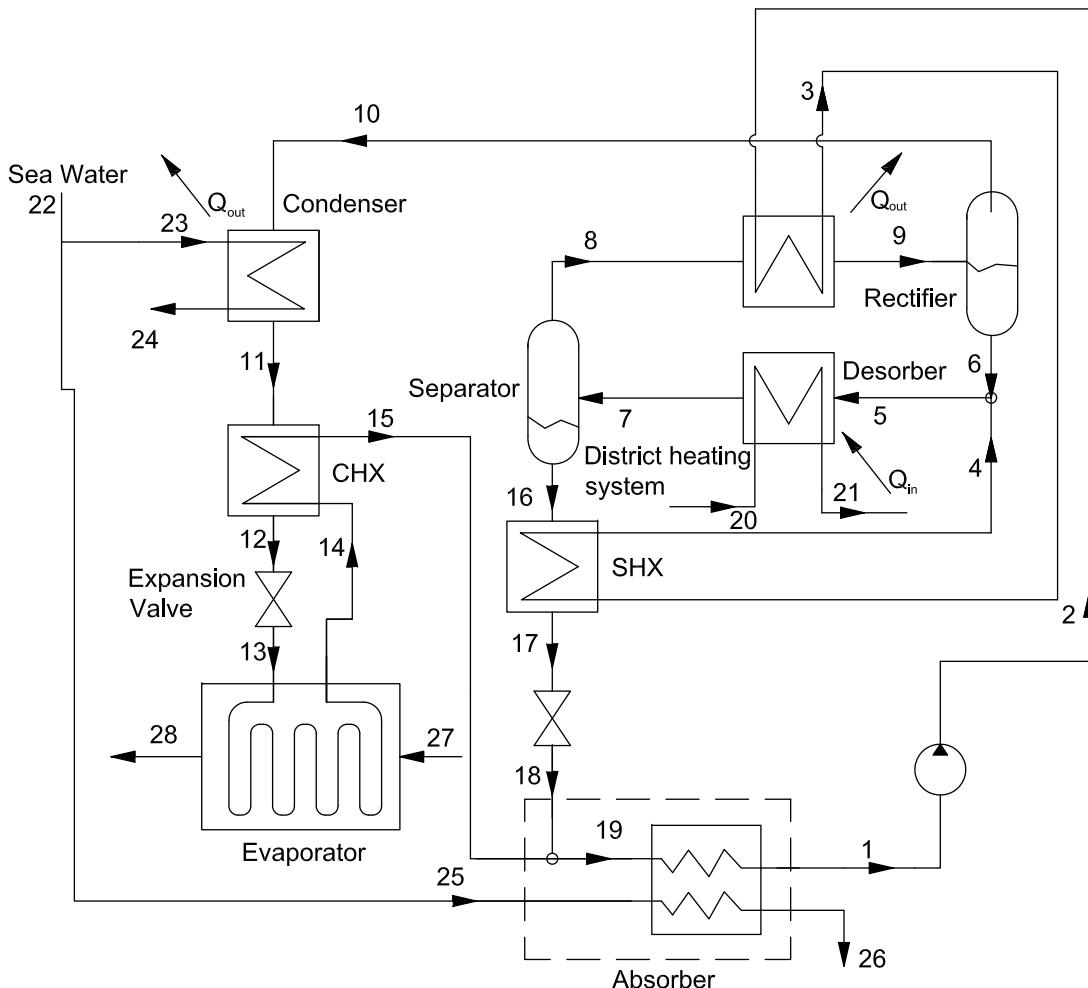


Figure 3.10: Modified single stage absorption cycle for case B

The following constraints for case B are different from case A.

- The temperature from the source is 90°C
- The source water out of the desorber must be above 70°C
- The maximum flow from HS-veitur is 150l/s
- Evaporator output must be above 1700 kW and maintain -40°C temperature.

Other relevant constraints are listed in section 3.3.1

When case B was optimized the constraint for higher pressure was lowered to 658 kPa but

it can't be any lower, since the condenser should be capable of liquidizing the refrigerant. The consequences of having lower pressure is that the flow of the coolant in the condenser will increase significantly which means we require more power for pumping seawater into the condenser.

The task is well constrained and there are not many variables to optimize. The NH₃ ratio at point 10 is set to 99,6 % to allow the higher pressure to go lower. The purpose of having lower pressure is to allow the solution to have a greater evaporation at 85 °C which is the maximum heating. NH₃ ratio at point 1 is 34 %.

3.4.1. Nesfiskur

We deduce the right mass flow of the working fluid and present the results in table 3.17 for the optimization.

Table 3.17: Optimization for the mass flow from the district heating system - Case B, Nesfiskur

\dot{m}_1 [kg/s]	\dot{m}_{20} [kg/s]	\dot{Q}_{Evap} [kW]	COP
26.923	103.19	1700	0.343

The mass flow of the working fluid has increased from case A but that's to be expected as only 6,4 % of the solution evaporates after the generation compared to 16 % in case A. The values for each point are found in section A.3. The work of the circulation pump is 19.77 kW. The COP is surprisingly high considering the low generation temperature. The results for the heat exchangers are shown in table 3.18 and the properties of the working fluid at each point and the temperature profiles in the heat exchangers are found in section A.3 in Appendix A.

Table 3.18: Area and energy consumption of the heat exchangers in - Case B, Nesfiskur

Comp.\Var.	Type	Q[kW]	A[m ²]
SHX	Shell&Tube	6020.6	184.2
Desorber	Shell&Tube	4929.6	1263.8
Rectifier	Shell&Tube	572.5	16.1
Condenser	Shell&Tube	2005.8	569.2
CEHX	Shell&Tube	101.3	25.1
Evaporator	Plate freezer	1700.1	30.6
Absorber	Shell&Tube	4644.0	1272.2

3.4.2. Skinnfiskur

The same calculation is performed for Skinnfiskur but the refrigeration power in the evaporator is now 1020 kW .

Table 3.19: Optimization for the mass flow from the district heating system - Case B, Skinnfiskur

\dot{m}_1 [kg/s]	\dot{m}_{20} [kg/s]	\dot{Q}_{Evap} [kW]	COP
16.28	61.91	1020	0.343

The result shows that if both systems are running continuously, the district system cannot sustain the demand where the total flow would be 165.1 kg/s to Skinnfiskur and Nesfiskur. The properties of the heat exchangers are found in table 3.20. The work of the circulation pump is 11.9 kW. Other results can be found in section A.4.

Table 3.20: Area and energy consumption of the heat exchangers at - Case B, Skinnfiskur

Comp.\Var.	Type	Q[kW]	A[m ²]
SHX	Shell&Tube	3612.2	110.5
Desorber	Shell&Tube	2957.6	758.4
Rectifier	Shell&Tube	343.5	9.7
Condenser	Shell&Tube	1203.4	321.0
CEHX	Shell&Tube	60.8	15.0
Evaporator	Plate freezer	1020.0	18.4
Absorber	Shell&Tube	2786.3	763.3

3.4.3. Piping system and pressure drop

The pipeline is connected to the pipeline in Vellir (see figure 3.9) from where the water is transported to its destination point. The pipe is divided in to three parts:

- Shared part, where the mass flow is 165.1 kg/s and should provide hot water for both Nesfiskur and Skinnfiskur.
- Pipeline to Nesfiskur, the joint pipeline splits into two parts. The mass flow to Nesfiskur is 103.2 kg/s.
- Pipeline to Skinnfiskur, the mass flow to Skinnfiskur is 61.9 kg/s.

The calculations in table 3.21 are based on equations that are described in section 3.3.1.

Table 3.21: Chosen pipe diameters in case B

Element.\Variable	L[m]	$\dot{m}[\text{kg/s}]$	$\Delta p_f[\text{Pa/m}]$	$p_f[\text{kPa}]$	$d_i[\text{mm}]$	$C_P[\text{kr/m}]$
Pipe(shared)	8300	165.1	89.7	744.5	300	20,282
Pipe(Nesfiskur)	5200	103.2	91.2	474.2	250	14,085
Pipe(Skinnfiskur)	3000	61.9	104.8	314.4	200	9,580

A stage pump is used to maintain the pressure, located in Vellir and needs to increase the pressure difference to 1218.7 kPa which means that the power consumption of the pump is 231.3 kW.

3.4.4. Cost estimation

The methodology in this section is similar to the method used in section 3.3.3. First the cost analysis for each component is examined for both companies then the total capital investment is determined and listed in a table and finally the present value of an annuity for each company is determined.

The weighted share ratio for Nesfiskur and Skinnfiskur is [0, 625 : 0, 375]. It's determined from the mass flow(m_{20}) in tables 3.17 and 3.19.

The cost of the pipeline from Vellir to the companies can be calculated from the values in table 3.21. The cost analysis for components needed by Nesfiskur and Skinnfiskur are listed in table 3.22. The price is calculated in equation 2.12 and the reference prices for components are listed in table 3.13.

Table 3.22: Estimate cost for components - Case B

Comp.\Var.	X _{Y,Nes}	Total[MISK]	X _{Y,Skinn}	Total[MISK]
Stage pump	231.3 kW	3.0	231.3 kW	1.8
Circulation pump	19.8 kW	0.9	11.9 kW	0.7
Total - Pumps		3.9		2.5
SHX	184.2 m ²	60.2	110.5 m ²	49.1
Desorber	1263.8 m ²	130.1	758.4 m ²	106.1
Rectifier	16.1 m ²	22.7	9.7 m ²	18.5
CEHX	25.1 m ²	27.1	15.0 m ²	22.1
Absorber	1272.2 m ²	130.4	763.3 m ²	106.3
Total Hx	3024.5 m ²	370.6	1920.0 m ²	302.1
Pipe(Shared)	8300 m	105.2	8300 m	63.1
Pipe	5200 m	73.2	3000 m	28.7
Total - pipes		178.4		91.8
Expansion valves, control valve, electrical control & monitor system	5 %	16.69		13.6

The total capital investment for case B is listed in table 3.23. Where it is summarized costs for all components involved and scheduled potential cost of the project

Table 3.23: Breakdown of total capital investment, Case B

Direct Cost (DC)	Nesfiskur	Skinnfiskur
Onsite cost (ONSC)	(MISK)	(MISK)
Pipes	178.4	91.8
Pumps	3.9	2.5
Heat Exchangers	370.6	302.1
Electrical control& monitor system	16.7	13.6
Total ONSC	569.6	410.0
Offsite cost(OFSC)		
Civil, structural and architectural work 15% of ONSC	85.4	61.5
Total DC	655.0	410.0
Indirect Cost (IDC)		
Engineering and Supervision (10% of DC)	65.5	47.2
Construction cost (15% of DC)	98.3	70.7
Total IDC	136.2	117.9
Total Capital Investment (TCI)	818.8	589.4

Next we calculate the PVOAA for each company with equation 2.13. The cost for the electricity is mainly because of the stage pump located at Vellir. The flow needed is a lot and the pressure drop in the pipes high. The cost for the equipment is quite high and the heat exchangers are expensive. The calculations are found in table 3.24

Table 3.24: PVOAA for case B and current mechanism

	Nesfiskur[MISK]	Skinnfiskur[MISK]
Electricity(C_{elect})	9.61	5.77
Maintenance(C_m)	0.30	0.3
Annual Cost(C_e)	9.91	6.07
Initial Cost(C_c)	818.8	589.4
PVOAA	912.24	646.61

As seen in table 3.24 the cost is far above the limit and thus case B is not recommended.

3.5. Case C - Freezing plant

In case C a refrigeration system and warehouse is assumed to be built and located next to RPP. The waste water from the plant is used as a heating source for the working fluid. Nesfiskur and Skinnfiskur could therefore transport their products to the warehouse for storage. The temperature of the waste water is quite high, 211 °C. This high temperature can be used to improve the efficiency of the cycle by using two stage absorption systems with two pressure levels. Seawater is assumed to be 9° C in Reykjaness, which means that the temperature of the cooling in the condenser and absorber is 2°C higher than in the other cases.

3.5.1. Model and optimization

The model which is modified from the model in figure 2.4, is shown in figure 3.11.

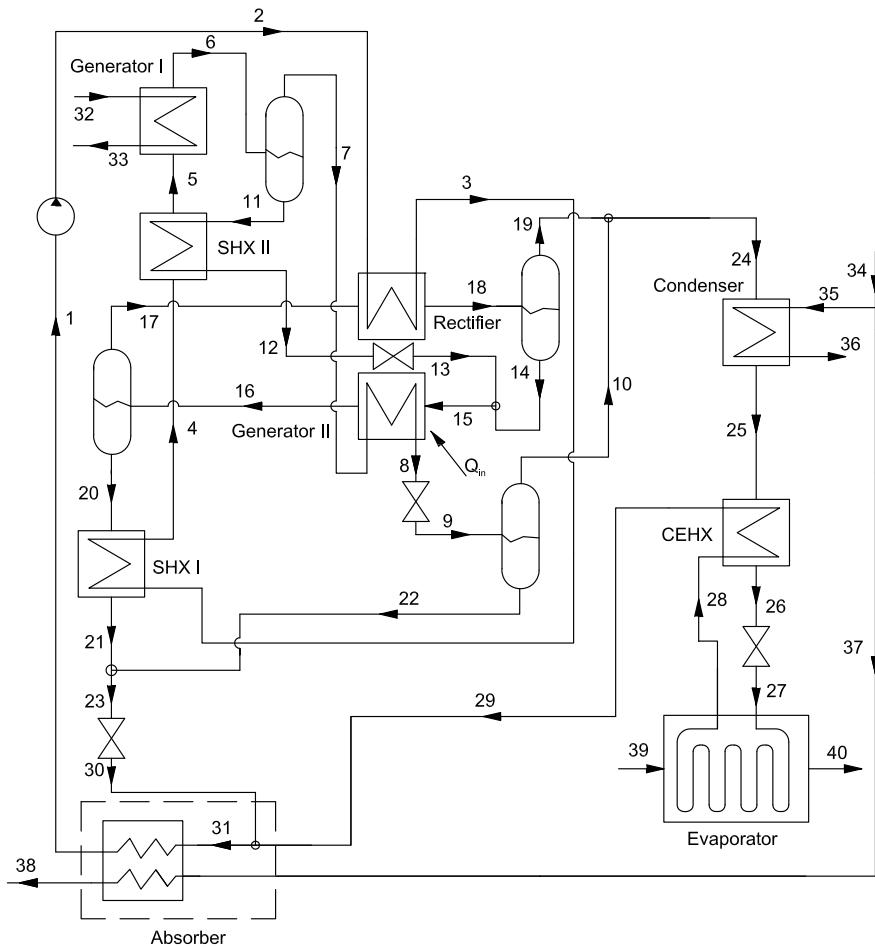


Figure 3.11: Modified of a two stage absorption cycle

The model has become more complex and has many factors that need to be considered for the simulation to function correctly. The constraints are the same as in section 3.3.1 but now the temperature for the coolant in the condenser and absorber is 9 °C. The COP is maximized in the calculation and the optimization variables are:

1. NH₃ : H₂O ratio at point 1, the bounds are: [0.29; 0.71]:[0.326; 0.674].
2. Temperature after the generation of Generator I at point 6, the bounds are: [140; 206]°C.
3. NH₃ : H₂O ratio for the steam to the condenser at point 10 and 19, the bounds are: [0.99; 0.01]:[0.99999; 0.00001].
4. Temperature for the output on SHX I at point 21, the bounds are [5; 35]°C addition to the temperature of point 3.
5. The higher pressure (p_{h1}) for generator I had the bounds [1700; 2800]
6. The lower pressure (p_{h2}) for generator II had the bounds [800; 1800]

The results from the optimization and other interesting parameters are listed in table 3.25

Table 3.25: Optimization for the COP in a freeze plant next to the RPP - Case C

Variables	Value	Variables	Value
p_{h1} [kPa]	2682, 9	T_{21} [°C]	6, 0
p_{h2} [kPa]	800, 0	Q_{evap} [kW]	2720, 1
x_1 [NH ₃ , H ₂ O]	[0.326, 0.674]	\dot{m}_{32}	22.68
$x_{10,19}$ [NH ₃ , H ₂ O]	[0.990955, 0.009045]	\dot{m}_1	41.33
T_6 [°C]	152, 2	COP	0, 465

Table 3.25 indicates an unexpected result where the optimum temperature is 152, 2 °C which is inside the bounds allowed. The COP is not as high as expected but high compared to case A and B, 84, 4 % and 35, 6 % higher respectively. The reason the COP is not higher is the higher temperature for the coolant in the absorber and condenser which lead to lower NH₃ : H₂O at point 1. The work of the pump is 134, 7 kW which is quite high but as seen in table 3.25 the mass flow of the working fluid is much and the pressure difference from evaporator pressure to p_{h1} is big.

The data for each point and the temperature profiles in each heat exchanger is given in section A.5. The energy and area for the heat exchangers are found in table 3.26.

Table 3.26: Area and energy consumption of the heat exchangers in - Case C

Comp.\Var.	Type	Q[kW]	A[m ²]
SHX I	Shell&Tube	12812.5	736.4
SHX II	Shell&Tube	11452.6	819.2
Generator I	Shell&Tube	5711.9	296.0
Generator II	Shell&Tube	2045.2	137.4
Rectifier	Shell&Tube	196.3	4.6
Condenser	Shell&Tube	3236.5	644.4
CEHX	Shell&Tube	258, 3	13.3
Evaporator	Plate freezer	2720.1	49.4
Absorber	Shell&Tube	5328.6	1435.9

There are more and larger heat exchangers than in the other cases but that follows higher COP.

3.5.2. Cost estimation

Table 3.28 lists the total capital investment.

Table 3.27: Breakdown of total capital investment, Case C

Direct Cost (DC)	Freezing plant	
	Onsite cost (ONSC)	(MISK)
Circulation pump		1.8
SHX I		104.9
SHX II		109.5
Generator I		72.9
Generator II		53.6
Rectifier		13.8
CEHX		21.1
Heat Exchangers -		
Total		375.7
Electrical control &		
monitor system (5% of		18.9
pump and Hx)		
Total ONSC	772.1	
Offside cost		
Civil, structural and		
architectural work 5%		38.6
of ONSC		
Total DC	810.7	
Indirect Cost (IDC)		
Engineering and		
Supervision (10% of		81.1
DC)		
Construction cost (10%		
of DC)		81.1
Total IDC	162.2	
Total Capital		
Investment (TCI)		972.8

It is assumed that the condensers and evaporators at Skinnfiskur and Nesfiskur can be used in this case. The result from table 3.27 is the best choice when comparing to cases A and B. If the companies choose this case the cost for each would be 753.9 MISK for Nesfiskur and 452.4 MISK for Skinnfiskur. The Construction cost is lowered to 10% from case B, the reason is that the pipe cost is negligible.

The PVOAA is found in table 3.28

Table 3.28: PVOAA for case C and current mechanism

	Freezing plant(case C)	Skinn. and Nes.(UC)
Electricity(C_{elect})	8.73	43.66
Maintenance(C_m)	0.50	3.34
Annual Cost(C_e)	9.23	47.00
Initial Cost(C_c)	972.8	185
PVOAA	1059.85	628.1

This case seems to be the most economic if the companies find it possible to transfer their product each day to RPP. The cost of transportation is not included in the calculations but Skinnfiskur get their ingredients from other fisheries and could transport the fish there. Nesfiskur could sail their trawlers to a nearby harbor, possibly Grindavík.

The initial cost is quite high and the project would not pay off in the end but if the companies had access to less expensive heat exchangers this could be profitable. If other companies would like to join the cost for each would decrease even more.

4. Conclusion

This chapter summarizes shortly the results from each case and discusses the results.

4.1. Pipeline from Reykjanes to Skinnfiskur and Nesfiskur

The idea of transporting the heat source through a pipe from RPP is interesting since seemingly infinite free energy is present. Unfortunately the route is too long and the pressure drop in the pipe depends mostly on the length and diameter, which means high electricity cost for pumping and high initial cost for the pipe.

The idea was to propose a simple system to avoid the high cost of the heat exchangers but if the desorber temperature profile in figure A.1a is considered the interval between temperature lines are far from each other which results in a higher ΔT_m value which in turn requires a larger area for the heat exchanger.

The estimated cost gives only an idea of what the investment would cost, there are many variables that can vary greatly. But these numbers give a good idea of the outcome and from the update cost in table 3.16 we determine that this case is not economical when looking at the next 30 years.

4.2. Use of a district heating system

This case was calculated to see if it was possible to design an absorption system where the heat supply could only heat the mixture up to $85^\circ C$. With very low pressure it was possible but with the expense of needing more seawater for the condenser. The pipeline was not as long as in case A but the amount of water we could transfer to the companies was too little. The pressure drop in the pipeline was high so the stage pump needed a lot of power to sustain the need.

Both the initial cost was high where there were many heat exchangers and the annual cost was also high, because of the electricity used in the stage pump. What can be learned from this is that if the heating source doesn't have sufficiently high temperature the energy needed for the cycle is much greater.

4.3. Freezing Hotel

In the freezing plant we needed to maximize the COP with many constraints which was a challenge. It could've been solved in another way for example optimizing the evaporation heat output, ignoring the mass flow and energy of the heat source. Another way would've been to optimize the energy consumption for each heat exchanger with the objective to achieve as high evaporation power output as possible, the heat source mass flow would not matter, thus lowering the cost for the heat exchangers. We leave these speculations as suggestions for further work.

This case was without doubt the most economical of all the cases but still not as profitable as the current situation. If many fisheries and food companies would unite in deep freezing this way, case C could be economical.

In Hellisheiði there is a lot of surplus water as well, it would be interesting to investigate if there is motivation among institutions in the Reykjavik area to do a in-depth research on a big freezing plant there and a storage for frozen products.

5. Future work

Since the subject of the thesis was extensive, there were several options to improve it. For example, exergy can be calculated for each case and the cost of the hot water that flows into the absorption cycle can be found and therefore improve the cost analysis. The cost analysis can also be more accurate by including the cost for the borehole in case A and the warehouse in case C which was not in the calculations.

It could be interesting to examine if there are other efficient ways to freeze or try to change the models to get more economical solution. For example use single stage absorption cycle in case C to decrease the cost of the heat exchangers. Other locations in Iceland can be explored for freezing hotel, for example examine if it would be more economical to plant it at Hellisheiðarvikjun which is a geothermal power plant located closer to Reykjavik, that would perhaps mean that additional investors could be involved.

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Appendices

A. Tables and Figures

In this appendix the solutions properties of each point is shown in table and the temperature profiles can be seen on a graph for each heat exchanger in the cases.

A.1. Nesfiskur, Case A

Table A.1: Properties for each point in case A at Nesfiskur

Point	$p[kPa]$	$h[kJ/kg]$	$T[K]$	$s[kJ/K]$	q	$d[kg/m^3]$	$v[m^3/kg]$	$m[kg]$	$x[NH_3, H_2O]$	$y[NH_3, H_2O]$
1	71,36	-53,9	285,5	0,513	0,00	887,3	0,001	11,98	[0.3393, 0.6607]	[0.9903, 0.0097]
2	700,47	-53,2	285,5	0,514	-0,14	887,5	0,001	11,98	[0.3393, 0.6607]	[0.3393, 0.6607]
3	700,47	42,1	307,3	0,835	-0,09	871,5	0,000	11,98	[0.3393, 0.6607]	[0.3393, 0.6607]
4	700,47	46,0	308,1	0,854	-0,09	868,5	0,001	12,44	[0.3462, 0.6538]	[0.3462, 0.6538]
5	700,47	139,9	318,7	1,243	0,00	792,5	0,001	0,46	[0.527, 0.473]	[0.996, 0.004]
6	700,47	591,8	373,0	2,416	0,16	24,9	0,040	12,44	[0.245, 0.755]	[0.8868, 0.1132]
7	700,47	1924,0	373,0	6,723	1,00	4,0	0,248	1,96	[0.245, 0.755]	[0.8868, 0.1132]
8	700,47	1341,7	318,7	5,055	0,77	6,2	0,161	1,96	[0.527, 0.473]	[0.996, 0.004]
9	700,47	1706,6	318,7	6,212	1,00	4,8	0,209	1,50	[0.5271, 0.4729]	[0.996, 0.004]
10	700,47	394,5	285,2	1,668	0,00	623,5	0,002	1,50	[0.996, 0.004]	[0.996, 0.004]
11	71,36	394,5	233,2	1,772	0,17	3,7	0,267	1,50	[0.9952, 0.0048]	[1,0, 0,0]
12	71,36	1525,0	238,2	6,617	0,98	0,6	1,561	1,50	[0.7919, 0.2081]	[1,0, 0,0]
13	700,47	342,7	373,0	1,611	0,00	850,5	0,001	10,48	[0.245, 0.755]	[0.8868, 0.1132]
14	71,36	342,7	320,8	1,688	0,12	3,7	0,270	10,48	[0.1563, 0.8437]	[0.8695, 0.1305]
15	71,36	491,0	316,6	2,327	0,23	2,1	0,484	11,99	[0.176, 0.824]	[0.899, 0.101]
16	1100,00	675,8	433,2	1,942	0,00	907,7	0,001	13,38	[0,0, 1,0]	[0,0, 1,0]
17	1100,00	168,4	313,1	0,572	-0,31	992,7	0,001	13,38	[0,0, 1,0]	[0,0, 1,0]
18	500,00	29,9	280,2	0,106	0,00	1000,1	0,001	174,68	[0,0, 1,0]	[0,0, 1,0]
19	500,00	29,9	280,2	0,106	0,00	1000,1	0,001	125,00	[0,0, 1,0]	[0,0, 1,0]
20	500,00	45,7	283,9	0,162	-0,28	999,8	0,001	125,00	[0,0, 1,0]	[0,0, 1,0]
21	500,00	29,9	280,2	0,106	0,00	1000,1	0,001	49,68	[0,0, 1,0]	[0,0, 1,0]
22	500,00	161,4	311,6	0,551	0,00	993,0	0,001	49,68	[0,0, 1,0]	[0,0, 1,0]
23	100,00	409,3	283,2	3,832	998,00	1,2	0,812	60,38	[0,0, 1,0]	[0,0, 1,0]
24	100,00	381,2	255,2	3,728	998,00	1,4	0,732	60,38	[0,0, 1,0]	[0,0, 1,0]

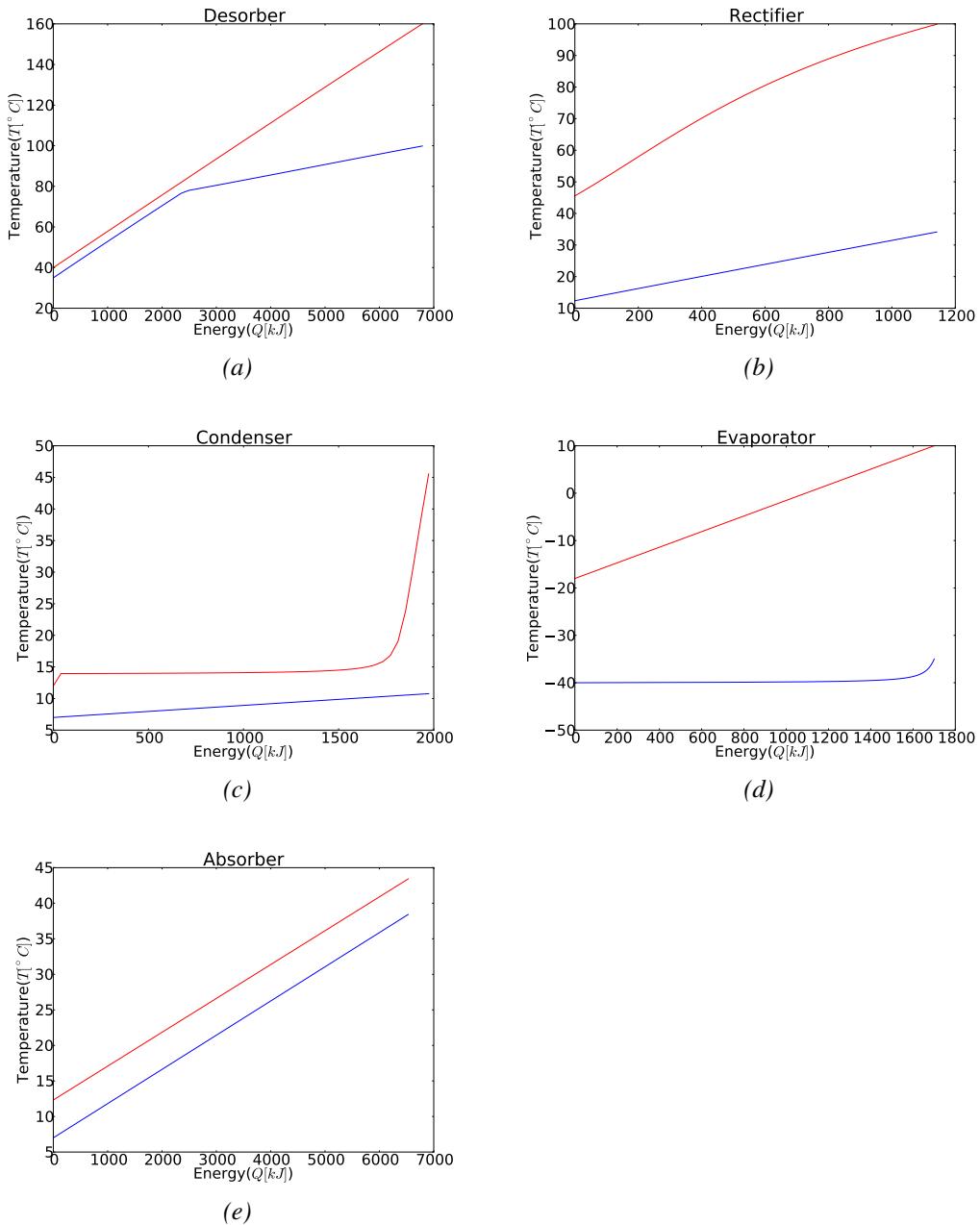


Figure A.1: Heat exchange process in each heat exchanger in the absorption cycle

A.2. Skinnfiskur, Case A

Table A.2: Properties for each point in case A at Skinnfiskur

Point	$p[kPa]$	$h[kJ/kg]$	$T[K]$	$s[kJ/K]$	q	$d[kg/m^3]$	$v[m^3/kg]$	$\dot{m}[kg]$	$x[NH_3, H_2O]$	$y[NH_3, H_2O]$
1	71,36	-54,5	285,3	0,512	0,0	887,1	0,001	9,00	[0,34, 0,66]	[0,9904, 0,0096]
2	700,00	-53,7	285,4	0,512	-0,1	887,3	0,001	9,00	[0,34, 0,66]	[0,34, 0,66]
3	700,00	4,6	298,8	0,712	-0,1	877,7	0,000	9,00	[0,34, 0,66]	[0,34, 0,66]
4	700,00	7,7	299,5	0,726	-0,1	875,8	0,001	9,20	[0,3441, 0,6559]	[0,3441, 0,6559]
5	700,00	139,8	318,7	1,242	0,0	792,5	0,001	0,20	[0,527, 0,473]	[0,996, 0,004]
6	700,00	507,3	368,0	2,185	0,1	32,8	0,030	9,20	[0,2669, 0,7331]	[0,9099, 0,0901]
7	700,00	1893,9	368,0	6,672	1,0	4,1	0,245	1,11	[0,2669, 0,7331]	[0,9099, 0,0901]
8	700,00	1419,1	318,7	5,301	0,8	5,9	0,171	1,11	[0,527, 0,473]	[0,996, 0,004]
9	700,00	1706,6	318,7	6,213	1,0	4,8	0,209	0,90	[0,527, 0,473]	[0,996, 0,004]
10	700,00	394,5	285,2	1,668	0,0	623,5	0,002	0,90	[0,996, 0,004]	[0,996, 0,004]
11	71,36	394,5	233,2	1,772	0,2	3,7	0,267	0,90	[0,9952, 0,0048]	[1,0, 0,0]
12	71,36	1525,0	238,2	6,617	1,0	0,6	1,561	0,90	[0,7919, 0,2081]	[1,0, 0,0]
13	700,00	318,1	368,0	1,573	0,0	846,4	0,001	8,10	[0,2669, 0,7331]	[0,9099, 0,0901]
14	71,36	318,1	316,5	1,651	0,1	3,7	0,268	8,10	[0,1764, 0,8236]	[0,8996, 0,1004]
15	71,36	439,1	313,5	2,164	0,2	2,3	0,437	9,00	[0,1905, 0,8095]	[0,9166, 0,0834]
16	1100,00	675,8	433,2	1,942	0,0	907,7	0,001	8,46	[0,0, 1,0]	[0,0, 1,0]
17	1100,00	132,3	304,5	0,455	-0,3	995,7	0,001	8,46	[0,0, 1,0]	[0,0, 1,0]
18	500,00	29,9	280,2	0,106	0,0	1000,1	0,001	137,41	[0,0, 1,0]	[0,0, 1,0]
19	500,00	29,9	280,2	0,106	0,0	1000,1	0,001	100,00	[0,0, 1,0]	[0,0, 1,0]
20	500,00	41,8	283,0	0,148	-0,3	999,9	0,001	100,00	[0,0, 1,0]	[0,0, 1,0]
21	500,00	29,9	280,2	0,106	0,0	1000,1	0,001	37,41	[0,0, 1,0]	[0,0, 1,0]
22	500,00	148,7	308,5	0,51	0,0	994,1	0,001	37,41	[0,0, 1,0]	[0,0, 1,0]
23	100,00	409,3	283,15	3,832	998,0	1,2	0,812	36,23	[0,0, 1,0]	[0,0, 1,0]
24	100,00	255,1	255,1	3,728	998,0	1,4	0,732	36,23	[0,0, 1,0]	[0,0, 1,0]

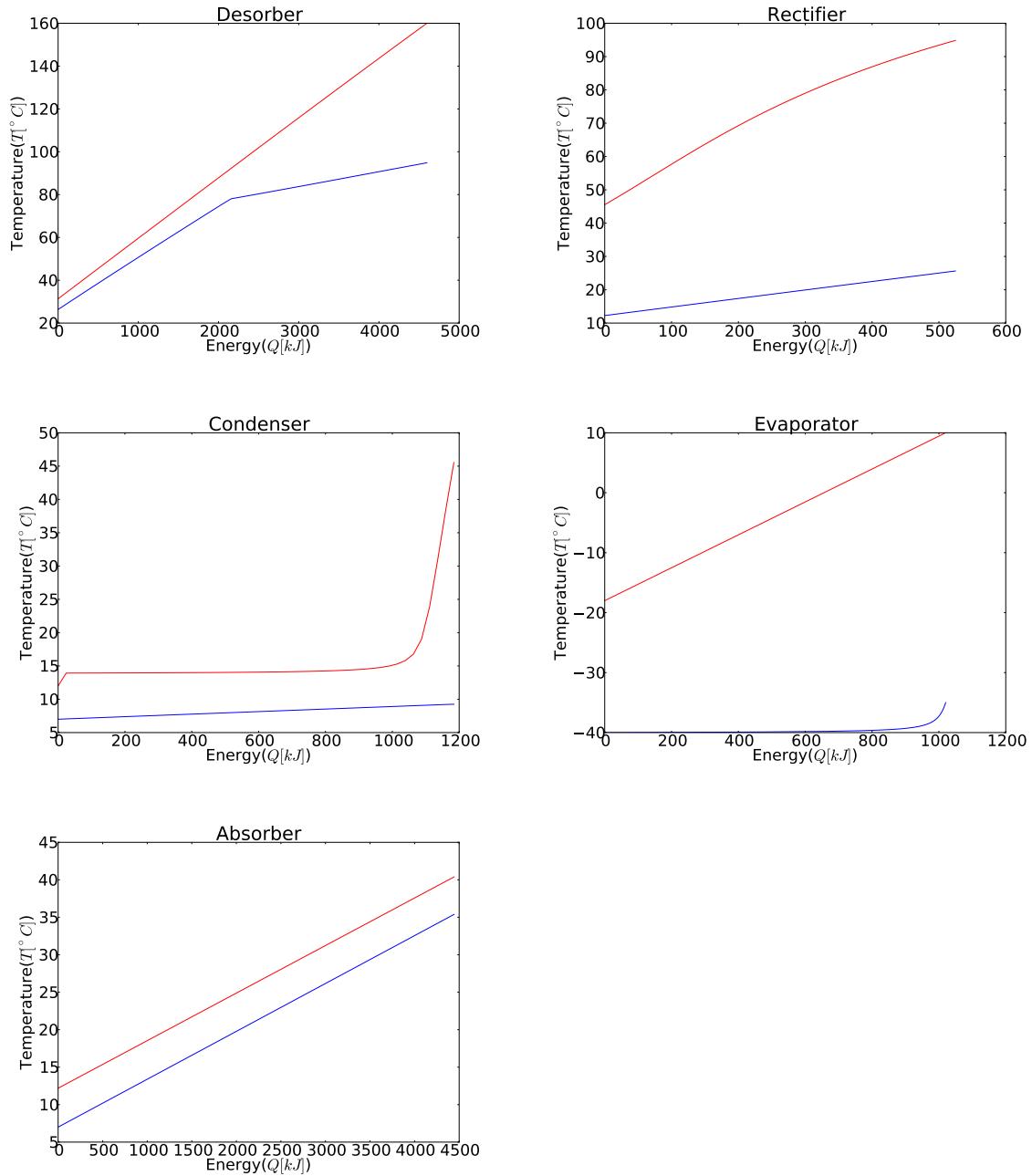


Figure A.2: Heat exchange process in each heat exchanger in the absorption cycle at Skinnfiskur

A.3. Nesfiskur, Case B

Table A.3: Properties for each point in case B at Nesfiskur

Point	$p[kPa]$	$h[kJ/kg]$	$T[K]$	$s[kJ/K]$	q	$d[kg/m^3]$	$v[m^3/kg]$	$\dot{m}[kg/s]$	$x[NH_3, H_2O]$	$y[NH_3, H_2O]$
1	71,66	-54,1	285,4	0,513	0,000	887,1	0,001	26,923	[0,34, 0,66]	[0,9904, 0,0096]
2	658,00	-53,4	285,5	0,514	-0,129	887,2	0,001	26,923	[0,34, 0,66]	[0,34, 0,66]
3	658,00	-32,1	290,4	0,588	-0,120	883,8	0,001	26,923	[0,34, 0,66]	[0,34, 0,66]
4	658,00	191,5	340,4	1,298	-0,019	843,4	0,017	26,923	[0,34, 0,66]	[0,34, 0,66]
5	658,00	191,1	340,3	1,298	-0,019	843,0	0,001	27,129	[0,3414, 0,6586]	[0,3414, 0,6586]
6	658,00	130,9	317,4	1,214	0,000	796,1	0,001	0,206	[0,5214, 0,4786]	[0,996, 0,004]
7	658,00	372,8	358,2	1,814	0,064	57,5	0,017	27,129	[0,3005, 0,6995]	[0,9398, 0,0602]
8	658,00	1848,7	358,2	6,613	1,000	3,9	0,255	1,736	[0,3005, 0,6995]	[0,9398, 0,0602]
9	658,00	1518,9	317,3	5,642	0,881	5,1	0,196	1,736	[0,5214, 0,4786]	[0,996, 0,004]
10	658,00	1705,6	317,3	6,238	1,000	4,5	0,222	1,53	[0,5217, 0,4783]	[0,996, 0,004]
11	658,00	394,9	285,2	1,670	0,000	623,4	0,002	1,53	[0,996, 0,004]	[1,0, 0,0]
12	658,00	328,7	271,0	1,432	0,000	643,3	0,002	1,53	[0,996, 0,004]	[0,996, 0,004]
13	71,66	328,7	233,2	1,490	0,123	5,2	0,193	1,53	[0,9954, 0,0046]	[1,0, 0,0]
14	71,66	1439,6	234,2	6,251	0,922	0,7	1,44	1,53	[0,9417, 0,0583]	[1,0, 0,0]
15	71,66	1505,8	279,1	6,546	0,914	0,6	1,72	1,53	[0,3781, 0,6219]	[0,9948, 0,0052]
16	658,00	271,9	358,2	1,486	0,000	842,3	0,001	25,393	[0,3005, 0,6995]	[0,9398, 0,0602]
17	658,00	34,8	305,4	0,771	0,000	885,9	0,001	25,393	[0,3005, 0,6995]	[0,3005, 0,6995]
18	71,66	34,8	295,5	0,776	0,025	19,9	0,05	25,393	[0,2834, 0,7166]	[0,9773, 0,0227]
19	71,66	118,4	294,7	1,108	0,076	6,6	0,151	26,923	[0,2877, 0,7123]	[0,9787, 0,0213]
20	700,00	377,5	363,2	1,192	0,000	965,6	0,001	103,193	[0,0, 1,0]	[0,0, 1,0]
21	700,00	329,8	351,8	1,059	-0,178	972,9	0,001	103,193	[0,0, 1,0]	[0,0, 1,0]
22	500,00	29,9	280,2	0,106	0,000	1000,1	0,001	445,219	[0,0, 1,0]	[0,0, 1,0]
23	500,00	29,9	280,2	0,106	0,000	1000,1	0,001	290	[0,0, 1,0]	[0,0, 1,0]
24	500,00	36,8	281,8	0,131	-0,286	1000,0	0,001	290	[0,0, 1,0]	[0,0, 1,0]
25	500,00	29,9	280,2	0,106	0,000	1000,1	0,001	155,219	[0,0, 1,0]	[0,0, 1,0]
26	500,00	69,8	289,7	0,246	0,000	999,0	0,001	155,219	[0,0, 1,0]	[0,0, 1,0]
27	100,00	409,3	283,2	3,832	998,000	1,2	0	60,377	[0,0, 1,0]	[0,0, 1,0]
28	100,00	381,2	255,2	3,728	998,000	1,4	0	60,377	[0,0, 1,0]	[0,0, 1,0]
29	658,00	233,2	349,4	1,420	0,000	834,6	0,001	27,129	[0,3414, 0,6586]	[0,9624, 0,0376]
30	700,00	340,8	354,4	1,090	0,000	971,3	0,001	103,193	[0,0, 1,0]	[0,0, 1,0]

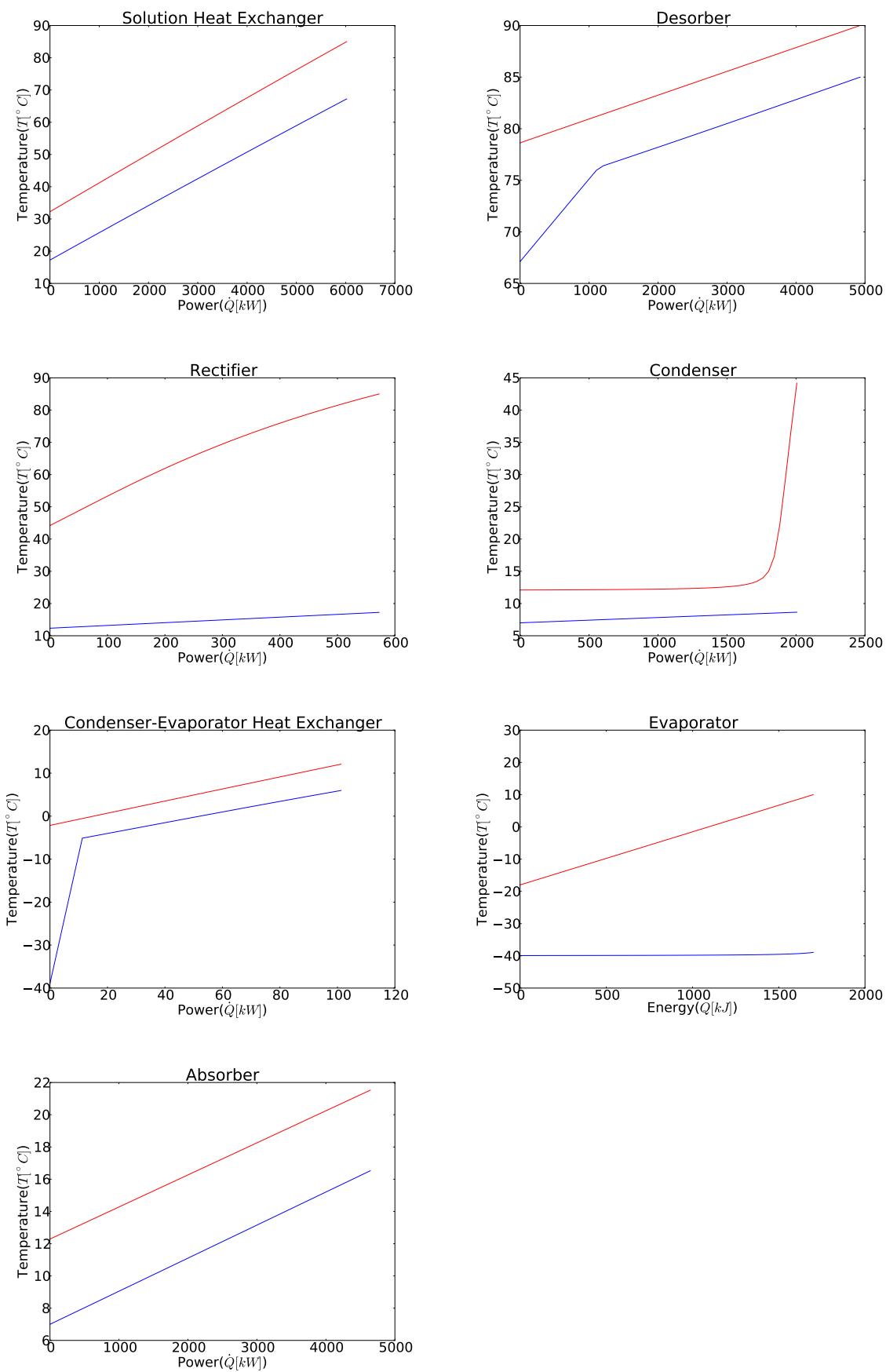


Figure A.3: Heat exchange process in each heat exchanger in Nesfiskur, case B

A.4. Skinnfiskur, Case B

Table A.4: Properties for each point in case B at Skinnfiskur

Point	$p[kPa]$	$h[kJ/kg]$	$T[K]$	$s[kJ/K]$	q	$d[kg/m^3]$	$v[m^3/kg]$	$\dot{m}[kg/s]$	$x[NH_3, H_2O]$	$y[NH_3, H_2O]$
1	71,66	-54,1	285,4	0,513	0,000	887,1	0,001	16,15	[0,34, 0,66]	[0,9904, 0,0096]
2	658,00	-53,4	285,5	0,514	-0,129	887,2	0,001	16,15	[0,34, 0,66]	[0,34, 0,66]
3	658,00	-32,1	290,4	0,588	-0,120	883,8	0,001	16,15	[0,34, 0,66]	[0,34, 0,66]
4	658,00	191,5	340,4	1,298	-0,019	843,4	0,017	16,15	[0,34, 0,66]	[0,34, 0,66]
5	658,00	191,1	340,3	1,298	-0,019	843,0	0,001	16,28	[0,3414, 0,6586]	[0,3414, 0,6586]
6	658,00	130,9	317,4	1,214	0,000	796,1	0,001	0,12	[0,5214, 0,4786]	[0,996, 0,004]
7	658,00	372,8	358,2	1,814	0,064	57,5	0,017	16,28	[0,3005, 0,6995]	[0,9398, 0,0602]
8	658,00	1848,7	358,2	6,613	1,000	3,9	0,255	1,04	[0,3005, 0,6995]	[0,9398, 0,0602]
9	658,00	1518,9	317,3	5,642	0,881	5,1	0,196	1,04	[0,5214, 0,4786]	[0,996, 0,004]
10	658,00	1705,6	317,3	6,238	1,000	4,5	0,222	0,92	[0,5217, 0,4783]	[0,996, 0,004]
11	658,00	394,9	285,2	1,670	0,000	623,4	0,002	0,92	[0,996, 0,004]	[1,0, 0,0]
12	658,00	328,7	271,0	1,432	0,000	643,3	0,002	0,92	[0,996, 0,004]	[0,996, 0,004]
13	71,66	328,7	233,2	1,490	0,123	5,2	0,193	0,92	[0,9954, 0,0046]	[1,0, 0,0]
14	71,66	1439,6	234,2	6,251	0,922	0,7	1,440	0,92	[0,9417, 0,0583]	[1,0, 0,0]
15	71,66	1505,8	279,1	6,546	0,914	0,6	1,720	0,92	[0,3781, 0,6219]	[0,9948, 0,0052]
16	658,00	271,9	358,2	1,486	0,000	842,3	0,001	15,24	[0,3005, 0,6995]	[0,9398, 0,0602]
17	658,00	34,8	305,4	0,771	0,000	885,9	0,001	15,24	[0,3005, 0,6995]	[0,3005, 0,6995]
18	71,66	34,8	295,5	0,776	0,025	19,9	0,050	15,24	[0,2834, 0,7166]	[0,9773, 0,0227]
19	71,66	118,4	294,7	1,108	0,076	6,6	0,151	16,15	[0,2877, 0,7123]	[0,9787, 0,0213]
20	700,00	377,5	363,2	1,192	0,000	965,6	0,001	61,91	[0,0, 1,0]	[0,0, 1,0]
21	700,00	329,8	351,8	1,059	-0,178	972,9	0,001	61,91	[0,0, 1,0]	[0,0, 1,0]
22	500,00	29,9	280,2	0,106	0,000	1000,1	0,001	383,13	[0,0, 1,0]	[0,0, 1,0]
23	500,00	29,9	280,2	0,106	0,000	1000,1	0,001	290,00	[0,0, 1,0]	[0,0, 1,0]
24	500,00	34,1	281,1	0,121	-0,287	1000,0	0,001	290,00	[0,0, 1,0]	[0,0, 1,0]
25	500,00	29,9	280,2	0,106	0,000	1000,1	0,001	93,13	[0,0, 1,0]	[0,0, 1,0]
26	500,00	69,8	289,7	0,246	0,000	999,0	0,001	93,13	[0,0, 1,0]	[0,0, 1,0]
27	100,00	409,3	283,2	3,832	998,000	1,2	0,000	36,23	[0,0, 1,0]	[0,0, 1,0]
28	100,00	381,2	255,2	3,728	998,000	1,4	0,000	36,23	[0,0, 1,0]	[0,0, 1,0]
29	658,00	233,2	349,4	1,420	0,000	834,6	0,001	16,28	[0,3414, 0,6586]	[0,9624, 0,0376]
30	700,00	340,8	354,4	1,090	0,000	971,3	0,001	61,91	[0,0, 1,0]	[0,0, 1,0]

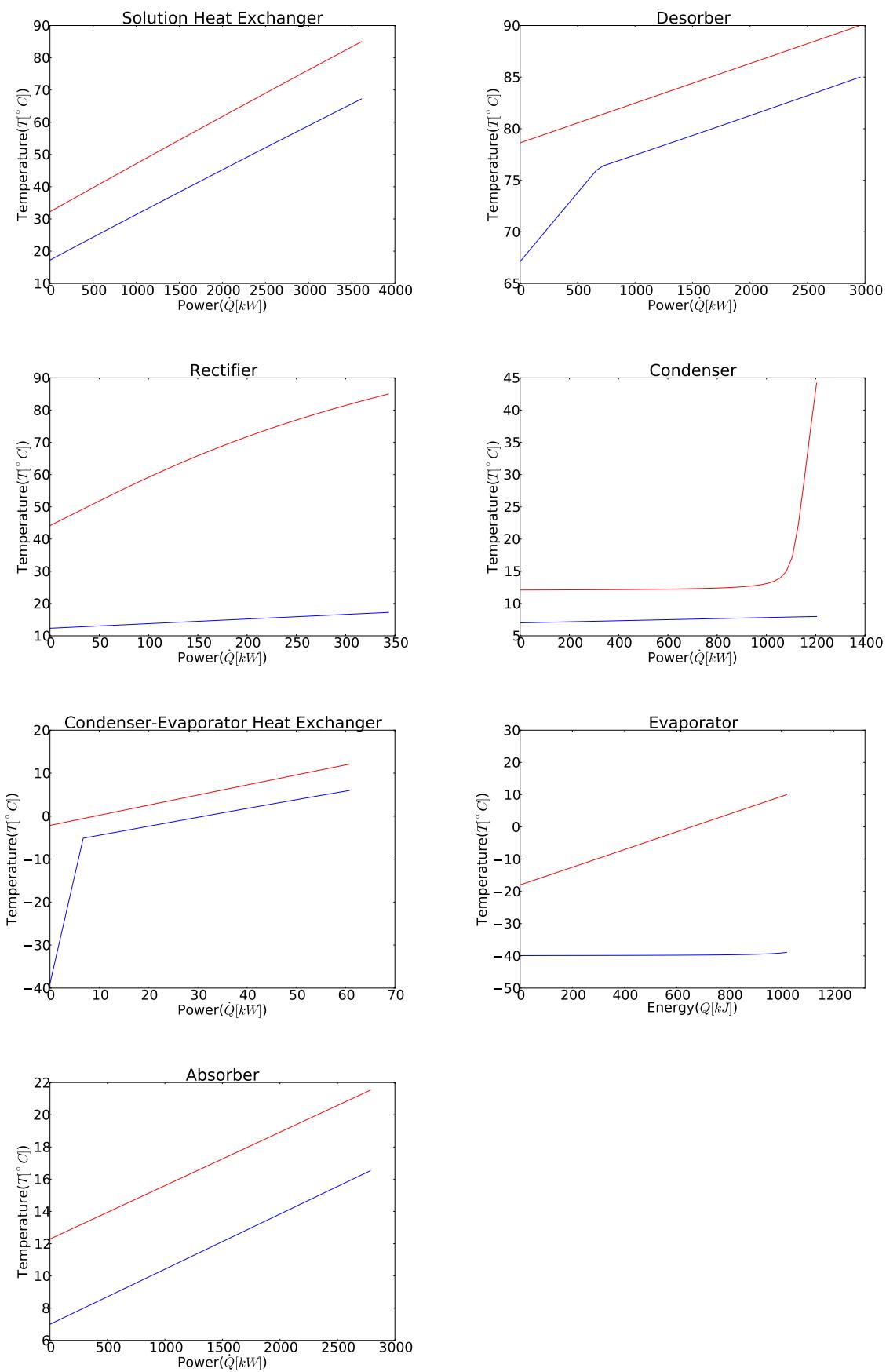


Figure A.4: Temperature profiles in each heat exchanger in Skinnfiskur, case B

A.5. Freezing plant, Case C

Table A.5: Properties for each point in case C

Point	$p[kPa]$	$h[kJ/kg]$	$T[K]$	$s[kJ/K]$	q	$d[kg/m^3]$	$v[m^3/kg]$	$m[kg]$	$x[NH_3, H_2O]$	$y[NH_3, H_2O]$
1	70,93	-44,4	287,6	0,534	0,000	889,9	0,001	41,3	[0,326, 0,674]	[0,9881, 0,0119]
2	2682,95	-41,1	287,8	0,535	-0,302	890,7	0,001	41,3	[0,326, 0,674]	[0,326, 0,674]
3	2682,95	-36,3	288,9	0,551	-0,299	889,9	0,001	41,3	[0,326, 0,674]	[0,326, 0,674]
4	2682,95	273,6	358,0	1,512	-0,142	833,4	0,001	41,3	[0,326, 0,674]	[0,326, 0,674]
5	2682,95	550,7	415,9	2,229	-0,002	771,4	0,001	41,3	[0,326, 0,674]	[0,326, 0,674]
6	2682,95	688,9	425,3	2,557	0,067	172,3	0,006	41,3	[0,289, 0,711]	[0,8403, 0,1597]
7	2682,95	2023,8	425,3	6,308	1,000	14,6	0,069	2,8	[0,289, 0,711]	[0,8403, 0,1597]
8	2682,95	1286,0	368,4	4,459	0,649	26,5	0,038	2,8	[0,5687, 0,4313]	[0,9868, 0,0132]
9	800,00	1286,0	331,9	4,826	0,710	7,4	0,136	2,8	[0,4721, 0,5279]	[0,991, 0,009]
10	800,00	1738,7	331,9	6,248	1,000	5,2	0,191	2,0	[0,4721, 0,5279]	[0,991, 0,009]
11	2682,95	593,0	425,3	2,288	0,000	776,7	0,001	38,6	[0,289, 0,711]	[0,8403, 0,1597]
12	2682,95	296,0	363,0	1,533	0,000	843,2	0,001	38,6	[0,289, 0,711]	[0,289, 0,711]
13	800,00	296,0	363,3	1,539	-0,010	842,0	0,001	38,6	[0,289, 0,711]	[0,289, 0,711]
14	800,00	179,7	331,9	1,351	0,000	800,9	0,001	0,1	[0,4723, 0,5277]	[0,991, 0,009]
15	800,00	295,8	363,3	1,539	-0,010	842,0	0,001	38,6	[0,2893, 0,7107]	[0,2893, 0,7107]
16	800,00	348,7	370,2	1,683	0,013	245,0	0,004	38,6	[0,2807, 0,7193]	[0,9163, 0,0837]
17	800,00	1890,3	370,2	6,608	1,000	4,7	0,215	0,5	[0,2807, 0,7193]	[0,9163, 0,0837]
18	800,00	1514,2	331,9	5,543	0,856	6,1	0,163	0,5	[0,4723, 0,5277]	[0,9909, 0,0091]
19	800,00	1738,7	331,9	6,248	1,000	5,2	0,191	0,4	[0,4721, 0,5279]	[0,991, 0,009]
20	800,00	327,6	370,2	1,616	0,000	838,9	0,001	38,1	[0,2807, 0,7193]	[0,9163, 0,0837]
21	800,00	-8,7	294,9	0,602	0,000	899,5	0,001	38,1	[0,2807, 0,7193]	[0,2807, 0,7193]
22	800,00	179,8	331,9	1,351	0,000	801,0	0,001	0,8	[0,4721, 0,5279]	[0,991, 0,009]
23	800,00	-4,8	295,9	0,620	-0,149	897,6	0,001	38,9	[0,2847, 0,7153]	[0,2847, 0,7153]
24	800,00	1738,7	331,9	6,248	1,000	5,2	0,191	2,4	[0,991, 0,009]	[0,991, 0,009]
25	800,00	398,1	287,2	1,694	0,000	622,9	0,002	2,4	[0,991, 0,009]	[0,991, 0,009]
26	800,00	290,8	264,0	1,305	0,000	654,9	0,001	2,4	[0,991, 0,009]	[0,991, 0,009]
27	70,93	290,8	233,1	1,346	0,100	6,3	0,159	2,4	[0,9899, 0,0101]	[1,0, 0,0]
28	70,93	1417,6	235,1	6,175	0,909	0,7	1,440	2,4	[0,89, 0,11]	[1,0, 0,0]
29	70,93	1524,8	261,3	6,175	999,000	0,0	0,000	2,4	[0,3984, 0,6016]	[0,9909, 0,0091]
30	70,93	-4,8	295,3	0,622	0,002	192,3	0,005	38,9	[0,2833, 0,7167]	[0,9774, 0,0226]
31	70,93	84,6	294,5	0,977	0,056	8,8	0,114	41,3	[0,2871, 0,7129]	[0,9786, 0,0214]
32	1900,00	896,7	482,9	2,423	0,000	853,0	0,001	22,7	[0,0, 1,0]	[0,0, 1,0]
33	1900,00	644,9	425,9	1,868	0,000	915,2	0,001	22,7	[0,0, 1,0]	[0,0, 1,0]
34	1900,00	39,7	282,2	0,136	0,000	1000,6	0,001	282,7	[0,0, 1,0]	[0,0, 1,0]
35	1900,00	39,7	282,2	0,136	0,000	1000,6	0,001	110,5	[0,0, 1,0]	[0,0, 1,0]
36	1900,00	69,0	289,2	0,239	0,000	999,8	0,001	110,5	[0,0, 1,0]	[0,0, 1,0]

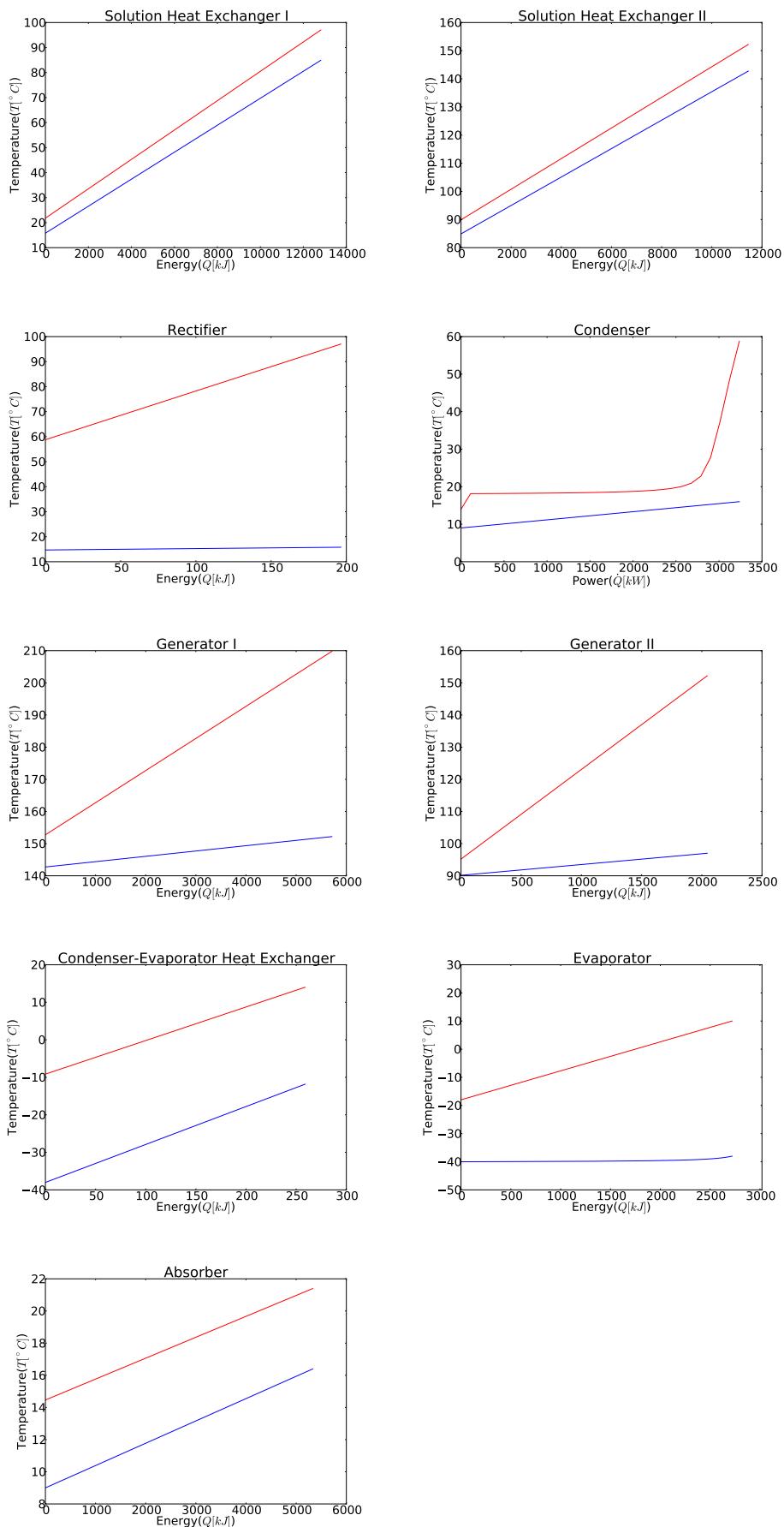


Figure A.5: Temperature profiles in each heat exchanger case C

B. Programs

All the programming can be observed in this appendix.

B.1. Assumptions - Integral

```
from numpy import *
import matplotlib.pyplot as plt
import csv
import datetime as dt
import matplotlib as mpl
from matplotlib.backends.backend_pdf import PdfPages
import matplotlib
matplotlib.rcParams.update({'font.size': 35})
from scipy.integrate import simps, trapz
i=0
hiti=[]
Dagsetning=[]
with open('nesfiskur/Rafmagn_ar.csv', 'rb') as csvfile:
    spamreader = csv.reader(csvfile, delimiter=';')
    for row in spamreader:
        try:
            h=float(row[2])
            hi=round(h,3)
            hiti.append(hi)
            Dagsetning.append(row[1])
        except ValueError:
            pass
max=size(hiti)
hitastig=[]
dagur=[]
k=0
u=0
for i in range(0,max):
    if i%5 == 0:#90 er 4 gildi a dag
        k+=1
        if 47102<k<51470:#Few days 47102 to 51470
            hitastig.append(hiti[i])
            dagur.append(Dagsetning[i])
            u+=1
print 'u:' +str(u) +' k: ' + str(k)
time_num_list = map(lambda x: mpl.dates.date2num(dt.datetime.strptime(x, '%d.%m.%Y %H:%M:%S:%f')),dagur)
Time_from_zero=[]
Time_hour=[]
for s in range(0,u):
    Time_from_zero.append(time_num_list[s]-time_num_list[0])
    Time_hour.append(time_from_zero[s]*600/0.00694444379799998*1/3600)
print 'Fyrsti dagur: ' +str(dagur[0]) +' Sidasti dagur: ' +str(dagur[u-1])
Integralall=simps(hitastig, x=Time_hour)
other=ones(size(Time_hour))*150
integralother=simps(other, x=Time_hour)
Integralall=Integralall-integralother
print 'kWh: ' + str(Integralall)
#Klukkutimi:
dx= 0.041667
fig = plt.figure()
plt.plot_date(x=time_num_list, y=hitastig, fmt="b-")
fig.autofmt_xdate()
plt.title("Temperature range in a freezer in Nesfiskur for few days in October")#Power in Nesfiskur for a year
plt.ylabel("Temperature[$^\circ$C]")#Power[$kW$]
plt.grid(True)
plt.show()
```

B.2. Programming for Case A

```

from numpy import *
import matplotlib.pyplot as plt
import matplotlib
from refprop import refprop
from pprint import pprint
import pkg_resources
from openpyxl.workbook import Workbook
from openpyxl.writer.excel import ExcelWriter
from openpyxl.cell import get_column_letter
import matplotlib
matplotlib.rcParams.update({'font.size': 35})
NUM_UNITS = 24
NUM_water = 6
KELVIN = 273.15
cp_ammonia=2.19 #kJ/(kg K)
cp_water=4.187 #kJ/(kg K)
p_high=700
aw=refprop('ammonia.fld','water.fld')
def main():
    vars = {}
    Q={}
    for i in range(1,NUM_UNITS + 1):
        vars[i] = {'h':0.0,'p':0.0,'s':0.0,'T':0.0,'q':0.0,'m':0.0,'v':0.0,'d':0.0,'x':[0.0,0.0],'y':[0.0,0.0]}
        Q['hx_1']=0.0,'Desorber':0.0,'Hx_3':0.0,'Condenser':0.0,'Rectifier':0.0,'Evaporator':0.0,'a':0.0, 'wdot_p':0.0,
        'Reykjanes':0.0,'Absorber':0.0,'Regenerator':0.0,'Reykjanes':0.0}
        Area={'SHX':0.0,'Desorber':0.0,'Hx_3':0.0,'Condenser':0.0,'Rectifier':0.0,'Evaporator':0.0, 'Absorber':0.0,
        'Regenerator':0.0,'Reykjanes':0.0}
        NH3=0.33925639
        NH3=0.34
        x1=[NH3, (1-NH3)]
        p_high=700.467681706
        p_high=700
        #T6opt=373.0176149#Nesfiskur
        T6opt=367.996437799#Skinnfiskur
        #m1=11.983125#Nesfiskur
        m1=9.00058285807#Skinnfiskur
        print 'NH3: ',NH3
        print 'p_high: ',p_high
        print 'T6opt: ',T6opt
        print 'm1: ',m1
        aw=refprop('ammonia.fld','water.fld')
        A = aw.thermo('h',t=285.15, p=p_high,x=[0.996,1-0.996] )
        h_low=A[0]
        A = aw.thermo('p',t=233.15, h=h_low,x=[0.996,1-0.996] )
        p_low=A[0]
        print p_low
        vars[1] = {'p':p_low}
        aw=refprop('ammonia.fld','water.fld')
        pr=1100
        #----- Point 1 -----
        A = aw.thermo('hpstqdx',q=0, p=vars[1]['p'],x=x1)
        [h, p, s, T, q, d, x, y] = A[0:8]
        if d==0:
            v=0
        else:
            v=1/d
        vars[1] = {'h':h, 'p':p, 's':s, 'T':T,'v':v, 'q':q, 'd':d , 'm':m1,'x':x, 'y':y}
        #-----Point 2, Pump-----
        vars[2] = {'p':p_high, 'x':x1}
        C = calculate_pump(vars[1]['p'], vars[2]['p'], vars[1]['m'],vars[1]['h'],vars[1]['v'],vars[1]['s'],vars[1]['x'])
        vars[2]=C[0]
        Q['wdot_p']=C[1]['wdot_p']
        #-----Point 3 Hx_1-----
        #Starting values
        m5=1.98
        x5=[0.5140202284,(1-0.5140202284)]
        vars[5]={'p':vars[2]['p'], 'q':0 , 'x':x5}#Water at pressure 1555.576 and quality 0
        h3old=1500/(vars[2]['m'])+vars[2]['h']
        A = aw.thermo('hpstqdx',h=h3old, p=p_high,x=vars[2]['x'])
        [h, p, s, T, q, d, x, y] = A[0:8]
        vars[3] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d , 'm':m1,'x':x, 'y':y}
        Dm5=1
        for i in range(0,4):
            A = aw.thermo('hpstqdx',q=1, p=p_high,x=[0.996,1-0.996] )
            [h, p, s, T, q, d, x, y] = A[0:8]
            v9=1/d
            vars[9] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'v':v9, 'd':d, 'x':x , 'y':y}

            vars[5]={'p':vars[2]['p'], 'q':0 , 'x':x5}#Water at pressure 1555.576 and quality 0
            A = aw.thermo('hpstqdx',q=vars[5]['q'], p=vars[5]['p'],x=x5 )
            [h, p, s, T, q, d, x, y] = A[0:8]
            v5=1/d
            vars[5] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v5, 'm':m5, 'x':x , 'y':y}
            #Mixed fluids
            vars[4]=calculate_mixed(vars[3],vars[5])
            #after heating
            A = aw.thermo('hpstqdx',t=T6opt, p=p_high,x=vars[4]['x'])
            [h, p, s, T, q, d, x, y] = A[0:8]
            m6=vars[4]['m']

```

```

v6=1/d
vars[6] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'm':m6,'v':v6, 'x':x , 'y':y}
#water from resevoir
A = aw.thermo('hpstqdx',p=vars[6]['p'], q=1 , x=vars[6]['y'])
[h, p, s, T, q, d, x, y] = A[0:8]
m7=vars[6]['m']*vars[6]['q']
v7=1/d
vars[7]={'h':h, 'p':p, 's':s, 'T':T, 'q':q,'v':v7, 'd':d,'x':x, 'y':y, 'm':m7}
A = aw.thermo('hpstqdx',t=vars[9]['T'], p=p_high,x=vars[7]['y'] )
[h, p, s, T, q, d, x, y] = A[0:8]
m8=vars[7]['m']
v8=1/d
vars[8] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q,'v':v8, 'd':d,'m':m8, 'x':x , 'y':y}
Q['Rectifier']=vars[7]['m']*(vars[7]['h']-vars[8]['h'])
h3n=Q['Rectifier']/(vars[2]['m']+vars[2]['h'])
A = aw.thermo('hpstqdx',h=h3n, p=p_high,x=vars[2]['x'])
[h, p, s, T, q, d, x, y] = A[0:8]
v3=1/3
vars[3] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q,'v':v3, 'd':d , 'm':m1,'x':x, 'y':y}
m5=vars[8]['m']*(1-vars[8]['q'])
x5=vars[8]['x']
vars[9]['m']=vars[8]['m']*(vars[8]['q'])

#Liquid part
A = aw.thermo('hpstqdx',p=vars[6]['p'], q=0 , x=vars[6]['x'])
[h, p, s, T, q, d, x, y] = A[0:8]
v13=1/d
vars[13]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'v':v13,'d':d, 'x':x, 'y':y}
vars[13]['m']=vars[6]['m']*(1-vars[6]['q'])
#----- Condenser -----
#The sea is 7 degrees 273.15+75
A = aw.thermo('hpstqdx',p=vars[9]['p'], t=285.15,x=vars[9]['y'])
[h, p, s, T, q, d, x, y] = A[0:8]
m=vars[9]['m']
v10=1/d
vars[10]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'x':x, 'v':v10, 'y':y, 'd':d,'m':m}
Q_c=vars[10]['m']*(vars[9]['h']-vars[10]['h'])
Q['Condenser']=Q_c
#----- Throttle -----
A = aw.thermo('hpstqdx',p=p_low, h=vars[10]['h'],x=vars[10]['x'])
[h, p, s, T, q, d,x,y] = A[0:8]
v11=1/d
vars[11]=(s':s, 'T':T, 'q':q, 'd':d, 'p':p, 'v':v11, 'm':vars[10]['m'], 'h':h, 'x':x,'y':y)
#----- Evaporator -----
A = aw.thermo('hpstqdx',t=vars[11]['T']+5, p=p_low,x=vars[11]['x'])
[h, p, s, T, q, d,x,y] = A[0:8]
m12=vars[11]['m']
v12=1/d
vars[12]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'x':x, 'y':y, 'v':v12 , 'd':d,'m':m12}
Q['Evaporator']=vars[12]['m']*(vars[12]['h']-vars[11]['h'])
#-----Point 14 -----
A=aw.thermo('hpstqdx',p=p_low, h=vars[13]['h'],x=vars[13]['x'])
[h, p, s, T, q, d,x,y] = A[0:8]
if d==0:
    v14=0.0
else:
    v14=1/d
m=vars[13]['m']
vars[14]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v14, 'm':m, 'x':x , 'y':y}
#-----absorption mixed fluids -----
#m_1*h_1+m_2*h_2=m_3*h_3
m15=vars[12]['m']+vars[14]['m']
h15=(vars[12]['m']*vars[12]['h']+vars[14]['m']*vars[14]['h'])/m15
A=aw.thermo('hpstqdx',p=p_low, h=h15,x=vars[1]['x'])
[h, p, s, T, q, d,x,y] = A[0:8]
v15=1/d
vars[15]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v15, 'm':m15, 'x':x , 'y':y}
#Absorber:
Q['Absorber']=vars[1]['m']*(vars[15]['h']-vars[1]['h'])
mr=13.3839443#Nesfiskur
pr=1100
w=wrefprop('water.fld')
#Point 17
Q['Desorber']=vars[4]['m']*(vars[6]['h']-vars[4]['h'])
A=w.thermo('hpstqdx',p=pr, t=160+273.15)
[h, p, s, T, q, d] = A[0:6]
m=mr
v=1/d
vars[16]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':m, 'x'::[0.0,1.0] , 'y'::[0.0,1.0]}
#Point 18
h17=vars[16]['h']-Q['Desorber']/mr
A=w.thermo('hpstqdx',p=pr, h=h17)
[h, p, s, T, q, d] = A[0:6]
m=mr
v17=1/d
vars[17]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v17,'m':m, 'x'::[0.0,1.0] , 'y'::[0.0,1.0]}

#point 23

#COP
COP=Q['Evaporator']/(Q['Desorber']+Q['wdot_p'])

#Condenser

```

```

pc=500
Tc1=273.15+7
A=w.thermo('hpstqdx',p=pc, t=Tc1)
[h, p, s, T, q, d] = A[0:6]
mc=125
v=1/d
vars[19]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':mc, 'x':[0.0,1.0] , 'y':[0.0,1.0]}

hc2=Q['Condenser']/mc+vars[19]['h']
A=w.thermo('hpstqdx',p=pc, h=hc2)
[h, p, s, T, q, d] = A[0:6]
v=1/d
vars[20]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':mc, 'x':[0.0,1.0] , 'y':[0.0,1.0]}

A=w.thermo('hpstqdx',p=pc, t=Tc1)
[h, p, s, T, q, d] = A[0:6]
#ma=80
v=1/d
vars[21]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v, 'x':[0.0,1.0] , 'y':[0.0,1.0]}

#h22=Q['Absorber']/ma+vars[21]['h']

A=w.thermo('hpstqdx',p=pc, t=vars[15]['T']-5)
[h, p, s, T, q, d] = A[0:6]
v=1/d
vars[22]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v, 'x':[0.0,1.0] , 'y':[0.0,1.0]}
ma=Q['Absorber']/(vars[22]['h']-vars[21]['h'])
vars[21]['m']=ma
vars[22]['m']=ma

A=w.thermo('hpstqdx',p=pc, t=Tc1)
[h, p, s, T, q, d] = A[0:6]
m18=vars[19]['m']+vars[21]['m']
v=1/d
vars[18]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':m18, 'x':[0.0,1.0] , 'y':[0.0,1.0]}

'''
#Rectifier
h22=Q['Rectifier']/mc+h21
A=w.thermo('hpstqdx',p=pc, h=h22)
[h, p, s, T, q, d] = A[0:6]
v=1/d
vars[22]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':mc, 'x':[1.00,0.00] , 'y':[1.00,0.00]}
'''

#Evaporator
w=refprop('air.ppf')
A=w.thermo('hpstqdx',p=100, t=273.15+10)
[h, p, s, T, q, d] = A[0:6]
v=1/d
vars[23]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v, 'x':[0.0,1.0] , 'y':[0.0,1.0]}
#370m^3 af lofti

A=w.thermo('hpstqdx',p=100, t=273.15-18)
[h, p, s, T, q, d] = A[0:6]
v=1/d
m24=Q['Evaporator']/(vars[23]['h']-h)
vars[24]={'h':h, 'p':p, 's':s, 'T':T,'m':m24, 'q':q, 'd':d, 'v':v, 'x':[0.0,1.0] , 'y':[0.0,1.0]}
vars[23]['m']=m24

aw=refprop('ammonia.fld','water.fld')
#Areas calculated
#Condenser(Shell and tube):
BTUtoW=5.6783
Uhx_1=1.1
Ucond=(125*BTUtoW)/1000#Shell and tube exchanger, builditsolar
Urect=(125*BTUtoW)/1000
Ushx=2500/1000 #Plate, builditsolar
Ueva=(800+2500)/2*10**(-3)
Uabs=(125*BTUtoW)/1000
Udes=(125*BTUtoW)/1000
print 'Ucond: ', Ucond
print 'Urect: ', Urect
print 'Ushx: ', Ushx
print 'Ueva: ', Ueva
print 'Uabs: ', Uabs
print 'Udes: ', Udes
Ureg=1.1
#U-tube horizontal bundle
#H=Horizontal, fixed or floating tube sheet
#(Q,U,Th1,Th2,Tc1,Tc2):
Area['Condenser']=HXarea(Q['Condenser'],Ucond,vars[9],vars[10],vars[19],vars[20],'Condenser')
Area['Rectifier']=HXarea(Q['Rectifier'],Urect,vars[7],vars[8],vars[2],vars[3],'Rectifier')
Area['SHX']=HXarea(Q['SHX'],Ushx,vars[14],vars[15],vars[3],vars[4],'Solution Heat Exchanger')
Area['Desorber']=HXarea(Q['Desorber'],Urect,vars[16],vars[17],vars[4],vars[6],'Desorber')
Area['Evaporator']=HXareaA(Q['Evaporator'],Ueva,vars[23],vars[24],vars[11],vars[12],'Evaporator')
Area['Absorber']=HXareaE(Q['Absorber'],Uabs,vars[15],vars[1],vars[21],vars[22],'Absorber')
#Solution Hx
#print 'Area: ' +str(Area)
pprint(vars)
pprint(Q)
pprint(Area)
print 'COP: ' + str(COP)
write_to_excel(vars)

def calculate_pump(p0, p1, m0, h0,v0,s0,x0):
    A = aw.thermo('h',s=s0, p=p1,x=x0)

```

```

h1 = A[0]
eta_p=0.9
h6nytt=h0+1/eta_p*(h1-h0)
A = aw.thermo('hpstqdx',p=p1, h=h6nytt,x=x0 )
[h, p, s, T, q, d, x,y] = A[0:8]
v=1/d
wdot_p=(m0*v)*(p1-p0)/eta_p
m = (m0 *h0+wdot_p)/h
return {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'x':x, 'd':d, 'v':v, 'm':m, 'y':y},{'wdot_p':wdot_p}

def calculate_mixed(vars1,vars2):
    m1=vars1['m']
    m2=vars2['m']
    mt=m1+m2
    h3=(m1*vars1['h']+m2*vars2['h'])/mt
    x3=(vars1['x'][0]*m1+vars2['x'][0]*m2)/((vars1['x'][0]+vars1['x'][1])*m1+(vars2['x'][0]+vars2['x'][1])*m2)

    A = aw.thermo('hpstqdx',h=h3, p=vars1['p'],x=[x3, (1-x3)])
    [h, p, s, T, q, d, x,y] = A[0:8]

    if d==0:
        v=0
    else:
        v=1/d
    return {'h':h, 'p':p, 's':s, 'T':T, 'q':q,'v':v , 'x':x, 'y':y, 'd':d, 'm':mt}

def calculate_HX(Qhx,m1,h1,p,x1):
    #Only the ammonia is calculated and its ratio is x1 of total
    h2=(Qhx/m1)+h1
    A = aw.thermo('hpstqdx',p=p, h=h2,x=x1)
    [h, p, s, T, q, d,x,y] = A[0:8]
    m=m1
    v=1/d
    return {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'v':v , 'd':d,'m':m,'x':x, 'y':y}

def calculate_Evaporator(Qe,h1,m1,p1,x0):
    he=Qe/m1+h1
    A = aw.thermo('hpstqdx',h=he, p=p1,x=x0)
    [h, p, s, T, q, d,x,y] = A[0:8]
    m=m1
    return {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'm':m, 'x':x, 'y':y}

def HXarea(Qtotal,U,varsh1,varsh2,varscl,varscl2,string):
    aw=refprop('ammonia.fld','water.fld')
    n=50
    DQ=(Qtotal+0) / (n-1)
    Q=zeros((n))
    Q[0]=0
    Q[-1]=Qtotal
    DTh=(varsh1['T']-varsh2['T'])/n
    DTC=(varscl['T']-varscl2['T'])/n
    ph=varsh1['p']
    pc=varscl['p']
    mh=varsh1['m']
    mc=varscl['m']
    yh=varsh1['y']
    yc=varscl['y']
    xh=varsh1['x']
    xc=varscl['x']
    xyh=xh
    xyc=xc
    qb=varsh1['q']
    qc=varscl['q']

    #-----Enthalpy-----
    #Hot solution
    hh=zeros((n))
    hh[-1]=varsh1['h']
    hh[0]=varsh2['h']
    Dhh=(varsh1['h']-varsh2['h'])/ (n-1)
    #Cold solution
    hc=zeros((n))
    hc[0]=varscl['h']
    hc[-1]=varscl2['h']
    Dhc=(varscl2['h']-varscl['h'])/ (n-1)
    #-----Temperature-----
    Th=zeros((n))
    Th[-1]=varsh1['T']-273.15
    Th[0]=varsh2['T']-273.15
    Tc=zeros((n))
    Tc[0]=varscl['T']-273.15
    Tc[-1]=varscl2['T']-273.15
    LMTD=zeros((n-1))
    da=zeros((n-1))
    for i in range(1,n-1):
        #Hot
        #Hot
        if string=='Evaporator':
            aw=refprop('air.ppf')
        if qb>1:
            xyh=yh
        Q[i]=DQ*i
        hh[i]=+(hh[i-1])+Dhh

```

```

A=aw.thermo('tyq',p=ph, h=hh[i],x=xyh)
Th[i]=A[0]-273.15
yh=A[1]
qh=A[2]
aw=refprop(' ammonia.fld','water.fld')
#Cold
if qc>=1:
    xyc=yc
    hc[i]+=(hc[i-1])+Dhc
    B=aw.thermo('tyq',p=pc, h=hc[i],x=xyc)
    Tc[i]=B[0]-273.15
    yc=A[1]
    qc=A[2]
for k in range(1,n):
    LMTD[k-1]=((Th[k]-Tc[k])-(Th[k-1]-Tc[k-1]))/log((Th[k]-Tc[k])/(Th[k-1]-Tc[k-1]))
    dA[k-1]=DQ/(LMTD[k-1]*U)
A=sum(dA)
plt.plot(Q,Th,'-r',label='Hot Solution')
plt.plot(Q,Tc,'-b',label='Cold Solution')
plt.title(string)
plt.xlabel('Energy ($Q[kJ]$)')
plt.ylabel('Temperature($T [^\circ C]$)')
plt.show()
return A
def HXareaA(Qtotal,U,varsh1,varsh2,varscl,varscl2,string):
    aw=refprop(' ammonia.fld','water.fld')
    n=50
    DQ=(Qtotal+0)/(n-1)
    Qh=zeros((n))
    Qc=zeros((n))
    Qh[0]=0
    Qh[-1]=Qtotal
    Qc[0]=0
    Qc[-1]=Qtotal
    DTh=(varsh1['T']-varsh2['T'])/(n-1)
    DTc=(varscl2['T']-varscl1['T'])/(n-1)
    ph=varsh1['p']
    pc=varscl1['p']
    mh=varsh1['m']
    mc=varscl1['m']
    yh=varsh1['y']
    yc=varscl1['y']
    xb=varsh1['x']
    xc=varscl1['x']
    xyh=xh
    xyc=xc
    qh=varsh1['q']
    qc=varscl1['q']

    #-----Enthalpy-----
    #Hot solution
    hh=zeros((n))
    hh[-1]=varsh1['h']
    hh[0]=varsh2['h']
    Dh=(varsh1['h']-varsh2['h'])/(n-1)

    #Cold solution
    hc=zeros((n))
    hc[0]=varscl1['h']
    hc[-1]=varscl2['h']
    Dhc=(varscl2['h']-varscl1['h'])/(n-1)
    #-----Temperature-----
    Th=zeros((n))
    Th[-1]=varsh1['T']
    Th[0]=varsh2['T']

    Thh=zeros((n))
    Thh[-1]=varsh1['T']-273.15
    Thh[0]=varsh2['T']-273.15

    Tc=zeros((n))
    Tc[0]=varscl1['T']
    Tc[-1]=varscl2['T']

    Tcc=zeros((n))
    Tcc[0]=varscl1['T']-273.15
    Tcc[-1]=varscl2['T']-273.15

    LMTD=zeros((n-1))
    dA=zeros((n-1))
    for i in range(1,n-1):
        #Hot
        if string=='Evaporator':
            aw=refprop('air.ppf')
        if qh>=1:
            xyh=yh

        Th[i]+=(Th[i-1])+DTh
        A=aw.thermo('hyqt',p=ph, t=Th[i],x=xyh)
        Qh[i]=(A[0]-hh[0])*mh
        yh=A[1]
        qh=A[2]
        Thh[i]=Th[i]-273.15
        aw=refprop(' ammonia.fld','water.fld')

```

```

#Cold
if qc>=1:
    xyc=y
Tc[i]+=(Tc[i-1])+DTc
B=aw.thermo('hyq',p=pc, t=Tc[i],x=xyc)
hc[i]=B[0]
Qc[i]=(B[0]-hc[0])*mc
yc=B[1]
qc=B[2]
Tcc[i]=Tc[i]-273.15

for k in range(1,n):
    LMTD[k-1]=((Th[k]-Tc[k])-(Th[k-1]-Tc[k-1]))/log((Th[k]-Tc[k])/(Th[k-1]-Tc[k-1]))
    dA[k-1]=DQ/(LMTD[k-1]*U)
A=sum(dA)
plt.plot(Qh,Thh,'-r',label='Hot Solution')
plt.plot(Qc,Tcc,'-b',label='Cold Solution')
plt.title(string)
plt.xlabel('Energy($Q[kJ]$)')
plt.ylabel('Temperature($T [^\circ C]$)')
plt.show()
return A

def HKareaE(Qtotal,U,varsh1,varsh2,varscl,varscl2,string):
    aw=refprop('ammonia.fld','water.fld')
    n=2
    DQ=Qtotal/(n-1)
    Qh=zeros((n))
    Qc=zeros((n))
    Qh[0]=0
    Qc[0]=0
    Qh[-1]=Qtotal
    Qc[-1]=Qtotal
    DTh=(varsh1['T']-varsh2['T'])/n
    DTc=(varscl['T']-varscl2['T'])/n

    #-----Temperature-----
    Th=zeros((n))
    Th[-1]=varsh1['T']-273.15
    Th[0]=varsh2['T']-273.15
    Tc=zeros((n))
    Tc[0]=varscl['T']-273.15
    Tc[-1]=varscl2['T']-273.15
    DTc=(Tc[-1]-Tc[0])/(n-1)
    LMTD=zeros((n-1))
    dA=zeros((n-1))
    for k in range(1,n):
        LMTD[k-1]=((Th[k]-Tc[k])-(Th[k-1]-Tc[k-1]))/log((Th[k]-Tc[k])/(Th[k-1]-Tc[k-1]))
        dA[k-1]=DQ/(LMTD[k-1]*U)
    A=sum(dA)
    plt.plot(Qh,Th,'-r',label='Hot Solution')
    plt.plot(Qc,Tc,'-b',label='Cold Solution')
    plt.title(string)
    plt.xlabel('Energy($Q[kJ]$)')
    plt.ylabel('Temperature($T [^\circ C]$)')
    plt.show()
    return A

def write_to_excel(vars):
    wb = Workbook()
    dest_filename = 'FON_v5.xlsx'
    ws = wb.worksheets[0]
    ws.title = "First Option Nesfiskur"
    stafir=('p','h','T','s','q','d','v','m','x','y')
    column = get_column_letter(1)
    ws.cell(row = 0, column = 0).value= 'Variables'
    ws.cell(row = 1, column = 0).value= 'p[kPa]'
    ws.cell(row = 2, column = 0).value= 'h[kJ/kg]'
    ws.cell(row = 3, column = 0).value= 'T[K]'
    ws.cell(row = 4, column = 0).value= 's[kJ/K]'
    ws.cell(row = 5, column = 0).value= 'q'
    ws.cell(row = 6, column = 0).value= 'd[kg/m^3]'
    ws.cell(row = 7, column = 0).value= 'v[m^3/kg]'
    ws.cell(row = 8, column = 0).value= 'm[kg]'
    ws.cell(row = 9, column = 0).value= 'x'
    ws.cell(row = 10, column = 0).value= 'y'
    for col_idx in xrange(1, NUM_UNITS+1):
        col = get_column_letter(col_idx+1)
        ws.cell('%s%s'%(col,1)).value= '%s'%(col_idx)
        for row in xrange(0,10):
            if row < 8:
                ws.cell('%s%s'%(col,row+2)).value= '%s'%'%.3f'.format(round(vars[(col_idx)][stafir[row]],4))
            else:
                xy=vars[(col_idx)][stafir[row]]
                xy_0=xy[0]
                xy_1=xy[1]
                xy_f0=format(xy_0, '.4f')
                xy_f1=format(xy_1, '.4f')
                xy_f=[float(xy_f0), float(xy_f1)]
                ws.cell('%s%s'%(col,row+2)).value= '%s'%(xy_f)
    ws = wb.create_sheet()
    wb.save(dest_filename)

if __name__ == "__main__":
    main()

```

B.3. Programming for Case B

```

from numpy import *
import matplotlib.pyplot as plt
import matplotlib
from refprop import refprop
from pprint import pprint
from openpyxl.workbook import Workbook
from openpyxl.writer.excel import ExcelWriter
from openpyxl.cell import get_column_letter
import matplotlib
matplotlib.rcParams.update({'font.size': 22})
NUM_UNITS = 30
NUM_water = 6
KELVIN = 273.15
cp_ammonia=2.19 #kJ/(kg K)
cp_water=4.187 #kJ/(kg K)
p_low=71.661
#p_low=70.9
#p_high=670
aw=refprop('ammonia.fld','water.fld')
def main():
    #----- Reykjanes -----
    vars = {}
    Q={}
    for i in range(1,NUM_UNITS + 1):
        vars[i] = {'h':0.0,'p':0.0,'s':0.0,'T':0.0,'q':0.0,'m':0.0,'v':0.0,'d':0.0,'x':[0.0,0.0],'y':[0.0,0.0]}
    Q['SHX']=0.0,'Desorber':0.0,'DesorberII':0.0,'Hx_3':0.0,'Condenser':0.0,'Rectifier':0.0,'Evaporator':0.0,'CEHX':0.0,
    'wdot_p':0.0,'Reykjanes':0.0,'Absorber':0.0,'Regenerator':0.0,'Reykjanes':0.0}
    Area={'SHX':0.0,'Desorber':0.0,'DesorberII':0.0,'CEHX':0.0,'Condenser':0.0,'Rectifier':0.0,'Evaporator':0.0,
    'Absorber':0.0,'Regenerator':0.0,'Reykjanes':0.0}
    #m=16.1531#Skinnfiskur
    m1=26.923
    #Q['Desorber']=2500#4500
    Q['Rectifier']=300
    #Q['Evaporator']=100
    #Q['c']
    x1=[0.34,(1-0.34)]
    vars[1] = {'p':p_low}
    aw=refprop('ammonia.fld','water.fld')
    p_high=658
    #----- Point 1 -----
    A = aw.thermo('hpstqdx',q=0, p=vars[1]['p'],x=x1)
    [h, p, s, T, q, d, x, y] = A[0:8]
    v1=d
    vars[1] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v , 'm':m1,'x':x, 'y':y}
    #----- Point 2, Pump -----
    vars[2] = {'p':p_high, 'x':x1}
    C = calculate_pump(vars[1]['p'], vars[2]['p'], vars[1]['m'], vars[1]['h'], vars[1]['v'], vars[1]['s'], vars[1]['x'])
    vars[2]=C[0]
    Q['wdot_p']=C[1]['wdot_p']
    print 'vars 2'
    print vars[2]
    #-----Point 3 Hx_1-----
    #Starting values
    m16=vars[2]['m']*0.9
    K16=aw.thermo('h',q=0, p=vars[2]['p'],x=[0.3,1-0.3])
    h16=K16[0]
    J=aw.thermo('h',t=(vars[2]['T']+25), p=vars[2]['p'],x=[0.3,1-0.3])
    h17=J[0]
    #starting values for vars 5
    m6=0.05*m1
    x6=[0.5140202284, (1-0.5140202284)]
    vars[6]=('p':vars[2]['p'], 'q':0 , 'x':x6)#Water at pressure 1555.576 and quality 0
    h3old=0.3*Q['Desorber']/(vars[2]['m'])+vars[2]['h']
    A = aw.thermo('hpstqdx',h=h3old, p=p_high,x=vars[2]['x'])#x eitthvad annan
    [h, p, s, T, q, d, x, y] = A[0:8]
    v3=d
    vars[3] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v3 , 'm':m1,'x':x, 'y':y}
    A = aw.thermo('hpstqdx',t=65+273.15, p=p_high,x=vars[3]['x'])#x eitthvad annan
    [h, p, s, T, q, d, x, y] = A[0:8]
    v4=d
    vars[4] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v4 , 'm':vars[3]['m'],'x':x, 'y':y}
    for i in range(0,4):
        A = aw.thermo('hpstqdx',q=1, p=p_high,x=[0.996,1-0.996] )
        [h, p, s, T, q, d, x, y] = A[0:8]
        v10=d
        vars[6] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v10 , 'x':x , 'y':y}
        A = aw.thermo('hpstqdx',q=vars[6]['q'], p=vars[6]['p'],x=x6 )
        [h, p, s, T, q, d, x, y] = A[0:8]
        v6=d
        vars[6] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v6 , 'm':m6,'x':x , 'y':y}
        #Mixed fluids
        vars[5]=calculate_mixed(vars[4],vars[6])
    #----- Desorber -----
    #Liquid phase q=0 point 5s
    A = aw.thermo('hpstqdx',q=0, p=p_high, x=vars[5]['x'])
    [h, p, s, T, q, d, x, y] = A[0:8]
    v29=d
    vars[29] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v29 , 'm':vars[5]['m'], 'x':x , 'y':y}
    A = aw.thermo('hpstqdx',t=273.15+85, p=p_high, x=vars[5]['x'])
    [h, p, s, T, q, d, x, y] = A[0:8]

```

```

v7=1/d
vars[7] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v7, 'm':vars[5]['m'], 'x':x, 'y':y}
Q['DesorberI']=vars[5]['m']*(vars[29]['h']-vars[5]['h'])
Q['DesorberII']=vars[5]['m']*(vars[7]['h']-vars[29]['h'])
A = aw.thermo('hpstqdx',p=vars[7]['p'], q=1, x=vars[7]['y'])
[h, p, s, T, q, d, x, y] = A[0:8]
v8=1/d
m8=vars[7]['m']*vars[7]['q']
vars[8]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v8,'x':x, 'y':y, 'm':m8}
A = aw.thermo('hpstqdx',t=vars[10]['T'], p=p_high,x=vars[8]['y'])
[h, p, s, T, q, d, x, y] = A[0:8]
v9=1/d
m9=vars[8]['m']
vars[9] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v9,'m':m9, 'x':x , 'y':y}
Q['Rectifier']=vars[8]['m']*(vars[8]['h']-vars[9]['h'])
h3n=Q['Rectifier']/(vars[2]['m']+vars[2]['h'])
A = aw.thermo('hpstqdx',h=h3n, p=p_high,x=vars[2]['x'])
[h, p, s, T, q, d, x, y] = A[0:8]
v3=1/d
vars[3] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v3 , 'm':m1,'x':x, 'y':y}
m6=vars[9]['m']*(1-vars[9]['q'])
x6=vars[9]['x']
vars[10]['m']=vars[9]['m']*(vars[9]['q'])
#Liquid part
A = aw.thermo('hpstqdx',p=vars[7]['p'], q=0 , x=vars[7]['x'])
[h, p, s, T, q, d, x, y] = A[0:8]
v16=1/d
vars[16]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'v':v16,'d':d, 'x':x, 'y':y}
vars[16]['m']=vars[7]['m']*(1-vars[7]['q'])
#Point 17
A = aw.thermo('hpstqdx',p=vars[16]['p'], t=(vars[3]['T']+15), x=vars[7]['x'])
[h, p, s, T, q, d, x, y] = A[0:8]
v17=1/d
m=vars[16]['m']
vars[17]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v17, 'x':x, 'y':y,'m':m}
h4=(vars[16]['m']*(vars[16]['h']-vars[17]['h']))/vars[3]['m']+vars[3]['h']
Dh4=h4-vars[4]['h']
#print 'Dh4: ',Dh4
A = aw.thermo('hpstqdx',h=h4, p=p_high,x=vars[3]['x'])#x eitthvad annad
[h, p, s, T, q, d, x, y] = A[0:8]
v4=1/d
vars[4] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v7 , 'm':vars[3]['m'],'x':x, 'y':y}
A = aw.thermo('hpstqdx',p=p_low, h=vars[17]['h'], x=vars[7]['x'])
[h, p, s, T, q, d, x, y] = A[0:8]
if d==0:
    v18=0
else:
    v18=1/d
m=vars[17]['m']
vars[18]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v18, 'x':x, 'y':y,'m':m}
Q['SHX']=vars[16]['m']*(vars[16]['h']-vars[17]['h'])
#----- Condenser -----
#The sea is 7 degrees 273.15+75
A = aw.thermo('hpstqdx',p=vars[10]['p'], q=0, x=vars[10]['y'])
[h, p, s, T, q, d, x, y] = A[0:8]
m=vars[10]['m']
v11=1/d
vars[11]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'x':x, 'v':v11, 'y':y, 'd':d,'m':m}
Q_c=vars[11]['m']*(vars[10]['h']-vars[11]['h'])
Q['Condenser']=Q_c
t12=270
t12=350
while(vars[11]['T']<t15+6):
    t12+=1
    A = aw.thermo('hpstqdx',t=t12, p=p_high,x=vars[11]['x'])
    [h, p, s, T, q, d,x,y] = A[0:8]
    m12=vars[11]['m']
    v12=1/d
    vars[12]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'x':x, 'y':y, 'v':v12 , 'd':d,'m':m12}
    #----- Throttle -----
    A = aw.thermo('hpstqdx',p=p_low, h=vars[12]['h'],x=vars[12]['x'])
    [h, p, s, T, q, d,x,y] = A[0:8]
    if d==0:
        v13=0
    else:
        v13=1/d
    vars[13]={ 's':s, 'T':T, 'q':q, 'd':d, 'p':p, 'v':v13, 'm':vars[12]['m'], 'h':h, 'x':x,'y':y}
    #----- Evaporator -----
    A = aw.thermo('hpstqdx',t=vars[13]['T']+1, p=p_low,x=vars[13]['x'])
    [h, p, s, T, q, d,x,y] = A[0:8]
    m14=vars[13]['m']
    if d==0:
        v14=0
    else:
        v14=1/d
    vars[14]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'x':x, 'y':y, 'v':v14 , 'd':d,'m':m14}
    h15=(vars[11]['h']-vars[12]['h'])+vars[14]['h']
    A = aw.thermo('hpstqdx',h=h15, p=p_low,x=vars[14]['x'])
    [h, p, s, T, q, d,x,y] = A[0:8]
    m15=vars[11]['m']
    if d==0:
        v15=0
    else:
        v15=1/d
    vars[15]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'x':x, 'y':y, 'v':v15 , 'd':d,'m':m15}

```

```

t15=vars[15]['T']
print 'T11: ', vars[11]['T']
print 'T15: ', vars[15]['T']
Q['Evaporator']=vars[14]['m']*(vars[14]['h']-vars[13]['h'])
#-----CEHX-----
Q['CEHX']=vars[11]['m']*(vars[11]['h']-vars[12]['h'])
#-----absorption mixed fluids -----
m19=vars[15]['m']+vars[18]['m']
h19=(vars[15]['m']*vars[15]['h']+vars[18]['m']*vars[18]['h'])/m19
A=aw.thermo('hpstqdx',p=p_low, h=h19,x=vars[1]['x'])
[h, p, s, T, q, d,x,y] = A[0:8]
v19=1/d
vars[19]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v19, 'm':m19, 'x':x, 'y':y)
#Absorber:
Q['Absorber']=vars[1]['m']*(vars[19]['h']-vars[1]['h'])
pr=700
w=refprop('water.fld')
#Point 17
A=w.thermo('hpstqdx',p=pr, t=90+273.15)
[h, p, s, T, q, d] = A[0:6]
v=1/d
vars[20]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':m, 'x':[0.0,1.0], 'y':[0.0,1.0])
#Point 18
#-----point 20s, thegar 5s q=0-----
A=w.thermo('hpstqdx',p=pr, t=vars[29]['T']+5)
[h, p, s, T, q, d] = A[0:6]
mr=Q['DesorberII']/(vars[20]['h']-h)
m=mr
v30=1/d
vars[30]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v30,'m':m, 'x':[0.0,1.0], 'y':[0.0,1.0])
vars[20]['m']=mr
h21=vars[30]['h']-Q['DesorberI']/mr
A=w.thermo('hpstqdx',p=pr, h=h21)
[h, p, s, T, q, d] = A[0:6]
v21=1/d
vars[21]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v21,'m':mr, 'x':[0.0,1.0], 'y':[0.0,1.0])
print ' mr: ' +str(mr) +' pressure: ' + str(p_high) + ' Evaporator: ' + str(Q['Evaporator'])+'7q: ' + str(vars[7]['q'])
print ' 13q and 14q: ' +str(vars[13]['q']) +' and ' + str(vars[14]['q']) + ' Evaporator temperature: ' + str(vars[13]['T'])
#point 23
#COP
COP=Q['Evaporator']/(Q['DesorberI']+Q['DesorberII']+Q['wdot_p'])
#Condenser
pc=500
Tc1=273.15+
A=w.thermo('hpstqdx',p=pc, t=Tc1)
[h, p, s, T, q, d] = A[0:6]
mc=290
v=1/d
vars[23]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':mc, 'x':[0.0,1.0], 'y':[0.0,1.0])
hc2=Q['Condenser']/mc+vars[23]['h']
A=w.thermo('hpstqdx',p=pc, h=hc2)
[h, p, s, T, q, d] = A[0:6]
v=1/d
vars[24]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':mc, 'x':[0.0,1.0], 'y':[0.0,1.0])
A=w.thermo('hpstqdx',p=pc, t=Tc1)
[h, p, s, T, q, d] = A[0:6]
v=1/d
vars[25]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v, 'm':mc, 'x':[0.0,1.0], 'y':[0.0,1.0])
A=w.thermo('hpstqdx',p=pc, t=vars[19]['T']-5)
[h, p, s, T, q, d] = A[0:6]
v=1/d
ma=Q['Absorber']/(vars[25]['h']-vars[26]['h'])
vars[25]['m']=ma
vars[26]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':ma, 'x':[0.0,1.0], 'y':[0.0,1.0])
pc=500
Tc1=273.15+
A=w.thermo('hpstqdx',p=pc, t=Tc1)
[h, p, s, T, q, d] = A[0:6]
m=ma+mc
v=1/d
vars[22]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v,'m':m, 'x':[0.0,1.0], 'y':[0.0,1.0])
#Evaporator
w=refprop('air.ppf')
#w=refprop('water.fld')
A=w.thermo('hpstqdx',p=100, t=273.15+10)
[h, p, s, T, q, d] = A[0:6]
v=0
vars[27]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'v':v, 'd':d, 'x':[0.0,1.0], 'y':[0.0,1.0])
A=w.thermo('hpstqdx',p=100, t=273.15-18)
[h, p, s, T, q, d] = A[0:6]
v=0
m28=Q['Evaporator']/(vars[27]['h']-h)
vars[28]=('h':h, 'p':p, 's':s, 'T':T,'m':m28,'v':v , 'q':q, 'd':d, 'x':[0.0,1.0], 'y':[0.0,1.0])
vars[27]['m']=m28
Q['Desorber']=Q['DesorberI']+Q['DesorberII']
aw=refprop('ammonia.fld','water.fld')
#Areas calculated
#Condenser(Shell and tube):
Q['SHX']=vars[14]['m']*(vars[16]['h']-vars[17]['h'])
BTUtoW=5.6783
Uhx_1=1.1
Ucond=(125*BTUtoW)/1000#Shell and tube exchanger, builditsolar
Urect=(125*BTUtoW)/1000
Ushx=2500/1000 #Plate, builditsolar
Ueva=1.65

```

```

Uabs=(125*BTUtoW)/1000
Udes=(125*BTUtoW)/1000
Ucehx=(125*BTUtoW)/1000
print 'Ucond: ', Ucond
print 'Urect: ', Urect
print 'Ushx: ', Ushx
print 'Ueva: ', Ueva
print 'Uabs: ', Uabs
print 'Udes: ', Udes
Ureg=1.1
#U-tube horizontal bundle
#H=Horizontal, fixed or floating tube sheet
#(Q,U,Th1,Th2,Tc1,Tc2):
Area['Evaporator']=HXareaA(Q['Evaporator'],Ueva,vars[27],vars[28],vars[13],vars[14],'Evaporator')
Area['Condenser']=HXarea(Q['Condenser'],Ucond,vars[10],vars[11],vars[23],vars[24],'Condenser')
Area['CEHX']=HXarea(Q['CEHX'],Ucehx,vars[11],vars[12],vars[14],vars[15],'Condenser-Evaporator Heat Exchanger')
Area['Rectifier']=HXarea(Q['Rectifier'],Urect,vars[8],vars[9],vars[2],vars[3],'Rectifier')
Area['SHX']=HXarea(Q['SHX'],Ushx,vars[16],vars[17],vars[3],vars[4],'Solution Heat Exchanger')
Area['Desorber']=HXarea(Q['Desorber'],Udes,vars[20],vars[21],vars[5],vars[7],'Desorber')
Area['DesorberII']=HXarea(Q['DesorberII'],Udes,vars[20],vars[30],vars[29],vars[7],'Desorber II')
#Area['Absorber']=HXareaE(Q['Absorber'],Uabs,vars[19],vars[1],vars[25],vars[26],'Absorber')
#plt.show()
#Solution Hx
#print 'Area: ' +str(Area)
pprint(vars)
pprint(Q)
pprint(Area)
print 'COP: ' + str(COP)
-----The def function can be found in the programming in case 1
if __name__ == "__main__":
    main()

```

B.4. Programming for Case C

```

from numpy import *
import matplotlib.pyplot as plt
import matplotlib
from refprop import refprop
from pprint import pprint
from openpyxl.workbook import Workbook
from openpyxl.writer.excel import ExcelWriter
from openpyxl.cell import get_column_letter
import matplotlib
matplotlib.rcParams.update({'font.size': 35})
NUM_UNITS = 36
NUM_water = 6
Kelvin = 273.15
cp_ammonia=2.19 #kJ/(kg K)
cp_water=4.187 #kJ/(kg K)
aw=refprop('ammonia.fld','water.fld')
def main():
    #----- Reykjanes -----
    vars = {}
    Q={}
    for i in range(1,NUM_UNITS + 1):
        vars[i] = {'h':0.0,'p':0.0,'s':0.0,'T':0.0,'q':0.0,'m':0.0,'v':0.0,'d':0.0,'x':[0.0,0.0],'y':[0.0,0.0]}
    Q['SHXII']=0.0,'SHXII'=0.0,'GeneratorI'=0.0,'GeneratorII'=0.0,'Condenser'=0.0,'CondenserII'=0.0,'Rectifier'=0.0,
    'RectifierII'=0.0,'Evaporator'=0.0,'CEHX'=0.0,'wdot_p1'=0.0,'wdot_p2'=0.0,'Reykjanes'=0.0,'AbsorberI'=0.0,'AbsorberII'=0.0,
    'Area='('SHXII'=0.0,'SHXII'=0.0,'GeneratorI'=0.0,'GeneratorII'=0.0,'DesorberII'=0.0,'CEHX'=0.0,'Condenser'=0.0,
    'Rectifier'=0.0,'Evaporator'=0.0,'Absorber'=0.0,'Regenerator'=0.0,'Reykjanes'=0.0)
    #Q['Desorber']=2500#4500
    #Q['Rectifier']=300
    #Q['Evaporator']=100
    #Q['c']
    """
    -----Optimization-----
    COP: 0.416021733401
    Evaporator: 588.507724076
    Generator I: 1382.021198
    x_1: [0.3259999999999999, 0.6740000000000000]
    x_rect1: [0.99095509860392428, 0.0090449013960757219]
    x_rect2: [0.99095509860392428, 0.0090449013960757219]
    p_h1: 2682.94832929
    p_h2: 800.0
    T6opt: 425.339890344
    T21opt: 6.0
    m1: 10
    """
    x_1=[0.326, 1-0.326]
    x_rect1=[0.99095509860392428, (1-0.99095509860392428)]
    x_rect2=[0.99095509860392428, (1-0.99095509860392428)]
    p_h1=2682.94832929
    p_h2=800.0
    p5=1900
    T_38=211+Kelvin
    m_1=41.330
    T6opt=425.339890344
    T21opt=6.0
    aw=refprop('ammonia.fld','water.fld')
    [hthrottle, xthrottle] = aw.thermo('hx',t=273.15+9+5, p=p_h2,x=x_rect2)
    [p_low] = aw.thermo('p',h=hthrottle, t=233.15,x=xthrottle)
    #----- Point 1 -----
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',q=0, p=p_low,x=x_1)
    v=1/d
    vars[1] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v , 'm':m_1,'x':x, 'y':y}
    print vars[1]
    #----- Point 2, Pump -----
    vars[2] = {'p':p_h1, 'x':x_1}
    C = calculate_pump(vars[1], vars[2])
    vars[2]=C[0]
    Q['wdot_p']=C[1]['wdot_p']
    #----- Point 6 , Generator I -----
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=T6opt, p=p_h1,x=vars[1]['x'])
    v6=1/d
    vars[6] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v6 , 'm':vars[2]['m'],'x':x, 'y':y}
    #----- Vapor from separator -----
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',p=p_h1, q=1 , x=vars[6]['y'])
    v7=1/d
    m7=vars[6]['m']*vars[6]['q']
    vars[7]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v7,'x':x, 'y':y, 'm':m7}
    #----- Ammonia ratio rect_1 at point 9 -----
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',q=1, p=p_h2,x=x_rect1)
    v10=1/d
    vars[10] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v10 , 'x':x , 'y':y}
    #-----Generator II and throttle-----
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=vars[10]['T'], p=p_h2,x=vars[7]['y'])
    v9=1/d
    m9=vars[7]['m']
    vars[9] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v9,'m':m9, 'x':x , 'y':y}
    vars[10]['m']=m9*vars[9]['q']
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',p=p_h1, h=vars[9]['h'], x=vars[7]['y'])
    m=vars[7]['m']
    v8=1/d

```

```

vars[8]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'x':x, 'v':v8, 'y':y, 'd':d, 'm':m}
Q['GeneratorII']=vars[8]['m']*(vars[7]['h']-vars[8]['h'])
#----- Point 11 -----
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',p=p_h1, q=0, x=vars[6]['x'])
v11=1/d
m11=vars[6]['m']*(1-vars[6]['q'])
vars[11]={'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d, 'v':v11,'x':x, 'y':y, 'm':m11}
#----- Rectifier, point 19 -----
#Without massflow
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',q=1, p=p_h2,x=x_rect2)
v19=1/d
vars[19] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v19, 'x':x , 'y':y}
# Iteration for Rectifier, SHXII and SHXII
# Start values
Q['Rectifier']=0.3*Q['GeneratorII']
h3=Q['Rectifier']/vars[2]['m']+vars[2]['h']
[h3, T3, x3] = aw.thermo('htx',h=h3, p=p_h1,x=vars[2]['x'])
[h21,T21, x21] = aw.thermo('htx',t=305, p=p_h2,x=[0.28,1-0.28])
[h20,T20, x20] = aw.thermo('htx',q=0, p=p_h2,x=[0.28,1-0.28])
T4guess=60
vars[4]['T']=T20-T4guess
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',q=0, p=p_h2,x=[0.514,(1-0.514)])
m14=vars[2]['m']*0.1
vars[14] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'m':m14, 'x':x , 'y':y}
#vars[18]['x']=0.514,(1-0.514)
for i in range(0,4):
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=vars[4]['T']+5, p=p_h1,x=vars[11]['x'])
    v12=1/d
    m12=vars[11]['m']
    vars[12] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v12,'m':m12, 'x':x , 'y':y}
    Q['SHXII']=vars[12]['m']*(vars[11]['h']-vars[12]['h'])
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',h=vars[12]['h'], p=p_h2,x=vars[12]['x'])
    v13=1/d
    m13=vars[12]['m']
    vars[13] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v13,'m':m13, 'x':x , 'y':y}
    vars[15]=calculate_mixed(vars[14],vars[13])
    h16=vars[15]['h']+Q['GeneratorII']/vars[15]['m']
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',h=h16, p=p_h2,x=vars[15]['x'])
    v16=1/d
    m16=vars[15]['m']
    vars[16] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v16,'m':m16, 'x':x , 'y':y}
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',q=1, p=p_h2,x=vars[16]['y'])
    v17=1/d
    m17=vars[16]['m']*vars[16]['q']
    vars[17] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v17,'m':m17, 'x':x , 'y':y}
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=vars[19]['T'], p=p_h2,x=vars[17]['y'])
    v18=1/d
    vars[18] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v18,'x':x , 'y':y}
    Q['Rectifier']=vars[17]['m']*(vars[17]['h']-vars[18]['h'])
    vars[18]['m']=vars[17]['m']
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',q=0, p=p_h2,x=vars[18]['x'])
    v14=1/d
    m14=vars[18]['m']*(1-vars[18]['q'])
    vars[14] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v14,'m':m14, 'x':x , 'y':y}
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',q=0, p=p_h2,x=vars[16]['x'])
    v20=1/d
    m20=vars[16]['m']*(1-vars[16]['q'])
    vars[20] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v20,'m':m20, 'x':x , 'y':y}
    h3=Q['Rectifier']/vars[2]['m']+vars[2]['h']
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',h=h3, p=p_h1,x=vars[2]['x'])
    v3=1/d
    m3=vars[2]['m']
    vars[3] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v3,'m':m3, 'x':x , 'y':y}
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=vars[3]['T']+T2lopt, p=p_h2,x=vars[20]['x'])
    v21=1/d
    m21=vars[20]['m']
    vars[21] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v3,'m':m21, 'x':x , 'y':y}
    Q['SHXII']=vars[21]['m']*(vars[20]['h']-vars[21]['h'])
    h4=vars[3]['h']+Q['SHXII']/vars[3]['m']
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',h=h4, p=p_h1,x=vars[3]['x'])
    v4=1/d
    m4=vars[2]['m']
    vars[4] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v4,'m':m4, 'x':x , 'y':y}
    h5=vars[4]['h']+Q['SHXII']/vars[4]['m']
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',h=h5, p=p_h1,x=vars[4]['x'])
    v5=1/d
    m5=vars[4]['m']
    vars[5] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v5,'m':m5, 'x':x , 'y':y}
    [h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',q=0, p=p_h2,x=vars[9]['x'])
    v22=1/d
    m22=vars[9]['m']*(1-vars[9]['q'])
    vars[22] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v22,'m':m22, 'x':x , 'y':y}
    vars[23]=calculate_mixed(vars[21],vars[22])
    vars[19]['m']=vars[18]['m']*vars[18]['q']
    vars[24]=calculate_mixedvapor(vars[10],vars[19])
#-----Generator I -----
Q['GeneratorI']=vars[5]['m']*(vars[6]['h']-vars[5]['h'])
aw=refprop('water.fld')
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',q=0, p=pS)
v=1/d
vars[32] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v,[0.0,1.0] , 'y':[0.0,1.0]}
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=vars[5]['T']+10, p=pS)
v=1/d
vars[33] = {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v,[0.0,1.0] , 'y':[0.0,1.0]}
vars[33]['m']=Q['GeneratorI']/(vars[32]['h']-vars[33]['h'])

```

```

vars[32]['m']=vars[33]['m']
aw=refprop('ammonia.fld','water.fld')
#----- Condenser -----
A = aw.thermo('hpstqdx',p=p_h2, t=287.15, x=vars[24]['y'])
[h, p, s, T, q, d, x, y] = A[0:8]
m=vars[24]['m']
v25=1/d
vars[25]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v25, 'x':x, 'y':y,'m':m)
#-----Prufa-----
t26=263
t29=350
while(vars[25]['T']<t29+5):
    t26+=1
    #A = aw.thermo('h',t=233.15, p=p_low,x=vars[11]['x'])
    #h12 = A[0]
    A = aw.thermo('hpstqdx',t=t26, p=p_h2,x=vars[25]['x'])
    [h, p, s, T, q, d,x,y] = A[0:8]
    m26=vars[25]['m']
    v26=1/d
    vars[26]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q,'v':v, 'x':x, 'y':y , 'd':d,'m':m26}
    #----- Throttle -----
    A = aw.thermo('hpstqdx',p=p_low, h=vars[26]['h'],x=vars[26]['x'])
    [h, p, s, T, q, d,x,y] = A[0:8]
    if d==0:
        v27=0
    else:
        v27=1/d
    vars[27]=('s':s, 'T':T, 'q':q, 'd':d,'p':p, 'v':v27, 'm':vars[26]['m'], 'h':h, 'x':x,'y':y)
    #----- Evaporator -----
    A = aw.thermo('hpstqdx',t=vars[27]['T']+2, p=p_low,x=vars[27]['x'])
    [h, p, s, T, q, d,x,y] = A[0:8]
    m28=vars[27]['m']
    if d==0:
        v28=0
    else:
        v28=1/d
    vars[28]= ('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'x':x, 'y':y, 'v':v28 , 'd':d,'m':m28}

    h29=(vars[25]['h']-vars[26]['h'])+vars[28]['h']
    A = aw.thermo('hpstqdx',h=h29, p=p_low,x=vars[27]['x'])
    [h, p, s, T, q, d,x,y] = A[0:8]
    m29=vars[28]['m']
    v=0
    vars[29]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q,'v':v, 'x':x, 'y':y , 'd':d,'m':m29}
    t29=vars[29]['T']

Q['Evaporator']=vars[28]['m']*(vars[28]['h']-vars[27]['h'])
COP=Q['Evaporator']/(Q['GeneratorI']+Q['wdot_p'])
Q['CEHX']=vars[25]['m']*(vars[25]['h']-vars[26]['h'])
#-----absorption mixed fluids -----
[h, p, s, T, q, d,x,y] = aw.thermo('hpstqdx',p=p_low, h=vars[23]['h'],x=vars[23]['x'])
if d==0:
    v30=0
else:
    v30=1/d
vars[30]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v30, 'm':vars[23]['m'], 'x':x , 'y':y)
m31=vars[29]['m']+vars[30]['m']
h31=(vars[30]['m']*vars[30]['h']+vars[29]['m']*vars[29]['h'])/m31
[h, p, s, T, q, d,x,y] = aw.thermo('hpstqdx',p=p_low, h=h31,x=vars[1]['x'])
v31=1/d
vars[31]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v31, 'm':m31, 'x':x , 'y':y)
#Absorber:
Q['Absorber']=vars[1]['m']*(vars[31]['h']-vars[1]['h'])
#Condenser
Q['Condenser']=vars[24]['m']*(vars[24]['h']-vars[25]['h'])
#Sea coolant
aw=refprop('water.fld')
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=Kelvin+9, p=pS)
v=1/d
vars[34]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v , 'x':[0.0,1.0] , 'y':[0.0,1.0]}
#condenser
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=Kelvin+9, p=pS)
v=1/d
vars[35]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v , 'x':[0.0,1.0] , 'y':[0.0,1.0]}
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=273.15+16, p=pS)
v=1/d
vars[36]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v , 'x':[0.0,1.0] , 'y':[0.0,1.0]}
mc=(Q['Condenser'])/(vars[36]['h']-vars[35]['h'])
vars[36]['m']=mc
vars[35]['m']=mc
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=Kelvin+9, p=pS)
v=1/d
vars[37]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v , 'x':[0.0,1.0] , 'y':[0.0,1.0]}
[h, p, s, T, q, d, x, y] = aw.thermo('hpstqdx',t=vars[31]['T']-5, p=pS)
v=1/d
vars[38]= {'h':h, 'p':p, 's':s, 'T':T, 'q':q, 'd':d,'v':v , 'x':[0.0,1.0] , 'y':[0.0,1.0]}
mc2=(Q['Absorber'])/(vars[38]['h']-vars[37]['h'])
vars[38]['m']=mc2
vars[37]['m']=mc2
vars[34]['m']=mc+mc2
#Evaporator
w=refprop('air.ppf')
A=w.thermo('hpstqdx',p=100, t=273.15+10)
[h, p, s, T, q, d] = A[0:6]
v=0
vars[39]=('h':h, 'p':p, 's':s, 'T':T, 'q':q, 'v':v , 'd':d, 'x':[0.0,1.0] , 'y':[0.0,1.0])

```

```

#370m^3 af lofti
A=w.thermo('hpstqdx',p=100, t=273.15-18)
[h, p, s, T, q, d] = A[0:6]
v=0
m40=Q['Evaporator']/ (vars[39]['h']-h)
vars[40]={'h':h, 'p':p, 's':s, 'T':T, 'm':m40, 'v':v , 'q':q, 'd':d, 'x':[0.0,1.0] , 'y':[0.0,1.0]}
vars[39]['m']=m40
aw=refprop('ammonia.fld','water.fld')
BTUtoW=5.6783
Uhx_1=1.1
Ucond=(125*BTUtoW)/1000#Shell and tube exchanger, builditsolar
Urect=(125*BTUtoW)/1000
Ushx=2500/1000 #Plate, builditsolar
Ueva=1.65
Uabs=(125*BTUtoW)/1000
Udes=(125*BTUtoW)/1000
Ucehx=(125*BTUtoW)/1000
Area['Evaporator']=HXareaA(Q['Evaporator'],Ueva,vars[39],vars[40],vars[27],vars[28],'Evaporator')
Area['Condenser']=HXareaE(Q['Condenser'],Ucond,vars[24],vars[25],vars[35],vars[36],'Condenser')
Area['Rectifier']=HXareaE(Q['Rectifier'],Urect,vars[17],vars[18],vars[12],vars[3],'Rectifier')
Area['SHXI']=HXareaE(Q['SHX1'],Ushx,vars[20],vars[21],vars[3],vars[4],'Solution Heat Exchanger I')
Area['SHXII']=HXareaE(Q['SHXII'],Ushx,vars[11],vars[12],vars[4],vars[5],'Solution Heat Exchanger II')
Area['GeneratorI']=HXareaE(Q['GeneratorI'],Udes,vars[32],vars[33],vars[5],vars[6],'Generator I')
Area['GeneratorII']=HXareaE(Q['GeneratorII'],Udes,vars[7],vars[8],vars[15],vars[16],'Generator II')
Area['CEHX']=HXareaE(Q['CEHX'],Ucehx,vars[25],vars[26],vars[28],vars[29],'Condenser-Evaporator Heat Exchanger')
Area['Absorber']=HXareaE(Q['Absorber'],Uabs,vars[31],vars[1],vars[37],vars[38],'Absorber')
#plt.show()
#Solution Hx
print 'Area: ' +str(Area)
pprint(vars)
pprint(Q)
print 'COP: ',COP
#pprint(vars)
write_to_excel(vars)
#pprint(Q)

#Sem def's as in program for case 1

```

B.5. Pressure drop

```
-----Pressure drop calculations -----
from numpy import *
g=9.82
d=[0.125,0.150,0.20,0.25,0.3]
#G=0.014745 #nesfiskur
#G=16.6*0.001 #skimnfiskur
G=24.065*0.001 #Total
G=170.98*0.001 #case 2
#G=32.616*0.001 #Total
rho=965.58
#rho=907.73743#p=1100
n=5
Inew=zeros((n))
Iold=25
L=1
u=zeros((n))
f=ones((n))*n
hloss=zeros((n))
Re=zeros((n))
hf=zeros((n))
#k=0.0048*0.001
k=0.001*0.001
#Kinematic viscocity
v=1.87753*10**(-7)
#v=1*10**(-6)
for i in range(0,n):
    for h in range(1,15):
        Inew[i]=(1.072*(G)**2)/(g*(d[i])**5*(log(0.27*k/d[i]+1.78*v/sqrt(g*d[i]**3*Iold))))**2
        Iold=Inew[i]
        Re[i]=(4*G)/(v*pi*d[i])
        s=-2.0*log10((k/d[i])/3.7+2.51/(Re[i]*sqrt(f[i])))
        f[i]=1/(s**2)
        u[i]=(4*G)/(pi*d[i]**2)
        Re[i]=(4*G)/(v*pi*d[i])
        hloss[i]=f[i]*(L/d[i])*(u[i]**2)/2*rho
print 'Inew: ',Inew
print 'hloss: ',hloss
print 'u: ',u
print 'Re: ',Re
print 'f: ',f
```