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Heat Storage for Vapour Based Solar Concentrators

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MASTER THESIS

Catharina Hoff

Heat storage for vapour based solar concentrators

Varmelager for dampbasert solkonsentrator

Background

In an on-going cooperation with African universities, we are examining different technical solutions for capturing and storing high temperature thermal energy (250 degrees Celsius). The motivation is small scale systems to cover parts of the energy demands at institutions (schools, universities, hospitals, health centres).

A heat storage is an important part of the energy system. The solar energy can then be stored and accessible after sunset. Nitrate mixtures can be used as heat storage. The advantage of using melting heat as storage is that the temperature stays almost constant. This is especially useful for cooking and frying applications (ca. 200 degrees).

The sunrays can be focused in a point absorber (parabolic disc) or along a pipe absorber (trough) where a liquid is heated and then transports the heat to the storage. Another possibility is to illuminate the heat storage directly, with focusing the reflection system on the storage.

The assignment is to consider a technical solution for a frying plate which connects to a heat storage. This storage can be heated by a flowing oil or condensed vapour (water vapour or oil vapour). A block of aluminium is perforated with channels for the heat conductive material and cavities are made for the nitrate salt. At the top of the plate it should then be possible to prepare food (frying or cooking) in the evening after sunset.

Objective

A heat storage (nitrate salt in a block of aluminium) heated with circulating oil or with condensed vapour shall be analysed, and if possible, designed, constructed and tested.

The following tasks are to be considered

1. Literature overview of small scale sun energy systems with heat storage
2. Thermic analysis and dimensioning of the heat storage
3. Construction, instrumenting and testing of the heat storage
4. Reporting and recommendations on further work

Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

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Department of Energy and Process Engineering, 1.February 2012

Olav Bolland

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Academic Supervisor

Preface

This thesis is done as a contribution to the NOFU project between NTNU and five African universities with the specific purpose to design, construct and analyse a heat storage for vapour based solar concentrators.

First of all I must express my excitement of having been allowed to work with such a rewarding master's thesis. I have really appreciated the fact that it has been a hands on thesis where I actually was able to construct a heat storage from scratch and perform experiments on it. The cooperation between the African universities has been good and it has been really worthwhile to develop something you know people are in need of. That said, it has been a lot of hard work (both mentally *and* physically), frustration (especially towards not very cooperative computer programs) and long hours at office B430. Nevertheless, I am in the end left with a feeling that this thesis is, albeit small, a contribution to future production and design of solar energy heat storages.

I have learned much from the work with this thesis, both professional and private. Among several things have I increased my own interest in solar energy and solar cooking.I have also gained important laboratory experience about the fact that theoretical ideas are much more time consuming to put into practice than they appear.

I must express my gratitude to professor Ole Jørgen Nydal that has been a present and enthusiastic supervisor with a real dedication to the project. Maxime Mussard and Asfafaw Haileselassie, that are doing their doctoral thesis at NTNU, have also contributed much to the thesis. Thank you, Jan-Terje Hagvåk, Paul Svendsen, Gisle, and all the other laboratory workers for your help and patient with all my hassling towards practicalities with the storage. Thank you, Hydro, for donating the aluminium bolt. Thank you too, Åsmund Eldhuset, for your superb Python code that calculates averages, and thank you Arne Nordmark and Trond Furu for your guidance concerning aluminium. Also, a thank you goes to the other people associated with the NOFU project.

Last but not least I have to thank Rune Herdlevær for his support and conversations (and that he really acknowledge the hard work associated with insulating), the coffee machine on 3rd floor, NTNU's "open university at all hours" policy, financial support for the NOFU project, Spotify, my family, friends, and all other classmates that have made the last five years a memory for life.

Trondheim, 11.06.2012

Catharina Hoff

Abstract

In a world where energy demand, population, and environmental concern are increasing by the day, the use of solar energy and other renewable energy sources becomes ever more important. Most of the African population lives in rural areas and uses wood as primary energy source for cooking. The wood, however, can be replaced by the energy in the abundant sunshine most African countries experiences and used in solar cookers. However, the biggest disadvantage of most common solar cookers available today is that they are dependent on direct solar radiation to work. This makes them vulnerable to the intermittent nature of the sun and limits the cooking to the sunny hours of the day.

In this thesis, a possible solution to that problem area is examined. A solar energy heat storage for vapour based solar concentrators is designed, constructed and analysed with cooking of the traditional Ethiopian bread injera in mind. The storage consists of an aluminium bolt with salt filled cavities that has working fluid (steam or oil) running through it. The energy stored during the salt melting (latent heat) is released at constant temperature between 210°C-220°C which is the melting temperature of the salt, and the temperature needed to cook injeras. One experiment was performed with heat transfer oil as working fluid, but did not yield any results due to air bubbles that prevented circulation. Two experiments were done with steam as working fluid. The first experiment measured the discharge of the storage which was found to be a temperature fall from 221.8°C to 50°C during a time span of 85 hours. The other experiment aimed for boiling of one litre of water, but the highest temperature reached was 70.9°C. However, several modifications can be done to improve the storage capacity and cooking procedure, as for instance increasing the amount of salt.

Sammendrag

I en verden hvor energibehovet, befolkningen, og miljømessige bekymringer øker for hver dag, blir bruken av solenergi og andre fornybare energikilder stadig viktigere. Flesteparten av den afrikanske befolkningen bor på landsbygda og bruker ved som primær energikilde for matlaging. Veden kan derimot erstattes av energien som finnes i den rikelig tilgjengelige solstrålingen, og brukes i solkokere. Den største ulempen med de vanligste solkokerne tilgjengelig i dag er derimot at de er avhengige av direkte solstråling for å fungere. Dette gjør de sårbare for uregelmessig solstråling og begrenser dessuten matlagingen til de solfylte timene på dagen.

I denne avhandlingen er en mulig løsning på det problemområdet undersøkt. Et varmelager for dampbaserte solkonsentratorer er designet, konstruert og analysert med tanke på å steke det tradisjonelle etiopiske brødet injera. Lageret består av en aluminiumbolt med hulrom fylt med salt. Enten damp eller olje fungerer som virksom væske og går gjennom bolten. Energien som lagres som latent varme når saltet smelter frigjøres ved konstant temperatur mellom 210 °C-220 °C som er smeltetemperaturen til saltet, og samtidig temperaturen er nødvendig for å steke injera. Ett eksperiment ble utført med olje som virksom væske, men det gav ingen resultater på grunn av luftbobler i rørene som hindret sirkulasjon av oljen. To forsøk ble gjort med damp som virksom væske. Det første eksperimentet målte tid og temperatur ved utladning av lageret som ble funnet til å være et temperaturfall fra 221.8 °C til 50 °C på et tidsrom på 85 timer. Det andre forsøket gikk ut på å koke en liter vann, men den høyeste temperaturen som ble nådd i vannet var 70.9 °C. Imidlertid kan flere endringer gjøres for å forbedre matlagingsmåten og lagringskapasiteten, for eksempel kan saltmengden i lageret økes.

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Nomenclature

Abbreviations

TES	Thermal Energy Storage
LHS	Latent Heat Storage
SHS	Sensible Heat Storage
PCM	Phase Change Material

Roman Letters

T	Temperature	°C
k	Thermal conductivity	W/mK
C_p	Heat Capacity	kJ/kgK
ρ -	Density	kg/m^3
h -	Enthalpy	kJ/kg

Greek Letters

η	Efficiency

1 Introduction

1.1 Background

After an idea from professor emeritus Jørgen Løvseth, NTNU and five African universities created the NUFU Solar Project. The project has the objective to encourage further cooperation between north and south, and to develop ideas and prototypes of systems driven by solar energy that can be used to produce food and hot water. Some of the focus areas to the NUFU project are to examine different technical solutions of capturing and storing high temperature thermal energy (250°C).

This thesis is done as a contribution to the NOFU project, with the specific purpose to design, construct and analyse a heat storage for vapour based solar concentrators that shall be used for cooking a typical Ethiopian bread called injera.

1.2 Motivation

Most of the population in Africa lives in rural areas with scarce infrastructure and electricity availability. The most common fuel is wood. Gathering of wood is often very hard work and time consuming as large amounts are needed and deforestation is increasing in several areas. Using wood as fuel also increases the release of carbon dioxide and the released smoke can be harmful to the health. To reduce the social and environmental load associated with the use of wood as energy source, solar energy is a very good energy alternative in Africa as most African countries have abundance of insolation.

However, solar energy systems in general face challenges towards conventional energy sources due to well-established cooking habits, natural solar intermittence, and reluctance for implementing new and unknown technologies. Most of the solar cooker systems that exist on the market are direct systems that need the presence of the sun in order to work. This does not comply with the fact that in many countries cooking traditionally takes place after dark, or at hours when the solar radiation is at its weakest. Also, the intermittence of the sun can disrupt the cooking process which in worst case can ruin the food, in addition to the fact that the people cooking needs to stay in direct sunlight. This mismatch needs to be managed to encourage solar energy as energy source for cooking purposes [1].

One way of reducing the mentioned disadvantages with direct solar cookers is to implement indirect systems whit heat storage possibilities. Indirect systems have the heat capturing section and the cooking utensils separated.

The traditional and most important Ethiopian bread is called injera. It is 40-50 cm in diameter and is cooked at a temperature of 220°C. Gallagher [2] calculated that one injera with a diameter of 42 cm requires 83 kJ to be fried, and assumes that each person eats 0.2 kg/day. Ethiopia is according to Solar Cookers International [3] rated as the fourth country with greatest potential benefits from solar cookers. The motivation of the thesis is to produce a small scale heat storage system that covers part of the energy demand at institutions (schools, hospital etc.) necessary for cooking injeras.

1.3 Limitations of Study

The aim of this study has been to design, construct and analyse a heat storage used for storing the energy from vapour based solar concentrators. The design of the storage has been done with the cooking of injera in mind. The analysis is done both through simulations on models of the storage, and by performed experiments. The storage can have both oil and steam circulating it, but mainly steam as heat transferring working fluid has been used. The emphasis throughout this study has been on the heat storage itself, in accordance with this studies aim.

1.4 Report Outline

This thesis is organized in 8 chapters, including this introduction, in addition to some appendixes. *Chapter 2* gives theoretical background about heat transfer, energy storage, steam behaviour and a literature overview over small scale solar energy systems with heat storage. *Chapter 3* describes the materials used, the design process and the energy content in the storage. *Chapter 4* gives information about the numerical models used in simulations to approximate the behaviour of the storage. *Chapter 5* describes the experimental setup for testing with oil and steam as working fluid and the risks associated with the experiments. *Chapter 6* both presents the results of the simulations and experiments, and discusses them. *Chapter 7* gives a conclusion of the work done, while *Chapter 8* gives some recommendation of further work.

2 Theoretical Background

2.1 Heat Transfer Theory

- **Conduction:** Conduction is heat transfer that occurs across a stationary fluid or a solid due to a temperature gradient in the material. The heat moves from high temperature to lower temperature through the substance. How much heat that is transferred depends on the conductivity of the material, the temperature difference and the distance between the mediums.

- **Convection:** Convection heat transfer occurs when a moving fluid and a surface have different temperature. How much that is transferred through convection depends on the temperature difference between the mediums and a heat transfer coefficient that depends on the geometry and thermophysical properties of the surface.

- **Radiation:** Radiation is energy emitted from a temperate surface in the form of protons. How much energy that leaves a medium depends on the emissivity of the medium and the temperature difference with the surroundings.

2.2 Energy Storage

2.2.1 Latent Heat Storage

Latent heat storage (LHS) is in addition to sensible heat storage (SHS) a method of thermal energy storage (TES) (see Figure 2.1). While sensible heat is the change in energy caused by a temperature change, latent heat is, as seen in Figure 2.2, the energy that is released or absorbed during a phase change while the temperature remains constant due to breaking of forming of intermolecular forces. Stored thermal heat increases when a solid turns into a liquid, and decreases for the opposite reaction. The latent heat is larger for a liquid-vapour phase change than a solid-liquid phase change, at the same time as a solid-liquid phase change has a higher latent heat than a solid-solid phase change. As long as two different phases are present at the same time the temperature remains constant, and when there is only one phase present the temperature will rise, or decrease, due to sensible heat. [4-6]

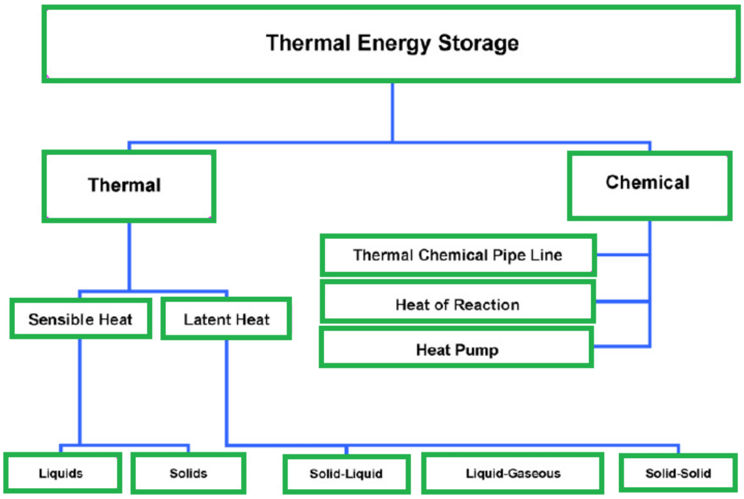


Figure 2.1: Overview of thermal energy storages (TES) [7]

The transition solid-liquid is called latent heat of fusion, whereas the transition liquid-vapour is called latent heat of vaporization. The *enthalpy of fusion* is a measure on how much energy that is necessary to melt one mole of a substance [6]. LHS can store more energy per volume than SHS precisely because of this enthalpy change, as it is much higher than the heat capacity for a sensible storage medium over a temperature range [8]. Latent heat storage capacity is in fact 5-14 times higher than for sensible heat storages, such as water or rock [7].

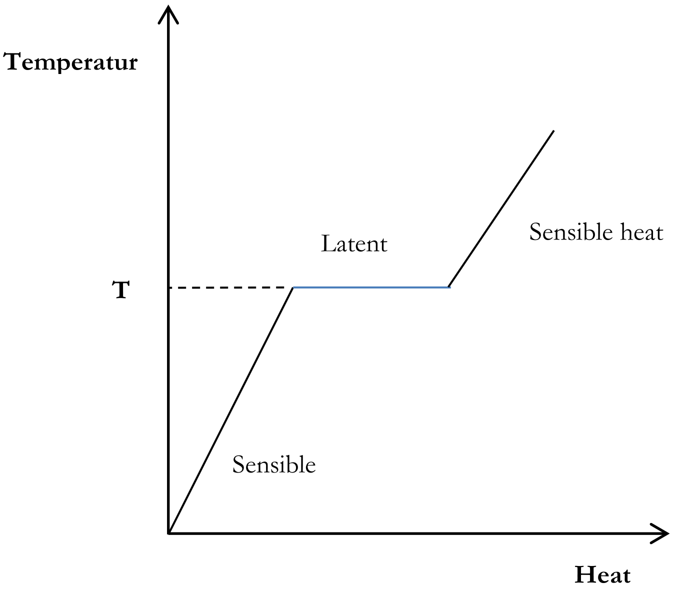


Figure 2.2: Phase change profile of a material. Tp = melting temperature

2.2.2 Phase Change Material

A phase change material (PCM) can be used to store thermal energy as latent heat with several benefits. For instance, PCMs has high heat storage capacity per unit mass because of the enthalpy change associated with the phase change. Moreover, the charge and discharge temperatures of the PCM are virtually constant and therefore controllable depending on the properties of the PCM. Distinctive mixtures made of various PCMs can namely be composed to achieve the qualities and characteristics required for a specific range of application, a fact that is beneficial for the utilization of PCMs in different areas of applications.

A disadvantage with the use of PCMs is the poor heat transfer rate they yield. The PCM in direct contact with a heat conducting surface will melt very rapidly. However, the next salt molecules will not have the possibility of direct contact with the conducting surface and therefore need to receive heat from PCM already melted but which conducts the heat very bad. Hence, the solid fraction of the PCM in a charge process depends on the heat transfer rate through an ever more increasing layer of liquefied salt which reduces the heat transfer velocity as it grows [9]. Another disadvantage is that the PCMs may cause corrosion on vessels and may experience crystallization of the different components it consists of. [5]

The energy will be transferred to the PCM in form of sensible heat until the temperature reaches the melting temperature. Then the temperature remains constant until the PCM is melted, while stored energy increases because of the latent energy. The temperature of the PCM will then increase again because of sensible heat.

To calculate the thermal capacity of a PCM these equations are used [7]:

$$Q = \int_{T_i}^{T_m} mC_p dT + m\Delta h_m + \int_{T_m}^{T_f} mC_p dT$$ **Equation 2.1**

$$Q = m\left[C_{sp}(T_m - T_i) + \Delta h_m + C_{lp}(T_f - T_m)\right]$$ **Equation 2.2**

T_i is the initial temperature, T_m is the melting temperature, m is the mass, C_{sp} is the average heat capacity between T_i and T_m, Δh_m is the heat of fusion of melted mass, T_f is the final temperature and C_{lp} is the average heat capacity between T_m and T_f .

Blending aluminium powder into the salt is one of many experiments done to improve the heat transfer in PCMs. However, the drawback on this procedure is the enhanced chance for crystallization of the different components in the PCM. [10]

2.3 Steam Diagram

When water is heated it follows the curves in Figure 2.3. To the left for the saturated water line is the liquid region (water). When water receives energy through heating it moves into the two-phase region where both water and steam is present at the same time. If the pressure remains constant the water-liquid mixture will only begin to increase its temperature when all the water is vaporized and the steam enters the superheated region.

When the two-phase mixture loses energy it moves towards the liquid region, and the amount of moisture increases. This is what occurs when steam condenses. As long as both phases are present at the same time the pressure and temperature will be at saturation and be the same at all places in the cycle.

Note that this principally is the same that occurs with the salt when it experiences a phase change.

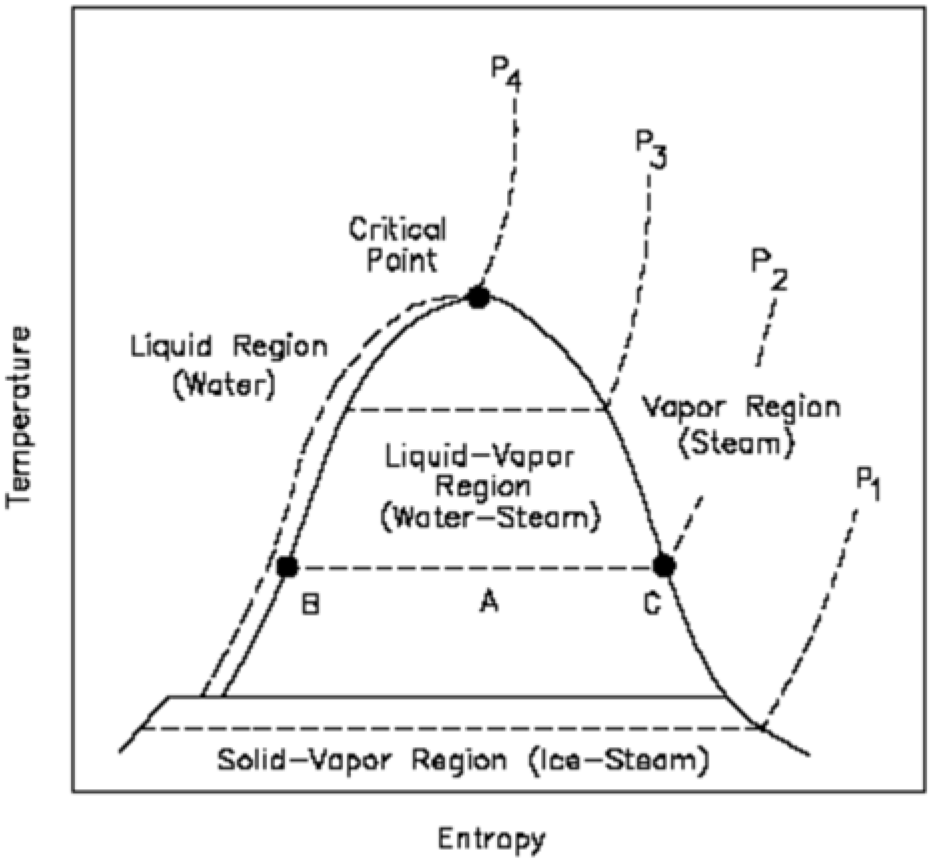


Figure 2.3: Temperature-enthalpy diagram of steam [11, 12]

2.4 Literature Overview of Small Scale Solar Energy Systems with Heat Storage

In this chapter there has been put emphasis on small scale solar heat storage energy systems used for cooking purposes since it is of most interest for the purpose of the heat storage in this thesis, and for the injera cooking process.

During the past years there has been increased focus on thermal heat energy storages (TES). Nevertheless, literature shows that there are large differences with the coverage of solar TES for cooking purposes and solar TES used for heating purposes. The former is in fact a little researched and experimented area, even though TES are important to increase both popularity and efficiency of solar cookers.[5] This is especially due to the intermittence of the solar radiation, and the TES ability to neutralize or compensate for the impact of the intermittence [1].

Karidena [5] summarize some important aspects that needs to be considered concerning the use of TES for cooking purposes. These aspects are: high storage capacity, high rate of heat transfer between storage medium and heat transfer medium, easy discharge of heat, good insulation, uncomplicated maintenance, and not least user-friendliness. Also, the TES should be economic in the making and use, and the materials chosen should opt for a small and light storage.

With respect to the topic of this report (heat storage for solar cooking), especially the study that van den Heetkamp [13] did on an idea from Løvseth [14] is of particular interest. The idea and study is about developing small concentrating systems with heat storage for rural food preparation, which also is the title of the study. The concept is to concentrate solar radiation with a parabolic reflector and use that concentrated energy to heat air to temperatures up to 400°. The air will thereafter be sucked by a fan from the parabola to a storage unit of pebbles. The hot air will transfer its energy to the pebbles and thus the energy is stored for later use. Heat is released from the storage by reversing the fan. The hot air can for instance be led to a convective oven (direct use) or to a heat exchanger (indirect use), depending on what is to be cooked and the local preferences. Van den Heetkamp also mentions the easy access and cost favourability of the pebbles used in the storage in South Africa as a benefit. The results of the study proved that a heat storage as described above indeed is realistic to be used for cooking purposes. However, optimization, improvement and research of the process are needed. Examples of such are system integration, enhanced knowledge of meal preparations, and hybrid operation (i.e. other energy sources to supplement the solar energy). Van den Heetkamps study is an example of SHS due to the increased temperature in the pebbles.

The most common solar cooking applications do not have heat storages [4]. Examples of that are panel type solar cookers and the simplest versions of solar box cookers. However, it has been done experimentation on improving the solar box cookers long cooking time and bad efficiency by implementing heat storages. Nahar [15] did such a study where he designed and constructed a solar box cooker with a heat storage consisting of used engine oil. The aim of the experiment was to see if the oil could store enough sensible heat to accelerate cooking processes.

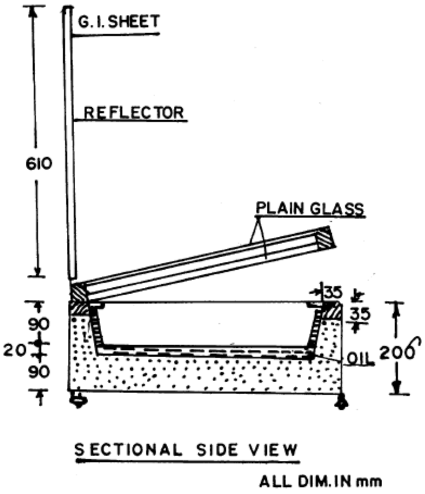
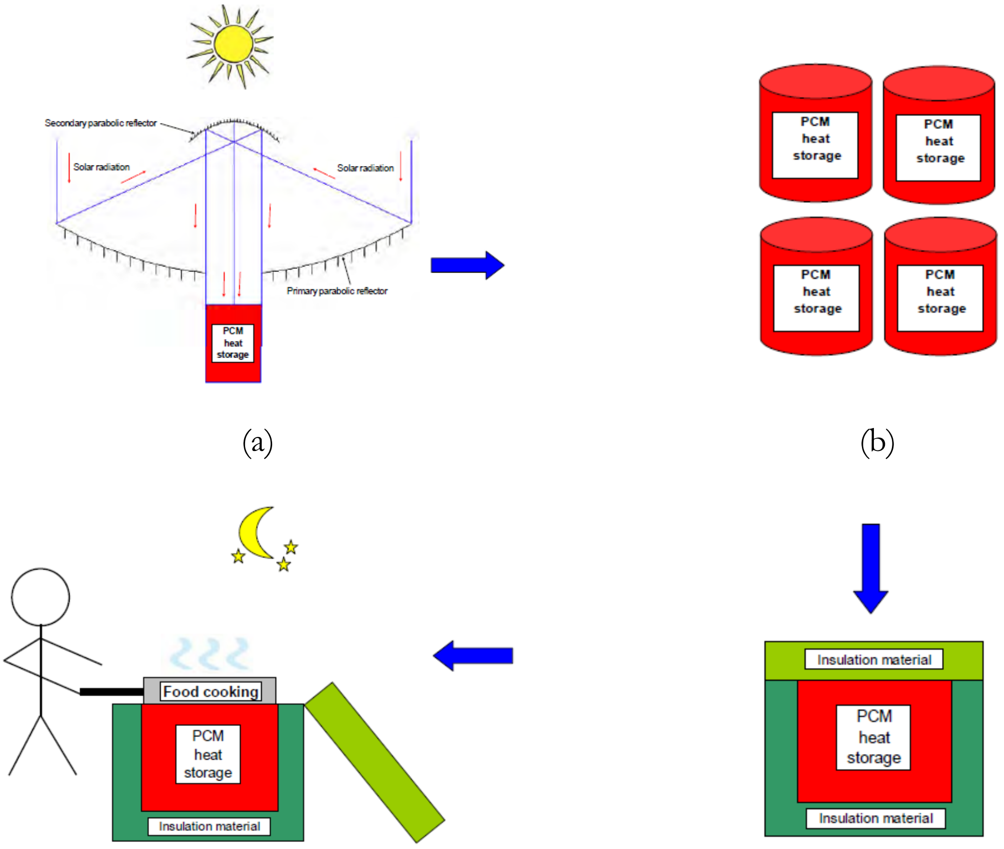


Figure 2.4: The schematics of Nahars hot box storage solar cooker [15]

The solar cooker designed by Nahar consists of a double walled box with used engine oil filled in the space between the boxes. The area where the oil is, is completely sealed. The outer part of the device is insulated, while the inner part is painted black. A glass window is placed over the boxes to keep the heat inside the box, while a moveable reflector is situated on the top, as seen in Figure 2.4. The box held room for four normal sized cooking utensils. Nahar also constructed an equal solar box that did not have storage installed. Both solar boxes had their stagnation temperatures measured, and cooking times for different types of food were compared. A combination of rice and mung beans (green gram), cooked completely in the box with the storage from 1730 hours to 2000 hours, while it was not cooked in box without the storage. The maximum stagnation temperature was the same for both solar boxes during the day, but it was measured much higher in the storage-box in the time period from 1700 hours to 2400 hours. These results are one proof of that implementing heat storages speed up cooking processes.

Foong [10] did experiments on a latent heat storage unit that could be used for cooking purposes. The idea of his study was to use a small scale double-reflector to heat the PCM heat storage directly (See (a) in Figure 2.5). Heat transportation mediums are therefore not necessary in this design. He used four storages (b) and filled them with NaNO$_3$-KNO$_3$ (60:40 mole %). The storages also contained aluminium fins to enhance the heat transfer to the PCM. After the charging, the heat was maintained in the storages by keeping them in a well-insulated container until used (c). The heat could thereafter be used for different applications; Foong used the storages for cooking (d). Some of the tests that Foong performed were cooking a variety of food and comparing the cooking times, but the main object of his study was to acquire information on how long time it was possible to retain the heat in the storages. The results showed that during a time period of 21.5 hours, the temperature inside the container decreased 90°C from the starting temperature of 250°C. The cooking tests proved that the food was cooked in a very reasonable time perspective.



(a) (b)

(d) (c)

Figure 2.5: Overall idea of the study executed by Foong [10]

Buddhi and Sahoo [16] did a similar study as Foong, but with stearic acid as PCM and a slightly different design of the solar box. This study was one of the preliminary studies of using heat storages with PCM. Also here the results of the experiments verified that the concept of using latent heat as energy storage had potential for further research.

Buddhi developed the idea of using LHS in solar cooking boxes in cooperation with Sharma in a study with the latter as lead author [17]. They designed and constructed a cylinder filled with PCM that was placed inside the solar box. The cylinder was made off two hollow cylinders, one larger than the other, with a certain wall thickness. The area between the cylinders was filled with PCM, and the open area in the centre of the two cylinders was where the cooking utensil was inserted. To enhance the heat transfer, fins were welded to the innermost cylinder facing the PCM. The PCM they used was Acetamide. A reference solar cooker box was also build, meaning that it did not have the cylindrical heat storage but was otherwise similar. During daytime the cooking results were quite similar for both solar boxes, but the box with the storage gave the opportunity to cook also after sunset. Also, the heat storage solar box gave better results than the reference solar box when it came to cooking performance through several batches. However, they also found the melting temperature for the Acetamide (82°C) to be too low. Better performance of the system would be attained by having a PCM with a melting temperature on around 110°C. In addition, to improve the performance further, more energy should be stored in the PCM. Therefore Buddhi et al. [18] made new experiments where they replaced the Acetamide with Acetanilide (that has a melting temperature of 118.9°C) and used three reflectors instead of the one reflector used in the previous experiments. Different tests were performed to verify that the three reflector storage held more energy than the one reflector storage, and to figure out how the performance depended on the amount of food cooked. The experimental results showed that more food could be cooked with the three reflector storage because of the extra energy supplied the storage, and that the cooking could be done over a longer time period than with one reflector.

Domanski et al. [19] did experiments on a similar design as the cylinder experiments done by Buddhi, but with magnesium nitrate hexahydrate as PCM in one of the tests they performed in addition to a test with stearic acid. Domanskis results coincide with Buddhis concerning storage capacity and its dependence on radiation intensity. Furthermore, the overall thermal efficiency of his storage was obtained ($\eta = 0.82$) through exposing the cooking device to maximal charge and solidify the hexahydrate. This thermal efficiency proved in fact to be 3-4 times higher than for some steam solar cookers used for indoor cooking.

Prasanna and Umanand [20] designed a hybrid solar cooking system. The concept can be seen in Figure 2.6. The idea of the system is to heat circulating servo-therm oil through a solar collector and lead that oil to a storage tank. The oil in the top of the tank is hottest and hence taken indoor to the kitchen. There, sensible heat is transferred from the oil to the cooking utensils through a heat exchanger. The heat from the circulating oil is meant to supplement LPG that often is used for cooking. With this design cooking can be done indoors and the need of conventional LPG is reduced through the oil in the heat storage tank. The study also treated different optimization solutions to the different components of the design.

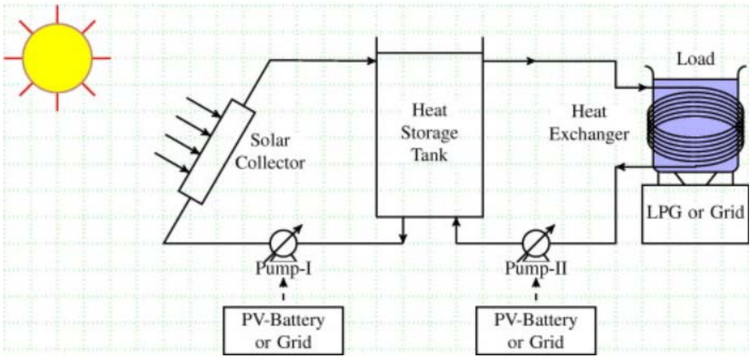


Figure 2.6: Hybride solar cooking system [20]

SHS have the benefits of being simple, often inexpensive (i.e. when water is used as storage medium) and that the technology already is developed. However, they also have disadvantages as low heat storage capacity per volume unit in contrast with LHS. Combined TES systems of both sensible and latent thermal energy can reduce the disadvantages of each of the systems, and increase the efficiency of a heat storage [5]. Ilusamy et al. [21], reports of such a combined small scale system with water as heat transfer medium and SHS and paraffin as the phase change material in the LHS. The purpose of the heat storage system was to produce hot water (45°C) for domestic use. The report concluded that a combined TES system gives better performance than a regular SHS system.

Another example of a combined system of SHS and LHS for heating of domestic water is given by Canbazoğlu [22]. In his report as well, water in a tank was heated by solar energy during the sunny hours of the day. These results were compared to the same heating process but with the presence of a phase change material (sodium thiosulfate pentahydrate). Also this report concluded that by using a PCM, large quantities of heat could be stored for later use. In fact, the stored heat was 2.59-3.45 times higher for the combined heat storage than for the conventional SHS of the same type.

There are also examples in the literature of research done on the popularity of solar cookers. Biermann et al. [23] investigated the acceptance of solar cookers in South Africa and found that on an overall basis, 38% of all the food was cooked on solar energy. The acceptance of solar cookers gives a good indication on the importance of heat storages as it would decrease the cooking time and thereby increase the possibilities of more food production.

In conclusion, literature overview shows that using heat storages have a very advantageous effect on the efficiency of solar cookers. In addition, latent heat storages provide more stable temperatures than sensible heat storages, but are still behind in popularity mainly because of the price difference (PCMs can be expensive) and also because of little knowledge of PCMs. Moreover, the choice of solar cooking system and heat storage has to be seen in conjunction with the local needs and food habits especially when it comes to cooking time of different types of food. Which type of heat storage that is chosen depends on the needed temperature range for the cooking process for the different types of food.

3 Materials and Methods

3.1 Materials

3.1.1 Aluminium Alloy

The main component of the heat storage is an aluminium bolt. Aluminium was chosen as conducting material because of its high conductivity and low density. It also has a good resistance to oxidation. However, pure aluminium is too soft for carving and machining so an alloy of aluminium was therefore selected.

A bolt made of an aluminium alloy was donated to this master's thesis by the Norwegian aluminium supplier Hydro. The exact alloy the bolt was made of was classified by Hydro, so the explicit composition of the alloy is unknown. However, Trond Furu, the contact person at Hydro, informed that the bolt was made of a standard 6xxx alloy and that the strength and firmness of the alloy was virtually the same as an aluminium 6082 alloy. Therefore, the thermophysical properties of a 6082 alloy are used as reference for the 6xxx alloy the heat storage consists of. [24]

The 6082 alloy has a melting temperature of 660°C, and tensile strength and mean tensile strain on approximately 240 MPa and 140 MPa, respectively. This means that the bolt would resist the 250°C and 4 MPa applied without melting or breaking, and is thus suitable for being used in the heat storage. [25]

The specific heat of the 6xxx alloy was calculated from the composition of the 6082 alloy, which is 1% Silicon, 0.5% Magnesia, ca. 0.4% Manganese, and the remaining 98.1% Aluminium [25]. The specific heats for each of the mentioned elements was found in *Specifc Heat: Metallic Elements and Alloys* [26] for a temperature of approximately 523 K (250°C), and calculated for the composition of these elements in the alloy. The specific heat for the elements in the aluminium alloy is seen in Appendix C. Hence, for 1 cal = 4.184 J, the result yields a specific heat on 1001.7 J/kgK for the alloy. The heat capacity for metals does not depend as much on temperature as for instance gases, so an intermediate heat capacity between 25°C and 250°C is used [6]. Hence, the heat capacity for the metal used in the simulations throughout this thesis is 953 J/kgK.

3.1.2 Solar Salt

The PCM chosen for the experiments was a homogeny binary mixture of 60% $NaNO_3$ and 40% KNO_3, also known as solar salt, or HitecXL as it is commercially called [5]. $NaNO_3$ has a melting temperature of 310°C, whereas KNO_3 has melting point of 330°C. However, the mixture of the solar salt has a melting temperature between 210°C to 220 °C, which makes it well suited for injera cooking which is the reason to why it was chosen [10].

The solar salt experience a solid-solid phase change at 110°C-120°C, and at 210°C-220°C it experience a solid-liquid phase change. Through experiments on solar salt with the mentioned composition, Foong [10] produced Equations 2.1-2.2 as an approximation for the temperature development in the solar salt. Equation 3.1 incorporates the transition enthalpy of the solid-solid phase change and the enthalpy of fusion, hence the heighten values of the heat capacity during the phase changes. The enthalpies can be seen in Table 3.1.

$$Cp\left(\frac{kJ}{kg\cdot°C}\right)=\begin{cases} 0.75 & T<110°C \\ 4.1 & 110°C \leq T \leq 120°C \\ 1.4 & 120°C<T<210°C \\ 12 & 210°C \leq T \leq 220°C \\ 1.6 & T>220°C \end{cases}$$

Equation 3.1

Equation 3.2 describes the density of the solar salt when it is solid and when it has melted. It can be noted that the density of the salt decreases when it has melted, and this causes an expansion in the salt.

$$\rho\left(\frac{kg}{m^3}\right)=\begin{cases} 1800 & T \leq 220°C \\ 1700 & T > 220°C \end{cases}$$

Equation 3.2

The conductivity of the solar salt is poor (0.8 W/m^2) and prevents a good heat transfer rate through the salt. It therefore emphasizes the importance of having a good conductor to lead the heat to the salt and facilitate easy melting.

This type of solar salt is low in cost and available on the marked [10].

3.1.3 Duratherm FG

When oil is used as the working fluid that runs through the storage, Duratherm FG is used. Duratherm FG is a food graded heat transfer oil that is NSF registered HT1. The latter means that if it incidentally comes in contact with food, no danger is exposed to the food. Duratherm FG withstands oxidation and has good longevity. This decrease the costs associated with the use of this oil. In addition, Duratherm FG is environmental friendly and user friendly as it is neither toxic nor hazardous, and can easily be disposed of with other waste oils when its service life is over [27].

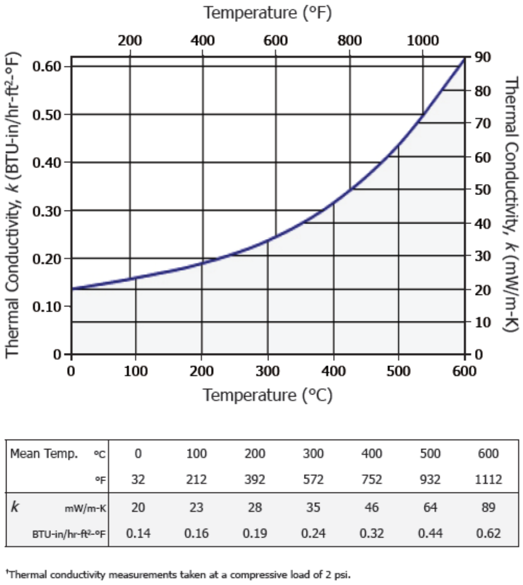
At 38°C the density of Duratherm FG is 845 kg/m^3, whereas it is 695 kg/m^3 at 260°C. For the same temperatures, the thermal conductivity is respectively 0.141 W/mK and 0.129 W/mK, and the heat capacity is 1.971 kJ/kgK and 2.704 kJ/kgK. It is a brownish clear and odourless liquid. The oil should not be used for temperatures higher than 326°C.

3.1.4 Pyrogel ® XT

For the insulation Pyrogel ® XT was mainly used. Pyrogel ® XT is made of silica aerogel which provides "the lowest thermal conductivity of any known solid" [28]. Pyrogel®XT is light yellow/beige in colour, and does not have any significant odour. It causes much dust. Therefore, the insulation material should be handled with safety glasses, gloves and mask to avoid skin and inhalation irritation. Pyrogel ® XT is delivered in rolls with a thickness of 5 mm and 10 mm. The latter thickness was used in this study. Pyrogel® XT can easily be cut into a wanted shape with the use of simple cutting tools as knifes or scissors. It is also hydrophobic, but allows vapour to pass, which reduces the corrosion on the storage.

The thermal conductivity is very low; about 0.032 W/mK (see Figure 3.1) at 250°C. Maximum temperature for the use of the insulation is 650°C. The surface emissivity is 0.15, and the density is 180 kg/m^3.

Pyrogel® XT was chosen as insulation material for its good insulation quality and that it already was available in the laboratory during the construction of the heat storage. A downside with this insulation material is that it is costly in addition to very dusty.



Mean Temp.	°C	0	100	200	300	400	500	600
	°F	32	212	392	572	752	932	1112
k	mW/m-K	20	23	28	35	46	64	89
	BTU-in/hr-ft²-°F	0.14	0.16	0.19	0.24	0.32	0.44	0.62

[1] Thermal conductivity measurements taken at a compressive load of 2 psi.

Figure 3.1: Thermal conductivity of Pyrogel ® XT [28]

3.1.5 Other materials

A 10 mm high plate of Aluminium 5754 (EN AW-5754-H111, AlMg3) was used to carve out two rings in doughnut-shape. These were later welded with the aluminium alloy. Aluminium 5754 has conductivity on 147 W/mK, melting point on 600°C, tensile strength on 215 MPa, and shear strength on 140 MPa. This makes the plate suitable for the temperature and pressure applied to the rings.

Rock wool is another type of insulation used.

3.1.6 Thermophysical Properties of Materials

A summary of the thermophysical properties of the four main materials used in the thesis follows in Table 3.1.

Table 3.1: Thermophysical properties of solar salt, aluminium alloy, insulation and heat transfer fluid

Thermophysical property	Value	Unit
$NaNO_3 – KNO_3$ (60:40 mol%)		
Thermal conductivity	0.8	W/mK
Density		
Temperature ≤ 220°C	1800	kg/m³
Temperature > 220°C	1700	kg/m³
Enthalpy of fusion	108.67	kJ/kg
Phase transition enthalpy	31.91	kJ/kg
Aluminium 6xxx-alloy		
Thermal conductivity	176	W/mK
Density	2700	kg/m³
Heat capacity	953	J/kgK
Pyrogel®XT (at 250°C)		
Thermal conductivity	0.032	W/mK
Density	180	kg/m³
Surface emissivity	0.15	
Duratherm FG (at 260°C)		
Thermal conductivity	0.129	W/mK
Density	695	kg/m³
Heat capacity	2704	J/kgK

3.2 Design and Dimensioning

3.2.1 General Idea of Design

The starting point to the design of the heat storage in this study is a cylindrical aluminium bolt. In the bolt it is made cylindrical cavities filled with solar salt (60% NaNO3, 40% KNO3). The general idea is to circulate water or oil through a solar trough to produce respectively steam or heated oil, and then use the steam or heated oil (henceforth called working fluid) to melt the solar salt in the storage. The working fluid enters the bolt in one horizontal channel on the side wall. This channel is connected to a circular channel (distribution ring) inside the bolt. The distribution ring has three vertical channels that go through the bolt. All three channels end up connected to another distribution ring close to the bottom where an outlet channel parallel with the inlet channel transports the working fluid out from the bolt. The idea is that the aluminium bolt conducts heat from the working fluid to the solar salt. As a result, the salt melts, and in the process it stores latent heat that can be used at a later time.

3.2.2 Dimensioning

A full-scale heat storage used for cooking injeras has a diameter of about 400-500 mm. For testing and research purposes however, a small-scale model would suffice to understand how the specific design affects the heat stored and released from the storage. The dimensioning of the heat storage treated in this thesis was done in cooperation with another heat storage being constructed simultaneously at the university (NTNU) [29]. This was done to allow for the possibility to compare the designs and hence obtain better knowledge of an ultimate design of heat storages opted for injera cooking. The other storage is based on the principle of having salt-filled cylinders submerged in a tank filled with oil (Duratherm FG is used). Through a piping system connected to the tank, the oil circulates the system and hence supplies the tank with hot oil continuously. The oil should also theoretically be heated up by using a solar trough.

The design was based upon the request that the two heat storages should have approximately the same total heat storage capacity. The aluminium alloy has a significantly higher density than the oil (2700 kg/m^3 vs. 695 kg/m^3), but the oil on the other hand has higher heat capacity (2704 J/kgK vs. 1001.7 J/kgK) than the alloy. Due to these facts, the heat capacity of the two storages in same size would approximately yield the same heat capacity, although this storage has slight higher capacity. The cylindrical cavities that contain the salt for the storage in this study were conic with an angle of 112° in the bottom because of mechanical restrictions on the equipment. If both storages are filled to the rim with liquid salt, this storage will contain approximately 4 % less salt than the other storage. However the small angle does virtually not constitute any difference in the total storage capacity and has not been considered throughout this study.

Too large cavities yield very long melting time which decrease the efficiency of the heat storage [30]. It was therefore preferable to maintain the cavities small in diameter. However, due to restrictions on the available mechanical equipment, the largest cavities possible to drill in the bolt had a diameter of only 32 mm. The length of the cavities is 150 mm from surface to bottom peak. It can also be mentioned that a certain distance between each cavity is preferable to maintain good heat conduction from the metal.

COMSOL simulations were not done prior to the design process due to time restrictions.

The most distinctive dimensions of the storage are enlisted in Table 3.2. These and additional dimensions may be seen in the following figures for a better illustration of the storage components.

Table 3.2: Dimensions of storage

Diameter aluminium bolt:	Ø$_{bolt}$ =	200 mm
Height aluminium bolt:	Hbolt =	200 mm
Diameter cylindrical cavities:	Øcav =	32 mm
Length cylindrical cavities (top to bottom peak):	Lcav =	150 mm
Height distribution ring:	H$_{channel}$=	10 mm
Height from upper surface to bottom of upper channel		30 mm

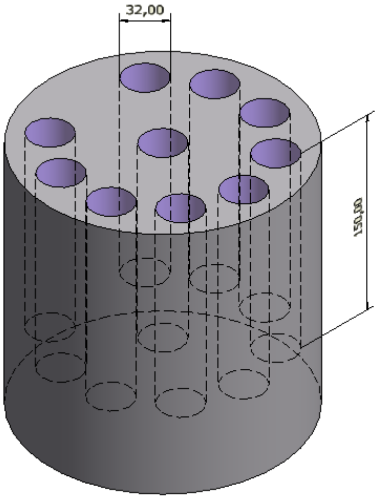


Figure 3.2: Cylindrical cavities [mm]

A total of ten cylindrical cavities were chosen as salt containers. Two of the cavities have to be empty when the storage is tested with oil as heat transfer fluid to be able to compare it with the storage made by Herdlevær [29]. If the working fluid is steam, all cavities ought to be filled with solar salt to make the most of the potential for heat storage. That is also the reason to why it was made two more cavities than the comparing storage. In addition, with nine cavities around the centre, a horizontal symmetry line parallel with the entrance and through the centre is obtained. Where the tenth cavity was intended to be, the entrance and exit was placed.

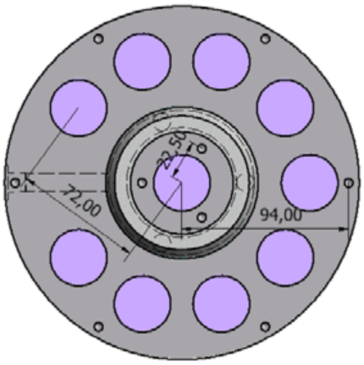


Figure 3.3: Distance from centre to screw threads and cylinders [mm]

As seen in Figure 3.3, the angle between the dashed circles that indicate where the vertical channels are, is not equal (60°) between each hole. This was done to obtain symmetry between each vertical channel and the cylindrical cavities, and hence have all cavities equally close to a vertical channel. The dashed circles are therefore displaced with 18° towards the hole that lies on the horizontal centre line.

The total of nine small circles in Figure 3.3 are screw threads where a top plate or a frying pan can be screwed onto the storage. This is done to avoid contact with the salt and obviously to make a surface where the injera can be cooked. The inlet and outlet channel are cylindrical with a diameter of 10 mm with the centre, respectively, 25 mm and 175 mm from the top surface. The outlet channel should preferably have an inclination downwards to ease the escape of the working fluid. However, it was not possible to apply this to the storage because of technical restrictions.

The direction the working fluid flows through the channels is showed in Figure 3.4. Note that the leftmost vertical channel hides the third vertical channel. The vertical channels are 10 mm in diameter, a size that was chosen to get an efficient heat transfer rate from the working fluid to the storage. The distribution rings are the ones seen in Figure 3.5 that the inlet and outlet channels are perpendicular to (dashed lines with diameter of 10 mm). They are equal at top and bottom, both to ease the machining and to provide more surfaces for welding and hence reduce the probability of leakages.

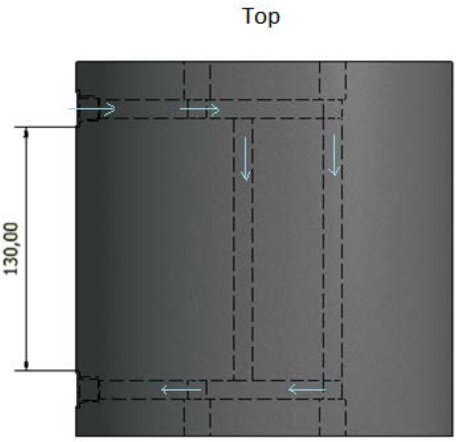


Figure 3.4: Channels where the working fluid flows [mm]. Arrows indicate flow area and direction

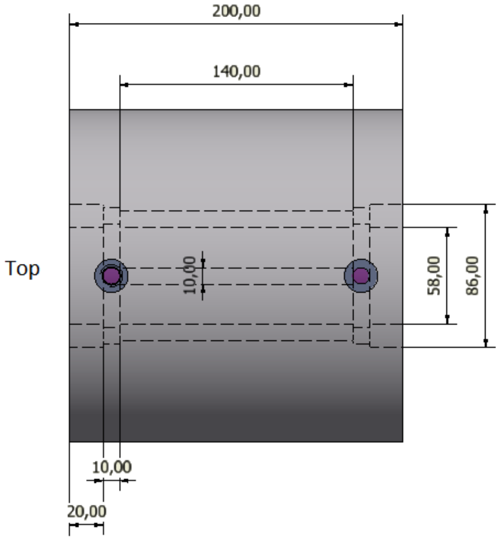


Figure 3.5: Dimensions of the channels [mm]

The threads used in the Figure 3.9 shows a section of the storage from centre to rim for a better overview of the measurements. In Figure 3.7 the violet circles represent the cavities where the salt is. Dashed lines indicate channels where the heat medium flows. Figure 3.8 shows the bottom surface of the storage and its similarity with the top surface. Dashed lines indicate where the cylinders are placed on the top surface and where the channels are. Figure 3.6 shows a sectional view of the storage with NPT threads especially design for operating under high pressures.

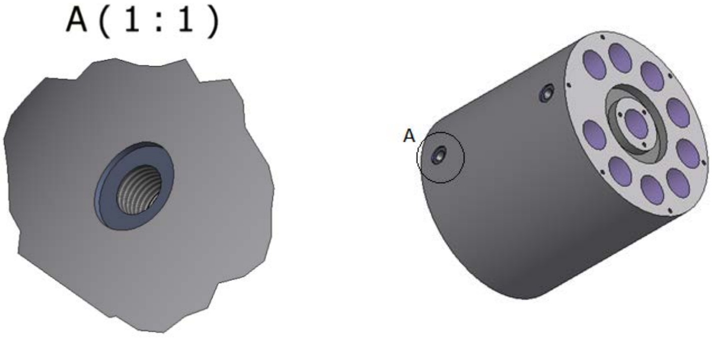


Figure 3.6: Close view on the thread on the side of the storage

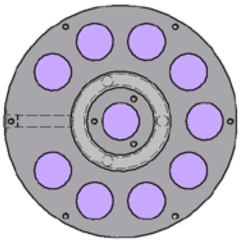
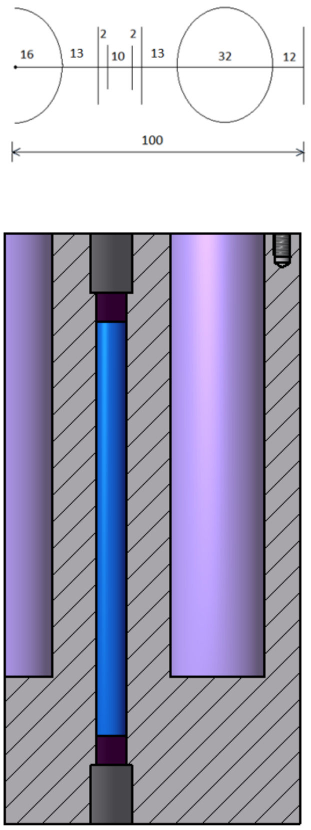


Figure 3.7: Horizontal overview of the top of the storage.



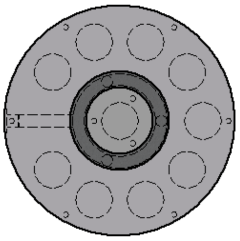


Figure 3.8: Horizontal view of the bottom of the storage.

Figure 3.9: Section of the storage from the centre to the rim [mm]

3.3 Autodesk® Inventor® Professional 2011

For the actual design process, Autodesk® Inventor® Professional 2011 (Inventor®) was used. Inventor® is a 3D CAD software that can be used to design and visualize products. It has the benefits of providing a good visualization of the end product, and can therefore prevent obvious practical mistakes. In addition, the designed geometries can be exported to other programs for simulation.

3.3.1 2D Models

A 2D model of the heat transfer through the three vertical channels was chosen as a good 2D model because the majority of the heat is transferred from the working medium to the storage and salt due to the height of the storage.

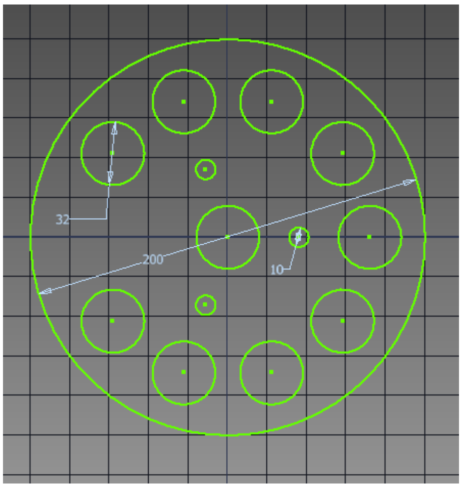


Figure 3.10: 2D model in Inventor® of the horizontal section of the storage [mm]

Another 2D model was made of the storage, namely a vertical section from the centre of the storage to the rim. Even though this is a poorer approximation of the heat transfer, it was done to see how the end effects (due to more aluminium in the ends) affect the melting rate of the salt, and to see how the heat propagates through the material.

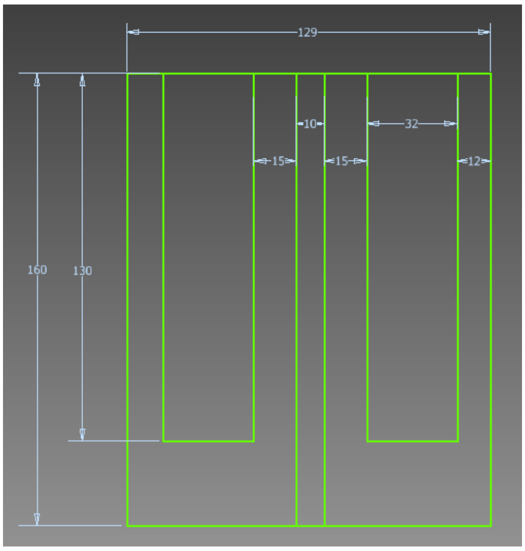


Figure 3.11: 2D model of vertical section from the centre to the rim of the heat storage [mm]

Both 2D models are exported to COMSOL in order to simulate heat transfer through the metal and to determine the time span this endure.

3.3.2 3D Model

A proper 3D model of the heat storage was built in Inventor®. At first this was done with the objective of exporting the 3D model to COMSOL. In order to designate the different parts of the storage their respective material properties, COMSOL needs to have all parts as separate volume units. Therefore, all parts of the storage and the heat medium was made as separate parts in Inventor®, and then put together in an assembly (also in Inventor®). The assembly was subsequently exported to COMSOL where all parts were given their material properties. The different parts the assembly consists of can be seen in Figure 3.12. To the left in Figure 3.12 are the components that represent the heat medium (orange, green and red parts). In the upper right corner are the cylinders that represent the solar salt. Below the cylinders, the two dark rings represent the metal rings that are welded on the top and bottom of the storage. When all parts are assembled together, these two rings are between the red circles in the figure and the atmosphere. The heat storage in the middle is the largest detached part of the assembly.

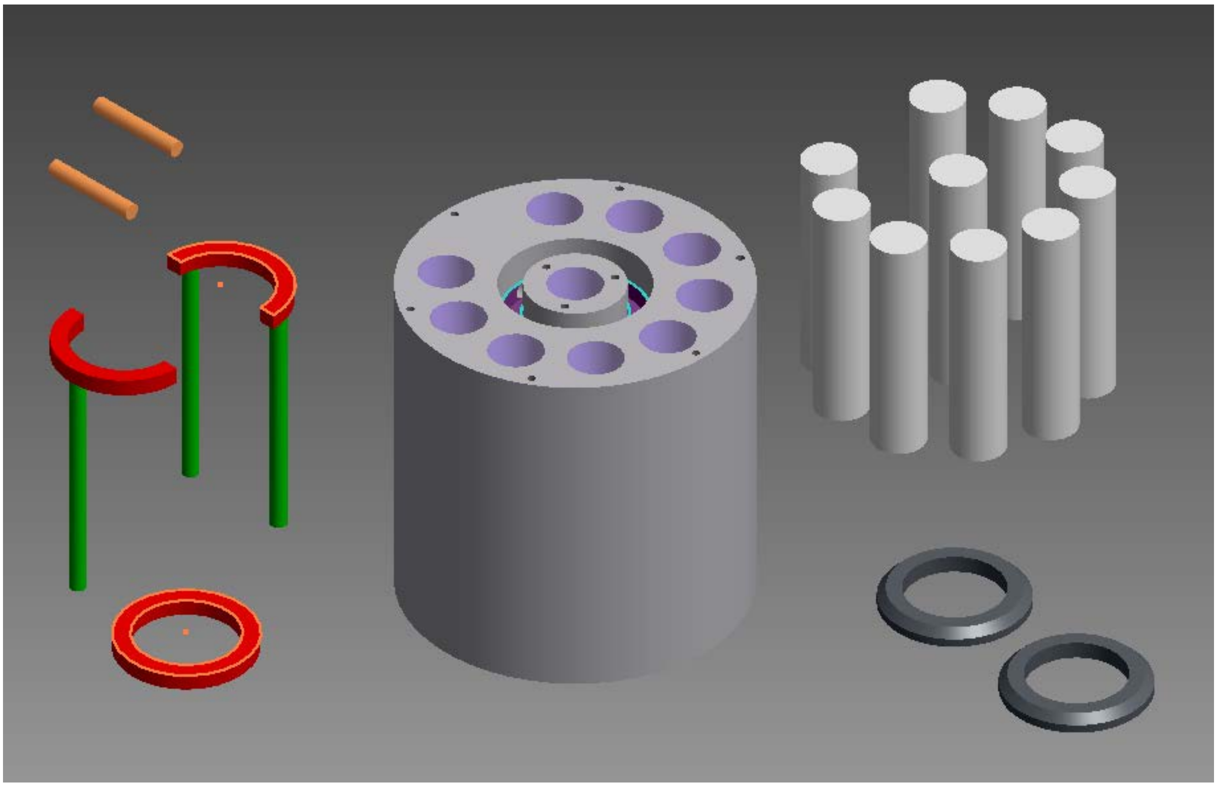


Figure 3.12: Assembly of the volume units to the components the storage consists of. The heat storage is in the middle. The red, green and orange parts to the left is the working fluid; the ten white cylinders to the right represents the salt; the two dark grey rings to the right are metal rings that is welded to the storage to form a channel.

When modelling a 3D assembly in Inventor with the intention of exporting the model to COMSOL via LiveLink™, it is very advisable to export the assembly after each new part is joined to it. The reason to this is that COMSOL sometimes has difficulties processing adjacent parts, especially if some parts are unintentionally overlapping in Inventor. By adding parts to the assembly stepwise, the problematic part can be discovered at once and modified in Inventor®, and big scale troubleshooting is avoided. Also, there may be problems with long continuous parts. One of the red rings in Figure 3.12 is split in half in an attempt to avoid this problem.

The complete 3D model of the heat storage with solar salt in all cavities can be seen in Figure 3.13.

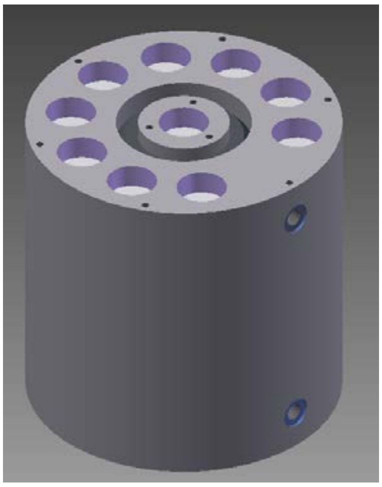


Figure 3.13: A 3D model of the heat storage made in Inventor®.

3.4 Energy Content

Solar salt in liquid phase was filled to the rim in eight of the cavities, and that yields a total salt volume of 9.25E-4 m^3. The original aluminium bolt had a volume of 0.00628 m^3, but after the addition of the two aluminium rings and excision of heat transfer channels, the total metal volume was 0.005 m^3. For insulation enclosing the storage, a total volume of 0.043 m^3 was used.

$$m = \rho * V$$ **Equation 3.3**

With the use of Equation 3.3, calculated volumes, and thermophysical properties in Table 3.1, the mass of the total storage is calculated. The results are presented in Table 3.3.

Table 3.3: Mass of components included in the heat storage, and the total storage itself.

Insulation weight	7.72 kg
Solar salt weight	1.57 kg
Metal weight	13.38 kg
Total storage weight	22.67 kg

The energy content of the solar salt is calculated from the ground principle in Equation 2.1, but with the enthalpy section omitted as the modified heat capacity in Equation 3.1 is used, and the following assumptions:

- Ambient temperature is 20°C
- Temperature of the working fluid is 250°C
- Masses as given in Table 3.3
- Thermophysical properties of materials from Table 3.1.

Table 3.4: Energy stored in the salt from 20°C to 250°C

20°C to 110°C	106.0 kJ
110°C to 120°C	64.4 kJ
120°C to 210°C	197.8 kJ
210°C to 220°C	188.4 kJ
220°C to 250°C	75.4 kJ
Total stored energy in the solar salt	632.0 kJ

Table 3.5: Energy stored in the metal from 20°C to 250°C

20°C to 250°C	2932.8 kJ
Total energy stored in the metal	2932.8 kJ

Table 3.6: Total energy stored in the storage from 20°C to 250°C

Energy stored in solar salt	632.0 kJ
Energy stored in metal	2932.8 kJ
Total energy stored	3564.8 kJ

Table 3.7: Energy stored in the phase transition from 210°C to 220°C.

Energy in solar salt	188.4 kJ
Energy in metal	127.5 kJ
Total energy stored in phase transition	315.9 kJ

The calculations yield a total amount of 315.9 kJ available for cooking when the storage operates in the phase transition. By assuming that the energy demand required to cook one injera is reduced from 83 kJ to 40 kJ the energy demand will be more adapted to the storage with 20 cm in diameter instead of the storage with 42 cm in centimetre mentioned in Motivation. The total theoretical amount of injeras that can be cooked on the energy stored in the phase transition at ideal conditions is seven, almost eight.

4 Numerical Models

4.1 COMSOL Multiphysics® 4.2

COMSOL Multiphysics® 4.2 is a simulation software used for analysing engineering applications and multiphysics modelling. It is based upon finite element analysis which approximates numerical solutions to partial differential equations [31]. The program can be used in all phases of a simulation process from designing to visualization of the results, and has several different pre-defined physics interfaces that can be applied to the geometries. The geometries used in COMSOL can also be imported from Inventor® via LiveLink™ that connects the two programs.

In this thesis, COMSOL was used to simulate the development of the heat transfer in the heat storage. The storage was meshed and heat transfer physics was applied. Meshing consists of dividing the storage in finite units connected by nodes where the temperatures are calculated simultaneously by for instance iteration. The more finite meshes one has on a geometry, the more accurate becomes the results and more time-consuming becomes the simulation. For meshing in 2D the finite units are unstructured triangulars, while for 3D meshing the units have the form of unstructured tetrahedrals. [32]

COMSOLs Heat Transfer Module was chosen for the simulations of the storage, and the simulations were chosen to be time dependent with temperature as variable. The Heat Transfer Module uses Equation 4.1 as the mathematical model, where the material properties are: ρ the density; C_p the heat capacity; k the thermal conductivity; and Q the heat source (or sink).

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = Q$$ **Equation 4.1**

Equation 3.1, the specific heat capacity, was in COMSOL made a global variable and given the following parameters:

Expression: 750*(T<=383)+4100*(383<T)-4100*(T>393)+1400*(393<T)-1400*(T>483)+12000*(483<T)-12000*(T>493)+1600*(T>493)

Arguments: T

Equation 3.2, the density, was also made a global variable and had the following parameters:

Expression: 1800*(T<=493)+1700*(T>493)

Arguments: T

These expressions were implemented in COMSOL under the thermophysical properties of solar salt.

4.1.1 COMSOL Bug

A problem emerged when the horizontal 2D sketch of the storage was imported from Inventor® to COMSOL. The error message "The imported file did not contain any geometries" appeared seemingly without any reason (the imported file did for a fact contain at least on geometry). However, this problem is due to a bug in COMSOL that prevents geometries that *only consists of circles* to be imported. To elude this problem, draw a rectilinear geometry (i.e. a pentagon) in Inventor® and then import the file to COMSOL. To remove the unwanted geometry in COMSOL, press "Geometry" under the model bar and choose "Split". Mark the unwanted geometry and press "Delete". Subsequently, the geometry will look like it was intended to before the bug appeared, and one can continue the COMSOL analysis.

4.2 3D Model

The meshes of the 3D model were set to three different sizes. The salt cavities were meshed *finer;* the working fluid channels were meshed *extra fine*; and the rest of the storage was meshed *fine.*

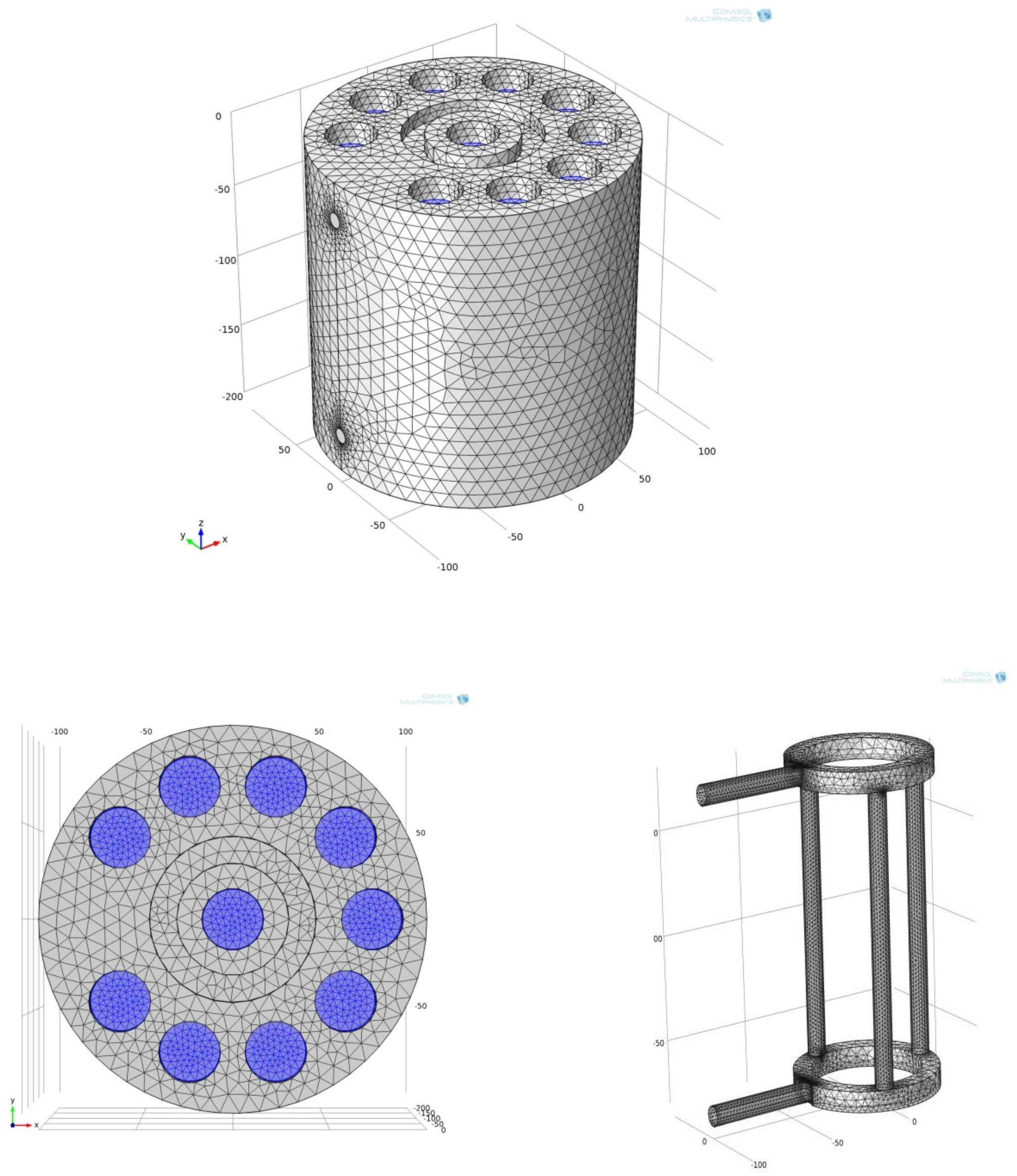


Figure 4.1: Meshing of the 3D model in COMSOL.

3D simulations demand a lot of free memory and fast processing of the computer, and generally take inconveniently long time to perform. Since the majority of the heat transfer in this study occurs in the three vertical channels that are much longer than the horizontal channels, it was chosen to only perform 2D simulations. Another important argument that supports this choice is that for an ideal heat transfer development with steam as working fluid, the temperature will remain constant as long as some of the steam condenses and there are two phases present (vapour and liquid in this case).

4.3 2D Model

4.3.1 Horizontal 2D model

For the horizontal 2D models the following assumptions are done:

- Design conditions on the steam
- Constant temperature along the whole length of the vertical channels
- Complete thermal insulation along the outer edges of the storage

The meshing of the horizontal 2D model is shown in Figure 4.2. The grid was chosen to be *fine* on the entire geometry except for the cavities where the grid was set to *extra fine*.

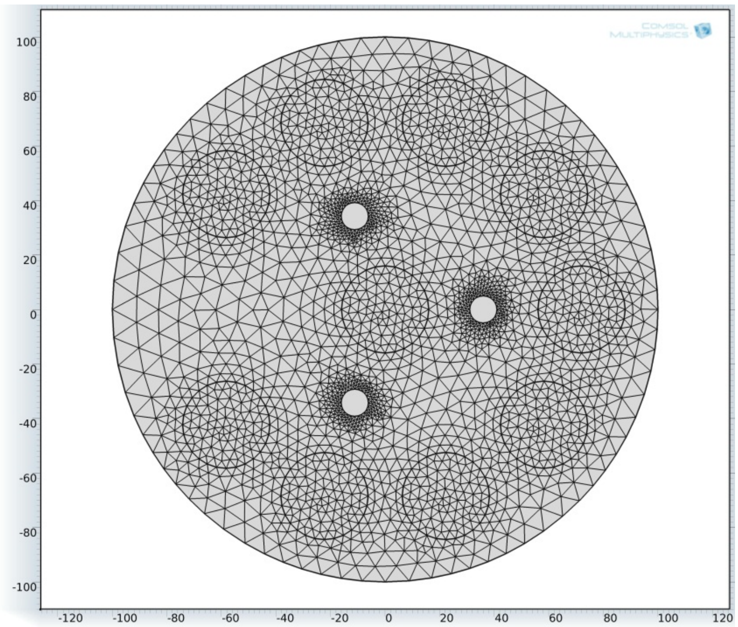


Figure 4.2: Meshing of horizontal 2D section

As mentioned in section 4.2 3D Model, it is during the 2D simulations assumed that steam is the heat transferring working fluid through the storage. Some of the steam will condense when in contact with the cooler storage walls. As two phases are present at the same time the temperature of the steam will remain constant and can easily be modelled in COMSOL.

The three smallest circles is a section view of the three vertical channels which experience constant temperature. The design conditions of the steam are 250°C and 40 bar. Thus, the boundary conditions of the three smallest channels are in COMSOL set to a constant temperature of 250°C and implemented under the *Heat Transfer* physic. Initial values are set to be 20°C and atmospheric pressure. *Heat Transfer in Solids* is chosen under the *Heat Transfer* physic as the heat transfer occurs through conduction. The storage is completely thermally insulated along the outer edge.

The temperature measurements were done by creating a *Cut Point 2D* under *Results→ Derived Values* and choosing the coordinates in the centre of each cavity. Thereafter a *1D plot group* was created, also under the results branch, and all the cut points were added as point graphs in this 1D group plot. This procedure is applied to all simulations done in COMSOL.

4.3.1.1 Model of Salt Melting in all Cavities

The first simulation was done to analyse the time necessary for melting all the salt in the salt filled cavities. The salt in the centre of the cavities melts theoretically latest since they are furthest away from the heat transferring surface, so that was where the temperatures were measured (see Figure 4.3).

During the experiments a time step of 0.5 was chosen.

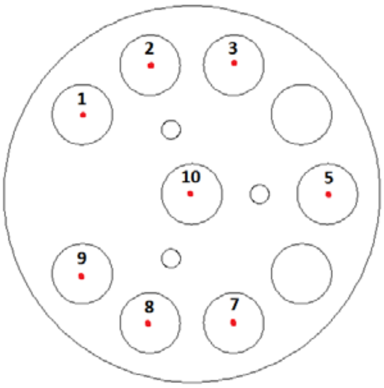


Figure 4.3: Location of temperature measurements in COMSOL

4.3.1.2 Model of Executed Experiments

For the executed experiments a total of eight thermocouples were placed in direct connection with the storage (see Figure 4.4). Five of them were placed in the salt, namely S1, S2.1, S2.2, S3 and S.4. S2.1 measures the salt temperature close to the wall and S2.1, a temperature gradient in the salt can thus be found. The thermocouples M1, M2 and M3 measure the temperature development in the metal. They were placed approximately 5 mm into the metal from the surface.

During the simulations, a time step of 0.5s was chosen.

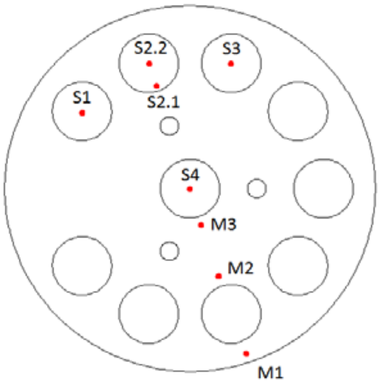


Figure 4.4: Location of thermocouples during real life experiments

4.3.2 Vertical 2D Model

For the vertical 2D model, the same assumptions and procedure as for the horizontal 2D model are made. The temperature of 250°C is applied along the walls of the channel.

The vertical 2D model seen in Figure 3.11 was meshed with a grid that was *fine* for the whole geometry except for the domains where the salt is. That grid was meshed as *extra fine*.

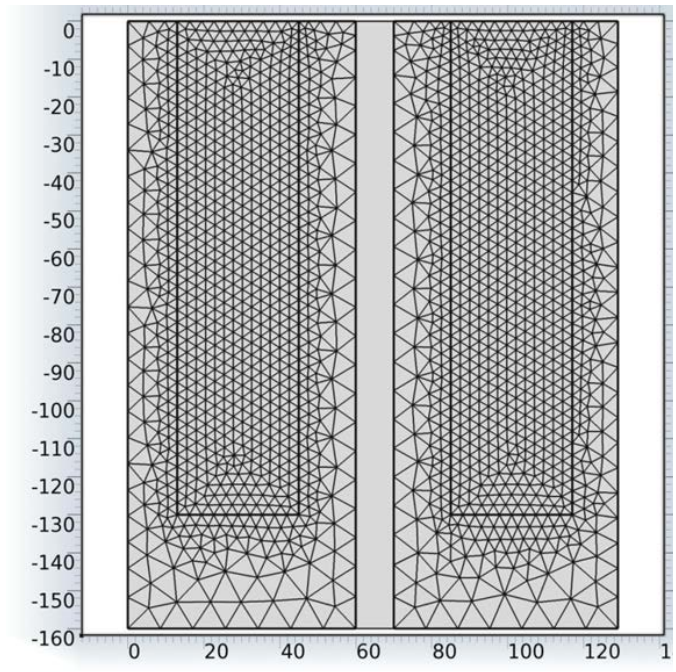


Figure 4.5: Meshing of vertical 2D section

‘Three cut points were placed in the leftmost cavity at the three different heights seen in Figure 4.6. The time step chosen for the simulation was 0.5s.

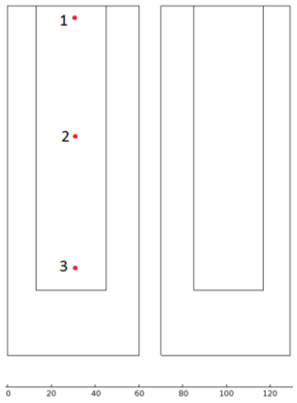


Figure 4.6: Locations of temperature measurements in COMSOL

5 Experimental Setup

5.1 Preparatory Work

A small scale heat storage constructed by Foong [10] that already contained the salt mixture chosen to be used in this study was present in the laboratory at NTNU. That heat storage was no longer in use, and the salt was therefore reused for the storage in study. Foongs storage was heated in an oven, and kept there over night until the salt was melted. The new storage was preheated to reduce the temperature gradient between the salt and the metal during the filling process. Subsequently, melted salt was poured into eight of the ten cavities in the heat storage. The election of the two cavities that remained empty was done to keep symmetry around the entrance of the working fluid. Other options were also possible.

The liquefied salt had a dark brown colour with a viscosity similar to that of water. The salt was poured all the way up to the horizontal top surface. Since the salt already was in its liquid state there was no need of filling the cylinders with only 90% salt to avoid flooding.

Figure 5.1: Storage after machining

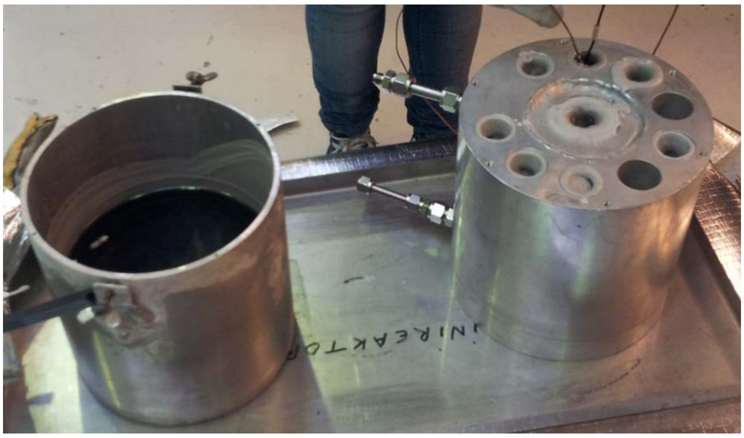


Figure 5.2: Procedure of salt filling. Liquid salt (left) and solidified salt in cavities in the storage (right)

Two thermocouples of type K (all thermocouples used during the experiments were type K) were placed in the salt in cavity number two (Figure 5.3). One of them was placed in the centre while the other was placed close to the wall furthest away from the centre of the storage. The salt solidified rather quickly along the edges of the cavities, a proof of the present temperature gradient between the salt and the aluminium.

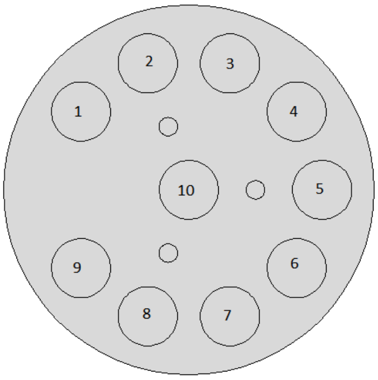


Figure 5.3: Numbering of cavities filled with solar salt. The three non-numbered circles are the vertical channels.

It can be noted that just by physical observation the aluminium bolt maintained a temperature higher than the surroundings long after the salt was solidified.

Figure 5.4: Placement of heat storage on the oil rig without insulation (left) and with parts of the insulation applied (right)

The storage was well insulated to reduce heat loss to the environment. Insulation of type Pyrogel ® XT was cut into nineteen circular pieces with a diameter of 40 cm, and one circle with a diameter of 20 cm. Ten of the circles were placed under the storage on top of a piece of aluminium foil. The smallest circle was placed directly in contact with the top surface of the storage, while the remaining nine insulation circles were wrapped in aluminium foil to reduce heat loss through radiation. This thermal insulated lid was in the end placed on top of the storage, over the smallest insulation circle. In addition, after the insulation of the pipes in direct contact with the storage, ten layers of insulation were laid around the storage and fastened with heat-resistant tape and wire. These layers had a height of 20 cm, and were tightened as much as possible around the storage to avoid heat loss through convection. Finally, the whole storage was wrapped in two layers of aluminium foil.

(a) (b)

(c) (d)

Figure 5.5: Application of insulation. (a-b) Horizontal view with and without upper lid. (c-d) Vertical view.

5.2 Oil as Working Fluid

The rig already contained a set up with a solar trough and accompanying piping system with an inner diameter of 10 mm. The inner diameter of the storage is 8 mm, so a transition pipe had to be applied the storage to be able to connect it to the already existing system.

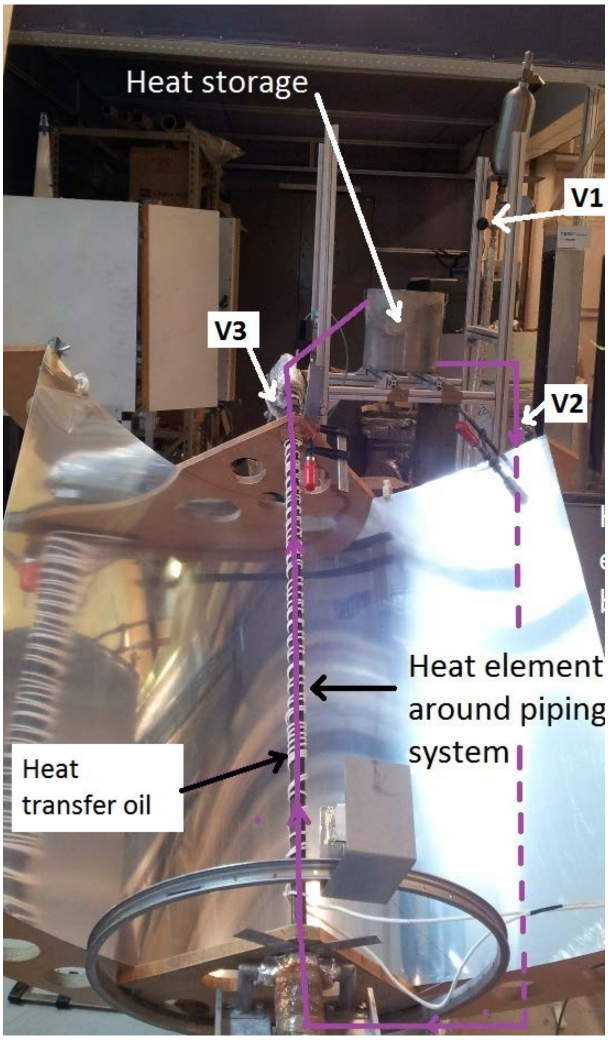
When the storage was connected to the pipes, air was sucked out from the system by the use of a vacuum pump. The pressure inside the pipes went almost down to 5 mbar while the pump was running. It did not reach 1 mbar as originally intended probably because of oil remnants in the pipes after previous experiments. After a couple of leakages were sealed, the pressure remained constant (less than 1/1000 of an atmosphere per minute movement of pressure gage) during the following minutes after the pump was turned off. The rig was left to itself for a while, then the valves were opened and a characteristic sound of air being sucked into the pipes was heard which proved that there still was vacuum inside the pipes. The vacuuming procedure was repeated and it was decided that the system could be filled with oil.

Three valves were connected the cycle (see Figure 5.6):

- V1: Under the filling tank (vessel)
- V2: Connecting the pipe from the filling tank and the rest of the system
- V3: On the opposite side of the storage and V2

V1 was removed during the oil filling process. Approximately 1 litre oil was continuously filled into the vessel. When about 0.25 litres of oil was filled into the vessel, V2 was opened, and when about 0.60 litres was filled, V3 was opened. The oil ran from the vessel and into the rest of the loop. Both valves remained open, and it was made sure that there always was oil present in the vessel to avoid entrance of air into the system.

The thermocouples in the system were connected to a logging device, and the power supply that provided the heat element with power was turned on 70 % efficiency. The pipe surrounded by the heat elements notably increased its temperature. However, no other parts of the system experienced an increase in temperature, which meant that the oil was not circulating. Most probably, this was due to one or more pockets filled with air inside the pipes. Therefore, flushing was effectuated. The two pipes attached to one another in front of the rig (in the bottom of Figure 5.6) were opened and allowed for air pockets to escape during the flushing. However, when the pipes were connected back together, air probably entered the pipes again because the oil did not circulate this time either. Further experimentation on the oil rig was aborted.



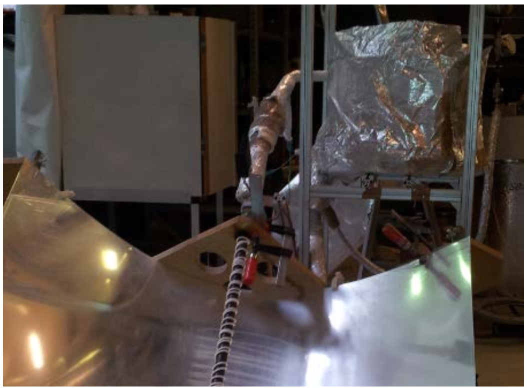


Figure 5.6: Self circulating oil cycle. V1, V2 and V3 indicate the valves.

5.3 Steam as Working Fluid

For the experiments with steam as working fluid, the storage was moved to another rig and placed on a surface 125 cm above ground level. Thereafter it was connected to a pipe system with the appropriate diameter for the storage (10 mm outer diameter). Part of the pipe system was coiled into three circles with a diameter of 28 cm. Around these coils a heat element in form of an approximately 10 mm thick thread was winded with the purpose of evaporating the water that circulates through the coil. Subsequently, the coil was enclosed with insulation (Pyrogel® XT), a layer of metallic foil, a layer of rock wool, and another layer of the metallic foil. The pipes where the steam flows was also insulated with rock wool, in addition to the bottom parts of the pipes where liquid ideally flows. An overview of the experimental setup can be seen in Figure 5.7.

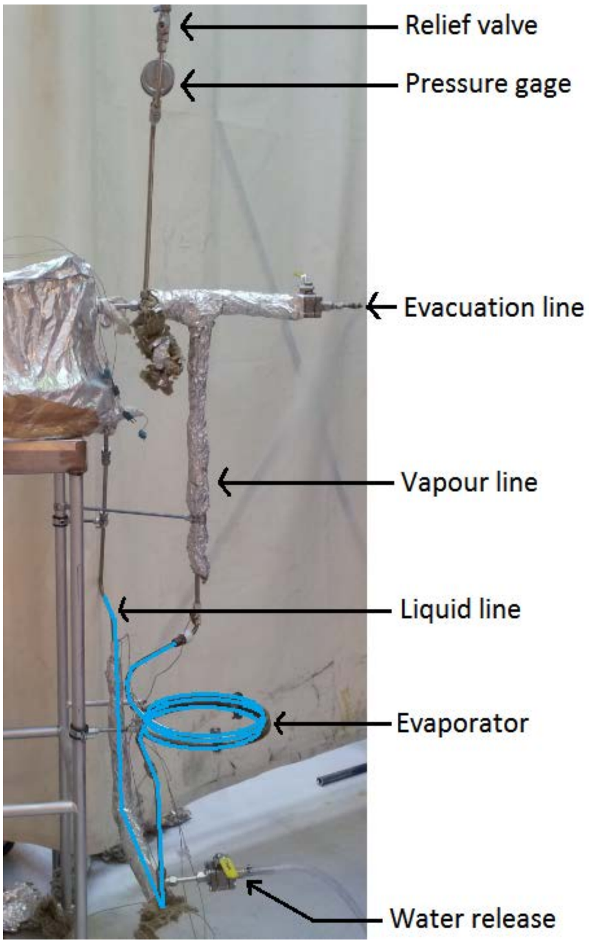


Figure 5.7: Experimental setup with steam as working fluid (taken at early stage during the construction)

5.3.1 Experiment 1

The aim of the first experiment was to test the rig, measure how long time it took to melt the salt, and how long time it took to discharge the storage.

Six new thermocouples were connected to the storage so the total of temperature measurements connected directly to the storage was eight. In addition, seven other thermocouples were connected to the pipes in the loop on specific locations. These are mentioned in the bullet points below, and can be seen in Figure 5.8. The thermocouples were fixed to the pipes with steel wire.

- Tx: Temperature measured directly on the heat thread
- T7: Temperature directly out of the coil (in flow direction)
- T10: Temperature into storage
- T5: Temperature between T7 and T10
- T11: Temperature directly out of storage

- T9: Temperature into coil
- T6: Temperature between T11 and T9

The thermocouples were connected to a temperature logging device where the temperature development was monitored and saved electronically. Some of the thermocouples turned out to be not functioning and gave poor or no results. The location of the thermocouples connected directly to the storage can be seen in Figure 4.4.

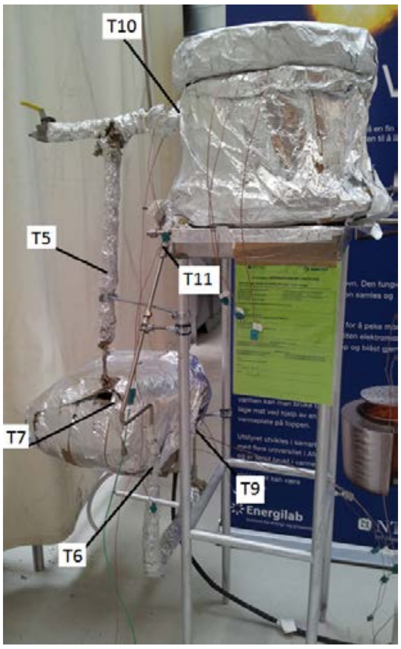


Figure 5.8: Location of thermocouples connected to the pipes

The total volume of the pipes and storage was calculated to be approximately 0.48 dm^3. The whole system was first filled completely with water through flushing to ensure that the system did not contain air. However, some air probably entered the system when the pipes were reconnected to each other after the flushing. Part of this air was released through the safety valve when the system was pressure tested with water before the experiment was started. The amount of 0.48 dm^3 of water circulating the system is too much as the water gets warmer and the pressure increases. The aim is to at least have enough water such as the pipes marked in blue in Figure 5.7 are filled with water, so approximately 1/3 of the water was removed during the experiment.

The heat thread endures a maximal temperature of 450°C. To prevent the destruction of the heat element, and thereby save both money and time, it was decided to connect thermocouple Tx directly between the heat element and the power supply. The power supply was thereafter set to provide constant temperature. Hence, when the heat element reached a preset temperature, Tx notified the power supply which then ceased delivering power until the temperature was beginning to decrease and it switched itself automatically on again. In this way, the temperature on the heat element was maintained constant, and always monitored so the heat elements destruction due to human error was avoided.

The first experiment was started at 08:33 hrs. Unfortunately, the temperature development for the first two hours was not carried out due to technical misunderstandings. The advance throughout Experiment 1 was as following:

- 25.05.12 08:33: Start of experiment. Heat element was set to 250°C
- 09:00: A small amount of water was removed. Pressure sank from 5 bar to 3 bar
- 09:21: Temperature set to 300°C
- 09:33: Temperature set to 330°C
- 09:40: Temperature set to 370°C
- 10:01: Temperature set to 390°C. More water was removed, which made the total amount to be 50 mL
- 10:11: Water removed until the total was 100 mL
- 10:13: Water removed until the total was 150 mL
- 10:20: Wet rags were applied to the pipes at the outlet (close to T6)
- 10:34: Logging of the experiment started
- 10:35: Temperature set to 400°C
- 10:49: Wet rags applied to the pipes at the outlet, and maintained there until 10:57.
- 21:00: Power supply turned off, new logging series started
- 29.05.12 10:33: End of experiment

The measured temperatures increased slowly and therefore the temperature of the power supply was increased. Water was removed to release pressure to allow for more evaporation and thus increase the circulation. The wet rags were applied to see if the system responded to the increased condensation of the vapour.

5.3.2 Experiment 2

The same storage used in Experiment 1 was moved to a new and higher rig which measured 210 cm from ground to top plate. The storage was placed on top and additional piping was added the straight parts of the pipes to make up for the height difference. The pipes connected to the coil and directly to the storage were not touched. With the added pipe length, the loop constituted a total volume of 0.82 litres. In addition, the insulation around the coil was modified. The already existing insulation was removed and rock wool was winded around the coil in the same style as the heating elements were. This improvement of the system was done to increase the head and

The thermocouples in direct connection with the storage have the same location as in Figure 4.4. The connection between thermocouples S1, S2.1 and the logging device was very poor so only the following thermocouples were made use of in Experiment 2:

- S2.2: Salt 2.2
- S3: Salt 3
- S4: Salt 4
- M1: Metal 1

The thermocouples connected to the pipes are seen in Figure 5.8, and are the following:

- Tx: Temperature measured directly on the heat thread
- T7: Temperature out of coil
- T10: Temperature at the inlet to the storage
- T11: Temperature at the outlet to the storage
- T9: Temperature in on coil

Some modifications were done to the location of the thermocouples, now only the most significant temperatures were measured. Also, the thermocouples placed around the coil were fastened with high-temperature silicone glue.

Figure 5.9: Set up of the storage and steam system during Experiment 2

Before the experiment started, the new system was pressure tested with water to find possible leakages. The pressure was increased until the safety valve went off. Only water came out, so it was assumed that the system only contained water. Thereafter the power was turned on at a temperature of 400°C, and when the pressure began to raise an amount of 150 ml was removed. The water proved to be very contaminated, as can be seen in Figure 5.10. An irregular hammering sound was heard in the pipes during the run, which can indicate the presence of water after all. The power was turned off after a couple of hours as this was done only to preheat the system.

Figure 5.10: Water removed from the system

The succeeding day Experiment 2 was started and it had the following advance:

- 02.06.12 08:27: Start of experiment. Heat element was set to 400°C.
- 17:15: All parts of the outlet pipe were insulated
- 23:41: Power was turned off, a new logging series started. A casserole with a diameter of 18 cm filled with one litre of water at 23°C was set on top of the storage with a lid (Figure 5.11).
- 03.06.12 12:31: End of experiment

Figure 5.11: Set up of boiling of water

5.4 Risk Assessment

Two risk assessments have been done on the heat storage and the experimental setup. One was done for experiments when oil was used as working fluid, and the other one was done for experimentation with steam as working fluid. Both setups were built in good laboratory practice (GLP). The solar salt is used in both experiments and is not considered harmful unless large quantities are inhaled.

A detailed version of the risk assessment for the experimental setup with steam as working fluid is attached in Appendix G. For a detailed overview of the experimentation with oil, reference is made to "Heat Storage for Oil Based Solar Concentrators" [29].

5.4.1 Oil as Working Fluid

For the case with oil as working fluid, the setup was considered not harmful. The setup operates on atmospheric pressure. The risk of damage on people or surroundings was considered very small. Possible things that could go wrong were getting burned on heat elements or to experience an oil leakage. As the heat element is hot it can cause skin damages, which also can be the case at an oil leakage. Both cases were considered unlikely to happen and scored, respectively, a C1 and A2 in Table 5.1. The oil that is used is classified harmless (see 3.1.3).

To reduce the risk of the above mentioned to occur, it is advisable to indicate hot surfaces with signs, always wear gloves when around the rig, and avoid non-operators to be around the rig during running of the experiment.

5.4.2 Steam as Working Fluid

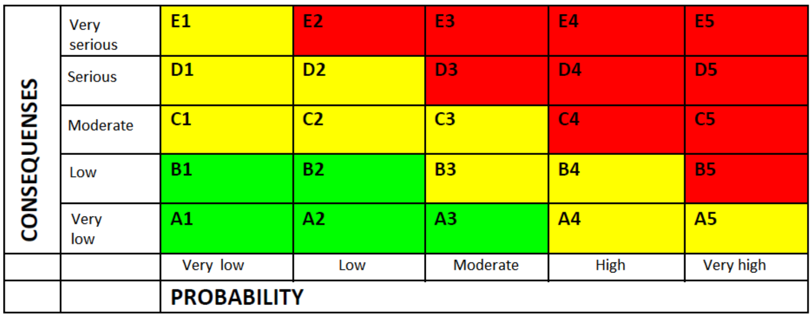
For the case with steam as working fluid the risk assessment is more thorough due to the operating pressure of 40 bar. The risk assessment was based upon an already completed and approved risk assessment for an experiment called "A Natural Circulation System with Pressurized Steam" performed by Abdulkadir and the EHS responsible at NTNU [33].

The risk on damage on people or surroundings was considered low due to severe testing of the equipment, and the construction of the setup in accordance with good laboratory practice. First of all the storage itself was pressure tested with a pressure of 100 bar and approved. Furthermore, the piping system that already was tested by Abdulkadir was tested another time with the storage connected. The piping system has a safety valve that is set to release excess steam if the pressure reaches 46 bar. During the testing, the pressure was set to more than 46 bar and the valve released steam as it was supposed to.

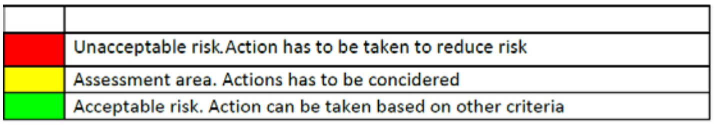
The dangers associated with this set up is the possibility of getting burned on hot surfaces or the hot steam in case of a leakage, in addition to the risk of parts being separated from the storage because of the pressure. The consequences can be severe skin damages if steam gets in contact with humans or other kinds of damages if people get hit by loose parts. To reduce the risks, the system is as already mentioned tested thoroughly. Furthermore, the weakest points of the setup, as the evacuation line and a plug where a thermocouple was placed during experimentation with oil, are faced away from the operators of the rig and other persons. In addition, the parts of the system where steam flows are covered with insulation which both protects against burning and leakages. An operator is present at all times during operation of the system to monitor the development of the system. To reduce the risks utterly, hot surfaces are indicated with signs, gloves and eye protection is always used when around the rig, and non-operators are ought to remain out of the test zone during running of experiments.

The consequences for getting burned or to have a leakage are evaluated to be low and not very probable. In Table 5.1, these risks scored, respectively, A1 and B1, which concludes that the risks are acceptable.

Table 5.1: Risk Matrix



CONSEQUENSES	Very serious	E1	E2	E3	E4	E5
	Serious	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Low	B1	B2	B3	B4	B5
	Very low	A1	A2	A3	A4	A5
		Very low	Low	Moderate	High	Very high
		PROBABILITY				



🟥	Unacceptable risk.Action has to be taken to reduce risk
🟨	Assessment area. Actions has to be concidered
🟩	Acceptable risk. Action can be taken based on other criteria

6 Results and Discussion

6.1 COMSOL Simulations

6.1.1 2D Horizontal Models

6.1.1.1 Model of Minimum Melting Time

Figure 6.1 shows the results after simulation of Figure 4.3, the temperature development in the centre of each cavity. Just by looking at Figure 6.1 the location of the phase changes is known, as the latent energy is stored at constant temperature.

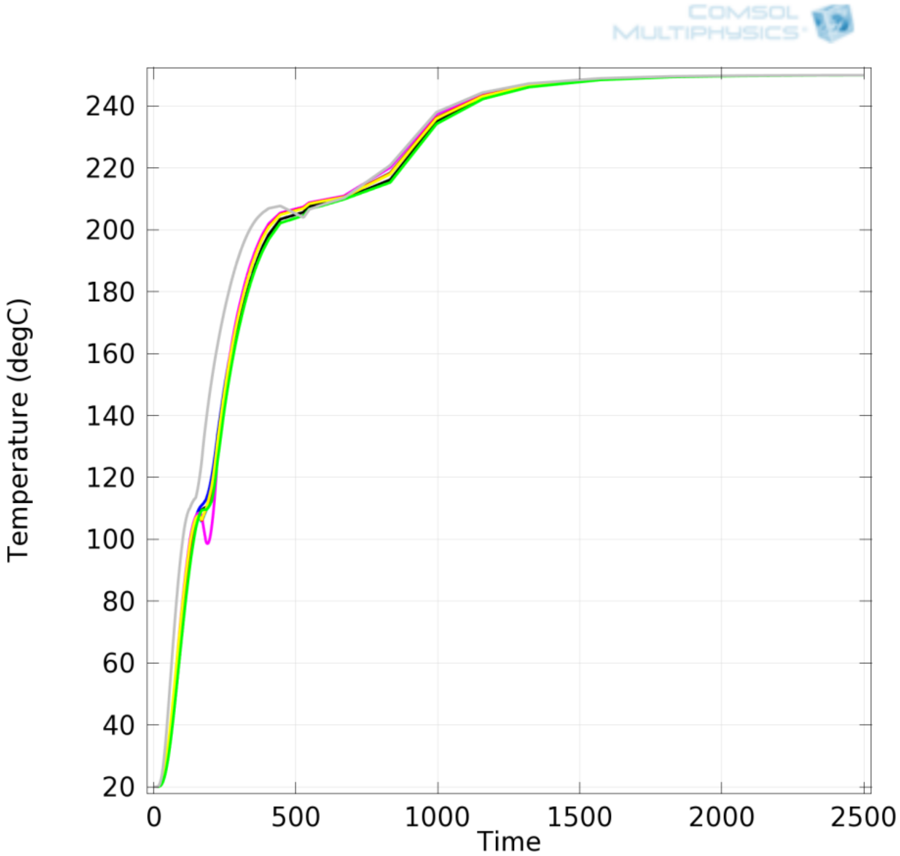


Figure 6.1: Simulation of the temperature development in the centre of the cavities from 0-2500s. (Number of cavity) Colour: (1) Black; (2) Blue; (3) Cyan; (5) Magenta; (7) Red; (8) Yellow; (9) Green; (10) Grey. Time is measured in seconds.

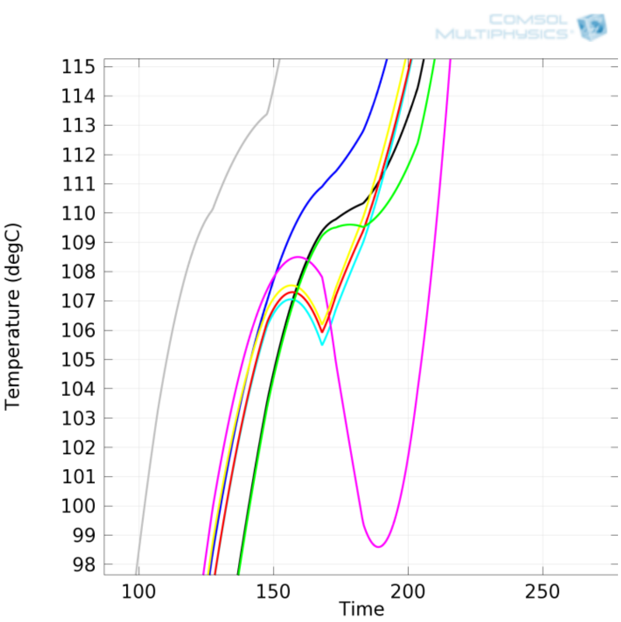


Figure 6.2: Solid-solid phase change. Time in seconds. Same numbering as in Figure 5.1.

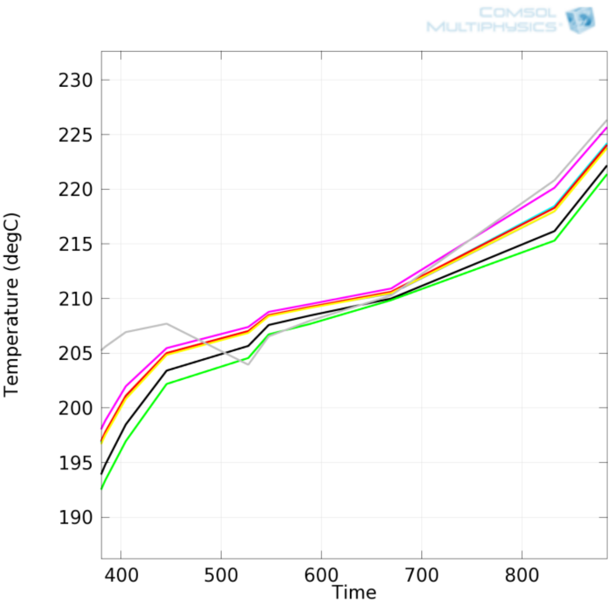


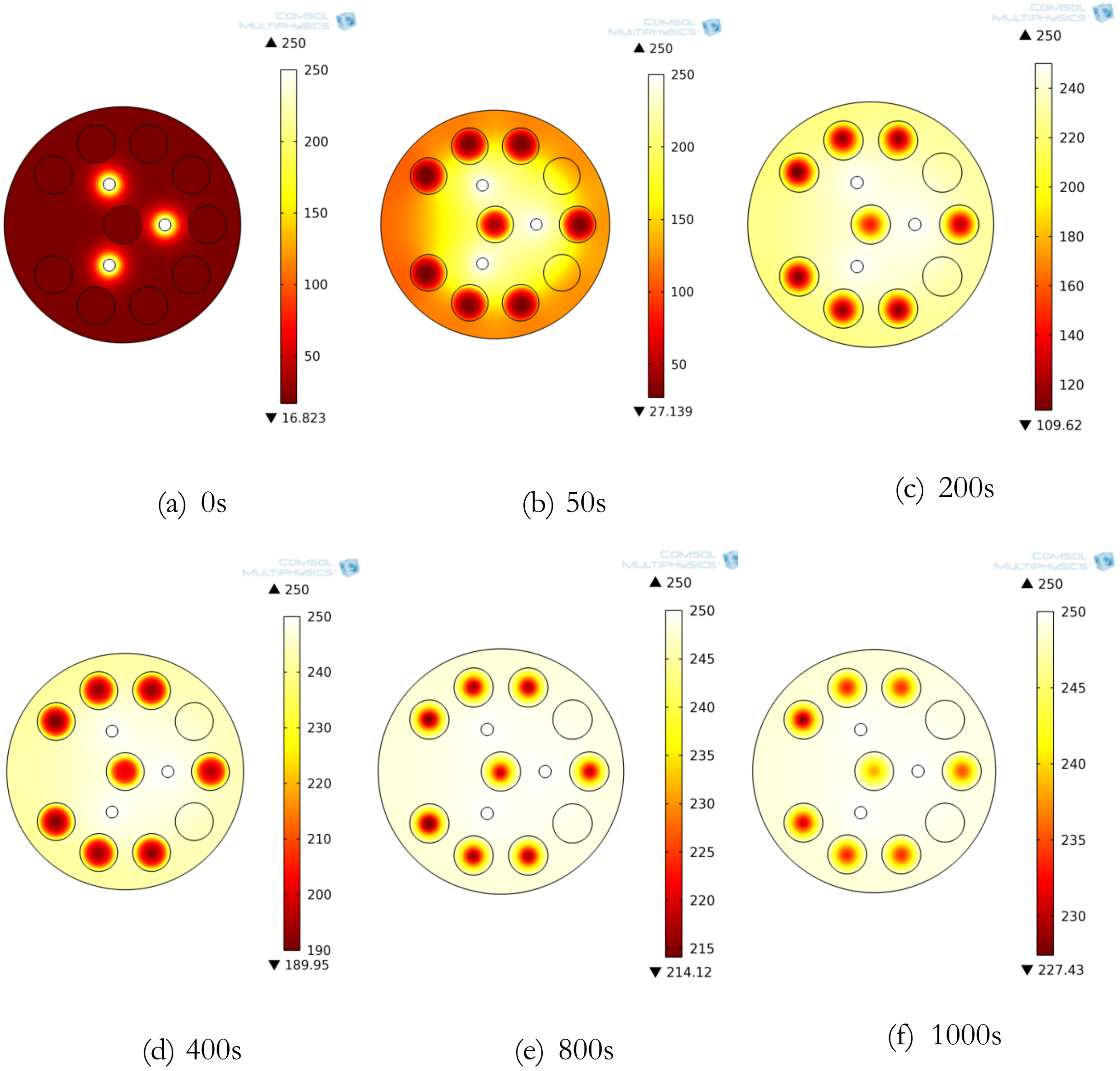
Figure 6.3: Solid-liquid phase change. Time in seconds. Same numbering as in Figure 5.1.

Approximately one can say that the first phase change starts around 140s on a temperature of approximately 106°C, and has a duration of 90s (see Figure 6.2). The second phase change starts around 450s, on a temperature of approximately 205°C, and continues for 400s (see Figure 6.3). The difference in time duration of the phase changes is in accordance with theory previously given, and is also a reason to why the salt needs to be completely melted in order to fully utilize the latent heat in the phase change.

The temperature measurement that stands out with respect to high temperature is the one done in cavity 10, the cavity in the middle of the storage. Cavity 10 reaches higher temperatures faster than the average of the other cavities and remains warmer throughout the advance until the second phase change where it obtains the same temperatures as the other cavities. This development is predictable, as cavity 10 receives equal amount of heat from all three vertical channels at the same time. Irregularities seen in the temperature developments are to be expected due to molecular fluctuations in the salts. Cavity 5, for instance, is in addition influenced differently from the other cavities as it is surrounded by the empty (air filled) cavities which rapidly obtains similar temperatures as the metal.

The effect the storage design has on the melting rates for the salt in the different cavities can also be interpreted. Take cavities 1 and 9, for instance. They are symmetrical equally close to all of the vertical channels. At low temperatures they experience the exact same temperature development, but after the solid-solid phase change cavity 1 gets a little higher temperature than cavity 9 which remains until the end of the experiment. Something similar occurs with symmetry pairs 2-8 and 3-7. At low temperatures the temperature development within each pair is the same, but after the first phase change the curves to cavities 2,3,5 and 7 are the ones close to each other (while the curves to cavities 1 and 9 still remains at lower temperature). After the solid-liquid phase change the curves again formed the “couples” they had at low temperatures. Cavity 10 melts the fastest, followed by cavity 5, and then the symmetry couples 3-7, 2-8 and 1-9. In the simulations cavity 5 obtains 220°C after 830 s while cavities 1 and 9 obtain the same temperature after, respectively, 866 s and 873 s.

The heat propagation from 0s to 1000s in the storage is presented in Figure 6.4.



(a) 0s (b) 50s (c) 200s

(d) 400s (e) 800s (f) 1000s

Figure 6.4: Heat propagation in storage from 0 – 1000s

The heat propagation shows how heat spreads out from the vertical channels through the metal and thereafter to the salt. The area close to the channels is somewhat warmer than the rest of the metal which fast obtains uniform temperature. The heat propagation also demonstrates the difference in conductivity between the salt and the metal, as the salts remain at lower temperatures for a longer time than the metal. It also shows that the salt in the middle do need more time to melt than the salt close to the metal, which as discussed in Energy Storage is due to the easy heat transfer to the salt along the rim.

6.1.1.2 Executed Experiments

Figure 6.5 shows the results after simulation of Figure 4.4, the location of the thermocouples in the executed experiments.

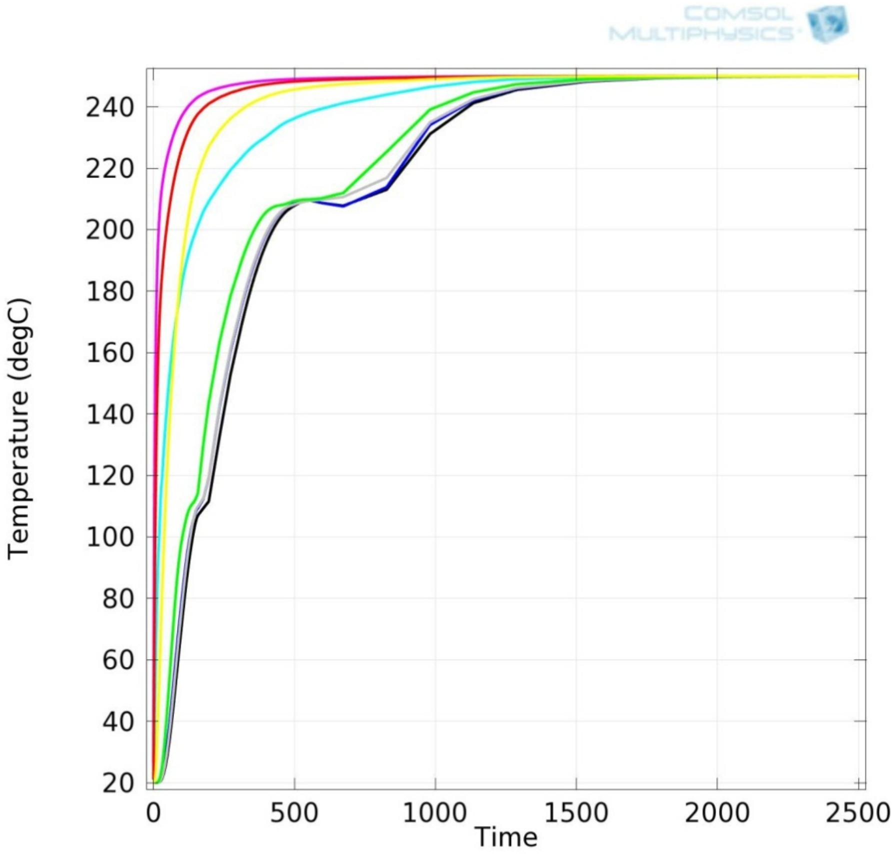


Figure 6.5: Simulations of real life experiment. (S1) Black; (S2.1) Cyan; (S2.2) Blue; (S3) Gray; (S4) Green; (M1) Yellow; (M2) Red; (M3) Magenta. Time is measured in seconds.

The temperature developments for the metals, M1, M2, and M3 show a fast increase in the beginning of the simulation. Almost immediately M2 and M3 reach 180°C, while M1 reaches 180°C after 130s. This is due to the fact that M2 and M3 are closer to the heat channels than M1.

With respect to the temperature development of the salt, S1, S2.2, S3, and S4 behaves as expected according to both theory and the salt simulations in 6.1.1.1 where two evident phase changes are seen. S2.1, on the other hand, has a more abnormal temperature development, but it is a result of its location. S2.1 is situated so close to the wall that the temperature development show how that exact point reacts when it is exposed to heat. As described in the theory, the salt touching the wall will melt very fast because of the good heat conduction from the metal. The other parts of the salt, however, will be melted by the heat of its adjacent salt molecules which have a very poor conductivity (0.8 W/mK in the salt vs.176 W/mK in the metal). The temperatures in the middle of the cavities are a better approximation for the average behaviour of the salt, especially since an increasing amount of liquid salt will flow around the solid part and melt it homogenously.

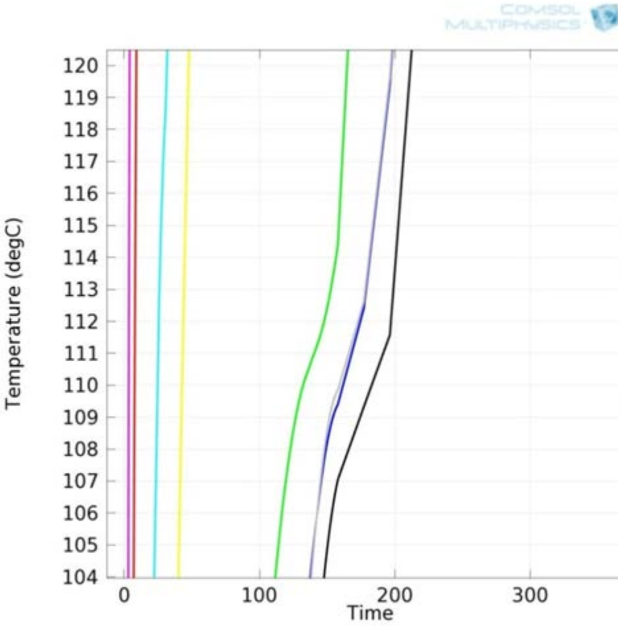


Figure 6.6: Solid-solid phase change (same notation as Figure 6.5)

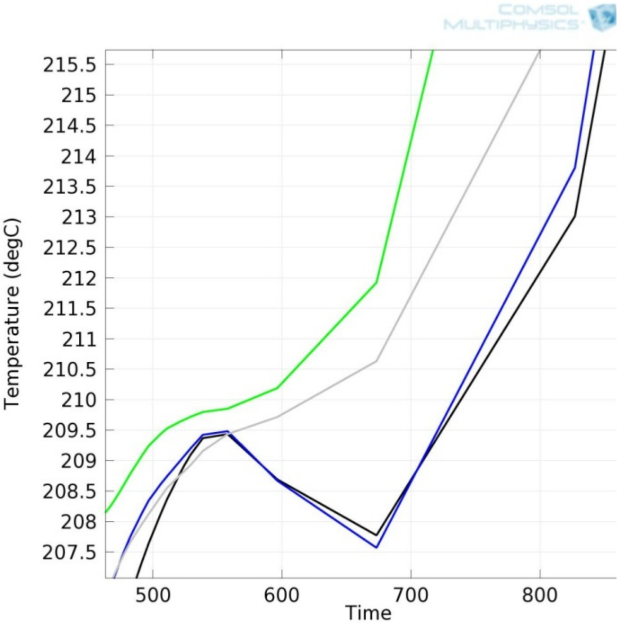


Figure 6.7: Solid-liquid phase change (same notation as Figure 6.5)

6.1.2 2D Vertical Model

Figure 6.8 shows the results after simulation of Figure 4.6, the temperature development of the vertical section of the storage.

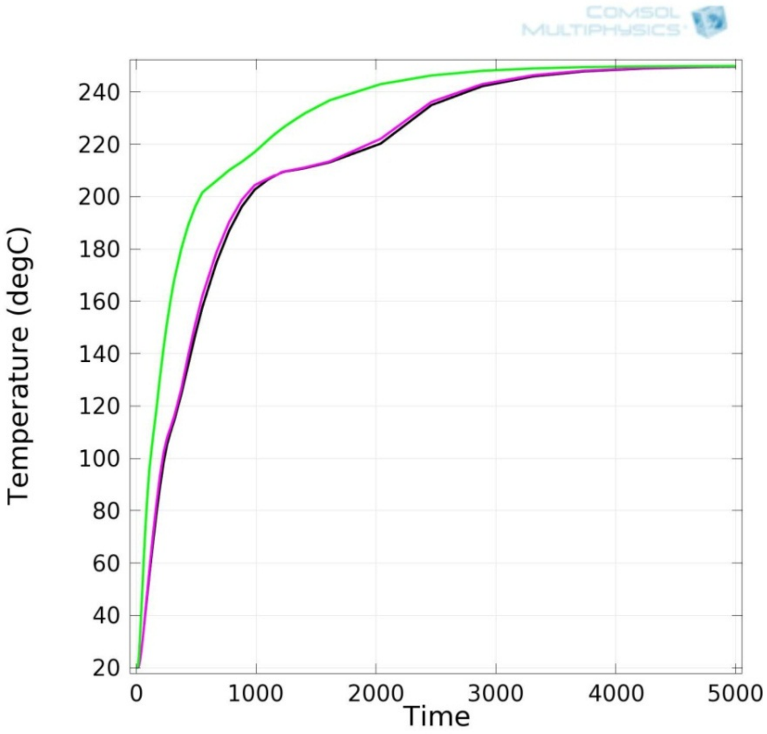
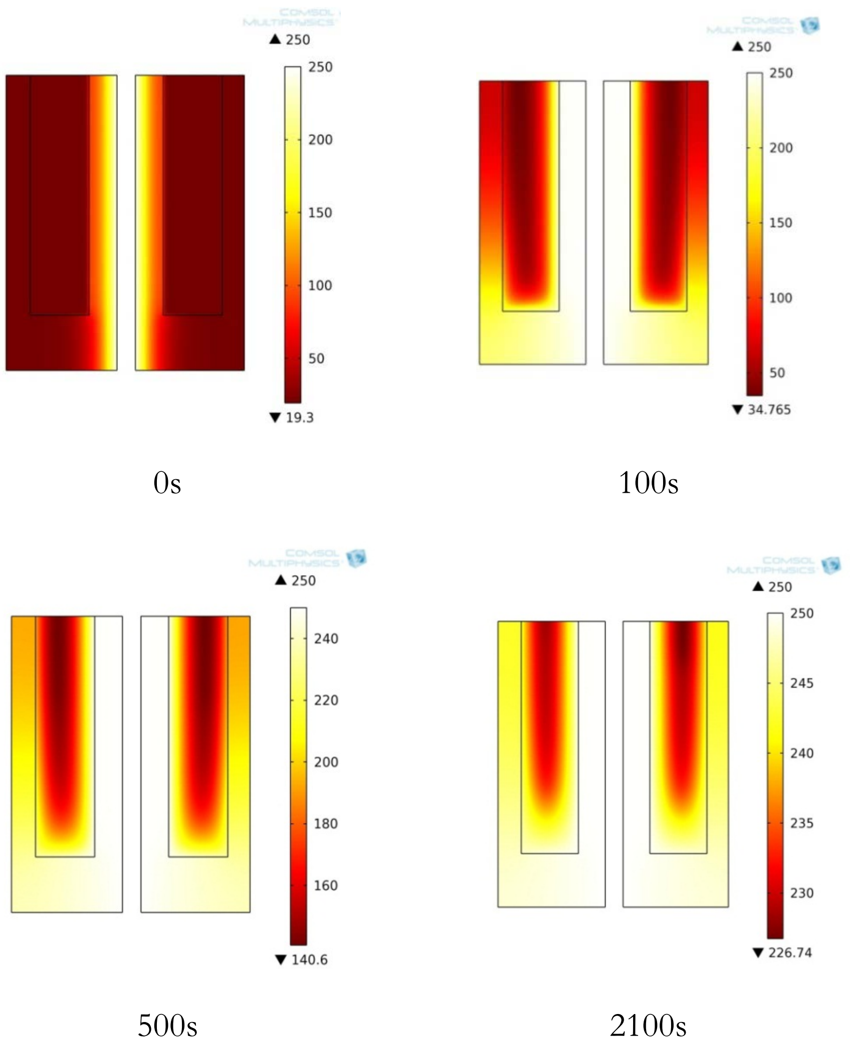


Figure 6.8: Simulation of the temperature development in the three points in Figure 4.6. (1) Black; (2) Magenta; (3) Green. Time is measured in seconds.

Figure 6.8 shows that point 3, which is in the bottom of the salt filled area, melts first and that the phase changes to point 3 are not very evident. The temperature development in point 1 is very similar to the one in point 2, and their phase changes are clearer in the graph. The first phase change occurs at around 110°C and the second one at 210°C. The reason to the faster melting in point 3 is due to the end effects that this point experiences. These end effects can be seen evidently in Figure 6.9 that demonstrates the vertical heat propagation in the storage. From the figures it emerges that the end effects increase the melting time for the salt close to the bottom of the cylinder, but also that this effect does not in large scale influence the melting in the rest of the cylinder. The longer the salt filled cylinders are, the less importance has the end effects.



0s 100s

500s 2100s

Figure 6.9: Simulation of the temperature development in the three points in Figure 4.6.

6.2 Experimental Results

All figures in this chapter are made in MATLAB with input values from the average formula in Appendix E, where averages per minute have been calculated to present the data more evidently. Examples of graphs made of raw data are seen in Appendix D.

6.2.1 Experiment 1

The first experiment aimed to measure the time needed to charge and discharge the storage, and compare the results of the charge with the simulations done in COMSOL. The location of the thermocouples used for the temperature measurement is seen in Figure 4.4 and Figure 5.8.

Figure 6.10 and Figure 6.11 show the temperature development in three of the salt filled cavities in the storage (S1, S2.2, and S4).

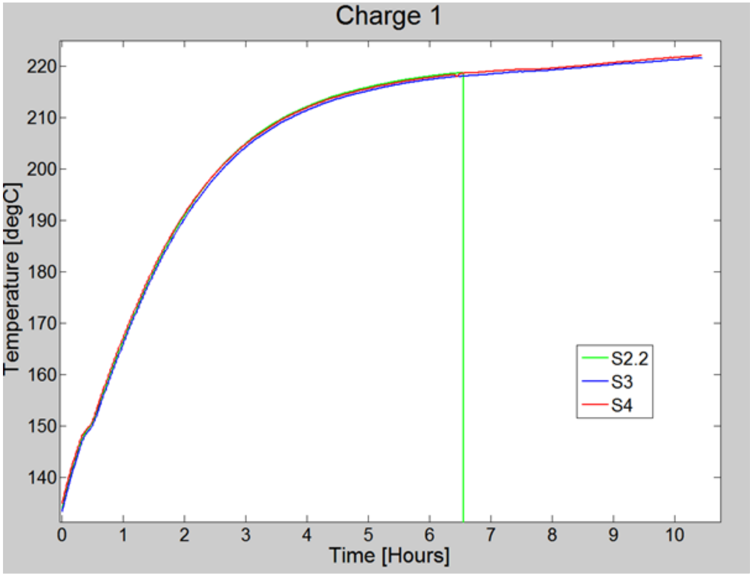


Figure 6.10: Temperature development in the salt during first charge of the storage

The experiment started two hours before the logging began, hence the heightened start temperature of the salt (133°C). After 6.5 hours the thermocouple in S2.2 stopped working, consequently only two salt temperatures were logged for the rest of the experiment.

From the figures it is shown that the salt in each cavity went through the first phase change which is indicated by the little break in the curve around 150°C. This occurred after approximately 18 minutes of logging, and lasted for 10 minutes. The temperature increase in the salt flattens out after 4.5 hours as a result of a reached steady state between the system and the surroundings. Due to the small temperature increase in the salt per time unit, the experiment was stopped after 10.5 hours of logging with a measured average salt temperature on 221.8°C and an inlet temperature on 216°C. Since the salt temperature is close to the expected melting temperature there is a possibility that not all of the salt was melted. This was not visually checked to avoid heat loss to the surroundings by removing the top layers of the insulation. However, a vague increase in the curve can be seen at 8.5 hours which again argues for the fact that all of the salt was melted, and that the salt began to experience an increase in the temperature due to sensible heat. It is evident that there is heat loss in the system that impedes a faster increase in temperature.

Another observation that can be made concerning the solid-solid phase change is the difference between the temperatures in the salts. S4 is warmest, then followed by S2.2 and S3 (Figure 6.11). This agrees somewhat with the simulations done in 6.1.1.2. S4 receives more immediate heat than the other cavities and has a higher temperature. That is equal for both cases. Though, in the experiment S2.2 and S3 have a larger temperature difference between one another than they do in the COMSOL simulations. It is important to remember, however, that the COMSOL simulations are all done in the same plane, while the thermocouples inserted into the salt will be affected by the molecular fluctuations and wander in the cavity which can affect the temperature measurement.

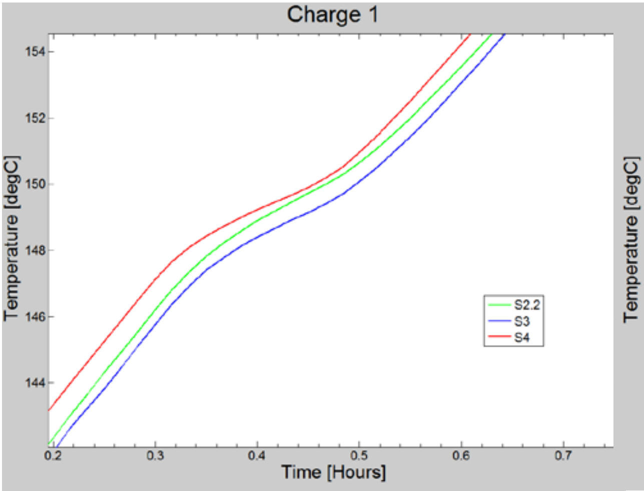


Figure 6.11: Close-up of the solid-solid phase change during first charge

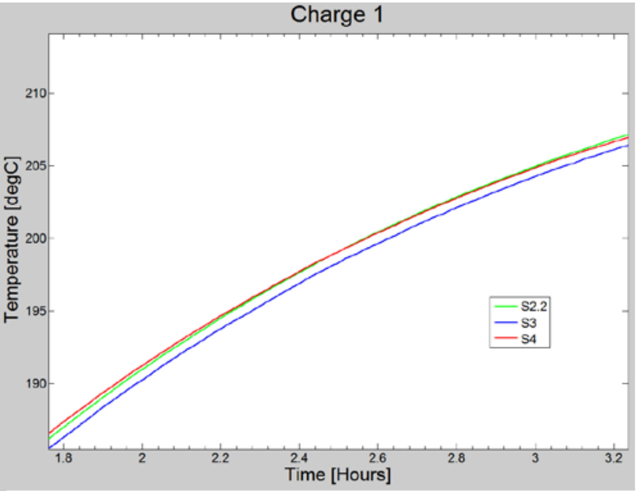


Figure 6.12: Close-up at the salt during first charge

After 2.3 hours S2.2 actually passed S4 (Figure 6.12), and stayed that way until it stopped functioning. This was not the case in the COMSOL simulations where S4 (cavity 10) always held a higher temperature than the rest of the salts except from a short time period during the solid-liquid phase change. This may imply that the heat distribution in fact is so good that it does not matter much in which cavity the temperature is measured in; that molecular fluctuations moved the thermocouple to a hotter spot; or simply just that the thermocouple was on the edge of being broken and thus acted abnormally.

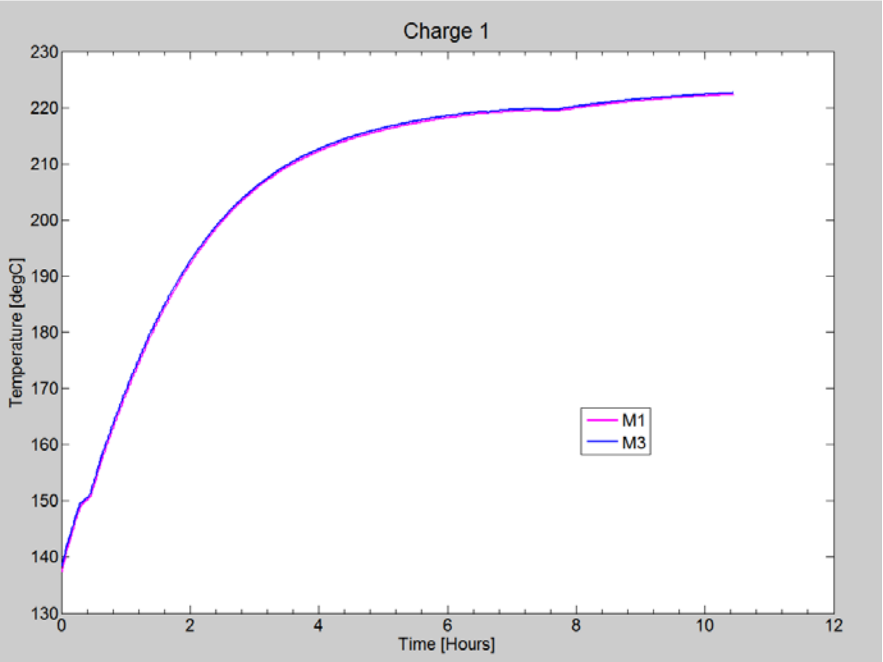


Figure 6.13: Temperature development in the metals during the first experiment

When studying the temperature development in the metal during the charge, it is first seen that it has the exact same advancement as the salt does. The metal does even experience change in temperature due to the phase change in the salt, and that at the same time as the salt. This is a result of the slow temperature increase in the storage, good insulation of the storage and constant movement of energy from lower temperature areas to higher temperature areas until the temperature difference is equalized. M3 has somewhat higher temperature than M1 because of its nearness to the channel where the steam flows.

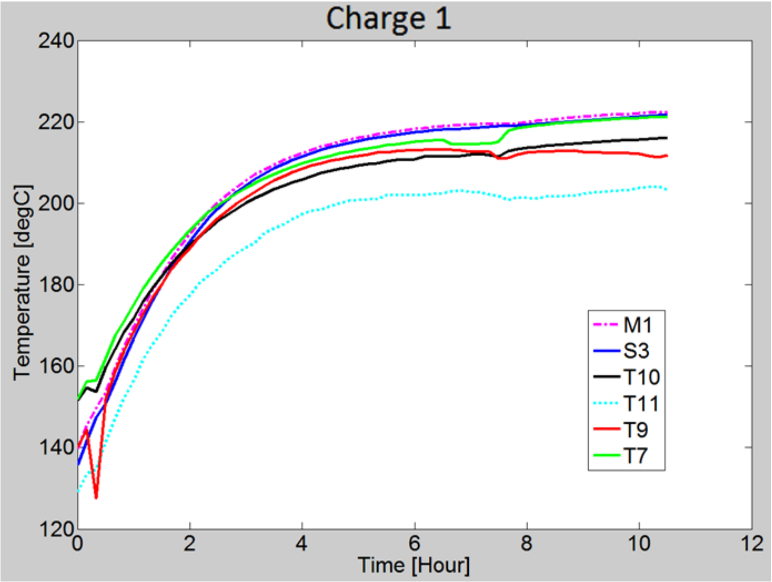


Figure 6.14: Temperature development in the salt, metal, outlet and inlet of storage (T10 and T11), and inlet and outlet of coil (T9 and T7)

The temperature development for the whole system during the heating of the storage is seen in Figure 6.14. The interesting aspect with that figure is the inlet temperature of the storage (T10) which actually is measured to be lower than the temperatures of the salt and metal for the greater part of the measurements. These results are due to an error in the measurements. All of the thermocouples that measure the pipe temperatures are placed on the outside of the pipe, attached between a metal ring and the pipe. This does not guarantee that only the temperature of the pipe is measured since the thermocouple also is surrounded by air with a lower temperature than the pipes. In addition, the pipe at the outlet of the storage was not insulated so the air surrounding the pipe was constantly renewed with cooler air.

The impact the application of wet rags on the outlet pipe had on the temperature development is seen in the abnormal oscillations in the left of Figure 6.14. Especially T9, which measures the temperature in on the coil, experience a large temperature drop, but the other temperatures that were measured on the pipes were also affected with decreased temperatures. This is due to the increased condensation of the steam which reduces the circulation in the pipes.

From Figure 6.14 it can also be seen that there is an increasing heat loss throughout the experiment between the outlet of the coil and the inlet of the storage. This could be one of the heat losses that impede a more rapid melting of the salt. Moreover, T11(temperature out of storage) should be higher than T9 (temperature in on coil) especially since the pipe between these two measuring points is not insulated. T9 should show the lowest temperature in the cycle since the steam in that point has experienced most heat losses through its passage through the pipes. T9 is, however, wrapped inside parts of the insulation that covers the heat element and is therefore affected by the heat thread which causes its raise in temperature.

There is a temperature difference between steam in and out of the storage too. This temperature difference is also due to the measuring error of the thermocouples and should theoretically not have existed. Ideally the only part where steam flows in the pipe system is between the outlet of the coil and the entrance of the storage. The vapour condensation should thus occur only inside the storage where energy in the steam is transferred to the storage. Practically, however, the steam will not condense entirely because the storage is not capable of receiving all the energy at once. The steam will only move towards the liquid region in Figure 2.3 which implies that both inlet and outlet temperature of the storage should be the same. When more energy is supplied to the steam than the storage manages to receive, the pressure will increase but still remain constant in the whole cycle.

This was supported by reading the pressure gage, finding the appurtenant temperature in pressure charts [12] and compare that temperature to the one logged for T10. This procedure showed that T10 was very close to the actual temperature based upon the pressure gage.

The temperature development during the discharge of the storage is seen in Figure 6.15. The logging started immediately after the power supply was turned off and lasted for 85 hours. When the logging started, the measurements showed that the salt had an average temperature on 221.8°C and the steam a temperature on 216°C.

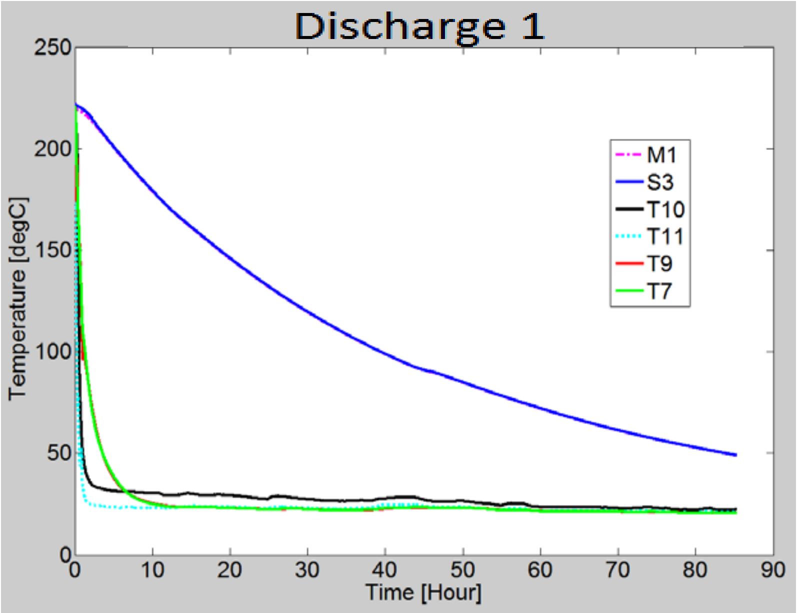


Figure 6.15: Temperature development during discharge of storage

The temperature of the salt (S1) and metal (S3) follow each other throughout the whole discharge, except during a short time period in the beginning which can be seen better in Figure 6.16. The temperature in the metal drops faster than the temperature in the salt which supports the idea that the salt did go through the solid-liquid phase change. The temperature of the salt is almost entirely constant during the first ten minutes of the discharge, and it remains higher than the temperature of the metal for about three hours. The sold-solid phase change can only just be seen in Figure 6.17 between 46 hours and 46.5 hours.

The temperatures at the inlet and outlet of the coil (T9 and T7) obtain equal values fast, while the inlet and outlet of the storage (T10 and T11) still maintain a difference in temperature due to the error in the measurements. 24 hours after the power was turned off, the temperature was 134°C, and after 85 hours it was 50°C. This proves that the storage can maintain heat quite well. However, the insulation lid was never removed during the discharge so the results discussed above show the optimal heat storage capacity. Also some of the losses can come from heat loss through the pipes that were not insulated

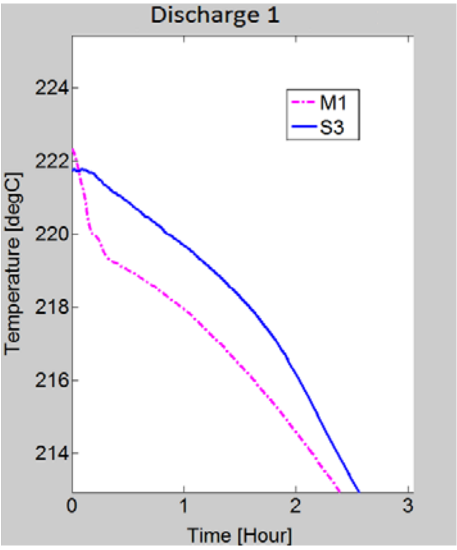


Figure 6.16: Close-up on liquid-solid phase change

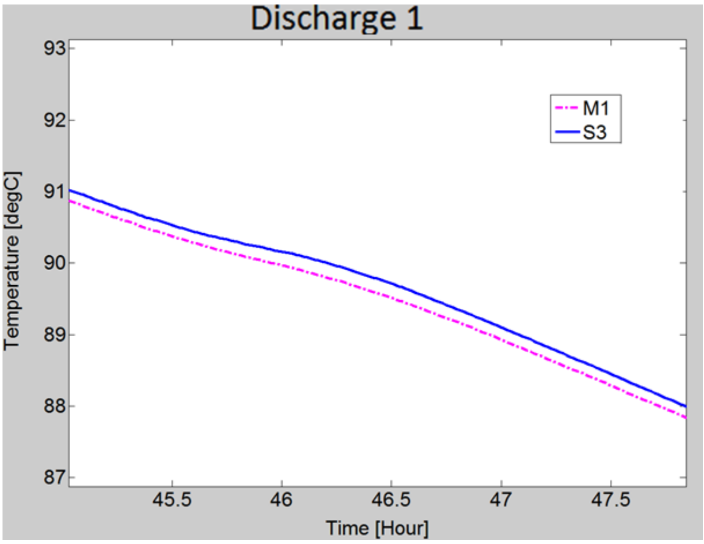


Figure 6.17: Close-up on solid-solid phase change

When comparing COMSOL simulations to the experiments one also has to remember that in COMSOL a constant temperature of 250°C is applied to the storage all the time during the simulations. This is not the case for the experiments as it takes quite a long time to increase the temperature of the steam in real time, and the highest temperature measured on the inlet during the first experiment was 216°C after running the experiment for ten hours.

6.2.2 Experiment 2

The aim of the second experiment was to boil one litre of water, and see if a better temperature profile of the salt could be developed. The location of the thermocouples is seen in Figure 4.4 and Figure 5.8.

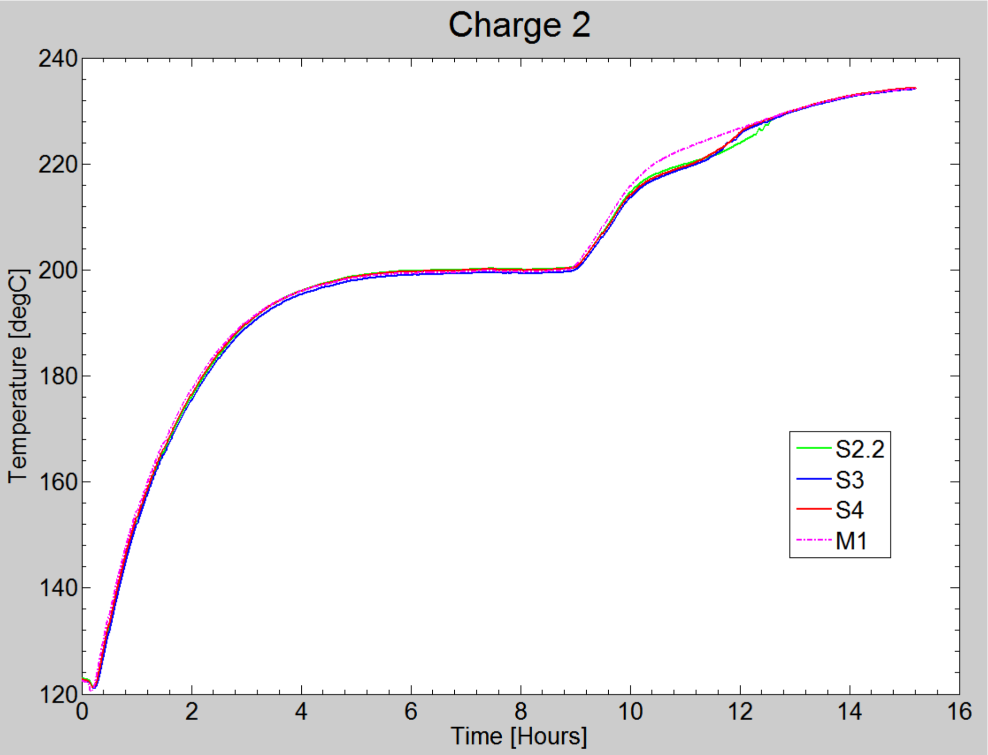


Figure 6.18: Temperature development in the salts and metal during second charge

In Figure 6.18 and Figure 6.19 the temperature development of the salts and metal during Experiment 2 is seen. The salt temperature was 122°C when the experiment started due to pre heating of the storage the day before. After four hours of logging, the temperature increase flattened out due to steady state between the system and the surroundings - the same that occurred in Experiment 1. The temperature in the salt stopped increasing at 199°C. To reduce the heat losses, the outlet pipe was insulated after nine hours and the temperature immediately began to increase. When the experiment was stopped after fifteen hours the temperature of the salt was 134°C - a temperature well over the expected melting point to the salt.

Figure 6.19 shows the solid-liquid phase change which occurs after around 9.8 hours at a temperature of 213°C, and has a duration for about 2 hours.

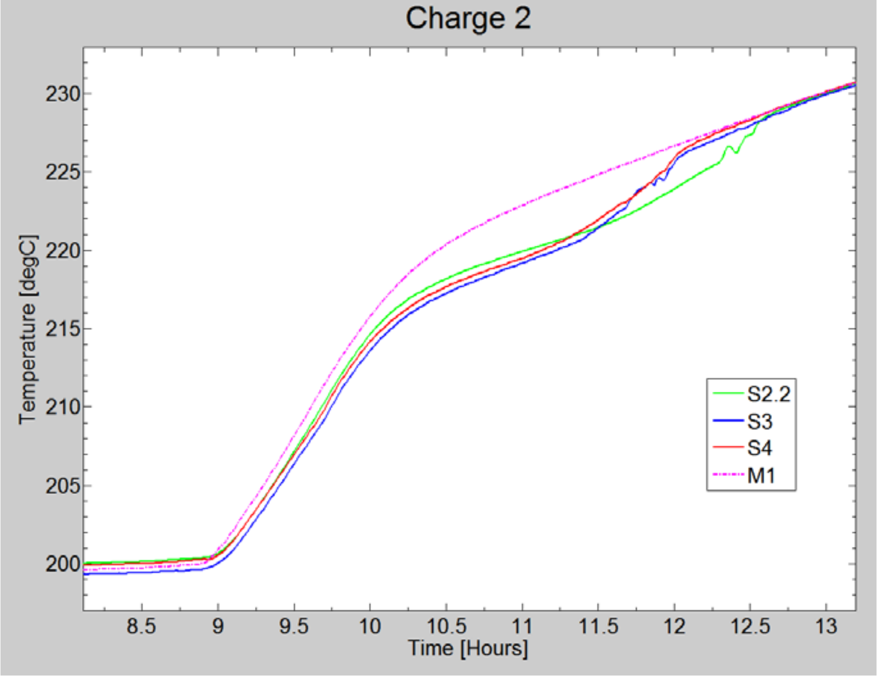


Figure 6.19: Close-up of temperature development in the salts and metal during second charge

While the salt goes through the phase change at constant temperature the metal continues to experience an increase in temperature since it does not go through a phase change. When the phase change is done, however, the salt also begins to increase its temperature due to sensible heat, and soon obtains the same temperature as the metal.

According to the measurements, S3 has the lowest temperature of the three salt filled cavities during the solid-liquid phase change. Then S4 and S2.2 follow with somewhat higher temperatures. After the temperature change S4 becomes hottest. However, the difference in temperature between the cavities is not very big (less than one degree in difference between S2.2 and S3 during the phase change). This proves at least that the design of the storage provides good heat transfer to S2.2, S3 and S4. Based upon the COMSOL simulations it is also good reason to believe that the symmetric couples to S2.2 and S.3, respectively cavities 8 and 7, will experience the same temperature development.

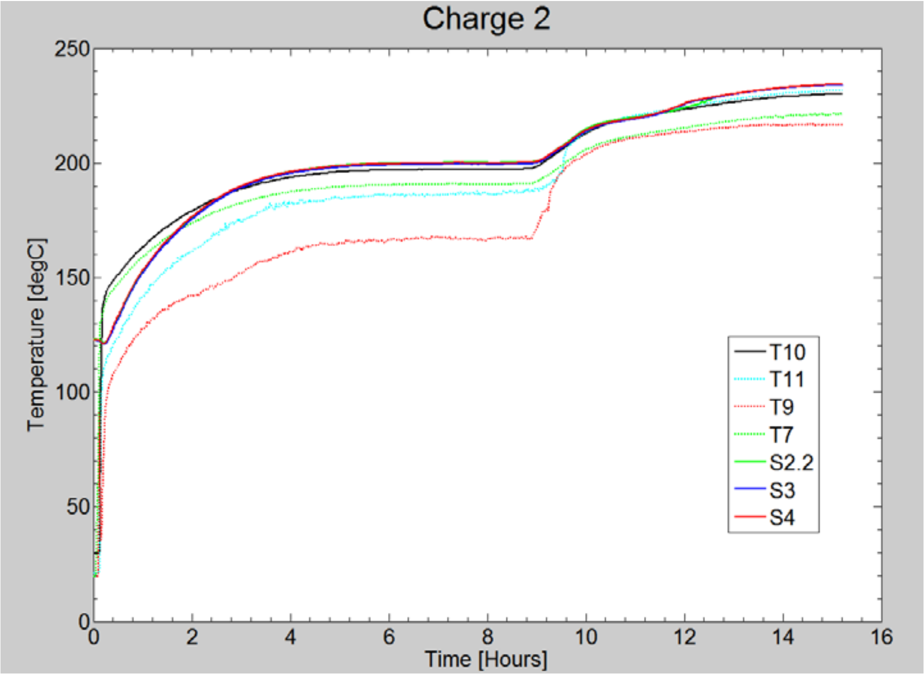


Figure 6.20: Temperature development in the outlet and inlet of storage (T10 and T11), inlet and outlet of coil (T9 and T7) and in the salt during experiment 2.

The temperature development in Figure 6.20 shows an improvement in the measurements from Figure 6.14 with respect to the errors in the measurements. The change of the insulation affected the measurements in T9 positively as it in Figure 6.20 has lowest temperature in the cycle. T7, on the other hand, shows a lower temperature than the actual temperature since it theoretically should be the hottest spot in the cycle.

After nine hours of logging, the extra addition of insulation on the outlet pipe is notable also in Figure 6.20. T9 immediately starts to rise and does by the end of one hour show the same temperature as T7. Nevertheless, these temperatures should not be equal since they are on different sides of the heat element in the flow direction. They were both, however, attached to the pipes with silicon glue that probably affects the measurements.

The most interesting improvement of the cycle is that the temperature difference between T10 and T11 that was so prominent before the insulation was applied disappeared. The reason is that T11 now was covered with insulation and showed a more accurate temperature.

The power was turned off when T10 showed 230°C, the salts showed an average of 134°C and the pressure gage showed a pressure of 30 bar. According to steam tables [12], the steam temperature at 30 bar is 233.90°C, which complies pretty well with the measured temperature.

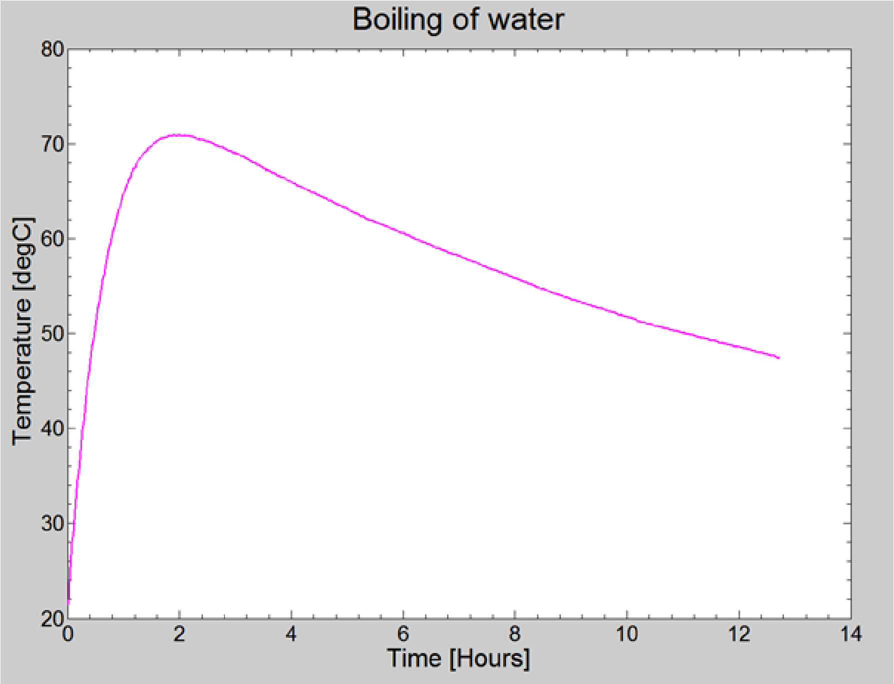


Figure 6.21: Boiling of water

Immediately after the power was turned off the logging of the temperatures in the salt during the discharge started and the casserole with one litre was placed on top of the storage with a lid on to maintain the heat. It can be noted that when the insulation was removed, much heat was sensible released to the surroundings. The temperature development of the water inside the casserole is seen in Figure 6.21 which shows that the water did not reach the boiling point. The highest measured temperature in the water was 70.9°C which occurred 121 minutes after the casserole was placed on the storage. There are several reasons for the rather poor results. First of all, the casserole was placed on top of the storage while all the eight thermocouples still were connected to the surface. This worsened the contact surface between the pan and the storage because of all the air gaps that emerged. Hence, much of the heat transfer happened through convection through the air which has low thermal conductivity and not by conduction. This setup also allowed for the hot air to be interchanged with the colder surrounding air and thus loose more heat. Moreover, no insulation was placed around the casserole to cover the small gap between the pan and the edge of the storage.

From Figure 6.22 the connection between the discharge of the heat stored in the salt and the temperature in the water is showed. The fastest temperature increase in the water occurs during the phase change in the salt. When this phase change (Figure 6.23) ended after 1.4 hours of logging the temperature increased slower than before and the heat losses were far too large for the water to reach boiling. However, the water maintained the achieved temperature pretty well. When the logging was turned off after almost 13 hours, the temperature in the water was 46°C.

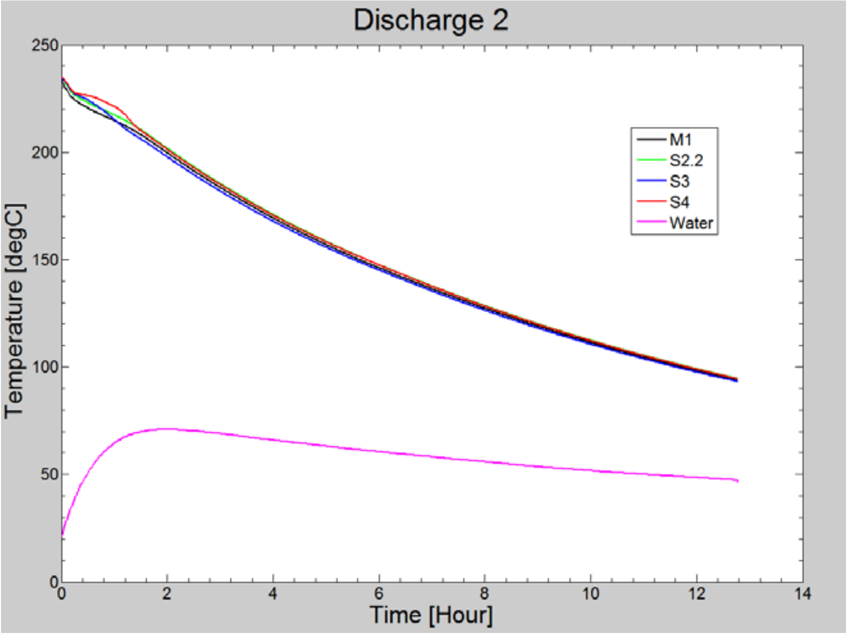


Figure 6.22: Boiling and discharge of heat in the salt

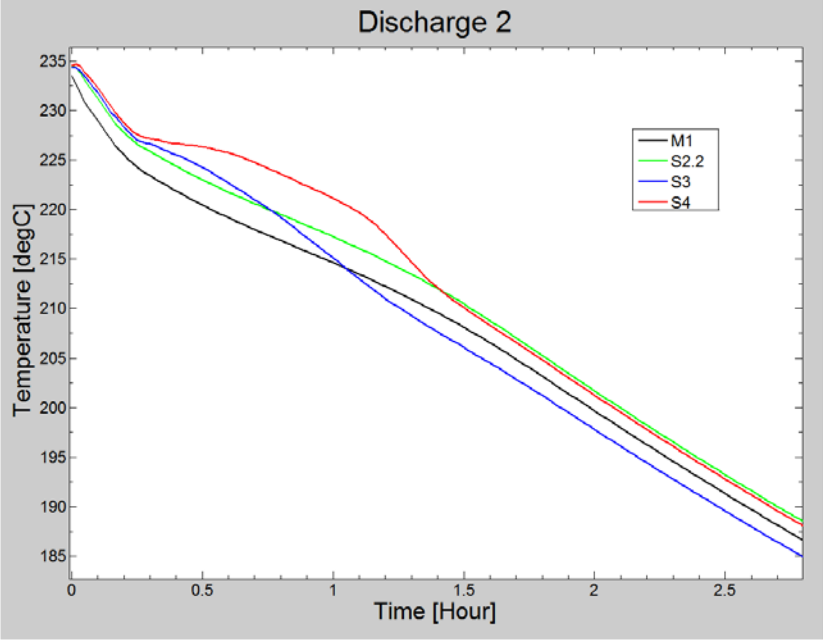


Figure 6.23: Close-up of liquid-solid phase change in the salt

7 Conclusion

From the theoretical and experimental results it is seen that the heat storage for vapour based solar concentrators in this thesis has potential for being used for cooking purposes with some modifications done to the existing system. First of all, the heat losses in the steam cycle should be localized and reduced in order to decrease the charging time of the storage. The importance of good insulation to avoid steady state with the surroundings has been experienced. Beyond that, a vapour system has been technical unproblematic to work with. With the existing system it takes close to ten hours to reach the melting temperature of 213° when the salt is preheated to 122°C, and then two more hours until all of salt melts. The storage has proved to store heat well over time. With an average start temperature on 221.8° in the salt, the temperature was 50° after 85 hours of storage without removing the insulation.

However, maybe the most important improvement with the system could be to increase the heat capacity of the storage itself by adding far more salt to the storage (see Recommendations on Further Work). This will especially be important as the salt stores more energy per kg than the metal, and will be an important contributor to increase the number of small injeras that can be cooked on the phase transition energy in the storage from 7.

It was tried to boil one litre of water without success. The water only reached a temperature of 70.9°C. However, the surface on top of the storage had thermocouples attached which prevented a fully good connection between the pan and the surface. The pan was covered with a lid, but there should also have been applied insulation around the bottom of the pan to cover the surface not covered by the pan.

The design of the storage has proved to be good with respect to conducting the heat to the cavities. The cavity in the middle of the storage melts first, and then cavities 2 and 3 melt. Based upon comparing these experimental results and the results from COMSOL simulations, there is reason to believe that also cavities 8 and 7 will melt easy since they are symmetrical couples with cavity 2 and 3. Cavity 1 and 9 will be the ones that melt slowest, but they will experience some extra heat from the inlet and outlet channels which contribute to their melting in the same way as end effects do it. The simulations and executed experiments so far show that the 2D approximation of the storage is justified, but it is also recommendable to perform measurements in the remaining cavities to support this theory.

8 Recommendations on Further Work

Through the work with this thesis a heat storage has been designed, built and tested. Due to the short time perspective for the actual testing, there are several more experiments and modifications that can be done to improve the efficiency of the storage.

First and maybe most important, the amount of solar salt should be increased in the storage. The most straightforward way to achieve that is to fill the remaining two cavities with solar salt. Another option is simply to increase the diameter of the cavities to allow more room for the solar salt, or to add smaller holes on strategic places that also are filled with salt. If planned in advance, inexpensive equipment can be bought for this purpose.

Further the heat losses need to be localized and reduced to improve the heat transfer. For this purpose it would be rewarding to use a thermo camera that can show just where the losses are.

It would also be interesting to obtain equipment that measures the effect that is emitted from the heat element. When the heat element is used as it was in this thesis, the thermocouple connected between the element and the power supply makes sure that the temperature surrounding the element has a pre-set value and hence that the energy supply alternating is turned on and off depending the temperature surrounding the heat element. With this setting the heat element is preserved, but the energy supply does not, however, provide information about how much effect the heat element emits. With information about supplied effect, more information about the storage and its heat storage abilities can be gained.

However, there will still be some loss from the heat element around the coil and to the surroundings. To utterly increase the efficiency of heat transfer it can be an alternative to remove the insulation and rewind the heat thread around the coil again. Heat transfer to the pipes depends on the temperature of the heat element, type of pipes, and the contact surface between the heat thread and the pipes. The steel pipes should not be removed as they can support the high pressure even if they have poor conductivity, but it can be rewarding to wind the heat thread another time with focus on increasing the contact surfaces with the pipes. Heat loss to the air inside the insulation can then be avoided in larger degree as air transfers heat poorly. The temperature of the heat thread should not be much higher than 400°C since the tolerate limit is 450°C.

Concerning the execution of different cooking experiments, a couple of enhancements should be performed. The most important one is to remove the thermocouples on the top surface of the storage and make sure that the bottom of the cooking utensil is in direct contact with the storage. A top plate could for instance be screwed into the already existing screw treads designed for this purpose to ensure that the majority of the heat is transferred to the cooking utensils by conduction as opposed to convection through the air. If continued monitoring of the temperature in the salt is pursued, the use of wireless thermocouples should be investigated. Oceana Sensor [34] does for instance produce a type K wireless thermocouple.

From an economic perspective regarding the choice of insulation for a real sized storage, a more inexpensive choice of insulation can be bought, for instance rock wool or fire plates.

Other rewarding options and ideas worth considering in order to improve and gain more information about the storage are summarized below:

- Calculate heat fluxes in COMSOL and compare them with the heat fluxes from the working fluid
- If the cooking utensils does not cover the whole top surface of the storage, insulation around the unused parts should be applied
- A cover over the cooking utensils should always be used to maintain the heat inside the utensils
- Physical changes to the storage should be simulated first in COMSOL to ensure that the optimal option is found
- Discharge analysis in COMSOL
- The whole system should be flushed with water several times before the start of next experiment to reduce impurities inside the loop
- Insulation should always cover the outlet pipe
- Placement of valves near the inlet and outlet of the storage to prevent the water to circulate.
- It can also be interesting to place thermocouples in all of the cavities so the temperature development of the cavities 1 and 9, 2 and 8, and 3 and 7 can be compared to the COMSOL simulations
- For oil testing the pipes can be fastened to each other in a bucket filled with oil to avoid air being sucked into the pipes

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Appendix A: Logged Average of Temperature Development in the Salt

The following presents an hourly average of the salt temperatures during both times the storage was charged (Experiments 1 and 2). This data, only more accurate because it is done on smaller averages, is what the graphs in Chapter 6 is based upon. The other results were omitted because of too extensive amount of data.

Charge 1

Time	S3	S4
25.05.2012 10:00	142,3214	143,6278
25.05.2012 11:00	163,7653	164,9496
25.05.2012 12:00	188,7046	189,6918
25.05.2012 13:00	203,3506	203,9738
25.05.2012 14:00	210,9811	211,4879
25.05.2012 15:00	214,9789	215,421
25.05.2012 16:00	217,2485	217,6407
25.05.2012 17:00	218,4194	218,9063
25.05.2012 18:00	219,2256	219,5754
25.05.2012 19:00	220,2254	220,5886
25.05.2012 20:00	221,1432	221,6023
25.05.2012 21:00	221,6224	222,0633

Charge 2

Time	S2.2	S3	S4
02.06.2012 08:00	124,9058	124,3689	125,0876
02.06.2012 09:00	152,1711	151,6472	152,8364
02.06.2012 10:00	176,1441	175,5239	176,6135
02.06.2012 11:00	189,6788	189,017	189,8138
02.06.2012 12:00	196,0259	195,3098	195,9662
02.06.2012 13:00	198,7818	198,0109	198,652
02.06.2012 14:00	199,7765	199,0375	199,6254
02.06.2012 15:00	200,0673	199,3682	199,9341
02.06.2012 16:00	200,1104	199,3972	199,9704
02.06.2012 17:00	202,1352	201,4398	202,0433
02.06.2012 18:00	214,1583	213,1712	213,6969
02.06.2012 19:00	219,9806	219,3133	219,7196
02.06.2012 20:00	224,2062	225,3475	225,6604
02.06.2012 21:00	230,038	229,9218	230,1506
02.06.2012 22:00	232,6972	232,5314	232,7501
02.06.2012 23:00	233,9219	233,7472	234,0114

Appendix B: COMSOL Temperatures

The following table is an excerpt of the data from the COMSOL simulations done in 4.3.1.1 Model of Salt Melting in all Cavities.

Time	1	2	3	5	7	8	9	10
820	215.7096	217.4249	217.8642	219.4424	217.723	217.4331	214.8951	220.032
821	215.7475	217.4711	217.9128	219.499	217.7702	217.4791	214.9285	220.0967
822	215.7854	217.5172	217.9614	219.5556	217.8173	217.5252	214.9619	220.1614
823	215.8233	217.5634	218.01	219.6121	217.8645	217.5712	214.9953	220.2261
824	215.8611	217.6095	218.0586	219.6687	217.9116	217.6172	215.0288	220.2908
825	215.899	217.6556	218.1072	219.7253	217.9588	217.6632	215.0622	220.3555
826	215.9369	217.7018	218.1558	219.7818	218.0059	217.7093	215.0956	220.4202
827	215.9748	217.7479	218.2043	219.8384	218.053	217.7553	215.129	220.4849
828	216.0126	217.7941	218.2529	219.895	218.1002	217.8013	215.1624	220.5496
829	216.0505	217.8402	218.3015	219.9515	218.1473	217.8473	215.1959	220.6143
830	216.0884	217.8864	218.3501	220.0081	218.1945	217.8933	215.2293	220.679
831	216.1263	217.9325	218.3987	220.0647	218.2416	217.9394	215.2627	220.7437
832	216.1641	217.9787	218.4473	220.1212	218.2887	217.9854	215.2961	220.8084
833	216.249	218.0642	218.5333	220.2079	218.3743	218.0707	215.3801	220.898
834	216.3636	218.1747	218.6429	220.3136	218.4842	218.1809	215.496	221.0033
835	216.4783	218.2852	218.7526	220.4194	218.5941	218.2911	215.612	221.1086
836	216.5929	218.3957	218.8623	220.5251	218.704	218.4013	215.728	221.2139
837	216.7076	218.5062	218.972	220.6309	218.814	218.5114	215.8439	221.3192
838	216.8222	218.6167	219.0817	220.7366	218.9239	218.6216	215.9599	221.4245
839	216.9368	218.7272	219.1913	220.8423	219.0338	218.7318	216.0758	221.5298
840	217.0515	218.8377	219.301	220.9481	219.1437	218.842	216.1918	221.6352
841	217.1661	218.9482	219.4107	221.0538	219.2536	218.9522	216.3078	221.7405
842	217.2808	219.0587	219.5204	221.1596	219.3635	219.0624	216.4237	221.8458
843	217.3954	219.1692	219.6301	221.2653	219.4734	219.1726	216.5397	221.9511
844	217.5101	219.2797	219.7397	221.371	219.5833	219.2827	216.6557	222.0564
845	217.6247	219.3902	219.8494	221.4768	219.6933	219.3929	216.7716	222.1617
846	217.7394	219.5007	219.9591	221.5825	219.8032	219.5031	216.8876	222.267
847	217.854	219.6112	220.0688	221.6883	219.9131	219.6133	217.0035	222.3723
848	217.9686	219.7217	220.1784	221.794	220.023	219.7235	217.1195	222.4776
849	218.0833	219.8322	220.2881	221.8997	220.1329	219.8337	217.2355	222.5829
850	218.1979	219.9427	220.3978	222.0055	220.2428	219.9439	217.3514	222.6882
851	218.3126	220.0532	220.5075	222.1112	220.3527	220.0541	217.4674	222.7935
852	218.4272	220.1637	220.6172	222.2169	220.4626	220.1642	217.5834	222.8989
853	218.5419	220.2742	220.7268	222.3227	220.5726	220.2744	217.6993	223.0042
854	218.6565	220.3847	220.8365	222.4284	220.6825	220.3846	217.8153	223.1095
855	218.7711	220.4952	220.9462	222.5342	220.7924	220.4948	217.9313	223.2148
856	218.8858	220.6057	221.0559	222.6399	220.9023	220.605	218.0472	223.3201
857	219.0004	220.7163	221.1656	222.7456	221.0122	220.7152	218.1632	223.4254

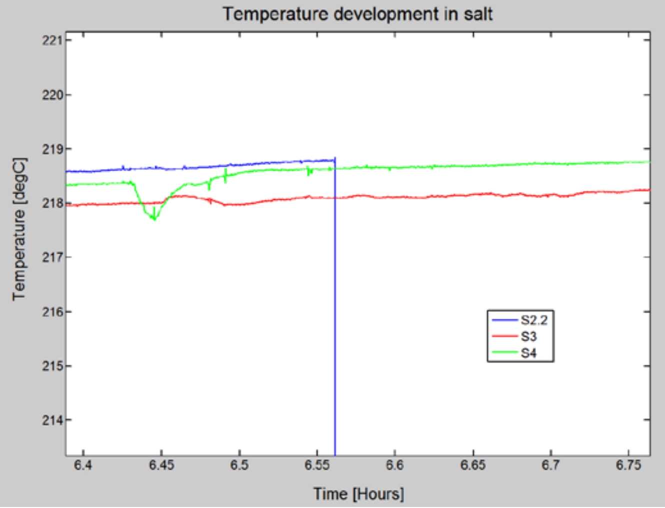
858	219.1151	220.8268	221.2752	222.8514	221.1221	220.8254	218.2791	223.5307
859	219.2297	220.9373	221.3849	222.9571	221.232	220.9355	218.3951	223.636
860	219.3444	221.0478	221.4946	223.0629	221.3419	221.0457	218.5111	223.7413
861	219.459	221.1583	221.6043	223.1686	221.4519	221.1559	218.627	223.8466
862	219.5736	221.2688	221.7139	223.2743	221.5618	221.2661	218.743	223.9519
863	219.6883	221.3793	221.8236	223.3801	221.6717	221.3763	218.859	224.0572
864	219.8029	221.4898	221.9333	223.4858	221.7816	221.4865	218.9749	224.1625
865	219.9176	221.6003	222.043	223.5916	221.8915	221.5967	219.0909	224.2679
866	220.0322	221.7108	222.1527	223.6973	222.0014	221.7069	219.2068	224.3732
867	220.1469	221.8213	222.2623	223.803	222.1113	221.817	219.3228	224.4785
868	220.2615	221.9318	222.372	223.9088	222.2212	221.9272	219.4388	224.5838
869	220.3762	222.0423	222.4817	224.0145	222.3312	222.0374	219.5547	224.6891
870	220.4908	222.1528	222.5914	224.1203	222.4411	222.1476	219.6707	224.7944
871	220.6054	222.2633	222.7011	224.226	222.551	222.2578	219.7867	224.8997
872	220.7201	222.3738	222.8107	224.3317	222.6609	222.368	219.9026	225.005
873	220.8347	222.4843	222.9204	224.4375	222.7708	222.4782	220.0186	225.1103
874	220.9494	222.5948	223.0301	224.5432	222.8807	222.5884	220.1345	225.2156
875	221.064	222.7053	223.1398	224.649	222.9906	222.6985	220.2505	225.3209
876	221.1787	222.8158	223.2494	224.7547	223.1005	222.8087	220.3665	225.4262
877	221.2933	222.9263	223.3591	224.8604	223.2105	222.9189	220.4824	225.5316
878	221.4079	223.0368	223.4688	224.9662	223.3204	223.0291	220.5984	225.6369
879	221.5226	223.1473	223.5785	225.0719	223.4303	223.1393	220.7144	225.7422
880	221.6372	223.2578	223.6882	225.1776	223.5402	223.2495	220.8303	225.8475

Appendix C: Specific Heat for the Elements in the Aluminium Alloy

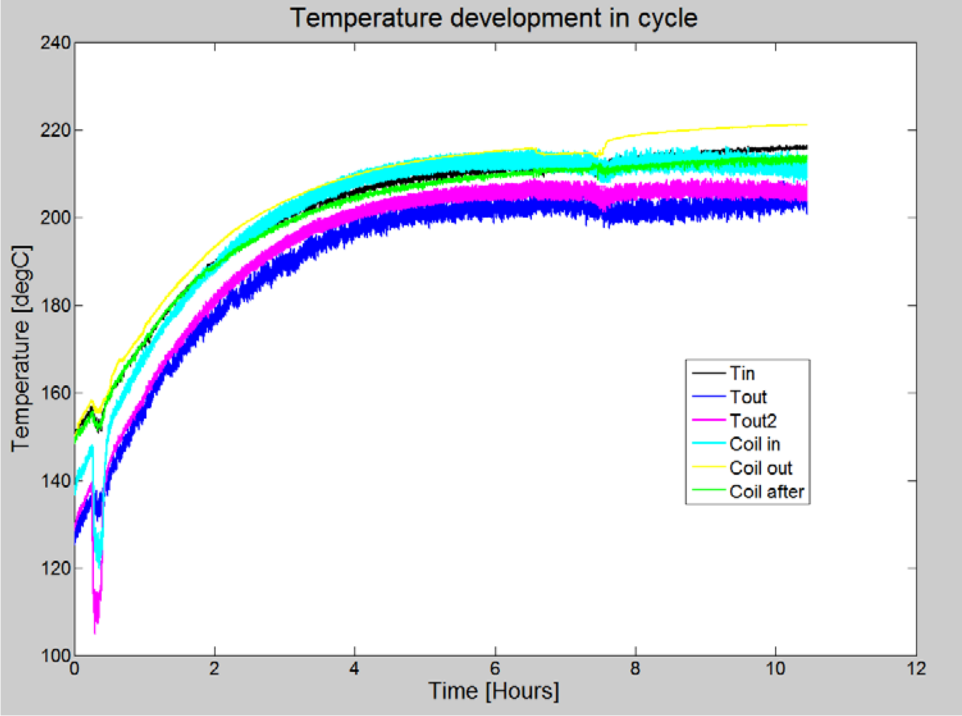
Element	Value (cal/gK)
Al	2.40
Si	2.1
Mg	2.69
Mn	1.32

Appendix D: Additional Graphs

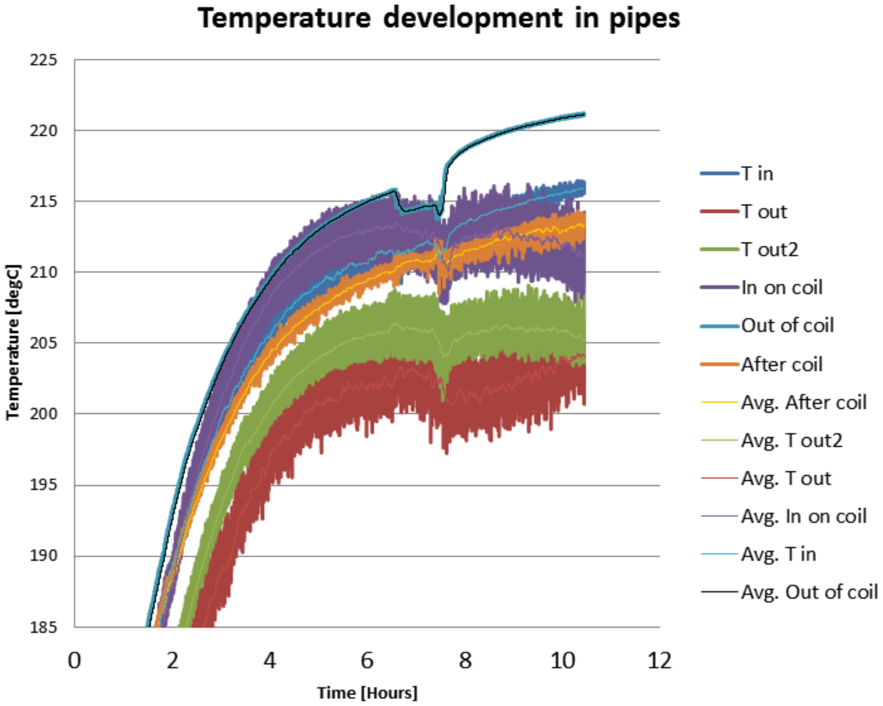
The following graphs are based upon raw data from the first graphs, without any averages. They show the temperature variations well, but also give rather over-complex illustrations over the temperature development.



Charge 1 (First Experiment)



Charge 1 (First Experiment)



Charge 1 (First Experiment)

Appendix E: Calculating Averages in Excel

The following code is written in the program Python by Åsmund Eldhuset [35]. It is used for calculating averages of Microsoft Excel files which are built up in the manner of the following table:

Time	Temperature 1	Temperature 2	Temp …
25.06.12 14:46:12	23,222	35,457	…
25.06.12 14:46:14	23,221	35,403	…
…	…	…	…

In other words:

- The entire first row includes only text lines
- The entire first column (except from in the first row) includes only dates in the form of: dd.mm.yy hh:nn:ss.
- The remaining part of the Excel file consists of temperatures with decimals separated from the integers by a comma (,)
- The number of columns in the Excel file can be infinite
- There cannot be any empty spaces in between the columns or rows
- The number of rows must be equal for all columns

The code calculates averages of each temperature measurement per time done in every column. The period of time it calculates the average is:

- Per minute
- Per 10 minutes
- Per hour
- Per day

In short, the code consists of four aggregation groups associated with one specific average. The function addToDictionary contains a matrix with 16 columns where the specific times are bein added as rows throughout the program. The function printAverage does the actual average calculation, and replaces a Pyhton built in period (.) with the commas (,) that can be seen in the new Excel file.

Note that the output lists with the averages are not sorted by the code. However, this is easily resolved by using the Excel built in function "Sort".

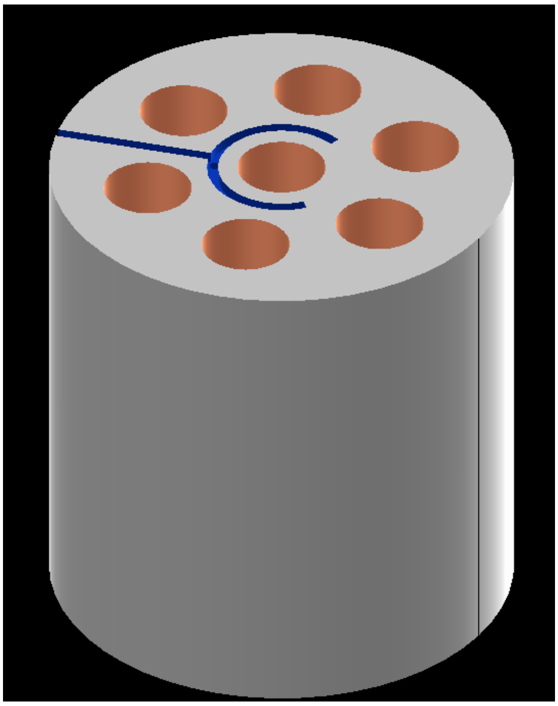
Use of code:

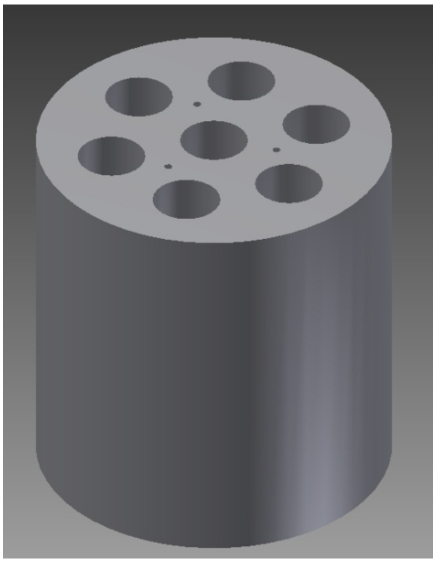
- Download Python
- Save the code in the end in this appendix as “discharge.py”
- Open the built in Windows command line
- Write the initial letter of the directory where the Python file is saved followed by a colon. Example: C:
- Write C:\\... discharge.py <Name of file one shall find the average of> Name*of*file*that*is averaged.csv
- Save Name*of*file*that*is averaged as .xls, and use it as it pleases.

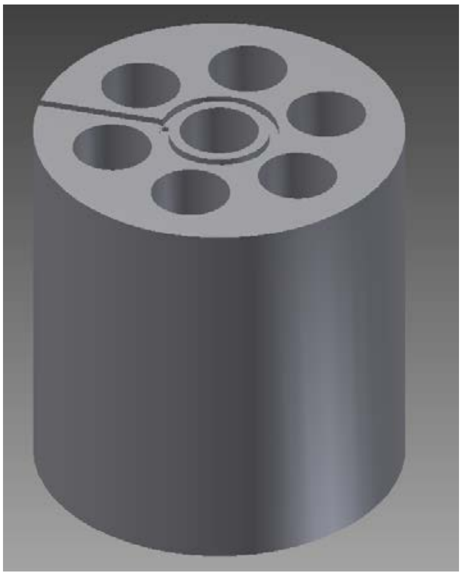
```
from sys import stdin

def addToDictionary(dictionary, key, values):
    if not key in dictionary:
        dictionary[key] = [[] for i in xrange(len(values))]
    series = dictionary[key]
    for i in xrange(len(values)):
        series[i].append(values[i])

def printAverages(dictionary):
    for key in dictionary:
        line = key
        series = dictionary[key]
        for i in xrange(len(series)):
            line += ";" + str(sum(series[i]) / len(series[i])).replace(".", ",")
        print line

minutes = {}
tenminutes = {}
hours = {}
days = {}

stdin.readline()
for line in stdin:
    items = line.strip().split(";")
    timestamp = items[0]
    values = [float(x.replace(",", ".")) for x in items[1:]]
    addToDictionary(minutes, timestamp, values)
    addToDictionary(tenminutes, timestamp[:-1] + "0", values)
    addToDictionary(hours, timestamp[:-3] + ":00", values)
    addToDictionary(days, timestamp[:-6], values)

print "Minutes:"
printAverages(minutes)
print "\nTen minutes:"
printAverages(tenminutes)
print "\nHours:"
printAverages(hours)
print "\nDays:"
printAverages(days)
```

Appendix F: Alternative Storages

The following versions were some of the preliminary versions of the storage. They did not become an option because it was decided that the inlet and outlet channels had to have solid aluminium around them because of the pressure. Also the heat capacity had to be modified to the other storage made by Herdlevær [29].







Appendix G: Risk Assessment Report

The following is the risk assessment for the experiments with steam as working fluid. The risk assessment goes under the title *"Steam Circulating through a Heat Storage"*.

Risikovurderingsrapport

Steam circulating through a heat storage

Prosjekttittel	**Steam circulating through a heat storage**
Prosjektleder	Ole Jørgen Nydal
Enhet	NTNU
HMS-koordinator	Erik Langørgen
Linjeleder	**Olav Bolland**
Plassering	VVS lab
Romnummer	C 136
Riggansvarlig	Ole Jørgen Nydal
Risikovurdering utført av	Abdulkadir Aman, Erik Langørgen, Catharina Hoff

1 INTRODUCTION

Description of experiment setup and the purpose of the experiments. Where is the rig located?

This experimental setup is constructed to study the melting of solar salt using pressurized steam as working fluid that circulates through a heat storage. It is planned to reach temperatures of in the order of 250°C by pressurizing up to 41 bar. The purpose of the experiment is utilizing the storage in solar cooking applications where the steam is generated by heat collected from solar energy. The rig is located in the VVS lab.

2 ORGANISERING

Rolle	NTNU	Sintef
Lab Ansvarlig:	Morten Grønli	Harald Mæhlum
Linjeleder:	Olav Bolland	Mona J. Mølnvik
HMS ansvarlig: HMS koordinator HMS koordinator	Olav Bolland Erik Langørgen Bård Brandåstrø	Mona J. Mølnvik Harald Mæhlum
Romansvarlig:	Harald Mæhlum	
Prosjekt leder:	Ole Jørgen Nydal	
Ansvarlig riggoperatører:	Ole Jørgen Nydal	

3 RISIKOSTYRING AV PROSJEKTET

Hovedaktiviteter risikostyring	Nødvendige tiltak, dokumentasjon	DTG
Prosjekt initiering Project initiation	Prosjekt initiering mal	21th May 2012
Veiledningsmøte Guidance Meeting	Skjema for Veiledningsmøte med pre-risikovurdering	22nd May 2011
Innledende risikovurdering Initial Risk Assessment	Fareidentifikasjon – HAZID Skjema grovanalyse	22nd May 2011
Vurdering av teknisk sikkerhet Evaluation of technical security	Prosess-HAZOP Tekniske dokumentasjoner	22nd May 2011
Vurdering av operasjonell sikkerhet Evaluation of operational safety	Prosedyre-HAZOP Opplæringsplan for operatører	22nd May 2011
Sluttvurdering, kvalitetssikring Final assessment, quality assurance	Uavhengig kontroll Utstedelse av apparaturkort Utstedelse av forsøk pågår kort	22nd May 2011

4 TEGNINGER, FOTO, BESKRIVELSER AV FORSØKSOPPSETT

6 WARNING

6.1 Before experiments

E-mail with information about the test run duration, (hour) and the involved to
HMS koordinator NTNU/SINTEF

iept-experiments@ivt.ntnu.no

Project Managers on neighboring units alerted for clarification around the use of the exhaust system without fear or interference of any kind, see rig matrix.

All experiments should be planned and put into the activity calendar for the lab. Experiment leader must get confirmation that the experiments are coordinated with other activity before start up.

6.2 Nonconformance

FIRE

Fire you are not able to put out with locally available fire extinguishers, activate, the nearest fire alarm and evacuate area. Be then available for fire brigade and building caretaker to detect fire place.
If possible, notify:

NTNU	SINTEF
Labsjef Morten Grønli, tlf: 918 97 515	Labsjef Harald Mæhlum tlf 930 149 86
HMS: Erik Langørgen, tlf: 91897160	Forskningssjef Mona J Mølnvik tlf 930 08 868
Instituttleder: Olav Bolland: 91897209	

GASALARM

At a gas alarm, close gas bottles immediately and ventilated the area. If the level of gas concentration not decrease within a reasonable time, activate the fire alarm and evacuate the lab. Designated personnel or fire department checks the leak to determine whether it is possible to seal the leak and ventilate the area in a responsible manner.
Alert Order in the above paragraph.

PERSONAL INJURY

- First aid kit in the fire / first aid stations
- Shout for help
- Start life-saving first aid•

CALL 113 if there is any doubt whether there is a serious injury

Other Nonconformance (AVVIK)

NTNU:

Reporting form for nonconformance at:
http://www.ntnu.no/hms/2007_Nettsider/HMSRV0401_avvik.doc

SINTEF:

8 VURDERING AV OPERASJONELL SIKKERHET

Sikrer at etablerte prosedyrer dekker alle identifiserte risikoforhold som må håndteres gjennom operasjonelle barrierer og at operatører og teknisk utførende har tilstrekkelig kompetanse.

8.1 Prosedyre HAZOP

Metoden er en undersøkelse av operasjonsprosedyrer, og identifiserer årsaker og farekilder for operasjonelle problemer.
Vedlegg: None
Vurdering: Simplified procedure, misunderstandings will not lead to hazardous situations.

8.2 Drifts og nødstopps prosedyre

Driftsprosedyren er en sjekkliste som skal fylles ut for hvert forsøk.
Nødstopp prosedyren skal sette forsøksoppsetningen i en harmløs tilstand ved uforutsette hendelser.
Vedlegg "Procedure for running experiments
Nødstopp prosedyre: Switch off the electric supply, unplug the wire.

8.3 Opplæring av operatører

Dokument som viser Opplæringsplan for operatører utarbeides for alle forøksoppsetninger.

- *Hvilke krav er det til opplæring av operatører.*
- *Hva skal til for å bli selvstendig operatør*
- *Arbeidsbeskrivelse for operatører*

Vedlegg*:* Opplæringsplan for operatører

8.4 Tekniske modifikasjoner

- Tekniske modifikasjoner som kan gjøres av Operatør
  - *Filling water amount*
- Tekniske modifikasjoner som må gjøres av *Teknisk personale:*
  - **modifications on the pressurized system**
- *Hvilke tekniske modifikasjoner utløser krav om ny risikovurdering;(ved endring av risikobildet)?* **Setting the Relief valve for different safe pressure limit**

Vurdering: Risk Assessment on a modified set up is required.

8.5 Personlig verneutstyr

- *Det er påbudt med vernebriller i sonen anlegget er plassert i.*
- *Det skal benyttes hansker når det er mulighet for kontakt med varme flater.*
- *Full-body Covering Clothing*

Vurdering: Using the goggles and gloves during the experiment.

11 LOVER FORSKRIFTER OG PÅLEGG SOM GJELDER

Se http://www.arbeidstilsynet.no/regelverk/index.html

- Lov om tilsyn med elektriske anlegg og elektrisk utstyr (1929)
- Arbeidsmiljøloven
- Forskrift om systematisk helse-, miljø- og sikkerhetsarbeid (HMS Internkontrollforskrift)
- Forskrift om sikkerhet ved arbeid og drift av elektriske anlegg (FSE 2006)
- Forskrift om elektriske forsyningsanlegg (FEF 2006)
- Forskrift om utstyr og sikkerhetssystem til bruk i eksplosjonsfarlig område NEK 420
- Forskrift om håndtering av brannfarlig, reaksjonsfarlig og trykksatt stoff samt utstyr og anlegg som benyttes ved håndteringen
- Forskrift om Håndtering av eksplosjonsfarlig stoff
- Forskrift om bruk av arbeidsutstyr.
- Forskrift om Arbeidsplasser og arbeidslokaler
- Forskrift om Bruk av personlig verneutstyr på arbeidsplassen
- Forskrift om Helse og sikkerhet i eksplosjonsfarlige atmosfærer
- Forskrift om Høytrykksspyling
- Forskrift om Maskiner
- Forskrift om Sikkerhetsskilting og signalgivning på arbeidsplassen
- Forskrift om Stillaser, stiger og arbeid på tak m.m.
- Forskrift om Sveising, termisk skjæring, termisk sprøyting, kullbuemeisling, lodding og sliping (varmt arbeid)
- Forskrift om Tekniske innretninger
- Forskrift om Tungt og ensformig arbeid
- Forskrift om Vern mot eksponering for kjemikalier på arbeidsplassen (Kjemikalieforskriften)
- Forskrift om Vern mot kunstig optisk stråling på arbeidsplassen
- Forskrift om Vern mot mekaniske vibrasjoner
- Forskrift om Vern mot støy på arbeidsplassen

Veiledninger fra arbeidstilsynet
se: http://www.arbeidstilsynet.no/regelverk/veiledninger.html

13 VEILEDNING TIL RAPPORTMAL

Kap 7 Vurdering av teknisk sikkerhet
Sikre at design av apparatur er optimalisert i forhold til teknisk sikkerhet.
Identifisere risikoforhold knyttet til valgt design, og eventuelt å initiere re-design for å sikre at størst mulig andel av risiko elimineres gjennom teknisk sikkerhet.
Punktene skal beskrive hva forsøksoppsetningen faktisk er i stand til å tåle og aksept for utslipp.

7.1 Fareidentifikasjon, HAZOP

Forsøksoppsetningen deles inn i noder: (eks *Motorenhet, pumpeenhet, kjøleenhet.)*
Ved hjelp av ledeord identifiseres årsak, konsekvens og sikkerhetstiltak. Konkluderes det med at tiltak er nødvendig anbefales disse på bakgrunn av dette. Tiltakene lukkes når de er utført og Hazop sluttføres.
(eks "No flow", årsak: rør er deformert, konsekvens: pumpe går varm, sikkerhetsforanstaltning: måling av flow med kobling opp mot nødstopp eller hvis konsekvensen ikke er kritisk benyttes manuell overvåkning og punktet legges inn i den operasjonelle prosedyren.)

7.2 Brannfarlig, reaksjonsfarlig og trykksatt stoff.

I henhold til Forskrift om håndtering av brannfarlig, reaksjonsfarlig og trykksatt stoff samt utstyr og anlegg som benyttes ved håndteringen

Brannfarlig stoff: Fast, flytende eller gassformig stoff, stoffblanding, samt stoff som forekommeri kombinasjoner av slike tilstander, som i kraft av sitt flammepunkt, kontakt med andre stoffer, trykk, temperatur eller andre kjemiske egenskaper representerer en fare for brann.
Reaksjonsfarlig stoff: Fast, flytende, eller gassformig stoff, stoffblanding, samt stoff som forekommer i kombinasjoner av slike tilstander, som ved kontakt med vann, ved sitt trykk, temperatur eller andre kjemiske forhold, representerer en fare for farlig reaksjon, eksplosjon eller utslipp av farlig gass, damp, støv eller tåke.
Trykksatt stoff: Annet fast, flytende eller gassformig stoff eller stoffblanding enn brann- eller reaksjonsfarlig stoff, som er under trykk, og som derved kan representere en fare ved ukontrollert utslipp.

Nærmere kriterier for klassifisering av brannfarlig, reaksjonsfarlig og trykksatt stoff er fastsatt i vedlegg 1 i veiledningen til forskriften "Brannfarlig, reaksjonsfarlig og trykksatt stoff"
http://www.dsb.no/Global/Publikasjoner/2009/Veiledning/Generell%20veiledning.pdf
http://www.dsb.no/Global/Publikasjoner/2010/Tema/Temaveiledning_bruk_av_farlig_stoff_Del_1.pdf

Rigg og areal skal gjennomgås med hensyn på vurdering av Ex sone

- Sone 0: Alltid eksplosiv atmosfære, for eksempel inne i tanker med gass, brennbar væske.

Her forstås kjemikalier som grunnstoff som kan utgjøre en fare for arbeidstakers sikkerhet og helse.
Se ellers: http://www.lovdata.no/cgi-wift/ldles?doc=/sf/sf/sf-20010430-0443.html
Sikkerhetsdatablar skal være i forøkenes HMS perm og kjemikaliene registrert i Stoffkartoteket.

Kap 8 Vurdering av operasjonell sikkerhet

Sikrer at etablerte prosedyrer dekker alle identifiserte risikoforhold som må håndteres gjennom operasjonelle barrierer og at operatører og teknisk utførende har tilstrekkelig kompetanse.

8.1 Prosedyre Hazop

Prosedyre-HAZOP gjennomføres som en systematisk gjennomgang av den aktuelle prosedyren ved hjelp av fastlagt HAZOP-metodikk og definerte ledeord. Prosedyren brytes ned i enkeltstående arbeidsoperasjoner (noder) og analyseres ved hjelp av ledeordene for å avdekke mulige avvik, uklarheter eller kilder til mangelfull gjennomføring og feil.

8.2 Drifts og nødstopp prosedyrer

Utarbeides for alle forsøksoppsetninger.
Driftsprosedyren skal stegvis beskrive gjennomføringen av et forsøk, inndelt i oppstart, under drift og avslutning. Prosedyren skal beskrive forutsetninger og tilstand for start, driftsparametere med hvor store avvik som tillates før forsøket avbrytes og hvilken tilstand riggen skal forlates.
Nødstopp-prosedyre beskriver hvordan en nødstopp skal skje, (utført av uinnvidde),
hva som skjer, (strøm/gass tilførsel) og
hvilke hendelser som skal aktivere nødstopp, (brannalarm, lekkasje).

Attachment to Risk Assessment report

Solar energy: Steam circulating through a heat storage

Project name	**Solar energy: Steam circulating through a heat storage**
Project leader	Ole Jørgen Nydal
Enhet	NTNU
HMS-koordinator	Erik Langørgen
Linjeleder	Olav Bolland
Riggnavn	
Plassering	VATL-Termisk Lab
Romnummer	B332
Riggansvarlig	Ole Jørgen Nydal

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- ATTACHMENT A HAZOP MAL 1
- ATTACHMENT B PRØVESERTIFIKAT FOR LOKAL TRYKKTESTING 1
- ATTACHMENT F HAZOP MAL PROSEDURE 1
- ATTACHMENT G PROCEDURE FOR RUNNING EXPERIMENTS 1
- ATTACHMENT H TRAINING OF OPERATORS 3
- ATTACHMENT I FORM FOR SAFE JOB ANALYSIS 4
- ATTACHMENT J APPARATURKORT UNITCARD 6
- ATTACHMENT K FORSØK PÅGÅR KORT 7

Project: Steam circulating through a heat storage (Solar Energy)
Node: Complete set up1
Page

Ref #	Guideword	Causes	Consequences	Safeguards	Recommendations	Action	Date Sign
10	Less temperature	heating element temperature is too low			Monitor temperature of the evaporator section (L1)	Replace the heater with alternative heating element.	
11	More viscosity	NA					
12	Less viscosity	NA					
13	Composition Change	NA					
14	Contamination	Contamination of water	Refer 1				
15	Relief	Refer 5					
16	Instrumentation	Failure in valves	Refer 1, 4,5 and 7				
17	Sampling	NA					
18	Corrosion/erosion	NA, short time experiments, (2 weeks)					
19	Service failure	Refer 9 and 10					
20	Abnormal operation					Turn off the power supply and maintain	
21	Maintenance	NA					
22	Ignition	Refer 1,6 and 9					
23	Spare equipment	NA					
24	Safety	Over pressure and leak	High pressure steam	Relief valve and warning sign over for hot surfaces			

- **ATTACHMENT B PRØVESERTIFIKAT FOR LOKAL TRYKKTESTING**

Trykktesten skal utføres I følge NS-EN 13445 del 5 (Inspeksjon og prøving).
Se også prosedyre for trykktesting gjeldende for VATL lab

Trykkpåkjent utstyr: ....Solar oven steam rig

Benyttes i rigg: ....

Design trykk for utstyr: ....61 ....bara

Maksimum tillatt trykk: ......46........bara
(i.e. burst pressure om kjent)

Maksimum driftstrykk i denne rigg: ....41...........bara

Prøvetrykket skal fastlegges i følge standarden og med hensyn til maksimum tillatt trykk.

Prøvetrykk: ......61...........bara (......1.5.... x maksimum driftstrykk)
I følge standard

Test medium: Water

Temperatur: 20 °C

Start: Tid: 11.20

Trykk: 60,8 bara

Slutt: Tid: 11.50

Trykk: 60.3 bara

Eventuelle repetisjoner fra atm. trykk til maksimum prøvetrykk:.........0.......

Test trykket, dato for testing og maksimum tillatt driftstrykk skal markers på (skilt eller innslått)

Sted og dato

Signatur

VEDLEGG B PRØVESERTIFIKAT FOR LOKAL TRYKKTESTING

Trykktesten skal utføres I følge NS-EN 13445 del 5 (Inspeksjon og prøving).
Se også prosedyre for trykktesting gjeldende for VATL lab

Trykkpåkjent utstyr: ....

Benyttes i rigg: SOLOVN/VARMELAGER

Design trykk for utstyr: 40 bara

Maksimum tillatt trykk: 45 bara
(i.e. burst pressure om kjent)

Maksimum driftstrykk i denne rigg: 40 bara

Prøvetrykket skal fastlegges i følge standarden og med hensyn til maksimum tillatt trykk.

Prøvetrykk: 100 bara (2,5 x maksimum driftstrykk)
I følge standard

Test medium: VANN

Temperatur: 20 °C

Start: Tid: 9 MAI 15.00

Trykk: 100 bara

Slutt: Tid: 10 MAI 09.00

Trykk: 90 bara

Eventuelle repetisjoner fra atm. trykk til maksimum prøvetrykk:................

Test trykket, dato for testing og maksimum tillatt driftstrykk skal markers på (skilt eller innslått)

TRONDHEIM 9-10 MAI 2012
Sted og dato

Gisle M Haugseth
Signatur

- **ATTACHMENT F HAZOP MAL PROSEDURE**

Project:
Node: 1

Page

Ref #	Guideword	Causes	Consequences	Safeguards	Recommendations	Action	Date Sign
	Not clear procedure	Procedure is to ambitious, or confusingly					
	Step in the wrong place	The procedure can lead to actions done in the wrong pattern or sequence					
	Wrong actions	Procedure improperly specified					
	Incorrect information	Information provided in advance of the specified action is wrong					
	Step missing	Missing step, or step requires too much of operator					
	Step unsucessful	Step has a high probability of failure					
	Influence and effects from other	Procedure's performance can be affected by other sources					

ATTACHMENT G PROCEDURE FOR RUNNING EXPERIMENTS

Experiment, name, number: **Solar energy: Steam circulating through a heat storage**	**Date/ Sign**
Project Leader: **Ole Jørgen Nydal** **(735)50564 , 97715994**	
Experiment Leader: **Ole Jørgen Nydal** **48341425**	
Operator, Duties: **Catharina Hoff**	

	Conditions for the experiment:	
1	Experiments should be run in normal working hours, 08:00-16:00 during winter time and 08.00-15.00 during summer time	
2	At least one person must always be present while running experiments and at least should be approved as an experimental leader	
3	There must be personal protection equipments and fire extinguisher in the working area	
4	Early warning is given: iept-experiments@ivt.ntnu.no	
	Preparations, System Construction, changing Heat Transfer Fluid	
5	Evacuating the whole system below atmospheric pressure (at P3,Refer Test Rig layout)	
6	Filling the system with cold water (at P4)	
7		
8	Testing the system for leaks, safety and blow off valves	
	Preparation for Operation	
13	Post the "Experiment in progress" sign.	
14	Wearing protective clothes, safety goggles, and gloves.	
15	Wire the electrical heater by the door to the research cell.	
16	Turn on the heating element and adjust to reach 300°C by controlling the temperature of thermocouple welded on the evaporator section (L1)	
	Operation	
	Temperature profiles on L1, L2, L3 and L4 are measured and recorded using K-type thermocouple.	
	The pressure gage (P2) is also monitored to see the fluctuation in pressure, whether it is above the set limit for the relief valve (P1) or not, and if the valve responds accordingly for readings above the set pressure limit.	
	Always be aware of leaks and pressure in the pipelines.	
	Assuring complete recirculation of the fluid is maintained in the system	
	Collecting the heat at the top plate by heating water in a pan.	
	Completion of experiments	
	Turn off the Electric heater	
	Remove all obstructions/barriers/signs around the experiment when	

• ATTACHMENT H TRAINING OF OPERATORS

Solar energy: Steam circulating through a heat storage	**Date/ Sign**
Project Leader: **Ole Jørgen Nydal**	
Experiment Leader: **Ole Jørgen Nydal**	
Operator **Catharina Hoff**	

	Knowledge to EPT LAB in general	
	Lab - Access -routines and rules -working hour	
	Knowledge about the evacuation procedures.	
	Activity calendar for the Lab	
	Knowledge to the experiments	
	Procedures for the experiments	
	Emergency shutdown.	
	Nearest fire and first aid station.	
	Hazards according to high pressurized steam	
	Solar Energy: Oil heat Storage	

Operatør

Dato

____

Signert

____

HMS responsible

Dato

____

Signert

____

HMS aspekt	**Ja**	**Nei**	**Ikke aktuelt**	**Kommentar / tiltak**	**Ansv.**
Dokumentasjon, erfaring, kompetanse					
Kjent arbeidsoperasjon?					
Kjennskap til erfaringer/uønskede hendelser fra tilsvarende operasjoner?					
Nødvendig personell?					
Kommunikasjon og koordinering					
Mulig konflikt med andre operasjoner?					
Håndtering av en evnt. hendelse (alarm, evakuering)?					
Behov for ekstra vakt?					
Arbeidsstedet					
Uvante arbeidsstillinger?					
Arbeid i tanker, kummer el.lignende?					
Arbeid i grøfter eller sjakter?					
Rent og ryddig?					
Verneutstyr ut over det personlige?					
Vær, vind, sikt, belysning, ventilasjon?					
Bruk av stillaser/lift/seler/stropper?					
Arbeid i høyden?					
Ioniserende stråling?					
Rømningsveier OK?					
Kjemiske farer					
Bruk av helseskadelige/giftige/etsende kjemikalier?					
Bruk av brannfarlige eller eksplosjonsfarlige kjemikalier?					
Må kjemikaliene godkjennes?					
Biologisk materiale?					
Støv/asbest?					
Mekaniske farer					
Stabilitet/styrke/spenning?					
Klem/kutt/slag?					
Støy/trykk/temperatur?					
Behandling av avfall?					
Behov for spesialverktøy?					
Elektriske farer					
Strøm/spenning/over 1000V?					
Støt/krypstrøm?					
Tap av strømtilførsel?					
Området					
Behov for befaring?					
Merking/skilting/avsperring?					
Miljømessige konsekvenser?					
Sentrale fysiske sikkerhetssystemer					
Arbeid på sikkerhetssystemer?					
Frakobling av sikkerhetssystemer?					
Annet					

- **ATTACHMENT K FORSØK PÅGÅR KORT**

Forsøk pågår!
Experiment in progress!

Dette kort skal settes opp før forsøk kan påbegynnes This card has to be posted before an experiment can start

Ansvarlig / Responsible Ole Jørgen Nydal	**Telefon jobb/mobil/hjemme** (735)50564 97715994
Operatører/Operators Catharina Hoff	**Forsøksperiode/Experiment time**(start – slutt)
Prosjektleder Ole Jørgen Nydal	**Prosjekt** Solar energy: Steam circulating through a heat storage

Kort beskrivelse av forsøket og relaterte farer
Short description of the experiment and related hazards

This experiment is performed to melt salt which is filled in some of the cavities in the heat storage. The working fluid is steam which is circulated through the storage. Temperature development in the salt is measured.

Hot surfaces and pressurized steam system, (<46 bar), when running the experiment.
If over pressurized, relief valve will open, spraying steam and give high noise.

NTNU
Institutt for energi og prosessteknikk

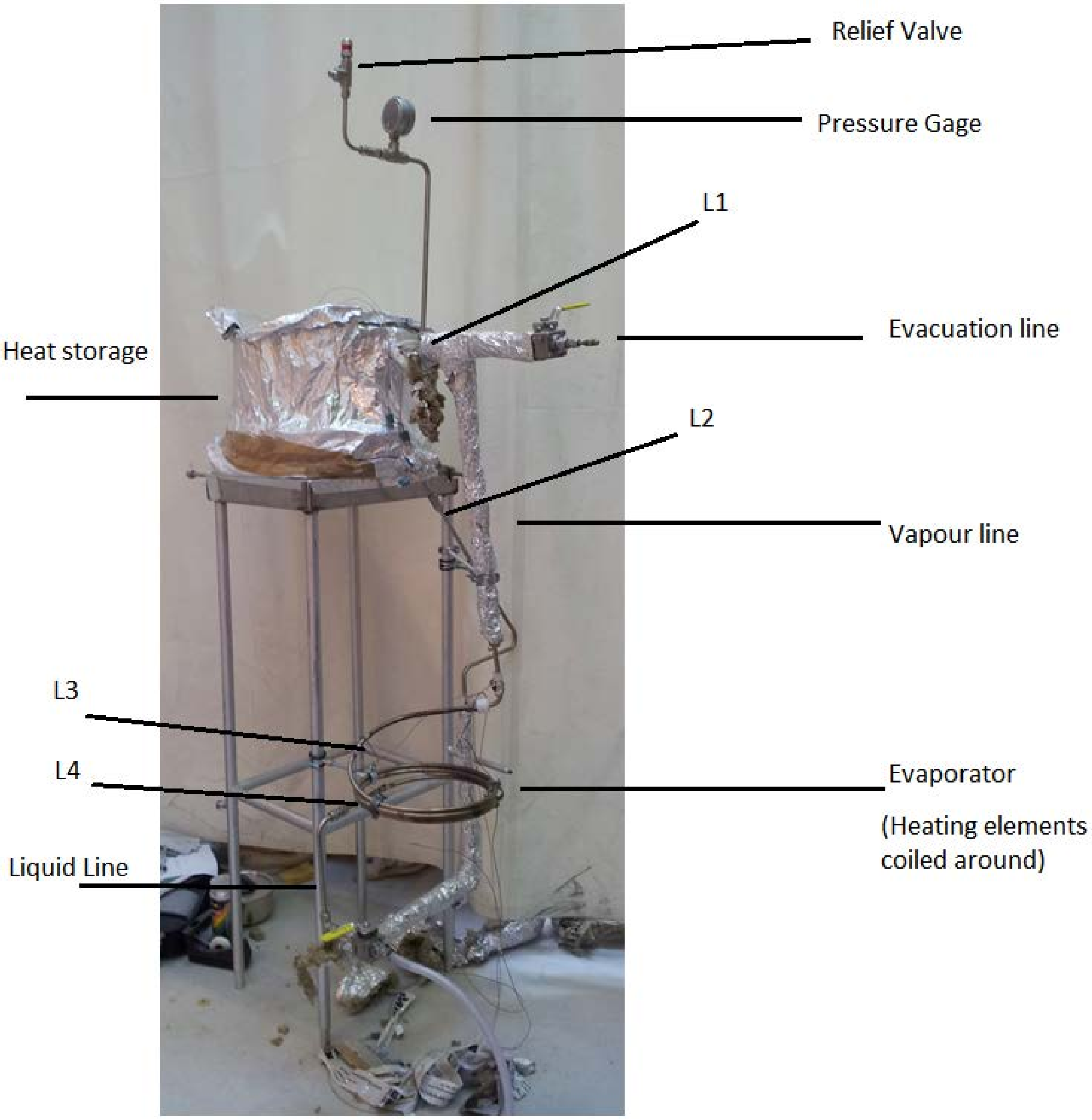
Dato

______________________ ______________________

Signert

______________________ ______________________

Photo and Description of the Setup



The system is flushed with water. When the heating elements coiled around the evaporator is turned on, the pressure gage is monitored, and excess steam is released until desired pressure (40 bars) is reached. The effect of the heating elements is controlled by a heat control element, and in addition, the temperature of the coil and the inlet and exit to the storage also is monitored. Thermocouples are also placed right before and after the coil.

1385624150

TRAINOR

Certificate

of core competence awarded September 28th 2011 to

Catharina Hoff

On successfully completing and passing the interactive course

NTNU-SINTEF - Health, Safety & Environment in the laboratories

The training was performed in accordance to ISO 9001
with relevant procedures, regulations and standards from IEC/CENELEC/NEK/DSB/NEMKO
The course is valid until 2014-09-28

Course specifics found on seperate appendix - ref 1385624150, www.trainor.no

Ranveig M. Eldevik
Ranveig Morberg Eldevik
Course manager

Terje Gravdal
Terje Gravdal
Managing Director

Trainor AS • Prestegaten 3-5 • Postboks 554 Sentrum • NO-3101 Tønsberg • t +47 33 37 89 00 • f +47 33 37 89 01 • post@trainor.no • www.trainor.no

1385624150

APPENDIX

NTNU-SINTEF - Health, Safety & Environment in the laboratories

Course objective

Provide an introduction to common HSE rules that apply to laboratories that are used by NTNU Department of Energy and Process Engineering, Department of Electric Power Engineering, and Sintef Energy Research. This applies to the Thermal Engineering Laboratory, the Electric Power Technology Laboratory, the Fluid Engineering Laboratory and the Waterpower Laboratory. This course provides an overview of the general rules applicable in the laboratories. In addition to this course you must have a guided tour of the laboratory you wish to have access to.

Course contents

: Presentation of laboratory and workshop handbook,
: Access control
: Room cards
: Preparedness for injuries
: Gas leaks or fire
: Procedures for risk assessment
: Apparatus and experiment-in-progress cards
: The report system Early Warning
: Special rules for experiments with electricity
: Handling of gases and chemicals
: Pressurised vessels and rigs
: Laser and other radiation sources
: Waste disposal
: Field work
: Required additional training beyond the scope of this course

Course arrangement

The training was performed in accordance to the procedures of Trainor Training Center, which is based on ISO 9001 and procedures, regulations and standards given by

NEK	**The Norwegian Electrotechnical Committee** is responsible for standardisation in the electrotechnical area, and is the Norwegian member of CENELEC and IEC
DSB	**Directorate for Civil Protection and Emergency Planning.** The Directorate is responsible for monitoring fire and electrical safety, hazardous substances and product safety. It is under the jurisdiction of the Ministry of Justice and Police
OLF	**The Norwegian Oil Industry Association** is a professional body and employer's association for oil and supplier companies engaged in the field of exploration and production of oil and gas on the Norwegian Continental Shelf.
Nemko	**Nemko is accredited as test laboratory** according to the standard EN ISO/IEC 17025, and as certification body according to EN 45011. Nemko is Notified Certification Body according to EU Directives such as **ATEX, LVD EMD R&TTE etc.** Nemko is approved test laboratory and certification body within the IECEx Scheme.
Ptil	**Petroleum Safety Authority Norway** are the regulatory authority for technical and operational safety, including emergency preparedness, and for the working environment.

Trainor AS are approved and certified by the Achilles Joint Qualification System as a supplier to the oil and gas industry, and by Sellihca as a supplier to the Nordic power distribution sector.

DURATHERM
EXTENDED LIFE FLUIDS

P.O. Box 563, Lewiston, NY 14092
Ph: 800-446-4910 / Fax: 905-984-6684
Web: www.heat-transfer-fluid.com

Material Safety Data Sheet

according to 1907/2006 EC, Article 31

Duratherm FG

High Temperature Heat Transfer Fluid

Revision Date: 01/2011
Revision #: 1

1. IDENTIFICATION OF THE SUBSTANCE / PREPARATION AND THE COMPANY

Product Name	Duratherm FG - High Temperature Heat Transfer Fluid
Company Name	Duratherm Extended Life Fluids P.O. Box 563, Lewiston, NY 14092
Telephone	800-446-4910
Fax	905-984-6684
Website	www.heat-transfer-fluid.com
Emergency telephone number	800-446-4910

2. HAZARDS IDENTIFICATION

Physical Sate	Viscous Liquid
Odor	Very slight hydrocarbon odor
HMIS (Canada)	Not controlled under HMIS (Canada)
OSHA/HCS Status	This material is not considered hazardous by OSHA Hazard Communication Standard (29 CFR 1910.1200. Refer to and retain this MSDS for safety and handling information
Emergency Overview	No specific hazard
Routes of Enter	Dermal contact, eye contact, inhalation, ingestion
Potential Acute Health Effect	
Inhalation	No known significant effects or critical hazards
Ingestion	No known significant effects or critical hazards
Skin	No known significant effects or critical hazards
Eyes	No known significant effects or critical hazards
Potential Chronic Health Effect	
Chronic Effects	No known significant effects or critical hazards
Carcinogenicity	Not listed as a carcinogenic by OSHA, NTP, or IARC
Mutagenicity	No known significant effects or critical hazards
Teratogenicity	No known significant effects or critical hazards
Development Effects	No known significant effects or critical hazards
Fertility Effects	No known significant effects or critical hazards
Medical Conditions Aggravated by Overexposure	Repeated or prolonged exposure with spray or mist may produce chronic eye irritation and severe skin irritation. Repeated skin exposure can produce local skin destruction or dermatitis

3. COMPOSITION / INFORMATION ON INGREDIENTS

Description	This product does not contain any substances classified as hazardous to health

4. FIRST AID MEASURES

Skin contact	Wash affected areas thoroughly with soap and water. Wash contaminated clothing before reuse. See medical attention if irritation or symptoms persist
Eye contact	Flush with clean, lukewarm water (low pressure) occasionally lifting eyelids. Seek physician assessment if eyes are inflamed.
Inhalation	Avoid breathing oil mists. Remove to fresh air. Give artificial respiration if not breathing. Oxygen may be given by qualified personnel if breathing is difficult. Get medical attention.
Ingestion	Do not induce vomiting. Force fluid. Has laxative effect.

5. FIRE FIGHTING MEASURES

Extinguishing media	For small fires: Carbon dioxide (CO2) Dry chemical. Foam. Water spray.
Fire hazards	LOW FIRE HAZARD - Do not cut, drill, or weld empty containers
Protective equipment	Wear suitable respiratory equipment when necessary.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions	Ensure adequate ventilation of the working area.
Environmental precautions	Do not allow product to enter drains. Prevent further spillage if safe.
Clean up method	Absorb with inert, absorbent material. Transfer to suitable, labelled containers for disposal. Clean spillage area thoroughly with plenty of water.

7. HANDLING AND STORAGE

Handling	Avoid contact with eyes and skin. Ensure adequate ventilation of the working area. Adopt best Manual Handling considerations when handling, carrying and dispensing.
Storage	Keep in a cool, dry, well ventilated area. Keep containers tightly closed. Store in correctly labelled containers. Store at a maximum of 40°C.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Engineering measures	Ensure adequate ventilation of the working area.
Occupational exposure contd.	Keep away from food, drink and animal feed.
Respiratory protection	Normally not necessary. If mist is generated, wear approved organic vapor respirator suitable for oil mist areas with sufficient oxygen.
Skin/Hand Protection	Normally none required, for direct contact of more than 2 hours, PVC, Viton, or Nitrile gloves are recommended.
Eye protection	Normally none required, chemical goggles if splashing is likely or high pressure systems are used.
Ventilation	General ventilation
Exposure limits	Practically non-toxic ACGIH TL (United States). Notes: (Oil Mist) TWA: 5mg/m^{3,}, 8 hour(s) / STEL: 10 mg/m^{3} 15 minute(s)
Protective equipment	Protect clothing from contact with the product.

9. PHYSICAL AND CHEMICAL PROPERTIES

Description	Liquid
Color	Slight yellow to brown tint
Odor	None
Boiling point	>400^{O}F (>204^{o}C)
Flash point	>440^{o}F (>226^{o}C)
Vapor pressure	<0.01 mmHg @ 20^{O}C
Specific Gravity	0.79 - 0.85
Volatilies, % Volume	0%
Solubility in water	Insoluble
Evaporation rate	Nil
Viscosity @40 ^{o}C (cSt)	Varies depending on grade

Revision #: 1

10. STABILITY AND REACTIVITY

Stability	Stable under normal conditions.
Hazardous polymerization	Will not occur
Materials to avoid	Strong oxidizing agents.
Decomposition products	Analogous compounds evolve, carbon monoxide, carbon dioxide, and other undefined fragments.

11. TOXICOLOGICAL INFORMATION

General Information	Acute Toxicity (LD_{50}): LD_{50} (oral, rabbit):> 5000 mg/kg LD_{50} (dermal, rat): > 2000 mg/kg LD_{50} (inhalative, rat):> 2500 mg/kg/4h
Other	In case of inhalation: no data available **Skin contact:** no data available **Eye contact:** no data available **Ingestion:** no data available **Irritation:** skin and eye irritating **Sensitization:** no sensitizing effects known **Subacute toxicity:** Intensive or prolonged exposition. Repeated or prolonged exposure with spray or mist may product chronic eye irritation and severe skin irritation. Repeated skin exposure can produce local skin destruction or dermatitis. **Chronic Toxicity:** not available **Subchronic Exposure:** not available **Specific symptoms observed in animal studies:** no data available **CMR Effects:** **Carcinogenity:** no data available **Reproductive toxicity:** no data available **Mutagenicity:** no data available **Summarized evaluation of the CMR properties:** not available

12. ECOLOGICAL INFORMATION

Ecological Information	Do not allow to enter sewer/soil/surface or ground water **Ecological Information:** LC50 (Rainbow Trout): > 100 000 MG/1/96 h **Mobility:** no data available **Persistence and biodegradation:** not readily biodegradable **Bioaccumulation potential:** no data available **Results of PBT assessments:** no data available **Other adverse side effects:** no data available

13. DISPOSAL CONSIDERATIONS

General information	Used product must be disposed of in accordance with Federal, State, and Local environmental control regulations. Incineration is preferred. DO NOT HEAT OF CUT EMPTY CONTAINER WITH ELECTRIC OR GAS TORCH.

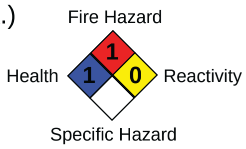
14. TRANSPORTATION INFORMATION

Technical Name	Paraffinic Hydrocarbon
D.O.T. hazard class	Not regulated
U.N. N.A. #	Not regulated
Product label	Duratherm FG - Duratherm High Temperature Heat Transfer Fluid

Revision #: 1

15. REGULATORY INFORMATION

EU Risk phrases	NSH - No Significant Hazard This product is not classified according to EU regulations
HMIS	Not controlled under HMIS (Canada)
EC Classification	Not classified as dangerous under EC classifications
EC Symbols	Not classified
OSHA status	Non Hazardous under 29 CFR 1910.1200
TSCA status	N/A
RCRA status	If discarded in its purchased form this product would not be a hazardous waste either by listing or characteristic. However it is the responsibility of the product user to determine at the time of disposal, whether the material being disposed of is a hazardous waste (40 CFR 261.20-24).
Other Information	Environmental Protection Act 1990 (as amended). Health and Safety at Work Act 1974. Consumers Protection Act 1987. Control of Pollution Act 1974. Environmental Act 1995. Factories Act 1961. Carriage of Dangerous Goods by Road and Rail (Classification, Packaging and Labelling) Regulations. Chemicals (Hazard Information and Packaging for Supply) Regulations 2002. Control of Substances Hazardous to Health Regulations 1994 (as amended). Road Traffic (Carriage of Dangerous Substances in Packages) Regulations. Merchant Shipping (Dangerous Goods and Marine Pollutants) Regulations. Road Traffic (Carriage of Dangerous Substances in Road Tankers in Tank Containers) Regulations. Road Traffic (Training of Drivers of Vehicles Carrying Dangerous Goods) Regulations. Reporting of Injuries, Diseases and Dangerous. Other Regulations. Health and Safety (First Aid) Regulations 1981. Personal Protective Equipment (EC Directive) Regulations 1992. Personal Protective Equipment at Work Regulations 1992.

OSHA status	Non Hazardous under 29 CFR 1910.1200
TSCA status	N/A
RCRA status	If discarded in its purchased form this product would not be a hazardous waste either by listing or characteristic. However it is the responsibility of the product user to determine at the time of disposal, whether the material being disposed of is a hazardous waste (40 CFR 261.20-24).
HMIS hazard ratings	Health Hazard ① Fire Hazard ① Reactivity ⓪ Personal Protection Ⓑ NFPA (U.S.A.)  Rating 0= Insignificant, 1=Slight, 2=Moderate, 3= High, 4= Extreme

16. OTHER INFORMATION

Further information	This information is furnished without warranty, expressed or implied, except that it is accurate to the best knowledge of Duratherm Extended Life Fluids. The data on this sheet related only to the specific material designed herein. Duratherm Extended Life Fluids assumes no legal responsibility for the use or reliance upon these data.

HMS-DATABLAD

Sist endret: 11.09.2007 Internt nr: Erstatter dato: 18.02.2005

Kaliumnitrat

1. IDENTIFIKASJON AV KJEMIKALIET OG ANSVARLIG FORETAK ☐

HANDELSNAVN	Kaliumnitrat
KJEMISK NAVN	Kaliumnitrat, Kalisalpeter
BRUKSOMRÅDE	Laboratoriekjemikalie
FORMEL	KNO_3
Cas-nr.	7757-79-1
EC-nr.	231-818-8
Indeksnr.	---
Reg.Nr.	---

Artikkelnummer
K093

Nasjonal produsent/importør

Foretak	VWR International AS
Adresse	Postboks 45
Postnr./sted	NO-0901 OSLO
Land	N
E-post	ehs@se.vwr.com
Telefon	02290
Faks	22 90 00 40

Navn	**E-post**	**Tlf. (arb.)**	**Land**
Miljø & Sikkerhet			

Nødtelefonnummer	**Bistandstype**	**Åpningstider**
112	Politi	24 h
110	Brann	24 h
113	Med.nødhjelp	24 h

2. VIKTIGSTE FAREMOMENTER ☐

Oksiderende

BRANN OG EKSPLOSJON
KONTAKT MED BRENNBART MATERIALE KAN FORÅRSAKE BRANN.

3. OPPLYSNINGER OM KJEMISK SAMMENSETNING ☐

Nr.	Ingrediensnavn	Reg.Nr.	EC-nr.	Cas-nr.	Kons.	Merking
1	Kaliumnitrat	---	231-818-8	7757-79-1	> 97 %	O,R8

Tegnforklaring: T+=meget giftig, T=giftig, C=etsende, Xn=helseskadelig, Xi=irriterende E=eksplosiv, O=oksiderende, F+=ekstremt brannfarlig, F=meget brannfarlig, N=miljøskadelig, Kreft=kreftfremkallende, Mut=arvestoffskadelig, Rep=reproduksjonsskadelig, Kons.=konsentrasjon

INGREDIENSKOMMENTARER
Uorganisk stoff.

4. FØRSTEHJELPSTILTAK ☐

GENERELT
Vis dette HMS-datablad til legen.

INNÅNDING
Frisk luft, hvile og varme. Skyll nese, munn og svelg med vann. Oppsøk lege hvis ikke symptomene gir seg.

HUDKONTAKT
Ta av forurenset tøy. Skyll huden med mye vann.

ØYEKONTAKT
Skyll straks med vann i flere minutter. Hold øynene vidåpne. Kontakt lege.

SVELGING
Drikk mye vann. Ved inntak av större kvanta: Kontakt lege umiddelbart.

5. TILTAK VED BRANNSLUKKING ☐

EGNET BRANNSLUKKINGSMIDDEL
Slukkes med vann.

BRANN- OG EKSPLOSJONSFARE
Brannfarlig i kontakt med brennbare stoffer. Forurenset tøy utgjør brannrisiko. Ved oppvarming dannes nitrøse gasser.

PERSONLIG VERNEUTSTYR VED SLUKKING AV BRANN
Ved brann skal passende beskyttelsesklær og pusteapparat benyttes. Evakuer alt personell.

ANNEN INFORMASJON
Beholdere i nærheten av brann flyttes og/eller nedkjøles med vann. Slå ned giftige røyk-gasser med vann. Forhindre vann fra slukningsarbeidet å forurense overflate- og grunnvann.

6. TILTAK VED UTILSIKTET UTSLIPP ☐

SIKKERHETSTILTAK FOR Å BESKYTTE PERSONELL
Unngå støvdannelse. Benytt hensiktsmessig verneutstyr ihht seksjon 8.

SIKKERHETSTILTAK FOR Å BESKYTTE YTRE MILJØ

Forhindre utslipp til kloakk.

METODER FOR OPPRYDDING OG RENGJØRING

Feies forsiktig sammen og samles opp. Send til destruksjon. Skyll rent med store mengder vann.

7. HÅNDTERING OG OPPBEVARING ☐

HÅNDTERING

Produktet håndteres varsomt, som kjemikalier i allminnelighet. Benytt personlig verneutstyr iht. seksjon 8.

OPPBEVARING

Oksyderende stoff. Oppbevares separat. Oppbevares adskilt fra antennelseskilder og varme.

Oppevaring skal skje i samsvar med lov om brannfarlige varer, med forskrifter, samt regler og bestemmelser fastsatt av Direktoratet for Brann- og Eksplosjonvern.

8. EKSPONERINGSKONTROLL OG PERSONLIG VERNEUTSTYR ☐

BEGRENSNING OG KONTROLL AV EKSPONERING

Alt arbeide med farlige kjemikalier skal utføres i avtrekkskap eller i godt ventilert og godkjent rom. Mulighet for øyeskylling skal finnes på arbeidsplassen. Unngå håndtering som medfører støvdannelse. Vask hendene etter arbeid med produktet.Skift forurensede klær.

ÅNDEDRETTSVERN

Åndedrettsvern kan behøves ved forekomst av støv. Støvfilter P3 kan være nødvendig.

ØYEVERN

Ved risiko for direkte kontakt eller sprut skal øyebeskyttelse benyttes. Tettsittende vernebriller.

HÅNDVERN

Vernehansker skal benyttes ved fare for direkte kontakt og sprut.

Vernehanskene som brukes må være i hht spesifikasjonerne i EU direktiv 89/686/EEC og standarden EN374. Våres anbefalding gjelder kun for produktet nevnt i HMS-databladet og leverert av oss for laboratoriebruk. Anbefaldingen gjelder ikke ved oppløsning eller blanding med andre stoffer under betingelser som er forskjellige fra det. Vernehansker av følgende materiale har normalt ved romtemperatur gjemnnombruddstid mer enn 4 timer: Nitril.

ANNET HUDVERN ENN HÅNDVERN

Bruk egnede verneklær.

9. FYSISKE OG KJEMISKE EGENSKAPER ☐

Tilstandsform	Krystaller.
Farge	Fargeløs. Hvit.
Lukt	Luktfri.
Løselighet	Glyserol.

FYSISKE OG KJEMISKE PARAMETERE

Parameter	Verdi/enhet	Metode/referanse	Merknad
pH i løsning	5 - 7,5	(50 g/l H2O)	
Smeltepunkt	334 °C		
Dekomponeringstemp.	> 400 °C		
Tetthet	2,11 g/cm³		
Molvekt	101.11 g/mol		
Løselighet i vann	320 g/l (20 °C)		

ANNEN INFORMASJON
Andre opplysninger ikke tilgjengelige.

10. STABILITET OG REAKTIVITET ☐

STABILITET
Ingen opplysninger tilgjengelige.

MATERIALER SOM SKAL UNNGÅS
Brennbare stoffer. Metaller. Organiske forbindelser. Sulfider. Karbon.Fosfider. Fosfor. Svovel. Bor.
Riskio for eksplosjon med: Magnesium.

FARLIGE SPALTINGSPRODUKTER
Ved brann dannes: Nitrøse gasser.

11. OPPLYSNINGER OM HELSEFARE ☐

Akutte toksiske testresultater

Kaliumnitrat

Eksponeringsvei	Verdi/enhet	Art	Kilde
LD50(Oralt)	3750 mg/kg	Rat	

GENERELT
Andre skadelige egenskaper hos stoffet kan ikke utelukkes. Produktet skal håndteres med den største forsiktighet!!!

ØYEKONTAKT
Kan virke irriterende.

SVELGING
Kvalme. Brekninger. Diaré. Methemoglobinemi. Påvirker hjertet. Blodtrykksfall. Sirkulasjonsproblemer. Cyanose.

MUTAGENE EFFEKTER
Ikke mutagen i AMES-test.

12. MILJØOPPLYSNINGER ☐

AKVATISK ØKOTOKSISITET

Kaliumnitrat

Test	Eksp.tid	Verdi/enhet	Art	Kilde
Akutt fisk(LC50)	96h	1378 mg/l	P.reticulata	
Akutt Daphnia(EC50)	48h	490 mg/l	Daphnia magna	

PERSISTENS OG NEDBRYTBARHET
Kriterier for biologisk nedbrytbarhet er ikke overførbart til uorganiske forbindelser.

ANNEN INFORMASJON

Nitrationer bidrar till eutrofiering av vassdrag. Unngå utslipp i drikkevannsreservoar, avløp eller på marken!!

13. FJERNING AV KJEMIKALIEAVFALL ☐

GENERELT
Klassifisert som farlig avfall. Destrueres i henhold til lokale forskrifter, eller kontakt et godkjent deponeringssted. Spørsmål om almenn kjemisk avfallshåndtering kan som regel besvares av kommunen eller NORSAS.

AVFALLSGRUPPER
06 04 99 (EWC) Annat uorg. avfall

Avfallsstoffnummer: 7091 Uorganiske salter og annet fast stoff

14. OPPLYSNINGER OM TRANSPORT ☐

Kjemikaliet er klassifisert som farlig gods: ☒ Ja ☐ Nei ☐ Ikke vurdert

UN-nr: 1486

VARENAVN OG BESKRIVELSE:
POTASSIUM NITRATE

ADR/RID (veitransport/jernbanetransport)

Klasse:	5.1	**Forpakningsgr:**	III
Fareseddel:	5.1		

IMDG (sjøtransport)

Klasse:	5.1	**Forpakningsgr:**	III
Sub. risiko:		**EMS:**	F-A,S-Q

IATA (lufttransport)

Klasse:	5.1	**Forpakningsgr:**	III

15. OPPLYSNINGER OM LOVER OG FORSKRIFTER ☐

Oksiderende

EF-etikett ☒ Nei ☐ Ja ☐ Ikke vurdert

SAMMENSETNING
Kaliumnitrat (> 97 %)

R-SETNINGER
R8 - Brannfarlig ved kontakt med brennbare stoffer.

S-SETNINGER
S16 Holdes vekk fra antennelseskilder - Røyking forbudt.
S41 Unngå innåndning av røyken som oppstår ved brann eller eksplosjon.

REFERANSER
Merck Safety Data Sheet

ANNEN INFORMASJON
Produktet og/eller dets ingredienser omfattes ikke av merkingsendringerne i 29 atp.

16. ANDRE OPPLYSNINGER AV BETYDNING FOR HMS ☐

LEVERANDØRENS ANMERKNINGER

Opplysningene i dette databladet baseres på vår nåværende kunnskap og er ment å beskrive produktet fra et sikkerhetsaspekt. Databladet er ikke å betrakte som en kjemisk spesifikasjon. Det er derfor kundens ansvar å kontrollere att produktet er egnet til kundens spesifike bruk.

RÅD OM OPPLÆRING

VWR International Norge forutsetter at personer som håndterer produktet har tilegnet seg de kunnskaper og ferdigheter som kreves for laboratoriearbeide.

UTGITT: 07.04.1995

REVISJONSOVERSIKT

Versjon	Rev.dato	Ansvarlig	Endringer
0.0.1	18.02.2005	Michaela Sandvik	Generell oppdatering
0.0.2	11.09.2007	Karin Edvinsson	Generell oppdatering

HMS-DATABLAD

Sist endret: 17.07.2007 Internt nr: Erstatter dato: 24.08.2006

Natriumnitrat

1. IDENTIFIKASJON AV KJEMIKALIET OG ANSVARLIG FORETAK ☐

HANDELSNAVN	Natriumnitrat
KJEMISK NAVN	Natriumnitrat
BRUKSOMRÅDE	Laboratoriekjemikalie
FORMEL	$NaNO_3$
Cas-nr.	7631-99-4
EC-nr.	231-554-3
Indeksnr.	---

Artikkelnummer
N127

Deklarasjonsnummer (PRN-nr.)
050452(NO)

Nasjonal produsent/importør

Foretak	VWR International AS
Adresse	Postboks 45
Postnr./sted	NO-0901 OSLO
Land	N
E-post	ehs@se.vwr.com
Telefon	02290
Faks	22 90 00 40

Navn	**E-post**	**Tlf. (arb.)**	**Land**
Miljø & Sikkerhet			

Nødtelefonnummer	**Bistandstype**	**Åpningstider**
112	Politi	24 h
110	Brann	24 h
113	Med.nødhjelp	24 h

2. VIKTIGSTE FAREMOMENTER ☐


Oksiderende


Helseskadelig

GENERELT
BRANNFARLIG I KONTAKT MED BRENNBARE STOFFER. FARLIG VED SVELGING.

Kan danne giftige gasser ved forbrenning. NOx.

3. OPPLYSNINGER OM KJEMISK SAMMENSETNING ☐

Nr.	Ingrediensnavn	Reg.Nr.	EC-nr.	Cas-nr.	Kons.	Merking
1	Natriumnitrat		251-554-3	7631-99-4	> 98 %	Xn,O,R22 - R8

Tegnforklaring: T+=meget giftig, T=giftig, C=etsende, Xn=helseskadelig, Xi=irriterende E=eksplosiv, O=oksiderende, F+=ekstremt brannfarlig, F=meget brannfarlig, N=miljøskadelig, Kreft=kreftfremkallende, Mut=arvestoffskadelig, Rep=reproduksjonsskadelig, Kons.=konsentrasjon

INGREDIENSKOMMENTARER
Uorganisk stoff.

4. FØRSTEHJELPSTILTAK ☐

INNÅNDING
Frisk luft. Skyll nese, munn og svelg med vann. Kontakt lege ved vedvarende symptomer.

HUDKONTAKT
Ta av forurenset tøy. Skyll huden med mye vann.

ØYEKONTAKT
Skyll straks øyet med mye vann. Løft øyelokket. Kontakt lege hvis irritasjon vedvarer.

SVELGING
Drikk mye vann. Forsøk å fremkalle brekning. Kontakt lege.

MEDISINSK INFORMASJON
Vis datablad eller etikett til legen.

5. TILTAK VED BRANNSLUKKING ☐

EGNET BRANNSLUKKINGSMIDDEL
Valg av slukningsmiddel gjøres på grunnlag av hva som lagres i nærheten.

BRANN- OG EKSPLOSJONSFARE
Brannfarlig i kontakt med brennbare stoffer. Stoffet er ikke brannfarlig, men er p.g.a. oksygenavgivning brannfremmende. Ved oppvarming dannes nitrøse gasser.

PERSONLIG VERNEUTSTYR VED SLUKKING AV BRANN
Ved brann skal passende beskyttelsesklær og pusteapparat benyttes. Evakuer alt personell.

ANNEN INFORMASJON
Beholdere i nærheten av brann flyttes og/eller nedkjøles med vann. Forhindre vann fra slukningsarbeidet å forurense overflate- og grunnvann. Slå ned giftige røyk-gasser med vann.

6. TILTAK VED UTILSIKTET UTSLIPP ☐

SIKKERHETSTILTAK FOR Å BESKYTTE PERSONELL
Unngå støvdannelse. Unngå innåndning av støv. Unngå kontakt med stoffet. Benytt hensiktsmessig verneutstyr ihht seksjon 8.

SIKKERHETSTILTAK FOR Å BESKYTTE YTRE MILJØ

Søl må ikke slippes ut i kloakk eller vassdrag. Saneringsavfall tas hånd om som farlig avfall.

METODER FOR OPPRYDDING OG RENGJØRING

Feies forsiktig sammen og samles opp. Skyll rent med store mengder vann.

7. HÅNDTERING OG OPPBEVARING ☐

HÅNDTERING

Produktet håndteres varsomt, som kjemikalier i allminnelighet.

OPPBEVARING

Oppbevares godt lukket. Tørt. Oppbevares adskilt fra antennelseskilder og varme. Oppbevares adskilt fra brennbare stoffer.

Oppevaring skal skje i samsvar med lov om brannfarlige varer, med forskrifter, samt regler og bestemmelser fastsatt av Direktoratet for Brann- og Eksplosjonvern.

8. EKSPONERINGSKONTROLL OG PERSONLIG VERNEUTSTYR ☐

BEGRENSNING OG KONTROLL AV EKSPONERING

Alt arbeide med farlige kjemikalier skal utføres i avtrekkskap eller i godt ventilert og godkjent rom. Mulighet for øyeskylling skal finnes på arbeidsplassen. Unngå håndtering som medfører støvdannelse. Fjern alle antennelseskilder.

ÅNDEDRETTSVERN

Støvfilter P3 kan være nødvendig.

ØYEVERN

Ved risiko for direkte kontakt eller sprut skal beskyttelsesbriller eller ansiktsbeskyttelse benyttes.

HÅNDVERN

Vernehansker bør benyttes ved direkte kontakt og sprut.

Vernehanskene som brukes må være i hht spesifikasjonerne i EU direktiv 89/686/EEC og standarden EN374. Våres anbefalding gjelder kun for produktet nevnt i HMS-databladet og leverert av oss for laboratoriebruk. Anbefaldingen gjelder ikke ved oppløsning eller blanding med andre stoffer under betingelser som er forskjellige fra det. Vernehansker av følgende materiale har normalt ved romtemperatur gjemnnombruddstid mer enn 4 timer: nitrilgummi.

ANNET HUDVERN ENN HÅNDVERN

Ved risiko for direktekontakt eller sprut bør verneklær benyttes. Bruk av barrierekrem (før arbeid med produktet) anbefales.

9. FYSISKE OG KJEMISKE EGENSKAPER ☐

Tilstandsform	Krystaller eller pulver.
Farge	Hvitaktig.
Lukt	Ingen eller ukarakteristisk lukt.
Løselighet	Etanol. Metanol.
Løselighet i vann	874 g/l (20 °C)

FYSISKE OG KJEMISKE PARAMETERE

Parameter	Verdi/enhet	Metode/referanse	Merknad
pH i løsning	5,5 - 8	50 g/l H_2O, 20 °C	
Smeltepunkt	308 °C		
Kokepunkt	400 °C		
Dekomponeringstemp.	> 380 °C		
Tetthet	2,26 g/cm³	20 °C	
Molvekt	84.99 g/mol		
log P(ow):	-3,8		

ANNEN INFORMASJON
Andre opplysninger ikke tilgjengelige.

10. STABILITET OG REAKTIVITET ☐

STABILITET
Hygroskopisk. Unngå oppvarming.

MATERIALER SOM SKAL UNNGÅS
Unngå kontakt med: Oksiderbare stoff. Cyanider. Anhydrider. Metallpulver. Alkalimetaller. Svovel. med mere.

FARLIGE SPALTINGSPRODUKTER
Ved forbrenning dannes: Nitrøse gasser (NOx).

11. OPPLYSNINGER OM HELSEFARE ☐

Akutte toksiske testresultater

Natriumnitrat

Eksponeringsvei	Verdi/enhet	Art	Kilde
LD50(Oralt)	1267 mg/kg	rat	

GENERELT
Andre skadelige egenskaper hos stoffet kan ikke utelukkes. Produktet skal håndteres med den største forsiktighet!!!

INNÅNDING
Kan irritere luftveiene.

HUDKONTAKT
Kan forårsake irritasjon/svie.

ØYEKONTAKT
Kan virke lett irriterende.

SVELGING
Farlig ved svelging. Irritasjon på slimhinnene i spiserøret. Kvalme. Brekninger. Diaré. Magesmerter. Absorpsjon av toksiske kvantiteter kan gi: Methemoglobinemi, påvirkning på hjerte, blodtrykksfall, pustevansker, kramper. Cyanose.

ANNEN TOKS. INFORMASJON
Øyeirritasjonstest (kanin):Mild øyeirritasjon.

12. MILJØOPPLYSNINGER ☐

ØKOTOKSISITET
Giftighet for fisk: : Ictalurus punctatus LC50 (96h) : 6200 mg/l
Giftighet for krepsdyr: Daphnia magna EC50 (48h): 3581 mg/l

PERSISTENS OG NEDBRYTBARHET
Kriterier for biologisk nedbrytbarhet er ikke overførbart til uorganiske forbindelser.

BIOAKKUMULERINGSPOTENSIAL
Forventes ikke å bioakkumulere. log P(ow) < 1

ANDRE SKADEVIRKNINGER
Kan bidra til eutrofiering (overgjødsling) av vannmiljøet. Fare for drikkevannskilder.
Fisk LC50:>500 mg/l

ANNEN INFORMASJON
Unngå utslipp i drikkevannsreservoar, avløp eller på marken!!

13. FJERNING AV KJEMIKALIEAVFALL ☐

GENERELT
Klassifisert som farlig avfall. Spørsmål om almenn kjemisk avfallshåndtering kan som regel besvares av kommunen eller NORSAS.

AVFALLSGRUPPER
Avfallsstoffnr. 7091 Uorganiske salter og annet fast stoff
Forslag til EAL-kode(r): 06 04 99 (EWC) Annat uorg. avfall

14. OPPLYSNINGER OM TRANSPORT ☐

Kjemikaliet er klassifisert som farlig gods: ☒ Ja ☐ Nei ☐ Ikke vurdert

UN-nr: 1498

VARENAVN OG BESKRIVELSE:
SODIUM NITRATE

ADR/RID (veitransport/jernbanetransport)

Klasse:	5.1	**Forpakningsgr:**	III
Fareseddel:	5.1		

IMDG (sjøtransport)

Klasse:	5.1	**Forpakningsgr:**	III
Sub. risiko:		**EMS:**	F-A,S-Q

IATA (lufttransport)

Klasse:	5.1	**Forpakningsgr:**	III
Etikett:	5.1		

15. OPPLYSNINGER OM LOVER OG FORSKRIFTER ☐

Oksiderende

Helseskadelig

EF-etikett ☒ Nei ☐ Ja ☐ Ikke vurdert

SAMMENSETNING

Natriumnitrat (> 98 %)

R-SETNINGER

Nr.	**R-setningstekst**
R8	Brannfarlig ved kontakt med brennbare stoffer.
R22	Farlig ved svelging.

S-SETNINGER

S22 Unngå innånding av støv.
S41 Unngå innåndning av røyken som oppstår ved brann eller eksplosjon.

REFERANSER

Merck Safety Data Sheet.
Merkingsendring fra Merck.

ANNEN INFORMASJON

Produktet og/eller dets ingredienser omfattes ikke av merkingsendringerne i 29 atp.

16. ANDRE OPPLYSNINGER AV BETYDNING FOR HMS ☐

LEVERANDØRENS ANMERKNINGER

Opplysningene i dette databladet baseres på vår nåværende kunnskap og er ment å beskrive produktet fra et sikkerhetsaspekt. Databladet er ikke å betrakte som en kjemisk spesifikasjon. Det er derfor kundens ansvar å kontrollere att produktet er egnet til kundens spesifike bruk.

RÅD OM OPPLÆRING

VWR International Norge forutsetter at personer som håndterer produktet har tilegnet seg de kunnskaper og ferdigheter som kreves for laboratoriearbeide.

UTGITT: 17.08.1999

REVISJONSOVERSIKT

Versjon	Rev.dato	Ansvarlig	Endringer
0.0.1	28.03.2003	PISE	Generell oppdatering
0.0.2	24.08.2006	Siri Lindström	Generell oppdatering
0.0.3	18.07.2007	Laura Hyötylä	Endret merking

SIKKERHETSDATABLAD

Sist endret: 22/06/2008 Internt nr: 69792 Erstatter dato:

Pyrogel ® XT

1. IDENTIFIKASJON AV STOFFET/STOFFBLANDINGEN OG SELSKAPET/FORETAKET ☐

☐	Godkjent for bruk	☐	Kontrollert iht gjeldende regelverk (2005)
☐	Godkjent for lab.bruk	☐	
☐	Godkjent av Fellesdatabasen	☐	

HANDELSNAVN	Pyrogel ® XT
SYNONYMER	Silica aerogel materials
BRUKSOMRÅDE	Isolasjonsmateriale.

Nasjonal produsent/importør

Foretak	Aspen Aerogels, Inc.
Adresse	30 Forbes Road
Postnr./sted	MA 01532 Northborough
Land	USA
Telefon	+1 (508) 261-1111

Nødtelefonnummer	**Bistandstype**	**Åpningstider**
+47 22 59 13 00	Giftinformasjonen	Døgnåpen

2. FAREIDENTIFIKASJON ☐

GENERELT

Produktet er ikke klassfisert som farlig.

3. SAMMENSETNING/OPPLYSNINGER OM BESTANDDELER ☐

Nr.	Ingrediensnavn	Reg.Nr.	EC-nr.	Cas-nr.	Kons.	R-liste	Merking
1	Trietoksymetylsilan-tetraetoksysilan copolymer			88029-70-3	42 - 52 %		
2	Glassfiber			65997-17-3	40 - 50 %		
3	titandioksid		236-675-5	13463-67-7	4 - 6 %		Ikke merkepliktig
4	Aluminium trihydrat			21645-51-2	2 - 4 %		

Tegnforklaring: T+=meget giftig, T=giftig, C=etsende, Xn=helseskadelig, Xi=irriterende E=eksplosiv, O=oksiderende, F+=ekstremt brannfarlig, F=meget brannfarlig, N=miljøskadelig, Kreft=kreftfremkallende, Mut=arvestoffskadelig, Rep=reproduksjonsskadelig, Kons.=konsentrasjon

4. FØRSTEHJELPSTILTAK ☐

INNÅNDING

Flytt til frisk luft. Drikk vann for å rense halsen og snyt nesen for å fjerne støv. Oppsøk lege ved illebefinnende.

HUDKONTAKT

Vask huden grundig med såpe og store mengder vann. Fjern forurensede klær og sko. Vask klær før de brukes på nytt. Oppsøk lege ved symptomer.

ØYEKONTAKT

Skyll straks med mye vann i flere minutter (hold øyenlokk utbrettet, ta av eventuelle kontaktlinser). Ved vedvarende irritasjon, kontakt lege.

SVELGING

Produktet vil passere normalt gjennom kroppen.

5. BRANNSLUKKINGSTILTAK ☐

EGNET BRANNSLUKKINGSMIDDEL

Slukningsmiddel velges med hensyn til omgivende brann.

BRANN- OG EKSPLOSJONSFARE

Produktet er et meget effektivt isolasjonsmateriale. Ruller av produktet kan isolere varme i indre lag og føre til retenning.

Farlige forbrenningsprodukter: Karbonmonoksid, karbondioksid og små mengder av ukjente produkter.

PERSONLIG VERNEUTSTYR VED SLUKKING AV BRANN

Brannpersonell bør benytte full vernedrakt og friskluftsutstyr.

6. TILTAK VED UTILSIKTEDE UTSLIPP ☐

SIKKERHETSTILTAK FOR Å BESKYTTE PERSONELL

Unngå støvdannelse. Sørg for tilstrekkelig ventilasjon. Bruk personlig verneutstyr.

SIKKERHETSTILTAK FOR Å BESKYTTE YTRE MILJØ

Produktet er ikke løselig. Unngå at produktet kommer i overflatevann eller kloakksystem.

METODER FOR OPPRYDDING OG RENGJØRING

Samles i passende emballasje for avhending. Støvsuging med passende filter anbefales. Unngå støvdannelse.

7. HÅNDTERING OG LAGRING ☐

HÅNDTERING

Genererer støv under håndtering. Sørg for tilstrekkelig ventilasjon og punktavsug for å kontrollere støvmengden. Støv bør fjernes umiddelbart. Støvsuging med passende filter anbefales. Kosting vil være ineffektivt. Vann vil også være ineffektivt fordi aerogel er hydrofobisk.

OPPBEVARING

Oppbevares i originalemballasjen. Pakk ut produktet der det skal brukes for å minimere støvdannelse. Sørg for hurtig avhending av kassert produkt.

8. EKSPONERINGSKONTROLL/PERSONLIG BESKYTTELSE ☐

BEGRENSNING OG KONTROLL AV EKSPONERING

Punktavsug og god industriell hygiene er anbefalt for å kontrollere støv. Vask huden grundig etter håndtering av produktet. Vask klær som inneholder støv. Vask hender før måltider.

ÅNDEDRETTSVERN

Ved fare for støvdannelse; bruk støvmaske.

ØYEVERN

Bruk vernebriller for å forhindre støv i øynene.

HÅNDVERN

Silika aerogels er hydrofobiske og kan føre til uttørring og irritasjon av hud, øyne og slimhinner. På bakgrunn av dette bør hansker av nitril, latex eller annet ugjennomtrengelig materiale benyttes.

ANNET HUDVERN ENN HÅNDVERN

Heldekkende arbeidstøy er anbefalt.

ADMINISTRATIVE NORMER

Ingrediensnavn	Cas-nr.	Intervall	ppm	mg/m3	År	Anm.
sjenerende støv, respirabelt støv		8 timer		5,0	2007	
Glassfiber	65997-17-3	8 timer		5,0	2007	
titandioksid	13463-67-7	8 timer		5,0	2007	
sjenerende støv, totalstøv		8 timer		10,0	2007	

9. FYSISKE OG KJEMISKE EGENSKAPER ☐

Tilstandsform	fast i teppeform
Farge	gul
Lukt	lett ammoniakk
Løselighet	Oppløselig i: uløselig

10. STABILITET OG REAKTIVITET ☐

STABILITET

Stabil under normale forhold.

FORHOLD SOM SKAL UNNGÅS

Forlenget eksponering for høy varme. Store støvdannelser.

MATERIALER SOM SKAL UNNGÅS

Reagerer med. Sterke syrer og baser.

FARLIGE SPALTINGSPRODUKTER

Ved vanlig bruk er det ikke forventet noen farlige spaltningsprodukter.
Farlig spaltning kan skje ved oksidasjon, oppvarming eller reaksjon med et annet materiale.

ANNEN INFORMASJON

Farlige forbrenningsprodukter:
Karbonmonoksid, karbondioksid og små mengder av ukjente produkter.

11. TOKSIKOLOGISKE OPPLYSNINGER ☐

INNÅNDING

Innånding av store mengder støv fra produktet kan føre til mekanisk irritasjon i pusterøret.

HUDKONTAKT

Hudkontakt kan forårsake tørrhet og mekanisk irritasjon.

ØYEKONTAKT

Kontakt med støv kan føre til tørrhet og mekanisk irritasjon på øyet.

SVELGING
Liten risiko for svelging.
Inntak av store mengder kan føre til mekanisk irritasjon og blokkeringer i spiserøret.

KREFT
I 2006 ble titandioksid reklassifisert av IARC til klasse 2B: "Mulig kreftfremkallende hos mennesker". Denne klassifiseringen var basert på ikke konkluderte bevis hos mennesker og fullstendige bevis i dyretester.

Syntetisk amorft silika er oppført som IARC klasse 3: Ikke klassifisert med hensyn til kreftfare hos mennesker.

AKUTTE OG KRONISKE SKADEVIRKNINGER
Støv fra produktet virker irriterende, og kan føre til forbigående kløe og rødhet i øyne og på hud.

Noen studier av lengre tids eksponering for amorft silika støv har påvist fare for nedsatt lungefunksjon.

Innånding av store mengder støv kan forverre eksisterende kroniske lungesykdommer som bronkitt, emfysem og astma. Hudkontakt kan forverre eksisterende dermatitt.

12. ØKOLOGISKE OPPLYSNINGER ☐

ØKOTOKSISITET
Syntetisk amorft silika:
Fisk LC50 > 10.000 mg/l (Brachydanio rerio: 96 timer) Metode OECD 203.
Daphnia magna EC50 > 10.000 mg/l (24 timer) Metode OECD 202.

Titandioksid:
Fisk LC50 > 1,000 mg/l (fathead minnow 96 timer).

Aluminium trihydrat:
Fisk LC50 > 10,000 mg/l.

MOBILITET
Ikke forventet da produktet er uløselig i vann.

PERSISTENS OG NEDBRYTBARHET
Ikke aktuelt for uorganisk materiale.

BIOAKKUMULERINGSPOTENSIAL
Ingen bioakkumulering forventet.

ANNEN INFORMASJON
Produktet er ikke klassifisert som miljøskadelig.

13. INSTRUKSER VED DISPONERING ☐

GENERELT
Avhendes i henhold til lokale myndighetskrav.

14. TRANSPORTOPPLYSNINGER ☐

Kjemikaliet er klassifisert som farlig gods: ☐ Ja ☒ Nei ☐ Ikke vurdert

ANNEN INFORMASJON
Produktet er ikke registrert som farlig gods.

15. REGELVERKSMESSIGE OPPLYSNINGER ☐

EF-etikett ☒ Nei ☐ Ja ☐ Ikke vurdert

REFERANSER
HMS-datablad fra produsent.
Forskrift om klassifisering, merking m.v. av farlige kjemikalier (Miljøverndepartementet, Arbeids- og administrasjonsdepartementet, 2005). Norsk stoffliste (Statens forurensningstilsyn, Olje- og energidepartementet, Direktoratet for arbeidstilsynet, Direktoratet for brann og eksplosjonsvern, 2005). Administrative normer for forurensning i arbeidsatmosfære (Arbeidstilsynet, 2007). Transport av farlig gods: ADR, RID, IMDG, IATA (2007).

EU-DIREKTIVER
HMS-DATABLAD i henhold til direktiv 2001/58/EU.

ANNEN INFORMASJON
Produktet er ikke klassfisert som farlig.

NFPA klassifisering:
Helse 1.
Brann 0.
Reaktivitet 0.

HMIS klassifisering:
Helse 1.
Brann 0.
Reaktivitet 0.

16. ANDRE OPPLYSNINGER ☐

LEVERANDØRENS ANMERKNINGER

Informasjonen i dette HMS-databladet er gitt i god tro men uten garantier. Informasjonen er ment å gi retningslinjer i forbindelse med helse, miljø og sikkerhet. Men det er brukerens ansvar å forsikre seg om at alle myndighetskrav etterfølges.

KVALITETSSIKRING AV SIKKERHETSDATABLAD

Oversatt og kvalitetssikret av Sensor Chemcontrol AS.

Sikkerhetsdatablad er utarbeidet av

Foretak	Sensor Chemcontrol AS

VURDERT DATO: