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Adsorption-Based Heat Storage for Cooking

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Natural Gas Technology
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Abstract

With the increasing effort to develop renewable technology, chemical heat storage has become more and more attractive. By using this type of storage, the heat dissipation issue is solved by storing the energy in the form of chemical potential. Moreover, with the motivation to find the cooking solution in rural African area without access to electricity, a study carried out to find a heat storage solution that can be used on a day and night.

The previous feasibility study has resulted in the salt-ammonia system as the potential candidate to be developed. As the first step, the laboratory prototype is designed and built. The simple prototype then used to demonstrate the charging and discharging concept of this system. Several discharging and charging tests with various circumstances is carried out, and the result has shown that the temperature difference between low-temperature salt and surrounding plays a vital role to control heat output in hot-temperature salt.

Even though the discharge output of 200°C has yet to be achieved, numerous indications during the tests suggest that the potential to achieve this goal is still there. As a continuation, a research idea to improve the process has been proposed. In addition, recommendations have been made to improve the measurement accuracy of the prototype.

Keywords: *chemical heat storage, salt-ammonia system, low-temperature salt, high-temperature salt*

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Chapter 1

Introduction

The introduction chapter consists of background and motivation, problem description, objectives, scope limitations, approach, and the report structure. In the background and motivation section, the reason to perform the research is elaborated. Next, the challenges and purposes of the study are explained in the problem description and objectives. The constraint consisted of technical and non-technical factor are also defined in this chapter. Finally, the approach of research and structure of the report provide the general idea of how the experiment carried out and reported.

1.1 Background and Motivation

Aside from the increasing movement to use renewable energy as a substitute of fossil energy due to climate change, there is another reason why it is important to keep moving with research and innovation in this type of energy. Even in the 21st century, there are still numerous underdeveloped areas without access to energy. By 2016, there is still 588 million population in Sub-Saharan Africa without electricity access. Consequently, the population without access to clean cooking is high, reaching 783 million by 2015 [3]. There are many households that still cook with solid fuel such as woods, coal, agricultural residue, dung, and kerosene. This practice possesses a high health risk due to the emission of pollutants inside the house [4].

Due to this issue, the initiative to study thermal energy storage arise. There are three types of thermal energy storage: sensible heat storage, latent heat storage, and chemical heat storage [10]. Among the three, the literature study of chemical heat storage which utilizes adsorption has been studied. The advantage of using this type of thermal energy storage is the fact that it has a higher energy density compared to other types and store heat in the form of chemical potential.

The previous literature study [7] focused on finding heat storage solution which able to generate heat at cooking temperature. The study resulted in salt-ammonia adsorption system as one of a potential candidate to be developed. Therefore, as the next step, demonstration of the concept is carried out by conducting experiments on the selected material.

1.2 Problem Description

With the idea to utilize heat from the adsorption process to generate and store heat sufficient for cooking, the literature study was performed on the semester project. The literature study resulted in several recommendations for adsorption materials [7]. As a continuation, the study involving adsorption-desorption experiment conducted with the primary purpose to prove the theory.

In the project, the adsorption and desorption process of the salt-ammonia system will be demonstrated to prove its theoretical concept. As a start, one high-temperature salt and one low-temperature salt are selected for the experiment. The construction of the laboratory prototype is carried out. While the main focus is to proof the adsorption and desorption process, the initial prototype needs to be compact, simple, and relatively self-sustained for the use in a remote area with limited to no access to electricity.

Due to the requirement above, the challenge might arise in the temperature and pressure prediction, as well as how the system will balance itself during the charging and discharging phase. These behaviors during the heat generation and storage phase will be studied. The experiments are performed with various system temperature and pressure as well as the amount of ammonia. The possibility to generate heat at cooking temperature up to 220°C will be tested. For the prototype design, the pressure rating of the rig is adjusted based on a worst-case scenario at high temperature, and low reaction rate. Ultimately, the evaluation from the experiment result will then be used to extend the work in the future.

1.3 Objectives

The main objectives of this project are:

1. To create the design of a small scale laboratory prototype of salt-ammonia adsorption system, taking into consideration the laboratory facilities at EPT (technical, economic, and safety).

2. To demonstrate the charging and discharging process of salt-ammonia system using the said prototype.

3. To evaluate the results and give recommendation for further work to improve the system and prototype.

1.4 Scope & Limitations

The main scope of the project is to create the design of a small laboratory scale salt-ammonia adsorption system and demonstrate the charging and discharging process using adsorption and desorption principle. The model of the rig has been developed from previous project semester and modified according to the purpose of the experiment. The research will focus on qualitative analysis of the test result as the primary parameter with supporting quantitative data from the digital temperature sensor and visual observation of pressure. The primary measurement tools are the thermocouple located inside the reaction cylinder. Meanwhile, pressure indicated in an analog pressure gauge and will be recorded manually. The focus of the study is to prove the adsorption-desorption cycle process of ammonia-salt concept.

1.5 Approach

The approach consists of a literature review, laboratory experiment, and discussion with the supervisor, co-supervisor, and laboratory engineer as below:

- Overview of the experiment setup from previous semester project and other literature, especially for salt-ammonia system
- Review of various high temperature and low-temperature salt pairs properties.
- Brainstorming the design idea for the simple equipment setup.
- Identify technical constraints regarding the equipment design.
- Building the equipment with the help of the laboratory engineer.
- Carrying out the experiment, followed by discussions during the process.
- Analyzing the result and discussion with the supervisor and co-supervisor.
- Formulating future suggestion based on the outcome.

Besides, the design idea for the adsorption-desorption rig was discussed during the risk assessment in the laboratory. Some modifications were made from the input during the discussion. The experiment consists of multiple repetitions with regards to temperature level, charging time, and the quantity of the reacting material to investigate the performance under different circumstances.

1.6 Structure of the Report

The report consists of six chapters and corresponds to the objectives. The structure of the chapters and their contents are as follow:

1. Chapter 2 provides the basic theory of the adsorption-desorption process in salt-ammonia system, the equilibrium pressure theory, list of potential salts, and the selection parameter for the salts.
2. Chapter 3 provides information about the equipment and materials setup. In this chapter, the development of rig design and explanation about individual components are presented. The reacting materials consist of salt and ammonia are also elaborated.
3. Chapter 4 provides the steps of experiment preparation and the procedures for the main experiments. The procedure used to produce a consistent process and result to be analyzed.
4. Chapter 5 presents the result of the experiment as well as the discussion related to the result. This chapter consists of the experiment result during ammonia filling and adsorption-desorption process.
5. Chapter 6 presents the conclusion of the experiment as well as the recommendation for the future study.

Chapter 2

Theory

The purposes of this chapter are to provide the basic theory of the adsorption-desorption process of salt-ammonia system as a potential thermochemical heat storage to generate heat in cooking range. This chapter contains the theoretical process of adsorption and desorption, the current system, equivalent salt mass, and the selection parameter for salt.

2.1 Thermochemical heat storage

Thermochemical heat storage is one of three thermal energy storage types. Compared to the sensible heat and latent heat storage, thermochemical heat storage posses the highest energy density. The thermochemical heat storage storing heat in the form of chemical potential. The reversible reaction used to store energy written as [5]:

$$AB + Heat <=> A + B \tag{2.1}$$

A and B represent adsorbent and adsorbate, respectively. The reaction between A and B formed a chemical bond and became AB. When the chemical bond is forming, an exothermic reaction occurs, and heat is released to the surrounding. Meanwhile, the reverse reaction where heat is subjected to AB will break the chemical bonds, resulting in an endothermic reaction. The exothermic and endothermic processes represent discharging and charging of heat.

Based on its mechanism, preventing the chemical bond from reforming will keep the energy stored for a very long time [10]. The ability to store energy without significant dissipation of energy is one of the motivations to study and develop thermochemical energy storage.

2.2 Salt-ammonia system

Based on previous literature study, salt-ammonia system posses a potential to generate heat at cooking temperature. The general reaction of the salt-ammonia system are below [10]:

$$MX * (n+m)G_{(s)} + \Delta H <=> MX * nG_{(s)} + mG_{(g)} \tag{2.2}$$

The MX represents metal salt as solid adsorbent, and G represents gas adsorbate, which is NH_3 in this system. The ΔH is reaction enthalpy representing heat. The m and n are reaction coefficients.

In addition, Clausius-Clapeyron equation is employed to determine equilibrium pressure and temperature [6]:

$$ln(p) = -\frac{\Delta H}{RT} + \frac{\Delta S}{R} \tag{2.3}$$

The p is equilibrium pressure of the pairs, ΔS is entropy changes during the reaction, R is universal gas constant, and T is absolute temperature. The profile of equilibrium temperature and pressure for various type of salt are generated using the Clausius-Clapeyron equation. Some of the equilibrium lines of salt-ammonia presented in figure 2.1.

There are two methods which have been studied by Li et al. [8]:one-salt system and two-salts system.

2.2.1 One Salt system

The one-salt system demonstrates a basic process of Clausius-Clapeyron. In this system, ammonia is being conditioned for adsorption and desorption using evaporator and condenser, respectively. In [8], the one-salt system was developed using the method called temperature-lift adsorption. The purpose of this process is to generate an increment in heat output relative to heat input by controlling the evaporation pressure during the reactor. The schematic diagram of the reaction shown in figure 2.2.

The reaction begins from point A. In point A, the adsorption takes place and ammonia released from the salt due to heating. This phase also called 'charging' mode. In B, the ammonia is condensed and heat released. The temperature-lift process is implemented in between point B-C. At point C, the ammonia evaporates at a specific pressure. The pressure level of evaporation will determine the output temperature in point D, where adsorption occurs.

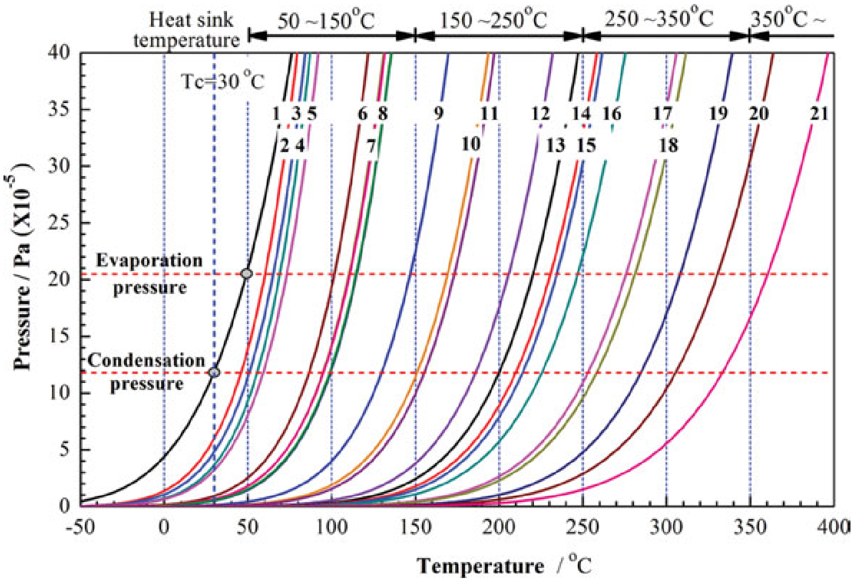


Figure 2.1: Equilibrium lines of metal chloride/bromine - ammonia in the Clapeyron diagram after Li et al. [8].

1: NH_3
2: $PbCl_2$;8/3.25
3: NaBr;5.25/0
4: $BaCl_2$;8/0
5: $PbBr_2$;5.5/3
6: $CaCl_2$;8/4
7: $SrCl_2$;8/1
8: $CaCl_2$;4/2
9: $SrBr_2$;8/2
10: $MnCl_2$;6/2
11: $CaBr_2$;6/2
12: $FeCl_2$;6/2
13: $MnBr_2$;6/2
14: $CoCl_2$;6/2 5
15: $MgCl_2$;6/2
16: $FeBr_2$;6/2
17: $CoBr_2$;6/2
18: $NiCl_2$;6/2
19: $MgBr_2$;6/2
20: $NiBr_2$;6/2
21: NiI_2;6/2

2.2.2 Two Salts system

The idea of two-salts system is that the ammonia stored in the form of a chemical bond with a metallic salt. Besides Li et al. [8], this has also been studied by Bao et al. [1]. In this method, the adsorption and desorption cycle takes place between low-temperature salt (LTS) and high-temperature salt (HTS). The terms low-temperature salt and high-temperature salt comes from their different equilibrium temperature at the same pressure. In this system, the adsorption and desorption occur at the same time but on the different side. Adsorption of high-temperature salt will be followed by desorption in low-temperature salt because the ammonia needs to be stored inside the salt and vice versa.

The schematic diagram of the two salts system is presented in figure 2.3.

This process aims to produce heat with higher temperature compared to the temperature level at the input. Based on the Clausius-Clapeyron process, increasing or decreasing pressure will affect the equilibrium temperature of the salts. By supplying heat at lower pressure in charging mode and later increasing the pressure in discharging mode, the heat output with higher temperature is generated.

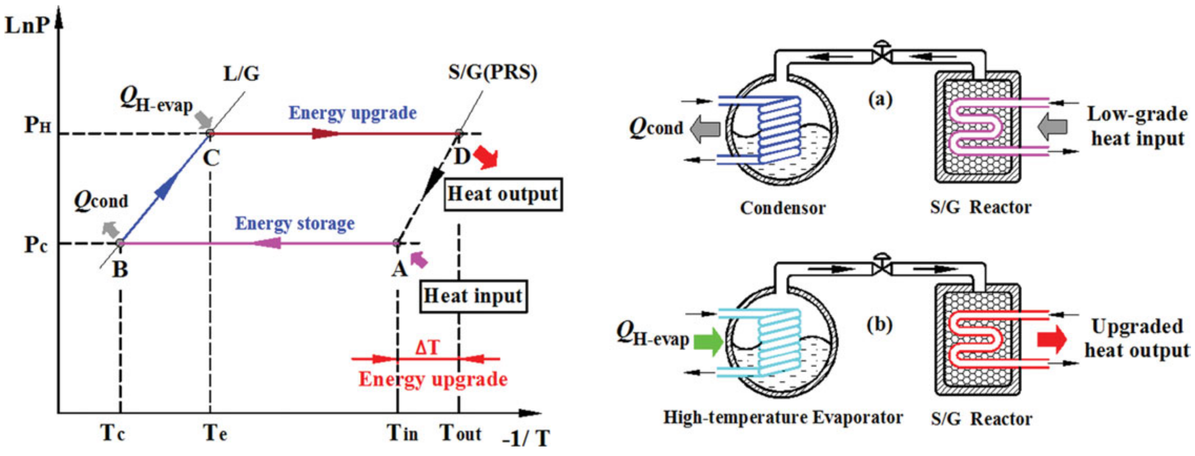


Figure 2.2: Schematic diagram of temperature-lift adsorption method after Li et al. [8].

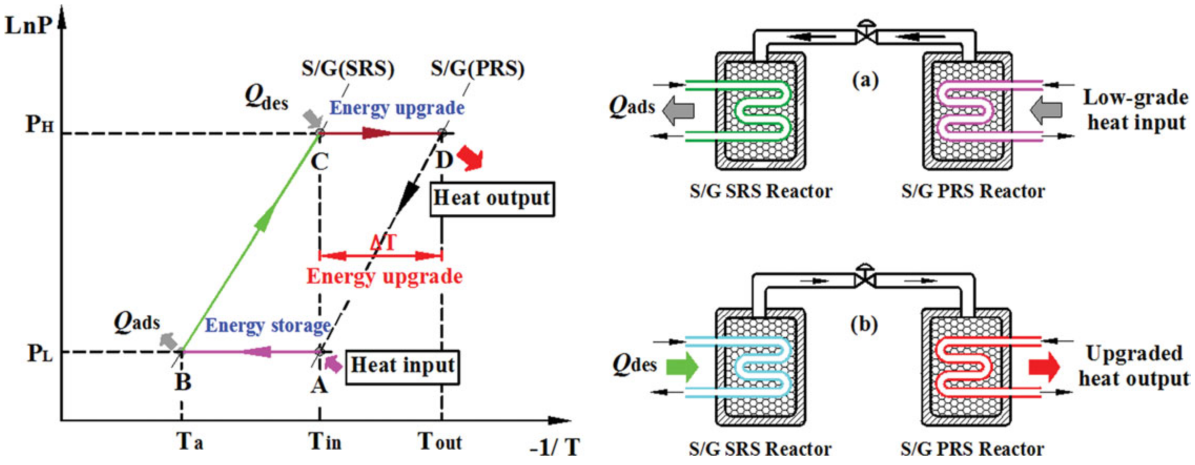


Figure 2.3: Schematic diagram of pressure-reducing adsorption process after Li et al. [8].

The process starts from point A, where the heat supplied at low operating pressure. When the desorption occurs on HTS, the ammonia gas flows to the other reactor containing LTS and adsorption takes place. The adsorption process illustrated in process B. The process A-B is also called the charging mode. In C, the operating pressure lifted and heat supplied to LTS. The ammonia desorbed and flowed into HTS. In point D, the adsorption occurs on HTS, generating heat in higher temperature relative to its charging condition.

2.2.3 Modified two salts system on the experiment

In this experiment, the principle of 2 salts from Li et al. [8] will be used. However, the pressure lifting effect will not be demonstrated. The experiment will focus on the reversible process between two salts without pressure lift. This modified process then translated into an experiment, and the deviation or alteration that occur during the test will be analyzed.

The working principle is similar to the former two salts system, as shown in Figure 2.3 but without energy upgrade. The simple process diagram can be seen in Figure 2.4 The process starts at point A, where the HTS is heated. The desorption occurs, and ammonia gas flows out from the HTS. At point B, the ammonia gas from the first reaction cylinder contains HTS flows into LTS and adsorption occurs. This process generates heat in LTS side. The process from A to B is the charging process. On the other hand, the similar process with opposite direction, C to D is the discharging process. Both of the processes happened at the same pressure level due to the absence of energy upgrade by pressure increase.

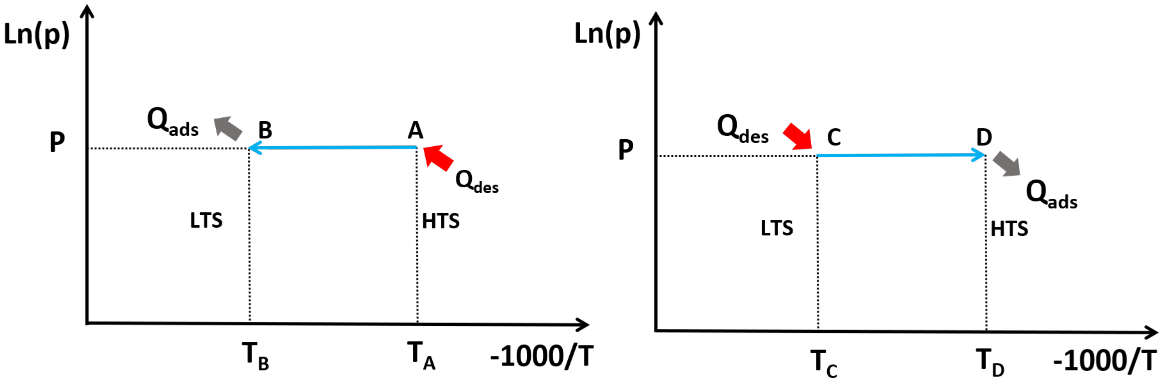


Figure 2.4: Diagram of 2 salts system for the experiment

2.3 Equivalent salt mass

The salt capacity to contain ammonia is calculated based on the stoichiometry of reaction between salt and ammonia. The reaction coefficient presented in the first column of Table 2.1 with sink temperature of 30 Celsius [8].

Referring to general reaction of salt-ammonia in Equation 2.2, the first number represent coefficient of ammonia after adsorption (m+n). The second number is n, which represents the coefficient of ammonia after desorption. Besides the reaction coefficient, the mass calculation requires basic information such as the molar mass of the component. Below is the example of calculation for NaBr-5.25/0 with 200 gr ammonia for adsorption:

The reaction for NaBr with ammonia:

$$NaBr * 5.25NH_{3(s)} + \Delta H <=> NaBr_{(s)} + 5.25NH_{3(g)} \tag{2.4}$$

Molar mass NH_3 = 17 g/mol

Molar mass NaBr = 102.9 g/mol

NH_3 = 100.756 mol

mol NaBr = Mol NH_3 / 5.25 * 1 = 2.2409 mol

mass NaBr = mol NaBr $*$ Molar mass NaBr = 230.59 gr

The coefficient of zero for n means that all of the ammonia can flow out of the salt by desorption. In another case, n>0 means the desorption reaction is not releasing all of the ammonia in the salt-ammonia bond. The calculation for all of the salt candidate will be performed in the next chapter.

2.4 Selection parameter for salt

Two salts consist of one low-temperature salt, and one high-temperature salt is selected for the experiment. In order to select the salt, three parameters are used:

- Driving equilibrium temperature
- The risk and safety precautions
- Price

The parameters of salt candidates will be evaluated during the design phase to select high-temperature and low-temperature salt. While it is possible to calculate the theoretical value of the parameters, the selection will also account external factor such as time constraint, the difficulty in the equipment assembly as well as practicality.

2.4.1 Driving equilibrium temperature

The reaction enthalpy, reaction entropy, and driving equilibrium temperature of salt-ammonia pairs taken from Li et al. [8] have been summarized in the previous semester project report. The list of the pairs is shown in Table 2.1.

Using the reaction enthalpy and entropy in the Table 2.1 and also Clausius-Clapeyron equation (2.3), the equilibrium temperature for each salt at certain operating pressure is calculated. The equilibrium temperature will be used as consideration for the pressure rating of the reactor cylinder in the design phase. In Table 2.1, the driving equilibrium temperatures are calculated for operating pressure of 11 bar referring to Li et al. [8].

Table 2.1: The reaction enthalpy, reaction entropy, and driving equilibrium temperature after Li et al. [8].

Reactive salt -coefficient	Reaction enthalpy ΔH (J mol^{-1})	Reaction entropy ΔS (J mol^{-1}K^{-1})	Driving equilibrium temperature (°C)
NH_4Cl-3/0	29,433	207.9	48
$PbCl_2$-8/3.25	34,317	223.6	47
NaBr-5.25/0	35,363	225.2	51
$BaCl_2$-8/0	38,250	232.4	56
LiCl-4/3	36,828	224.6	67
$CaCl_2$-8/4	41,013	230.1	87
NaI-4.5/0	39,339	224.5	90
$BaBr_2$-8/4	41,850	229.8	95
$SrCl_2$-8/1	41,432	228.6	96
$CaCl_2$-4/2	42,269	229.7	99
$SrBr_2$-8/2	45,617	229.3	130
$MnCl_2$-6/2	47,416	227.9	152
$CaBr_2$-6/2	48,965	230.4	156
$FeCl_2$-6/2	51,266	227.8	186
$MnBr_2$-6/2	53,066	228.3	200
$CoCl_2$-6/2	53,987	227.9	210
$MgCl_2$2-6/2	55,661	230.4	214
$FeBr_2$-6/2	55,828	228.1	226
CaI_2-6/2	58,590	231	237
$CoBr_2$-6/2	58,590	227.5	253
$NiCl_2$-6/2	59,218	227.6	259
MnI_2-6/2	59,301	227.4	260
FeI_2-6/2	60,683	227.5	272
$MgBr_2$-6/2	63,612	230.2	285
$NiBr_2$-6/2	64,240	227.2	306
NiI_2-6/2	65,453	224.1	334

2.4.2 The risk and safety precautions

The risk and safety precautions are important during the selection of high temperature and low temperature salt. To ensure the safety of experiment, hazardous salt material should be identified. The salt which possess dangerous characteristic such as high flammability, cancerous, explosive, and toxicity to human and environment will be avoided in this experiment. The general risk and safety precautions of the salts are gathered from Chemicalbook [2] and summarized into Table A.1 in Appendix A.

2.4.3 Price

The price information of the salt candidate is essential as a consideration in salt selection. This factor is related to the budget and further possible development. Besides, the availability of salt can inhibit the experiment process. Even though the availability is a factor that somewhat uncertain and not explicitly mentioned in the criteria, this information can be retrieved during purchasing. The price information was mainly taken from Sigmaaldrich [9]. The price of the salt candidates shown in Table 2.2.

Table 2.2: The price list of salt candidates [9]

No	Name	Price (NOK/100gr)	No	Name	Price (NOK/100gr)
1	NaBr	108	14	NaI	472
2	$BaCl_2$	2880	15	$BaBr_2$	23400
3	$CaCl_2$	274	16	$SrCl_2$	25200
4	$MnBr_2$	2810	17	$CaCl_2$	66.6
5	$CoCl_2$	1080	18	$SrBr_2$	46000
6	$MgCl_2$	71.7	19	$MnCl_2$	83
7	$FeBr_2$	5440	20	$CaBr_2$	29200
8	CaI_2	4200	21	$FeCl_2$	1696
9	$CoBr_2$	1444	22	MnI_2	62500
10	$NiCl_2$	820	23	FeI_2	34800
11	NH_4Cl	132.4	24	$MgBr_2$	1294
12	$PbCl_2$	162.4	25	$NiBr_2$	1900
13	LiCl	344	26	NiI_2	6840

Chapter 3

Equipment and Materials

In this chapter, the components of the system and the reaction materials will be elaborated. The process of designing, building, as well as calculating the salt is done simultaneously to ensure that they can accommodate the experiment while still comply with the safety requirements. Furthermore, the rig building process provides a valuable learning experience in terms of execution and the importance of detailed design.

3.1 Equipment

The design of the equipment begin with the simple process diagram in the specialization project. Later on, the design develops into the detailed version through further discussion with supervisor, co-supervisor, laboratory engineer, and literature study. The component of the system consist of equipment made in the lab and commercial product.

3.1.1 Design

The concept of the salt-ammonia system was created based on the literature review performed in the semester project. The general idea is to circulate the ammonia gas between two salts and generating usable heat on top of the HTS side. The initial design can be seen in figure 3.1.

The simple design consists of two boxes with a cooking plate on top of the primary reactive salt. Here, the primary reactive salt is called high-temperature salt due to its high equilibrium temperature. The secondary reactive salt represents low-temperature salt for the same reason. The HTS and LTS connected through a pipe, and the adsorption-desorption process takes place in turn. Number 1 indicates the charging process where heat from sun supplied to HTS to desorb the ammonia, while adsorption occurs in LTS side. The process number 2 shows the opposite

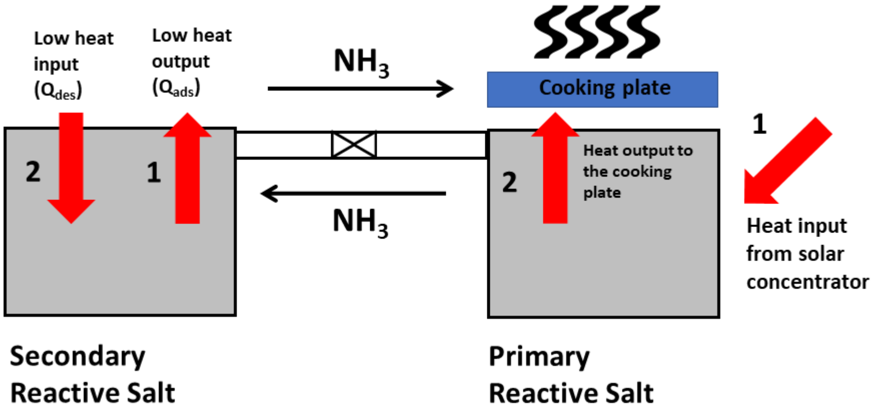


Figure 3.1: Initial simple design for the salt-ammonia experiment.

where desorption in LTS release the ammonia and adsorption in HTS produce heat for cooking.

As mentioned in the previous chapter, the purposes of the experiment focused on demonstrating the adsorption and desorption process as a proof of concept. Therefore, the design needs to be modified to fit the objective. The cooking plate is removed, and the measurement is conducted inside the reactor cylinders. The main measurement parameter is temperature and measured with a thermocouple, while analog pressure gauges are installed as an additional indicator. Figure 3.2 shows the modified diagram of experiment setup.

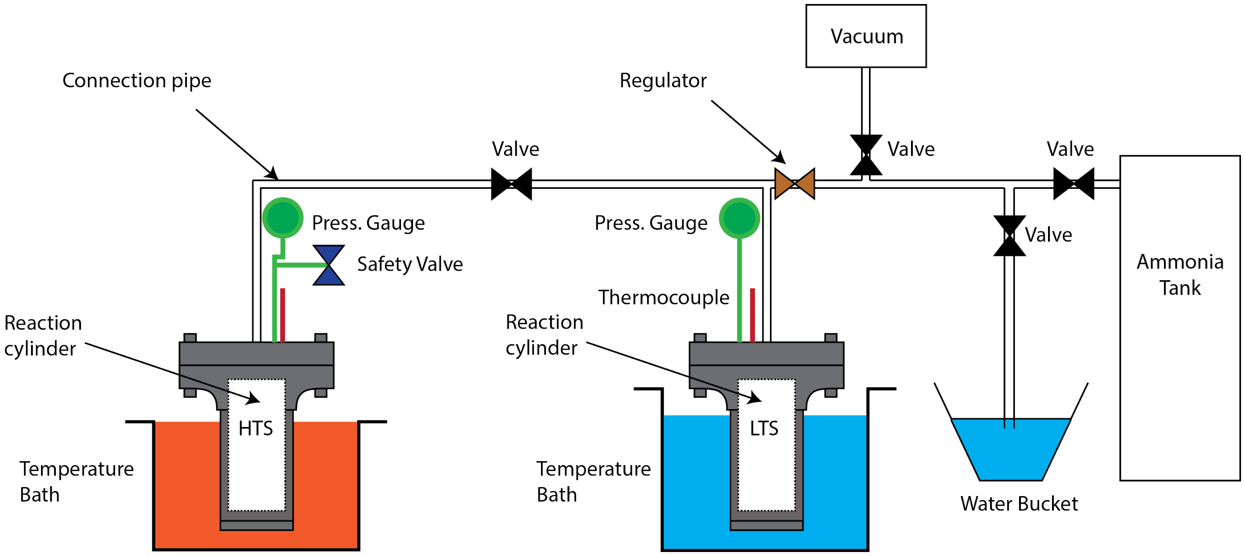


Figure 3.2: Modified design for the salt-ammonia experiment.

3.1.2 Components

The setup components consist of reaction cylinder, steel wool, cylinder hanger, ammonia tank, vacuum pump, weighing scale, temperature bath, pressure gauge, thermocouple, and logger.

3.1.2.1 Reaction cylinder

The reaction cylinder is composed of pipes, flanges, and the cylinder plugs. The flange is a carbon-steel-weld-neck flange with a tube diameter of 88.9 mm and pressure rating of 28.4 bar at 250°C. The pipe and the cylinder plug are made of carbon steel as well. The components are welded together and the pressure test performed at 51 bar, 20°C. The inside dimension is 255 mm in height and 80 mm in diameter. The reaction cylinder can be seen in Figure 3.3.

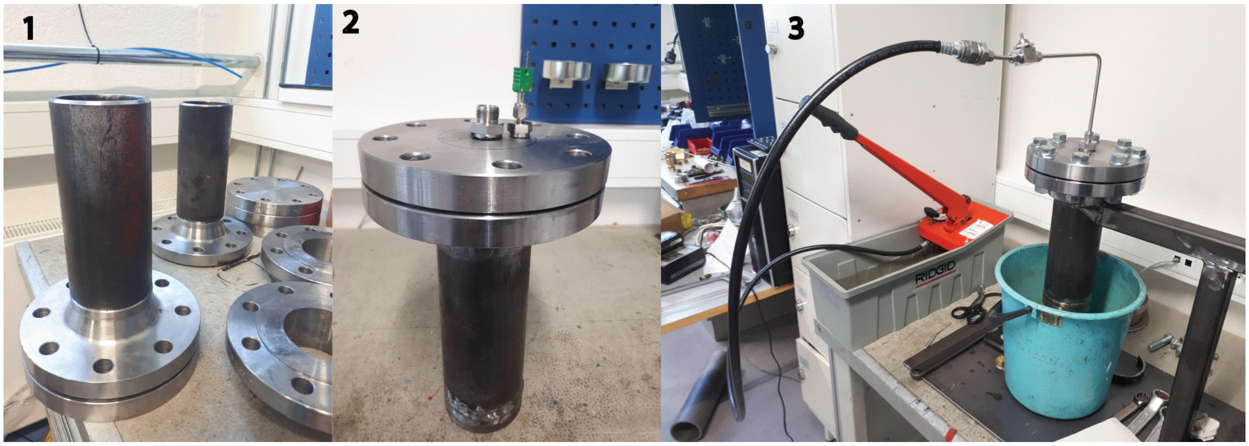


Figure 3.3: Reaction cylinder. (1. Before welding; 2. After welding; 3. Pressure test).

3.1.2.2 Hanger

The hanger is made to hang the system. It is designed such that the reaction cylinder is floating inside the temperature bath during the heating process. The picture of the hanger shown in Figure 3.4.

3.1.2.3 Steel wool

The steel wool is a strand of steel usually used for abrasive/smoothing the surface. The idea to test steel wool came with the intention to give salt power more reaction surface and to keep the salt inside the reactor during the experiment. However, it must be noted that commercial steel wool can rust due to contact with oxygen in a humid environment. During the experiment, the

Figure 3.4: The hanger.

system will be kept dry. The steel wool used inside the reaction cylinder together with the salt material and arranged into layers with salt in between. The steel wool can be seen in Figure 3.5.

Figure 3.5: Fine and coarse steel wool.

3.1.2.4 Temperature bath

The temperature bath is a HAAKE N2 digital controller with a HAAKE B temperature bath. The equipment obtained from the laboratory facility and used to control the temperature of reaction cylinders. Based on the specification, the temperature bath able to heat to 320°C. Figure 3.6 shows the temperature bath.

Figure 3.6: Temperature bath.

3.1.2.5 Ammonia tank, vacuum pump, and weighing scale

The ammonia tank is a Swagelok double ended cylinder, with 124 bar pressure rating and 2250 cm^3 volume. The ammonia is filled up from the larger ammonia source to allow accurate measurement of the mass change during filling up. The weighing scale can measure up to 32 kg with an accuracy of 0.1 gram. The vacuum pump is the CPS two-stage vacuum pump. The ammonia tank, weighing scale, and vacuum pump can be seen in Figure 3.7.

Figure 3.7: Ammonia tank, weighting scale, and vacuum pump.

3.1.2.6 Pressure gauge

Two analog pressure gauges are used to indicate the pressure, one for each cylinder. The pressure gauges are compatible for use with ammonia gas and have pressure range between -1 and 25 barg. The pressure gauges can be seen in Figure 3.8.

Figure 3.8: Pressure gauge.

3.1.2.7 Thermocouple and logger

The thermocouple used to measure the temperature inside the cylinders. Both of thermocouple are type-K and installed on top of the cylinder lid. The logger being used is PICO logger. The picture of the thermocouple and logger can be seen in Figure 3.9.

Figure 3.9: Pico logger and thermocouple.

3.2 Materials

The selection of the salt followed by the design of salt and ammonia were performed simultaneously with the equipment design. In this section, the material selection and calculation will be elaborated.

3.2.1 Salts selection

As mentioned in chapter 2, the consideration in selecting the salt consists of the driving equilibrium temperature, the risk and safety precautions, and the price of the salt. The price of the salt material is set to be a maximum of 200 nok / 100 gram to keep the cost low. The salt which poses a severe risk such as cancer, explosion, burn, high toxicity, and harm to the environment is eliminated. As for the equilibrium temperature, the operating pressure should not exceed the rig pressure rating.

For the equilibrium temperature, one for each low and high equilibrium temperature salt is desired. The salt with low equilibrium temperature stores ammonia gas in charging mode. Therefore, it requires low heat level to perform desorption in the discharging phase. On the other hand, the salt with high equilibrium temperature generates heat at cooking temperature during the discharging phase. Table 3.1 shows the salts candidate which pass the price and safety criteria.

Table 3.1: The potential salt candidates after screening

No.	Reactive salt -coefficient	Price NOK/100gr	Risk and safety	Driving equilibrium temperature (°C) at 11 bar
1	NaBr-5.25/0	108	Pass	50
2	$CaCl_2$-8/4	66.6	Pass	85
3	$CaCl_2$-4/2	66.6	Pass	97
4	$MgCl_2$2-6/2	71.7	Pass	212
4	$MnCl_2$2-6/2	83	Pass	149

Based on the screening, five candidates fulfill the price and risk & safety criteria. However, it does not mean that all other salts are hazardous and not economic. Some salts are safe to use but have a relatively high price for the experiment while some salt has a low price but deemed unsafe for the existing design.

There is only one salt candidate with driving equilibrium temperature near cooking temperature, while salt with the lowest driving temperature of 51°Celsius is NaBr. Therefore, it is decided to choose NaBr and $MgCl_2$ as low-temperature salt (LTS) and high-temperature salt (HTS).

3.2.2 Equilibrium pressure

The equilibrium pressure and temperature are specific for each salt-ammonia pairs. The values are calculated using equation (2.3). The equilibrium pressure for each 10 degree increase in temperature starting from 10°C to 220°C are calculated and showed in Table 3.2.

Table 3.2: Salt equilibrium pressure at certain temperature

No	Temperature (°C)	Equilibrium pressure (bar)	
		NaBr	$MgCl_2$
1	10	1.722	0.001
2	20	2.876	0.001
3	30	4.644	0.003
4	40	7.271	0.006
5	50	11.074	0.011
6	60	16.446	0.020
7	70	23.866	0.036
8	80	33.910	0.063
9	90	47.259	0.106
10	100	64.700	0.174
11	110	87.137	0.278
12	120	115.589	0.433
13	130	151.198	0.661
14	140	195.221	0.989
15	150	249.034	1.450
16	160	314.128	2.090
17	170	392.106	2.963
18	180	484.672	4.136
19	190	593.630	5.691
20	200	720.876	7.726
21	210	868.386	10.357
22	220	1038.209	13.719

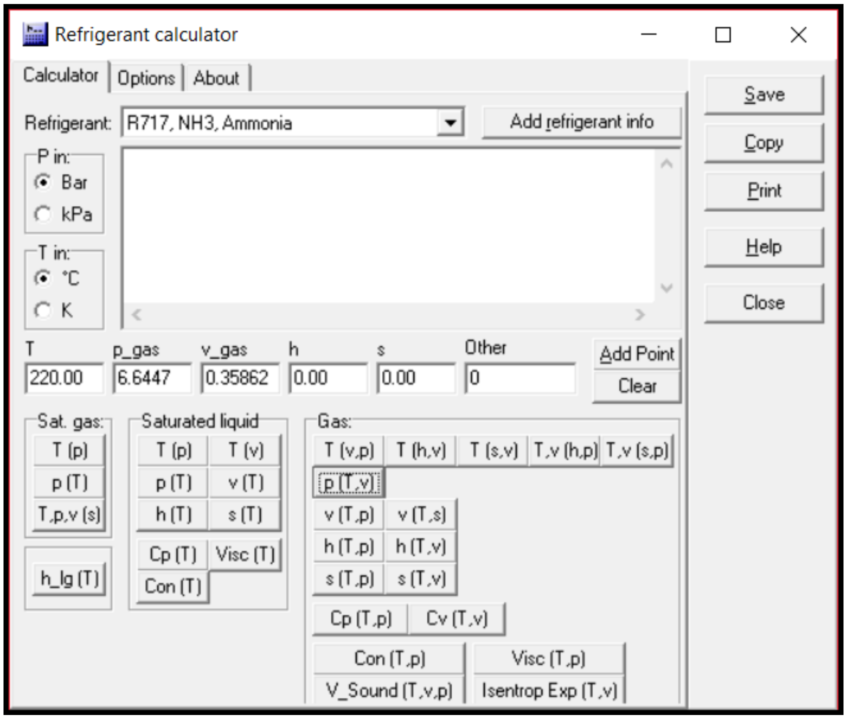
3.2.3 Salt and ammonia amount

The design of salt and ammonia is related to maximum system pressure. The maximum pressure of the system will limit the maximum amount of free ammonia and salt allowed in the system. During the experiment, The maximum pressure condition will occur when the amount of free ammonia at specific temperature build up pressure and reaches the pressure limit of the system.

In order to predict the state of ammonia gas, including the amount, pressure, and temperature, an application called coolpack is used — the input consist of pressure, specific volume, and temperature. The screenshot of the interface can be seen in Figure 3.10.

Specific volume is calculated from volume divided by mass. The mass is mass of ammonia and volume is the system volume subtracted by salt and steel wool volume. The volume components of the setup and the net volume can be seen on table 3.3.

As an initiation, several calculation of free ammonia gas in the system were performed. The purpose is to identify whether the adsorption reaction is happening during ammonia filling by comparing the pressure during ammonia filling process. Four case of free ammonia gas were created and the pressure predicted at temperature between 10°C and 220°C. The calculation



Refrigerant: R717, NH3, Ammonia

P in: ● Bar ○ kPa

T in: ● °C ○ K

T	p_gas	v_gas	h	s	Other
220.00	6.6447	0.35862	0.00	0.00	0

Figure 3.10: Coolpack interface.

Table 3.3: The volume components of the setup.

No	Volume component	Volume (m^3)
1	NaBr salt	0.00008
2	$MgCl_2$ salt	0.00012
3	Steel wool	0.00060
4	Reaction cylinder	0.00128
5	Pipe (6 mm ID)	0.00003
Net volume		0.00179

can be seen on Table 3.4.

For the salt amount, it is decided to use a constant amount of salt equivalent to adsorb 200 gram of ammonia for each salt to simplify the process in the experiment. Using said strategy, the ammonia amount can be gradually increased during the tests without needs to repeatedly disassemble the whole cylinder to fill up the salt.

Table 3.4: Salt amount, ammonia amount, and maximum system pressure at certain temperature.

Ammonia amount	5 gr	10 gr	15 gr	20 gr
NaBr amount	230.6 gr	230.6 gr	230.6 gr	230.6 gr
gCl$_2$ amount	279.8 gr	279.8 gr	279.8 gr	279.89 gr
Specific volume	0.439	0.219	0.146	0.109
Temperature (°C)	Pressure (bar)			
10	3.66	6.95	9.87	12.44
20	3.81	7.28	10.40	13.20
30	3.96	7.60	10.92	13.93
40	4.11	7.91	11.42	14.64
50	4.25	8.22	11.91	15.33
60	4.40	8.53	12.40	16.01
70	4.54	8.83	12.87	16.67
80	4.69	9.13	13.34	17.32
90	4.83	9.43	13.80	17.96
100	4.97	9.72	14.26	18.59
110	5.11	10.01	14.71	19.21
120	5.25	10.30	15.16	19.83
130	5.39	10.59	15.61	20.44
140	5.53	10.88	16.05	21.05
150	5.67	11.17	16.49	21.65
160	5.81	11.45	16.93	22.25
170	5.95	11.74	17.37	22.84
180	6.09	12.02	17.80	23.43
190	6.23	12.31	18.24	24.02
200	6.37	12.59	18.67	24.61
210	6.51	12.87	19.10	25.19
220	6.64	13.15	19.53	25.78

Chapter 4

Procedures

This chapter provides the steps of experiment from the preparation phase to the execution of main experiments.

4.1 Experiment preparation

4.1.1 Pressure test

After the main setup completed, the system moved into the designated laboratory area. The pressure test using nitrogen performed on the rig. At first, there was a leak in the pressure gauge connection during 5 bar pressure test. After fixing the leak, the pressure test repeated for 5 bar and 23 bar, resulting in no pressure loss. In addition, as mentioned in 3.1.2.1, the pressure test for the cylinders has been performed using water at 41 bara, 20°C.

4.1.2 Salt and steel wool filling

After the pressure test, the filling process began. The arrangement inside the cylinder consist of layers between salt and steel wool. The steel wool is shaped like doughnut to allow ammonia gas to react more efficiently with the salt. Additionally, some parts of the salt are also inserted inside the steel wool. During the filling process, a metal rod is inserted to the middle of cylinder to keep the hole for ammonia flow. There are 12 alternating layers between steel wool and salt. The activities during filling can be seen on Figure 4.1.

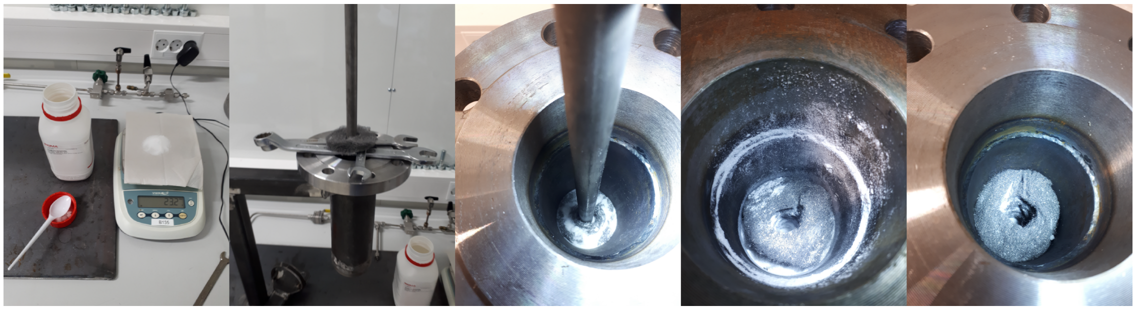


Figure 4.1: Salt and steel wool filling process.

4.1.3 Temperature control

After the salt filling, the system is assembled and temperature bath installed such that it covers most of the cylinder body. Due to the reaction temperature, the HTS side is filled with cooking oil and the LTS side is filled with water.

4.1.4 Ammonia filling

Before injecting the ammonia, all the system need to be vacuumed to remove the air inside the system. In addition to vacuum, the leak test is performed four times during vacuum. The result can be seen on Table 4.1.

Table 4.1: Measurement of leak during vacuum.

No.	Duration (minute)	Pressure leak (mBar)
1	16.1	1.5
2	59.0	4.0
3	171.3	7.5
4	977	5.5

From Table 4.1, it can be seen that the leak is small and insignificant. Therefore, it is safe to process to the next step.

As mentioned in 3.1.2.5, the ammonia tank need to be light enough to measure the mass change during system filling accurately. Before filling ammonia into the tank, a vacuum is applied.

The next step is injecting ammonia gas into the system. Since the mass-flow meter is not available, the ammonia amount injected to the rig will be predicted using two methods. The first is simply by measuring the change of the ammonia tank's mass. To measure the mass in the gram, weighing scale with high accuracy is used.

The second prediction is by using system pressure. With the information of volume and temperature inside the system, the initial system pressure recorded during the ammonia filling process can be used to predict the mass of ammonia gas.

Figure 4.2 shows the setup during ammonia filling to the system. The valves are indicated with the numbers, and the function for each are listed below.

- valve 1: connection between two cylinders
- valve 2: regulator
- valve 3: to vacuum
- valve 4: to water bucket/exhaust to release ammonia
- valve 5: valve between ammonia tank and ammonia source

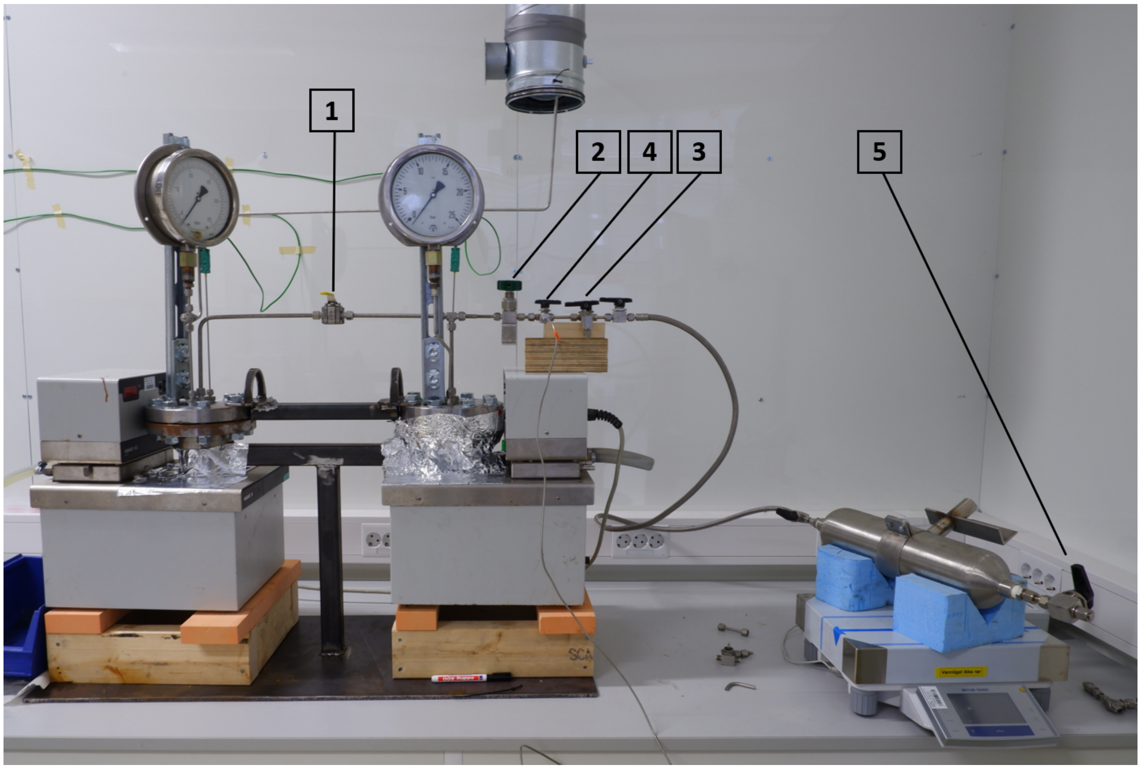


Figure 4.2: The rig setup with valves indicator.

The procedure of ammonia filling after vacuum are below:

1. Set valve 2,3, and 4 into close position.
2. Fill the ammonia to ammonia tank and tube to valve 2.

3. Close valve between ammonia tank to ammonia source.
4. Start recording the temperature and observe pressure.
5. Open valve 2 slowly and close when the pressure reach the target or the weighting scale indicated that it has reach the designated weight.
6. Open valve 4 slowly to release it to water or the exhaust.

The strategy during ammonia filling is by controlling the regulator or valve-2 slowly while checking the pressure during the process. However, since the amount of salt can adsorb 200 gr of ammonia, the maximum ammonia in theory should be 200 gram.

4.2 Adsorption-Desorption

During the adsorption-desorption experiment, the relationship between equilibrium pressure and temperature theoretically follow the Clausius-Clapeyron equation. The duration of charging and discharging can be different depending on the pressure condition and expected to vary with the ammonia mass and temperature of the reaction. The desorption and adsorption temperature for HT salt and LT salt is determined using rules below:

- Adsorption: Apply temperature start with the condition where equilibrium pressure is lower than the system pressure.
- Desorption: Apply temperature start with the condition where equilibrium pressure is higher than the system pressure.

The rules above are the initial condition to start the process. During the experiment, various condition can be tested to study the effect of temperature and pressure for the adsorption and desorption process.

General procedure for adsorption and desorption during the charging process are:

1. Start recording the temperature profile and record the temperature and pressure change in HTS and LTS periodically.
2. Make sure valve 1 is in open position.
3. Set the HTS side to the desorption temperature. Check the pressure increase to indicate that ammonia gas is flowing out from the HTS.

4. Set LTS side to the selected surrounding temperature.
5. Close valve 1 when the charging process finished.

General procedure for adsorption and desorption during the discharging process are similar to charging procedure. The difference is that now desorption takes place in LTS and adsorption in HTS.

1. Make sure valve 1 is in the closed position.
2. Start recording the temperature profile and check the pressure intermittently.
3. Set the LTS side to the selected desorption temperature.
4. Set HTS side to the selected adsorption temperature.
5. Open valve 1.
6. Observe the temperature and pressure change in HTS and LTS.

Chapter 5

Result and Discussion

In this chapter, the results of the experiment are presented and discussed. The experiment consists of two parts: ammonia filling and adsorption-desorption process. The ammonia filling consists of measurement of ammonia, and the adsorption occurred in the filling process. On the next section, the main experiment consisted of charging and discharging by the adsorption-desorption process are performed and analyzed.

5.1 Ammonia filling

5.1.1 Ammonia amount

As mentioned in 4.1.4, Two measurements are being made: the first measurement was performed based on mass while the second measurement was carried out using initial pressure and temperature when the ammonia filled into the system. Some findings and issues were found for both measurement procedure.

When measuring the mass changes using weighing scale, opening and closing the valve caused a small disturbance which affects the weight reading because the tank was connected between the system and a big ammonia tank through a flexible steel tube. The slightest movement of the pipe will oscillate the weight reading, and it usually does not come back to its initial value due to a difference in mass distribution after the movement. Figure 5.1 shows the arrangement of a small ammonia tank used to transfer ammonia from the bigger tank.

On the other hand, the measurement using initial pressure and temperature condition after the ammonia filled into the system has several uncertainties related to the initial pressure and temperature as well as the reaction that occurs in the filling process.

First, the reaction that happened in the system is a fixed bed reaction, which means that

Figure 5.1: The arrangement of the ammonia tank.

ammonia-salt reaction occurred locally, layer by layer from the top side of salt to the bottom. When the ammonia flows into the system, it will react with the salt located at the top of the salt layer before flowing to the lower part of the salt. Due to this phenomena, the pressure displayed on the pressure gauge will show a lower pressure because a part of ammonia gas has reacted with the salt.

Secondly, during the ammonia filling process, both cylinder is exposed to ammonia gas. Therefore, some part of ammonia will react with LTS when the pressure reaches the equilibrium condition. The adsorption in LTS is indicated with temperature increase in LTS side shown in Figure 5.2. The profile shows that most of the ammonia adsorption occurs in HTS.

The filling process performed multiple times throughout the experiment. The mass measurement by pressure and weighing scale are recorded. The comparison of the ammonia amount between two measurement method for all of the tests can be seen in table 5.1.

Based on the data gathered in Table 5.1, there is almost no correlation between the two measurement method. Due to the uncertainties found in the experiment, only rough estimation can be made to predict the amount of ammonia filled into the system. In addition, the first three data for initial pressure method is not available due to constant pressure reading in the filling process. This happens because the range of pressure gauge is limiting the real pressure state, which has a lower value.

The primary purpose of measuring ammonia amount in this experiment is to ensure the pressure level comply with system pressure limits. The initial pressure in Table 5.1 shows that the pressure is way below the maximum pressure allowed in the system.

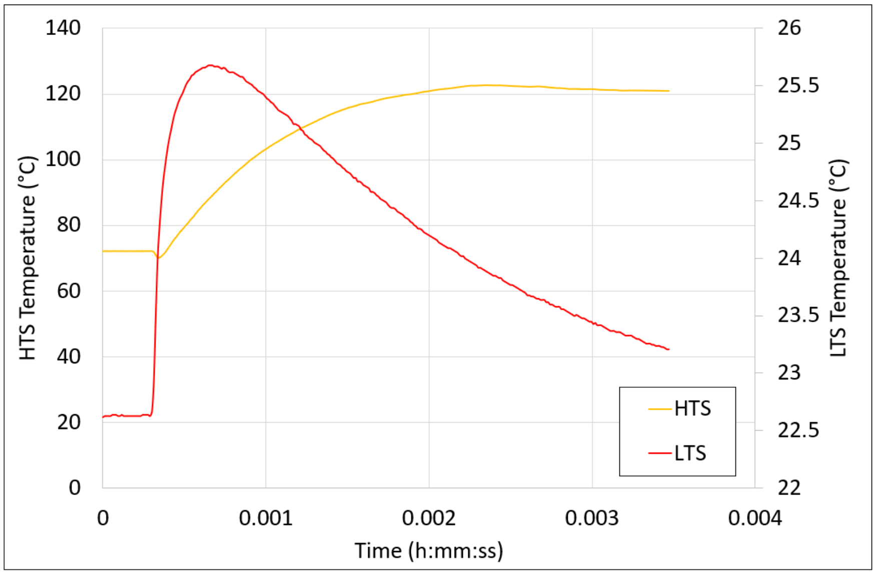


Figure 5.2: Temperature profile of HTS and LTS in the filling process.

Table 5.1: Ammonia mass comparison from two measurements.

No. of test	Ammonia mass (gram)	
	By weighing scale	By pressure
1	5.90	-
2	11.30	-
3	5.60	-
4	40.00	3.01
5	20.00	5.21
6	20.80	4.49
7	17.40	3.88
8	17.00	4.21
9	13.40	4.10
10	24.00	4.36
11	19.30	4.64
12	17.20	4.44

5.1.2 Adsorption in HTS in the ammonia filling

During the ammonia filling process, the adsorption takes place in both of the salt. The adsorption in the LTS occurs at the beginning of the process where the pressure is relatively high and stopped once the pressure decrease. On the other hand, the adsorption process in HTS requires lower pressure level. Figure 5.3 shows the temperature vs. pressure profile of HTS and LTS in ammonia filling.

In Figure 5.3, the comparison between the theoretical equilibrium line and the experiment result are presented. Apart from the delay response due to the nature of fixed bed reaction and thermocouple location, there is a possibility that the property of the salt is different from the lit-

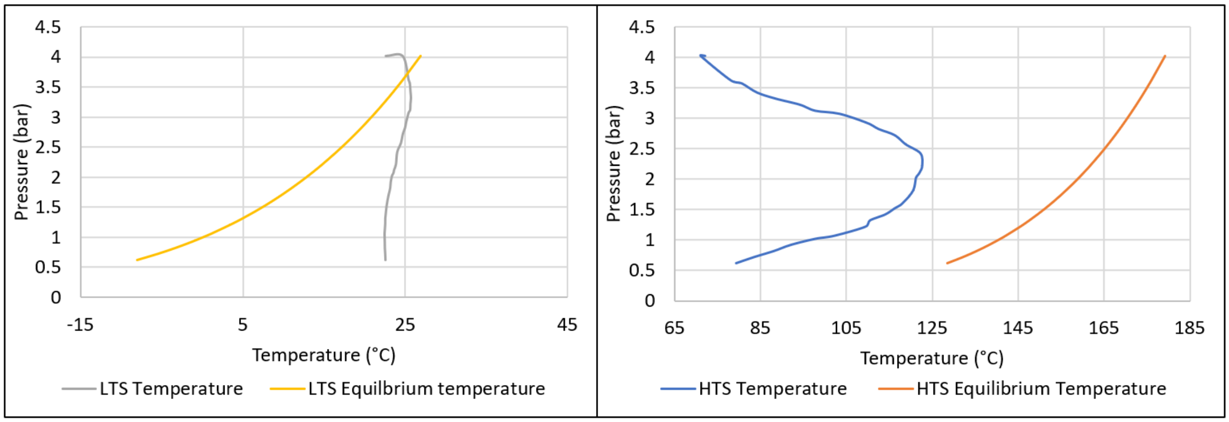


Figure 5.3: Pressure-Temperature profile of the salts in filling process.

erature. The further test is needed because to compare the equilibrium state, the salt condition should be in equilibrium state.

Another observation has been made regarding the adsorption process is that almost all of the ammonia is adsorbed to the salt on all of the filling tests, indicated by final pressure of the system. Table 5.2 shows the estimated initial, final, and the difference in system pressure and its corresponding ammonia mass difference.

Table 5.2: Changes in system pressure and free ammonia mass in filling process

Test No.	System pressure (bar)			mass difference (gr)
	Initial	Final	Difference	
1	0.30	0.30	0.00	0.000
2	0.30	0.30	0.00	0.000
3	0.30	0.30	0.00	0.000
4	0.30	0.52	0.22	0.057
5	0.52	0.52	0.00	0.003
6	0.52	0.52	0.00	-0.001
7	0.52	0.57	0.05	0.052
8	0.57	0.62	0.05	0.053
9	0.62	0.67	0.05	0.053
10	0.47	0.52	0.05	0.055
11	0.52	0.62	0.10	0.104
12	0.62	0.57	-0.05	-0.052
13	0.42	0.57	0.15	0.178
14	0.57	0.62	0.05	0.059
15	0.62	0.82	0.2	0.219
16	0.52	1.02	0.5	0.584
17	1.02	1.27	0.25	0.293
18	1.27	1.32	0.05	0.068

The result in Table 5.2 shows that the saturation of the salt does not affect the equilibrium condition. The differences between initial and final pressure, as well as mass, are insignificant.

5.2 Charging and discharging test

The desorption and adsorption in the charging and discharging process are the main focus of the experiment. In this section, the charging and discharging process performed using different temperature and ammonia amount to study its behavior. In addition, the findings and observations from the experiments are presented.

5.2.1 Experiment 1

The first charging test performed after the third ammonia filling. Initially, there is an attempt to heat HTS to 220°C using the temperature bath. However, the temperature bath stop responding whenever the target temperature is set above 200°C. So, the target temperature is set to 200°C instead of 220°C. During charging process, the system experienced a minimal increase in pressure from 0.32 bar to 0.87 bar before reduced to 0.62 bar after 38 minutes desorption on the HTS side as can be seen in Figure 5.4. This pressure drop is likely because HTS desorption stopped because the ammonia already drained, but LTS continue to adsorb the remaining ammonia in the system. Valve number 2 then closed to separate and monitor the pressure condition of the HTS and LTS. After the system cooled down, the pressure gauge indicated that the system went back to vacuum.

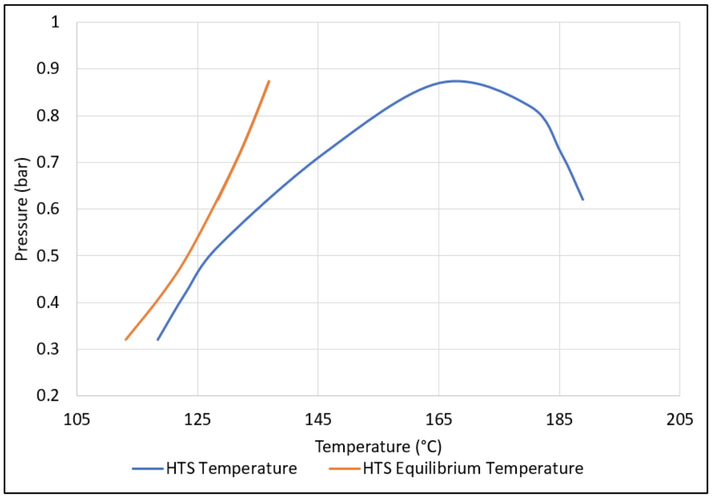


Figure 5.4: HTS Temperature vs Pressure profile during the charging process of experiment 1.

5.2.2 Experiment 2

The second experiment performed after 6th ammonia filling because the previous experiment indicates the lack of ammonia in the system. The temperature increment during charging process in HTS performed slowly so that the temperature-pressure profile shows near equilibrium condition. In this test, the charging process was modified such that the charging followed by cooling down without closing the valve between HTS and LTS. The purpose of this modification is mainly to check the equilibrium condition as mentioned early. The observation about the equilibrium state will be presented in the last section of this chapter. Figure 5.5 shows the temperature profile in HTS and LTS in the test.

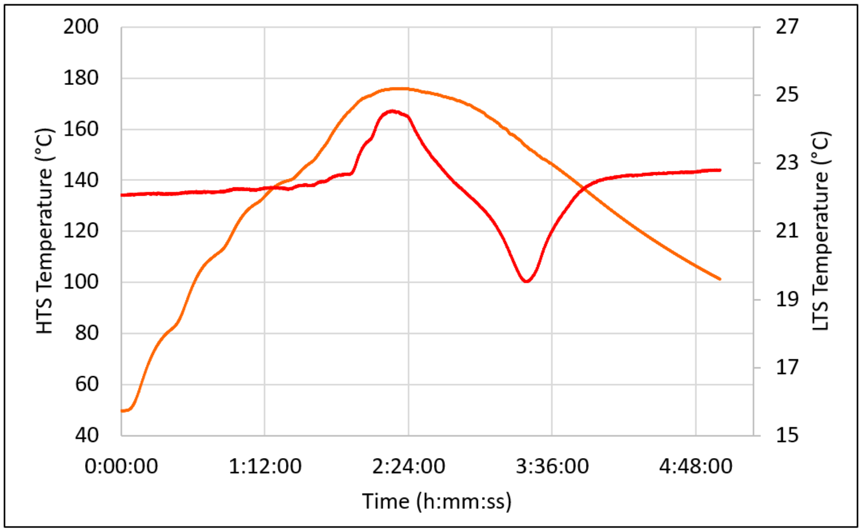


Figure 5.5: HTS and LTS Temperature profile of discharging mode in experiment 2.

The adsorption and desorption in LTS can be seen in Figure 5.5, indicated by temperature increase and decrease, respectively. The LTS temperature increased during charging because of the exothermic reaction. On the contrary, LTS temperature dropped during desorption in the cool-down period because endothermic reaction occurred in LTS. The endothermic reaction takes heat from the surrounding.

5.2.3 Experiment 3

In the third experiment, the charging process with peak desorption temperature above 177°C in HTS carried out for 24 minutes. During the charging, LTS temperature increased from 22.8°C to 27°C due to ammonia adsorption. According to the procedure in section 4, the valve between HTS and LTS is closed after charging completed. In the discharge process, the temperature in LTS is set to 40°C using temperature bath, while HTS temperature is 25.5°C. The discharge starts when valve one is opened. The temperature and pressure profile of HTS and LTS can be seen in Figure 5.6.

After the valve opened, HTS temperature increased, and LTS temperature decreased rapidly,

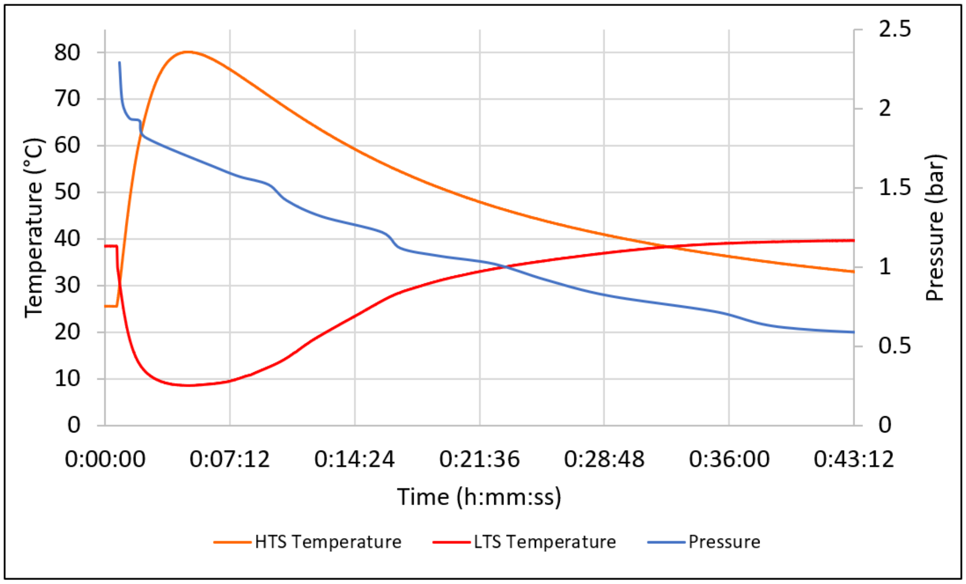


Figure 5.6: Pressure and temperature profile of discharging mode in experiment 3.

as shown in Figure 5.6. However, the HTS discharge temperature can only stay above 77°C for 4.5 minutes. Furthermore, the pressure trend, which already starts showing a decreasing trend from the beginning of discharge indicates that the equilibrium condition is not reached, with the faster reaction in HTS than LTS. The ammonia gas released from LTS is not able to match the rate of ammonia adsorption in HTS. There are two reasons which are causing this to happen. First, the total amount of ammonia in the system is too low to support the reaction process at the current discharging temperature. Second, the charging duration is too short such that most of the ammonia is still inside the HTS.

5.2.4 Experiment 4

In this experiment, more ammonia filled into the system before the charging started. In the charging phase, a total of 3.5 hours desorption above 180°C in HTS was carried out to ensure enough ammonia released from HTS and adsorbed to LTS. After the charging, the rig cooled down overnight. Unlike the previous experiment, a thermocouple now installed in each temperature bath to measure the change in oil and water surrounding the salts.

Before the discharge process began, HTS and LTS heated to 40°C to simulate the room temperature in a warm area. While the temperature in HTS was kept constant in the discharge mode, the LTS heated with a target temperature of 80°C after 20 minutes discharge. The purpose of heating is to see how the changes in desorption temperature in LTS affect the adsorption in HTS. The profile of temperature in the discharging process can be seen in Figure 5.7.

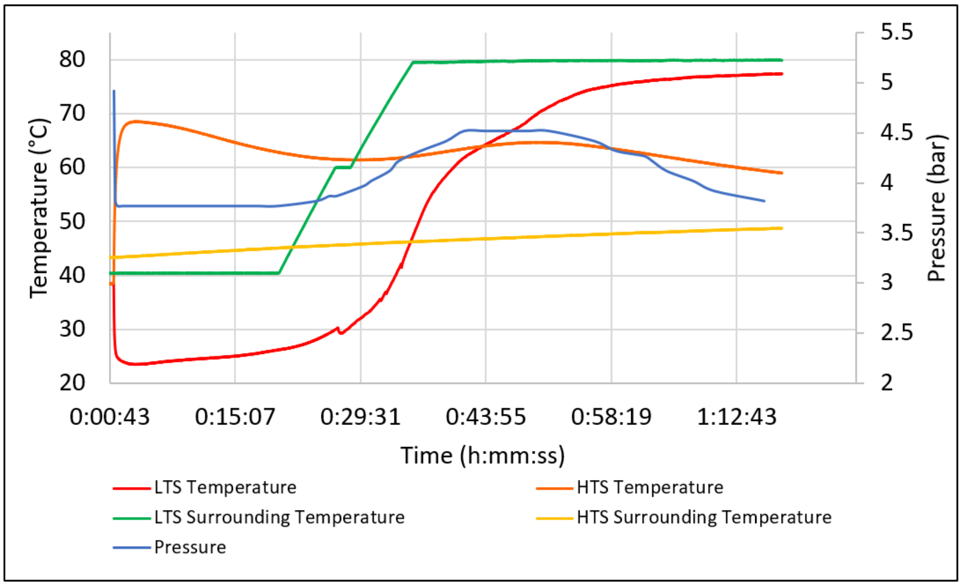


Figure 5.7: Pressure and temperature profile of discharging mode in experiment 4.

In the initial discharge, the system pressure was stable at 3.7 bara. But, despite the stabilized pressure, HTS temperature shows a decreasing trend. In this period, the reaction rate should be decreased at the same speed on both salts so that the system pressure is constant. Related to this hypothesis, the driving force is likely to be the cause. The ΔT between LTS temperature bath and LTS salt decreased, and at the same time, HTS temperature declined.

During the heating of LTS temperature bath to 80°C, the significant increase in ΔT LTS when heating the LTS to 80 ΔT did not translate to the considerable rise in ΔT between HTS and HTS temperature bath, but in the system pressure. This happened because the desorption rate in LTS is higher than the adsorption rate in HTS. The ammonia in the system increase while temperature increased by a little due to the lower adsorption rate in HTS. Then, as the desorption rate in LTS decreased, the pressure stabilized at one point where desorption and adsorption rate equal. The desorption rate in LTS continued to decline and became lower than the adsorption rate in HTS, and the system pressure decreased.

5.2.5 Experiment 5

Similar to the previous experiment, charging in HTS for around 3 hours with a desorption temperature above 180°C has been done. The rig also cooled down overnight.

Before discharging, HTS is heated to 40°C using HTS temperature bath and LTS temperature bath heated to 80°C with the plan to heat LTS to 80°C before start to discharge. However, at 52°C LTS temperature and 70°C LTS temperature bath, the pressure reached 12.5 bara. Because of high pressure, it is decided to start the discharge before LTS reached the target temperature and to set LTS temperature bath to 80°C once the discharging process started. Consequently, the HTS did not reach it's target temperature of 40°C when discharging began.

HTS temperature increase for 42.42°C, from 32.62°C to 75.04°C as soon as the HTS and LTS connected. Meanwhile, LTS temperature decreased about 16°C, from 52°C to 36°C. The pressure and temperature profile during the discharging process of experiment 5 can be seen in Figure 5.8.

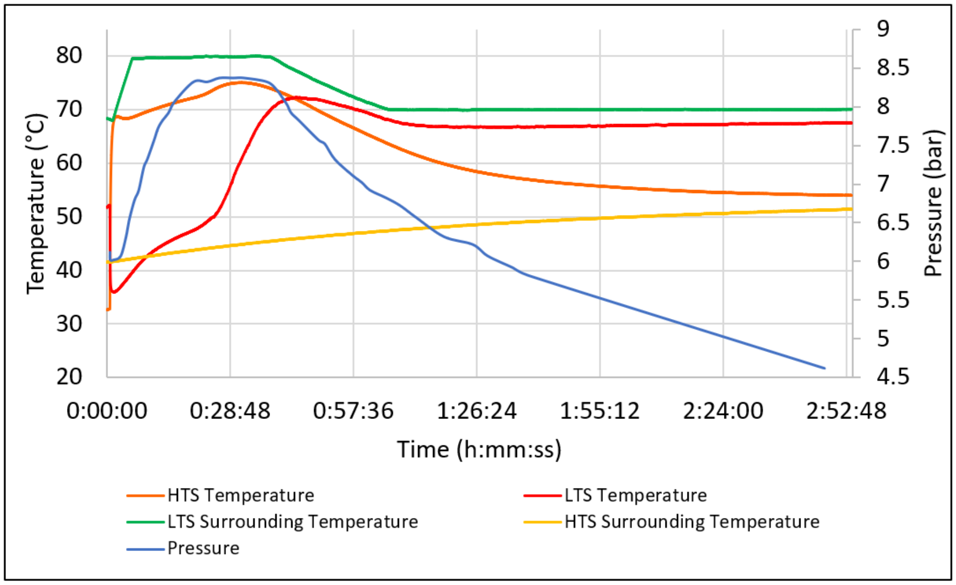


Figure 5.8: Pressure and temperature profile of discharging mode in experiment 5.

The HTS temperature and system pressure increased due to ΔT increase in LTS demonstrated in the first part of this experiment, where the LTS temperature bath set from 70°C to 80°C right after discharge began. This created a large ΔT between LTS, and it's surrounding temperature, boosting the ammonia release rate in LTS, so that system pressure and HTS temperature increased. Later part of this experiment also shows similar behavior with test 4, where the pressure and HTS temperature declined as the ΔT between LTS and LTS temperature bath start decreased 40 minutes into the discharge.

5.2.6 Experiment 6 and 7

In experiment 6 and 7, the comparison is made to see whether the initial temperature in HTS affects temperature lift magnitude. The charging temperature, LTS discharge temperature, and LTS temperature bath are the same for both of experiment.

The charging process lasts for a total of 5 hours with 3 hours at temperatures higher than

180°C. During the charging in experiment 6, the system pressure increased before stabilized at 7.9 bar for the last 1.5 hours. In experiment 7, the pressure maintained at 8.22 bar. The temperature in LTS is set constant at 40°C throughout the test.

In the discharging process, the LTS heated to 70°C for the initial discharge and LTS temperature bath set to 80°C for both tests. The HTS was heated to 40°C in experiment 6 and HTS for experiment 7 is left at room temperature. The discharging process lasts for about 3 hours for both tests. The pressure and temperature profiles of discharging mode can be seen in Figure 5.9 and Figure 5.10.

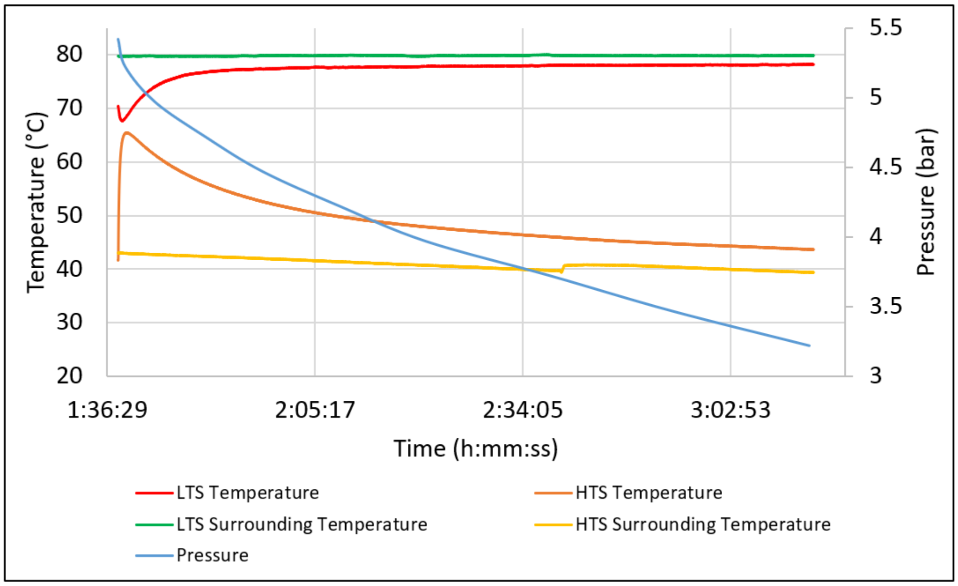


Figure 5.9: Pressure and temperature profile of discharging mode in experiment 6.

The result the Figure 5.9 and Figure 5.10 show experiment 6 has 5°C more temperature lift in HTS than experiment 7. So, it can be said that the initial HTS temperature does not give a significant effect on the temperature lift. In terms of pressure, experiment 7 experienced a 0.9 bar pressure decrease in the first 5 minutes of discharge compared to 0.5 bar decrease in experiment 6.

5.3 Other observations

In this section, the additional observation from the experiments is presented. The observation consists of the equilibrium state and the salt's physical changes.

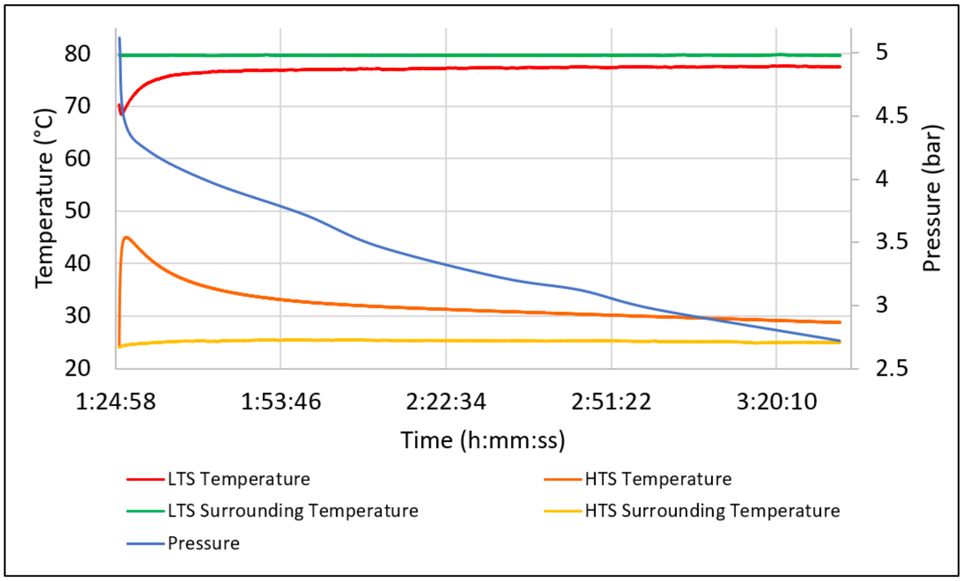


Figure 5.10: Pressure and temperature profile of discharging mode in experiment 7.

5.3.1 Equilibrium state of the salts

In the second and third charging and discharging experiment, a test carried out to check the equilibrium condition of the salts and to see the comparison between the salt equilibrium data from the literature. The test performed in the desorption process of each salt. To measure the pressure and temperature in equilibrium condition, temperature increase must be small and slow to ensure the pressure close to the equilibrium condition for the selected temperature. Figure 5.11 shows the result of equilibrium test during desorption for HTS and LTS.

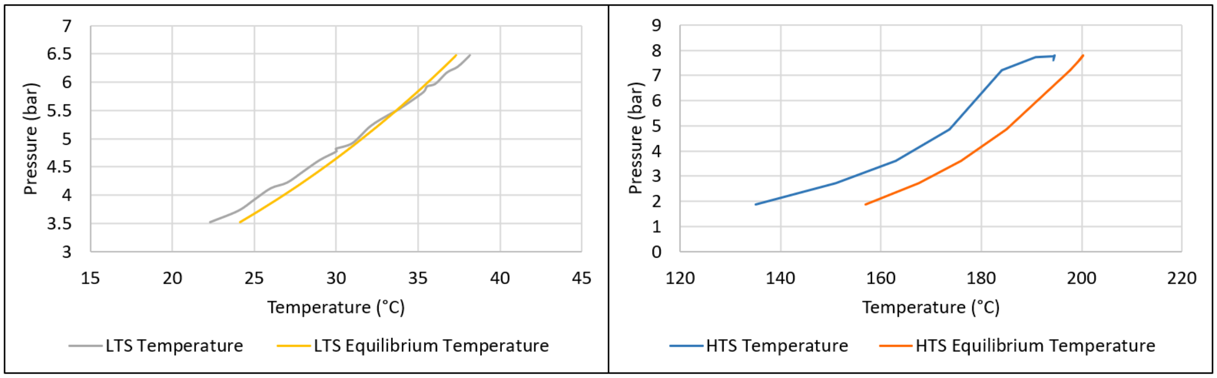


Figure 5.11: Comparison of equilibrium state between experiment and literature.

The comparison in Figure 5.11 shows very small difference in LTS side with average difference of 0.17°C. The equilibrium line from experiment and literature is intersecting between each other. Meanwhile, the result in the HTS side shows some gap between experiment and literature data with the average difference of 10.34°C between experiment and literature data. However, there is a big possibility that the equilibrium state was not achieved due to the decreasing trend of temperature increase between experiment and literature data as can be seen in Figure 5.12. The total experiment time for HTS side is six hours, which display a slow process to an equilibrium condition.

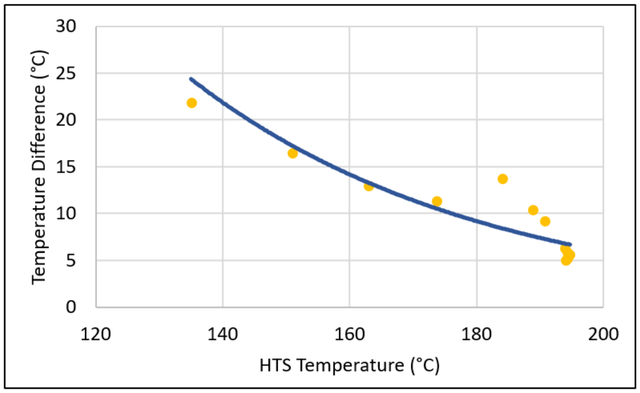


Figure 5.12: Equilibrium-temperature difference profile between experiment and literature data of HTS.

5.3.2 Heat distribution in discharging process

In the experiment 7, a thermal camera was used to observe the heat distribution in the discharging process. Figure 5.13 shows heat distribution profile in the discharging process.

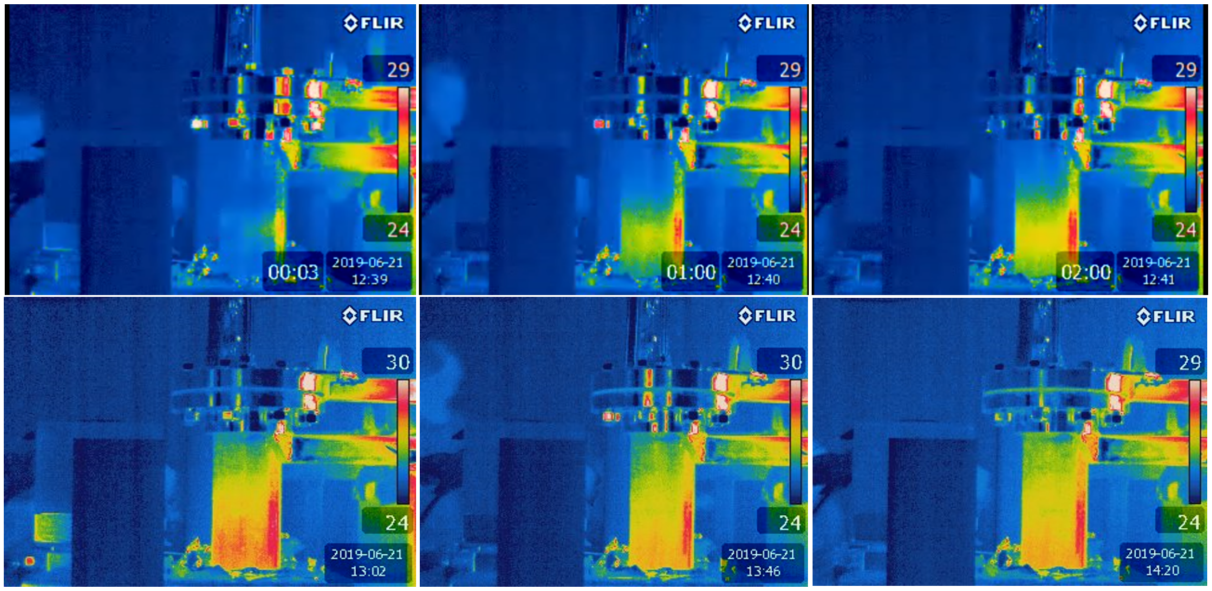


Figure 5.13: Heat distribution profile in the discharging process of experiment 7.

The first three images were taken in the first 3 minutes of discharging while the remaining pictures captured 23 minutes, 67 minutes, and 101 minutes into the process, respectively. The thermal camera shows unequal heat distribution, with the hottest point being on the side of the cylinder. Considering the arrangement of salt around the cylinder wall with a hole in the middle as in Figure 4.1, the reaction temperature in the salt occurs unevenly or only in certain spots. Therefore, some of the salts might not react or slowly react during the process.

5.3.3 Salt physical changes and reduced performance

After the experiment finished, the rig was disassembled, and the salts inside the reactor cylinder were examined. Although they have been depressurized, the ammonia gas still exists in the salt. The HTS, which is $MgCl_2$, showed noticeable expansion compared to the initial condition. The form is no longer powdery and became agglomerated. The salt in the upper side of the cylinder is brittle, but it is more solid on the lower part of the cylinder. There is no change in the color except for a slightly orange stain which came from the rusted steel wool.

In the LTS cylinder, most of the NaBr are concentrated on the bottom part of the cylinder. The grain size of NaBr does not show significant change, and it has been agglomerated. Figure 5.14 shows salt physical condition after the experiment.

Figure 5.14: The salts condition after the experiment (left:NaBr, right:$MgCl_2$).

The agglomeration in the salts will reduce the reaction surface. Except for test 1, which executed with a small amount of ammonia, the peak temperature of adsorption in the ammonia filling process gradually reduced. The reduce in performance also happened in the main experiment. Although the settings for each test are different, the trend of temperature lift in HTS shows a decrease. Figure 5.15 shows the decreasing trend of HTS temperature lift in ammonia filling process.

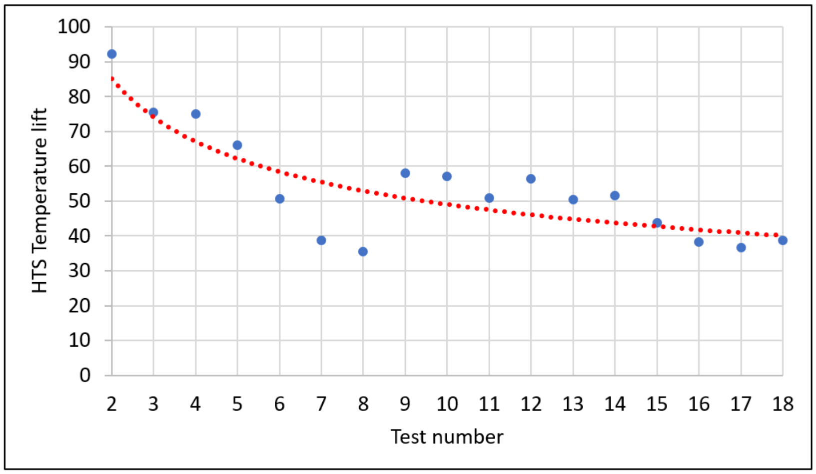


Figure 5.15: Temperature lift trend in ammonia filling process

Chapter 6

Conclusion and Recommendation for Further Work

In this chapter. The conclusion and future recommendation of the project will be presented. The process of creating the rig, as well as the activities throughout the experiments have been carried out. The suggestions for future work have been created based on the findings in the experiment.

6.1 Conclusion

The design of an adsorption system has been developed from the project semester. The improved prototype design then communicated with the laboratory technician to be adjusted and built. The building process and the discussion with laboratory technician have given many new insights and sense in equipment building.

The theoretical concept of charging and discharging in the salt-ammonia system has been demonstrated through desorption and adsorption process. Seven charging and discharging experiments have been carried out under various circumstances and analyzed. The behavior of the system pressure and salts temperature during the tests have been studied. The temperature difference between the surrounding and LTS surface has been identified as one of the most critical parameters to produce high temperature in HTS.

Although 220°C heat output in HTS is not demonstrated in this experiment, there are indicators which suggest that the potential to reach the heat output in cooking temperature is still there. Among them, the substantial signs are a considerably high temperature lift in HTS adsorption during ammonia filling despite limited ammonia in low system pressure and the ability for the system pressure to balance in the discharge mode.

Furthermore, the analysis and shortcomings that have been found during the design and experiment are discussed, and the suggestion for improvement and further study are presented in the next section.

6.2 Recommendations for Further Work

In this section, several recommendations were made to improve the accuracy of the measurement. Besides, a suggestion was made for further research based on the current results and discussions.

6.2.1 Recommendation for prototype improvement

Aside from using the mass-flow meter, which is expensive, a suggestion has been made to minimize the uncertainties that happened during the experiments with current systems. Instead of using the weighing scale, ammonia intake calculation can be applied to the ammonia tank using state equation by installing pressure gauge and thermocouple in the small ammonia tank. With the constant volume and temperature, initial and final pressure of the tank provides the information about the total amount of gas injected to the adsorption rig.

Another suggestion related to measurement during charging and discharging is to use a pressure sensor instead of the pressure gauge. The pressure sensor will enable real-time measurement and avoid the parallax error during continuous measurement with pressure gauge.

6.2.2 Further research

The result from the study shows the sign of deterioration in the salts. Besides, observation on the physical salt condition after charging and discharging process have shown that most of the salts were agglomerated. The agglomeration in the salts greatly reduces the reaction surface and salts performance.

Therefore, the study to improve the reaction surface and create an adsorption model in the salt-ammonia system considered to be essential to improve the charging and discharging performance. It also needs to be noted that the study does not necessarily limited to the current selection of salt. Instead, the study can involve a comparison from different salts and its arrangement to maximize the salt surface.

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Appendix A

Risk and safety precautions

Table A.1: The summarized risk and safety precautions of the salt candidates from [2]

No	Name	Risk and safety precautions
1	NaBr-5.25/0	Non-flammable. Incompatible with a strong acid (sulphate etc). Easily soluble in water. Under acidic condition, it can be oxidized by oxygen and release free bromine. Avoid eye and skin contact.
2	$BaCl_2$-8/0	Non-combustible. Toxic if swallowed, inhaled (0.8 gr ingestion may be fatal). Irritating to the eyes and skin. May cause cancer. When contact with boron trifluoride, violent reaction can occur.
3	$CaCl_2$-8/4	Toxicity: 4g/ kg. Generally approved to be safe (USFDA). Inhalation, ingestion, and contact with eyes cause irritation. Long term exposure of Calcium chloride solution upon a zinc coated galvanized iron vessel caused may cause ignition and explosion. Dissolves violently in water with generation of much heat.
4	$SrBr_2$-8/2	Irritating to eyes, respiratory system, and skin. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Do not empty into drains. This material and its container must be disposed of in a safe way. Wear suitable protective clothing.

5	$MnBr_2$-6/2	Stable, but very hygroscopic. Incompatible with strong oxidizing agents. Store under a dry atmosphere. Harmful by inhalation, contact with skin, and swallowed. Irritating to the eyes.
6	$CoCl_2$-6/2	May cause cancer by inhalation. May cause sensitization by inhalation. Risk of serious damage to eyes and harmful if swallowed. Very Toxic to aquatic organisms. Possible risk of irreversible effects. Avoid exposure. Do not breathe gas/fumes/vapor/spray. Wear suitable protective clothing and gloves, eyes, face. This material and/or its container must be disposed of as hazardous waste.
7	$MgCl_2$2-6/2	May cause sensitization by skin contact. Irritating to the eyes. Irritating to the respiratory system.
8	$FeBr_2$-6/2	Harmful and very toxic by inhalation, contact with skin and swallowed. Contact with water or acids liberates toxic gas. Can be highly flammable in use. Causes severe burns and irritating to the eyes. Avoid adding water. Wear suitable protective clothing.
9	CaI_2-6/2	Exposures can cause adverse health effects on the skin, blood, kidneys, and lungs. Causes irritation to the eyes and skin and corrosive effects to the skin. Extremely hazardous in case of ingestion. Suspected for human carcinogen.
10	$CoBr_2$-6/2	May cause cancer. Harmful by inhalation, contact with skin, and swallowed. Causes severe burns, sensitization, and irritating to eyes and respiratory system. Do not breathe dust. Wear suitable protective clothing, gloves, and eye/face protection. In case of accident or if you feel unwell, seek medical advice immediately. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Avoid exposure.
11	$NiCl_2$-6/2	May cause cancer by inhalation and swallowed. Danger of serious damage to health by prolonged exposure. Toxic and harmful if swallowed. Possible risk of irreversible effects. May cause harm to the unborn child.

12	NH_4Cl-3/0	Harmful if swallowed. Irritating to respiratory system and skin. Irritating to the eyes and risk of serious damage to eyes. Do not breathe dust. Wear suitable protective clothing.
13	$PbCl_2$-8/3.25	May cause harm to the unborn child. Harmful by inhalation and in contact with skin. Possible risk of impaired fertility. Avoid exposure. In case of accident or if you feel unwell, seek medical advice immediately (show label where possible). This material and/or its container must be disposed of as hazardous waste.
14	LiCl-4/3	Highly Flammable. Irritating and harmful to eyes, respiratory system and skin. Causes severe burns. Do not breathe dust. May form explosive peroxides. May impair fertility. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear suitable protective clothing, gloves and eye/face protection. Keep away from sources of ignition. In case of accident or if you feel unwell, seek medical advice immediately (show label where possible). Do not empty into drains.
15	NaI-4.5/0	Irritating to eyes, respiratory system, and skin. Very Toxic to aquatic organisms. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Avoid release to the environment.
16	$BaBr_2$-8/4	Harmful by inhalation and swallowed. After contact with skin, wash immediately.
17	$SrCl_2$-8/1	Irritating to eyes, respiratory system, and skin. Risk of serious damage to eyes. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear eye/face protection.

18	$MnCl_2$-6/2	Danger of serious damage to health by prolonged exposure if swallowed. Harmful to aquatic organisms. Do not breathe dust. Wear suitable protective clothing. In case of accident or if you feel unwell, seek medical advice immediately (show label where possible). Avoid release to the environment.
19	$CaBr_2$-6/2	Irritating to the skin. Risk of serious damage to eyes. Do not breathe dust. Wear eye/face protection. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
20	$FeCl_2$-6/2	Harmful if swallowed. Causes burns. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear suitable protective clothing, gloves, and eye/face protection. In case of accident or if you feel unwell, seek medical advice immediately (show label where possible).
21	MnI_2-6/2	May cause harm to the unborn child. Wear suitable protective clothing, gloves, and eye/face protection. Avoid exposure. In case of accident or if you feel unwell, seek medical advice immediately (show label where possible).
22	FeI_2-6/2	Harmful by inhalation, in contact with skin and if swallowed. Irritating to eyes, respiratory system, and skin. Do not breathe dust. May cause harm to the unborn child. Avoid exposure. Wear suitable protective clothing, gloves, and eye/face protection. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. In case of accident or if you feel unwell, seek medical advice immediately (show label where possible).
23	$MgBr_2$-6/2	Irritating to eyes, respiratory system, and skin. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear suitable protective clothing.

24	$NiBr_2$-6/2	May cause cancer. Harmful if swallowed. May cause sensitization or cancer by inhalation and skin contact. Very Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment. Danger of serious damage to health by prolonged exposure through inhalation. May cause harm to the unborn child. Avoid exposure. Wear suitable protective clothing and gloves. In case of accident or if you feel unwell, seek medical advice immediately (show label where possible). This material and/or its container must be disposed of as hazardous waste. Avoid release to the environment.
25	NiI_2-6/2	May cause cancer. May cause harm to the unborn child. May cause sensitization by inhalation and skin contact. Avoid exposure. Do not breathe dust. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear suitable protective clothing, gloves, and eye/face protection. In case of accident or if you feel unwell, seek medical advice immediately (show label where possible).

Appendix B

Risk assessment report

This appendix contains risk assessment report as a requirement to perform the experiment.

NTNU

Risk Assessment Report

Adsorption of Salt-Ammonia

Project description	Adsorption-based Heat Storage for Cooking
Apparatus	Salt-Ammonia adsorption equipment
Unit	NTNU-EPT
Apparatus responsibility	Ole Jørgen Nydal
Supervisor	Ole Jørgen Nydal
HSE coordinator	Morten Grønli
HSE leader (linjeleder)	Terese Løvås
Place	VATL
Room number	C162
Risk assessment done by	Pomto Jaya

Approval:

Apparatur kort (UNIT CARD) valid for:	12 months
Forsøk pågår kort (EXPERIMENT IN PROGRESS) valid for:	12 months

Role	Name	Date	Signature
Supervisor	Ole Jørgen Nydal	3/6/19	Ole Jørgen Nydal
HSE coordinator	Morten Grønli	4/6/19	M Grønli
HSE leader (linjeleder)	Terese Løvås	12/6-19	Terese Løvås

NTNU

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NTNU

1 INTRODUCTION

This experiment involves the small double-reactor connected by steel pipe. Each of the reactors will be filled with different salt which sits on steel wool (*stålull*). The salts will be reacted with ammonia gas at certain pressure and temperature to generate heat. The reaction will be reversible in between two reactors. Salt in reactor 1 desorb ammonia while salt in reactor 2 adsorb ammonia, and vice versa. Oil and Water bath will also be used to regulate the reactor temperature. The maximum temperature of the experiment will be around 215 Celsius and the maximum system pressure will be around 22 bar.

The purpose of the experiment is to prove the adsorption and desorption process in salt-ammonia adsorption equipment on its capability to produce heat.

2 ORGANIZATION

Role	
Supervisor	Ole Jørgen Nydal
App. responsibility	Ole Jørgen Nydal
Room responsibility	Paul Svendsen
HSE coordinator	Morten Grønli
HSE leader (linjeleder):	Terese Løvås

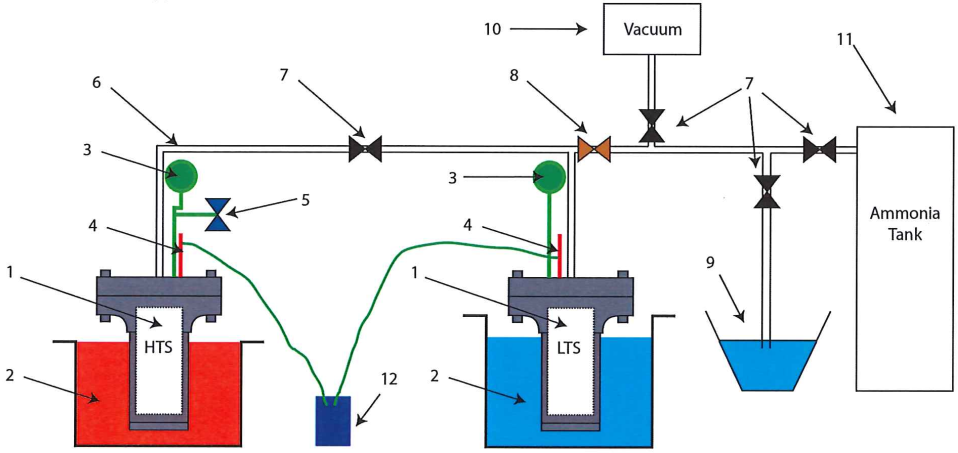
3 RISK MANAGEMENT IN THE PROJECT

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

4 DESCRIPTIONS OF EXPERIMENTAL SETUP

The system consists of the following components (see the sketch below):

1. Reaction cylinders filled with salt (NaBr and $MgCl_2$) and steel wool
2. Temperature bath
3. Analog pressure gauges
4. Thermocouples
5. Safety valve
6. Pipe
7. Valves
8. Regulator
9. Water bucket
10. Vacuum pump
11. Ammonia tank
12. Pico logger



The shutdown of the system is done by turning off the temperature bath.

5 EVACUATION FROM THE EXPERIMENTAL AREA

The experiment will use ammonia, $MgCl_2$ salt, NaBr salt, water and oil. The operating pressure during the experiment is maximum 22 bars. Evacuation may be necessary if there is a gas leak from the adsorption setup, or other unrelated lab activity.

Evacuate at signal from the alarm system or local gas alarms with its own local alert with sound and light outside the room in question, see 6.2

Evacuation from the experiment area takes place through the marked emergency exits to the assembly point, (corner of Old Chemistry Kjelhuset or parking 1a-b.)

Action on the equipment setup before evacuation:
The unit shall be shut down by turning off the temperature batch and taking out the temperature bath from reaction cylinder.

6 WARNING

6.1 Before experiments

Send e-mail with information about the planned experiment to:
iept-experiments@ivt.ntnu.no

The e-mail must include the following information:

- Name of responsible person
- Experimental setup
- Start Experiments (date and time)
- Stop Experiments (date and time)

You must get the approval back from the laboratory management before starting up. All running experiments are notified in the activity calendar for the lab to be sure they are coordinated with other activity.

6.2 Abnormal situation

FIRE

If you are NOT able to extinguish the fire, activate the nearest fire alarm and evacuate area. Then, be available for fire brigade and building caretaker to detect place of fire.
If possible, notify:

NTNU
Morten Grønli, Mob: 918 97 515
Terese Løvås: Mob: 918 97 007
NTNU – SINTEF Beredskapstelefon

GAS ALARM

If a gas alarm occurs, close gas bottles immediately and ventilate the area. If the level of the gas concentration does 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.

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 NON-CONFORMANCE (AVVIK)

NTNU:
You will find the reporting form for non-conformance on:
https://innsida.ntnu.no/wiki/-/wiki/Norsk/Melde+avvik

7 ASSESSMENT OF TECHNICAL SAFETY

7.1 HAZOP

Node 1	Ammonia-$MgCl_2$-NaBr reaction on reaction cylinder 1 and 2

Attachments: Hazop.
Conclusion: The equipment has been designed above operating pressure. Avoid touching the equipment without safety/heat proof gloves. The dangers are manageable.

7.2 Flammable, reactive and pressurized substances and gas

Are any flammable, reactive and pressurized substances and gases in use?

YES	Pressurized ammonia gas.

Attachments: not required.
Conclusion: The equipment has been designed above predicted maximum pressure. Avoid touching the equipment without safety/heat proof gloves. The dangers are manageable.

7.3 Pressurized equipment

Is any pressurized equipment in use?

YES	Pressurized ammonia tank

Attachments: not required.
Conclusion: The equipment will be checked before use. Avoid touching the equipment without safety/heat proof gloves. The dangers are manageable.

7.4 Effects on the environment (emissions, noise, temperature, vibration, smell)

Will the experiments generate emission of smoke, gas, odor or unusual waste?
Is there a need for a discharge permit, extraordinary measures?

YES	Ammonia gas

Attachments: not required.
Conclusion: The set-up shall be checked for any leakages before, during and after the experiment. The release valve is connected to water bucket to dissolve the ammonia gas. The amount of ammonia gas in use is relatively small.

7.5 Radiation

NO	

7.6 Chemicals

YES	$MgCl_2$ salt.
YES	NaBr salt.

Attachments: not required.
Conclusion: The salt is non-flammable. Avoid direct contact with skin, eyes, and inhaled. Safety google, gloves, and mask must be used when handling the chemicals.

7.7 Electricity safety (deviations from the norms/standards)

NO	

8 ASSESSMENT OF OPERATIONAL SAFETY

Ensure that the procedures cover all identified risk factors that must be taken care of. Ensure that the operators and have enough expertise.

8.1 Procedure HAZOP

The method is a procedure to identify causes and sources of danger to operational problems. Procedure:

1) Put a board in the bottom of the equipment setup and another board beside it to avoid spills of hot oil or hot water when taking out the reactor from temperature control box.
2) Test all the connections using water to check for leaks.
3) Ensure the heater is working and the temperature setting can be controlled.

Attachments: Hazop procedure template
Conclusion: Simplified procedure. Misunderstandings will not lead to unacceptable hazardous situations.

8.2 Operation procedure and emergency shutdown procedure

The operating procedure is a checklist that must be filled out for each experiment.
Be careful to operate the valves slowly. To avoid any severe damage to equipment and people, it is vital that the stepwise start up and shut down procedure included in the attachments is followed.
Emergency procedure should attempt to set the experiment set up in a harmless state by unforeseen events.

Attachments: Procedure for running experiments
Emergency shutdown procedure: Turn off the oil and water heater.

8.3 Training of operators

A Document showing training plan for operators

- *What are the requirements for the training of operators?*
- *What it takes to be an independent operator*
- *Job Description for operators*

Attachments: Training program for operators

8.4 Technical modifications

The operator cannot modify the adsorption setup using available parts, i.e. change pipe diameters, pipeline length, etc.
The operator can modify the salt amount inside the reactor and ammonia supply to the system.
No technical modifications needed which produce risk.

Conclusion: No dangerous modifications during the experiment.

8.5 Personal protective equipment

Safety goggles, mask, and gloves should be used to prevent contact with eye and skin damage.

8.6 General Safety

- The area around the adsorption setup should be tidy. Cables, pipelines, and tools shall be stored neatly to prevent stumbling accidents
- Gantry crane and truck driving should not take place close to the experiment and they should be turned off during the experiments.
- Operator cannot leave the lab during experiments.
- The warning signs for the hot equipment must be used.

Conclusion*:* Signs and monitoring by operator.

8.7 Safety equipment

Safety equipment: warning signs, gloves, safety googles, mask.

8.8 Special predations

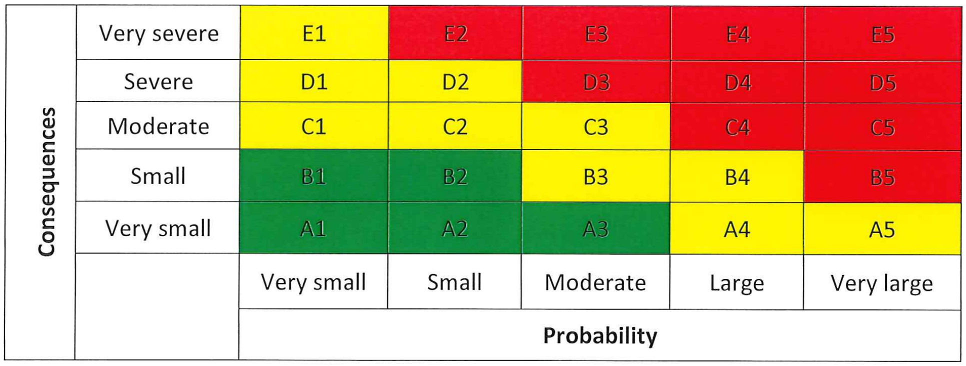
One operator must be near the adsorption setup during tests to make sure the temperature and pressure are within the design range and no major leaks.

9 QUANTIFYING OF RISK - RISK MATRIX

The risk matrix will provide visualization and an overview of activity risks so that management and users get the most complete picture of risk factors.

Activity from the identification process form	**Potential undesirable incident/strain**	**Likelihood:**	**Consequence:**			**Risk Value (human)**	**Comments/status Suggested measures**
		Likelihood (1-5)	Human (A-E)	Environment (A-E)	Economy/ material (A-E)		
Filling the salts into the reactors.	Inhaled, in contact with eyes or skin.	2	B	A	A	B2	Always use mask, google, and gloves during the activity.
Filling the ammonia gas into the system	Leaked ammonia.	2	A	A	A	A2	Always use mask during the activity.
Adsorption and desorption process in the system (by heating).	Leaked ammonia.	2	A	A	A	A2	Always use mask during the activity.
Shutting down the system.	Contact with hot apparatus	2	A	A	A	A2	Use heat-proof gloves during the activity.
Ammonia gas and salts removal.	Inhaled, in contact with eyes or skin.	2	B	A	A	B2	Always use mask, google, and gloves during the activity.

Conclusion: There are no intolerable risks connected to the experiment. The ground around the adsorption setup should be kept dry and clean and protective equipment should be used during experiment.



Consequences	Very severe	E1	E2	E3	E4	E5
	Severe	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Small	B1	B2	B3	B4	B5
	Very small	A1	A2	A3	A4	A5
		Very small	Small	Moderate	Large	Very large
		Probability				

The principle of the acceptance criterion; explanation of the colors used in the matrix

Color		**Description**
Red	🟥	Unacceptable risk Action has to be taken to reduce risk
Yellow	🟨	Assessment area. Actions has to be considered
Green	🟩	Acceptable risk. Action can be taken based on other criteria

10 REGULATIONS AND GUIDELINES

See 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 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 Tekniske innretninger
- Forskrift om Tungt og ensformig arbeid
- Forskrift om Vern mot eksponering for kjemikalier på arbeidsplassen (Kjemikalieforskriften)
- Forskrift om Vern mot mekaniske vibrasjoner

Guidelines from *Arbeidstilsynet*
se: http://www.arbeidstilsynet.no/regelverk/veiledninger.html

11 DOCUMENTATION

- Drawings, photos, description of the experimental setup
- Hazop template
- Certificate for local pressure testing
- Hazop procedure template
- Procedure for running experiments
- Training of operators
- Form for safe job analysis (SJA)
- Unit card
- Experiment in progress card

NTNU

Attachment to Risk Assessment report

Adsorption of Salt-Ammonia

Prosjektnavn	Adsorption-based Heat Storage for Cooking
Apparatur	Salt-Ammonia adsorption equipment
Enhet	NTNU
Apparaturansvarlig	Ole Jørgen Nydal
Prosjektleder	Ole Jørgen Nydal
HMS-koordinator	Morten Grønli
HMS-ansvarlig (linjeleder)	Terese Løvås
Plassering	VATL
Romnummer	C162
Risikovurdering utført av	Pomto Jaya

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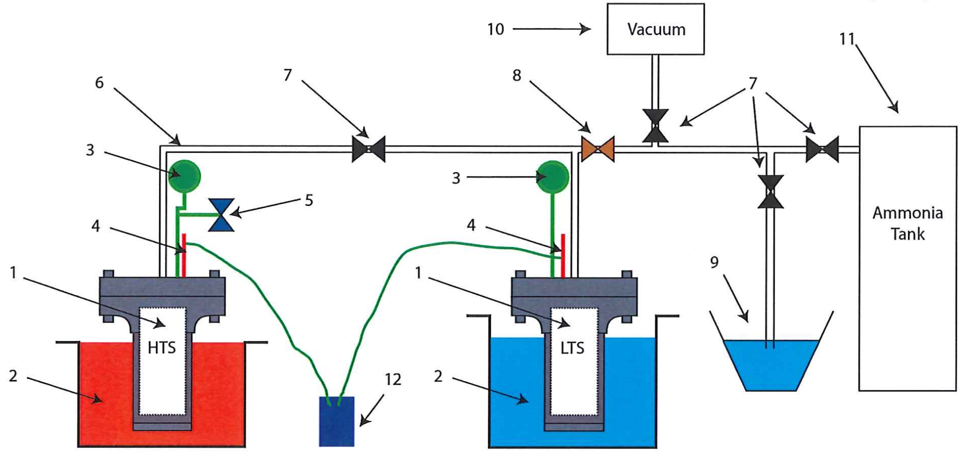
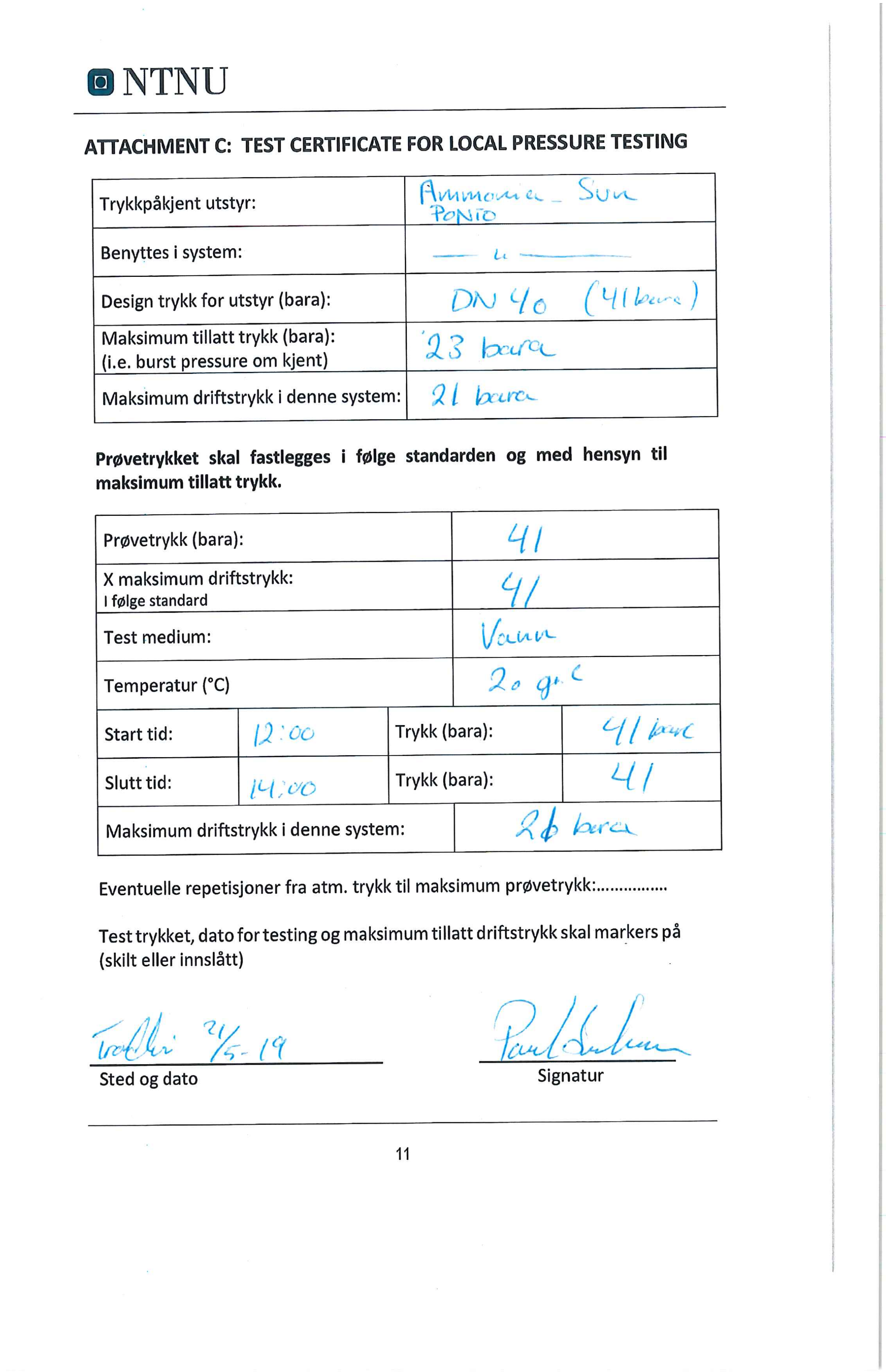
ATTACHMENT A: PROCESS AND INSTRUMENTATION DIAGRAM (PID)



Legend:

1. Reaction cylinders filled with salt (NaBr and $MgCl_2$) and steel wool
2. Temperature bath
3. Analog pressure gauges
4. Thermocouples
5. Safety valve
6. Pipe
7. Valves
8. Regulator
9. Water bucket
10. Vacuum pump
11. Ammonia tank
12. Pico logger



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ATTACHMENT C: TEST CERTIFICATE FOR LOCAL PRESSURE TESTING

Trykkpåkjent utstyr:	Ammonia_Sun PONTO
Benyttes i system:	— " —
Design trykk for utstyr (bara):	DN 40 (41 bara)
Maksimum tillatt trykk (bara): (i.e. burst pressure om kjent)	23 bara
Maksimum driftstrykk i denne system:	21 bara

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

Prøvetrykk (bara):	41		
X maksimum driftstrykk: I følge standard	41		
Test medium:	Vann		
Temperatur (°C)	20 gr. C		
Start tid:	12:00	Trykk (bara):	41 bara
Slutt tid:	14:00	Trykk (bara):	41
Maksimum driftstrykk i denne system:	26 bara		

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

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

Trheim 21/5-19

Sted og dato

Signatur

11

NTNU

ATTACHMENT E: PROCEDURE FOR RUNNING EXPERIMENTS

Prosjekt Adsorption-based Heat Storage for Cooking		
Apparatur Salt-Ammonia adsorption equipment	**Dato**	**Signatur**
Prosjektleder Ole Jørgen Nydal	3/6/19	Ole Jørgen Nydal

	Conditions for the experiment:	**Completed**
	Experiments should be run in normal working hours, 08:00-16:00 during winter time and 08.00-15.00 during summer time.	
	One person must always be present while running experiments and should be approved as an experimental leader.	
	Be sure that everyone taking part of the experiment is wearing the necessary protecting equipment and is aware of the shutdown procedure and escape routes.	
	Preparations	**Carried out**
	Post the "Experiment in progress" sign.	
	Be sure that the ventilation in the room is working	
	Start of Experiment	**Carried out**
	Fill the ammonia into the system.	
	Turn on the temperature bath and set the temperature according to the plan.	
	Dip the reactors into temperature bath.	
	During the experiment	
	Control of temperature and pressure.	
	Control the valves.	
	End of experiment	
	Turn the temperature bath off.	
	Take the reactors out from temperature bath if necessary.	
	Remove all obstructions/barriers/signs around the experiment.	
	Tidy up and return all tools and equipment.	
	Tidy and cleanup work areas.	
	Return equipment and adsorption setup back to their normal operation settings (fire alarm)	
	To reflect on before the next experiment and experience useful for others	
	Was the experiment completed as planned and on scheduled in professional terms?	
	Was the competence which was needed for security and completion of the experiment available to you?	
	Do you have any information/ knowledge from the experiment that you should document and share with fellow colleagues?	

Operator(s):

Navn	Dato	Signatur
Pomto Jaya	03/06/2019	

NTNU

ATTACHMENT F: TRAINING OF OPERATORS

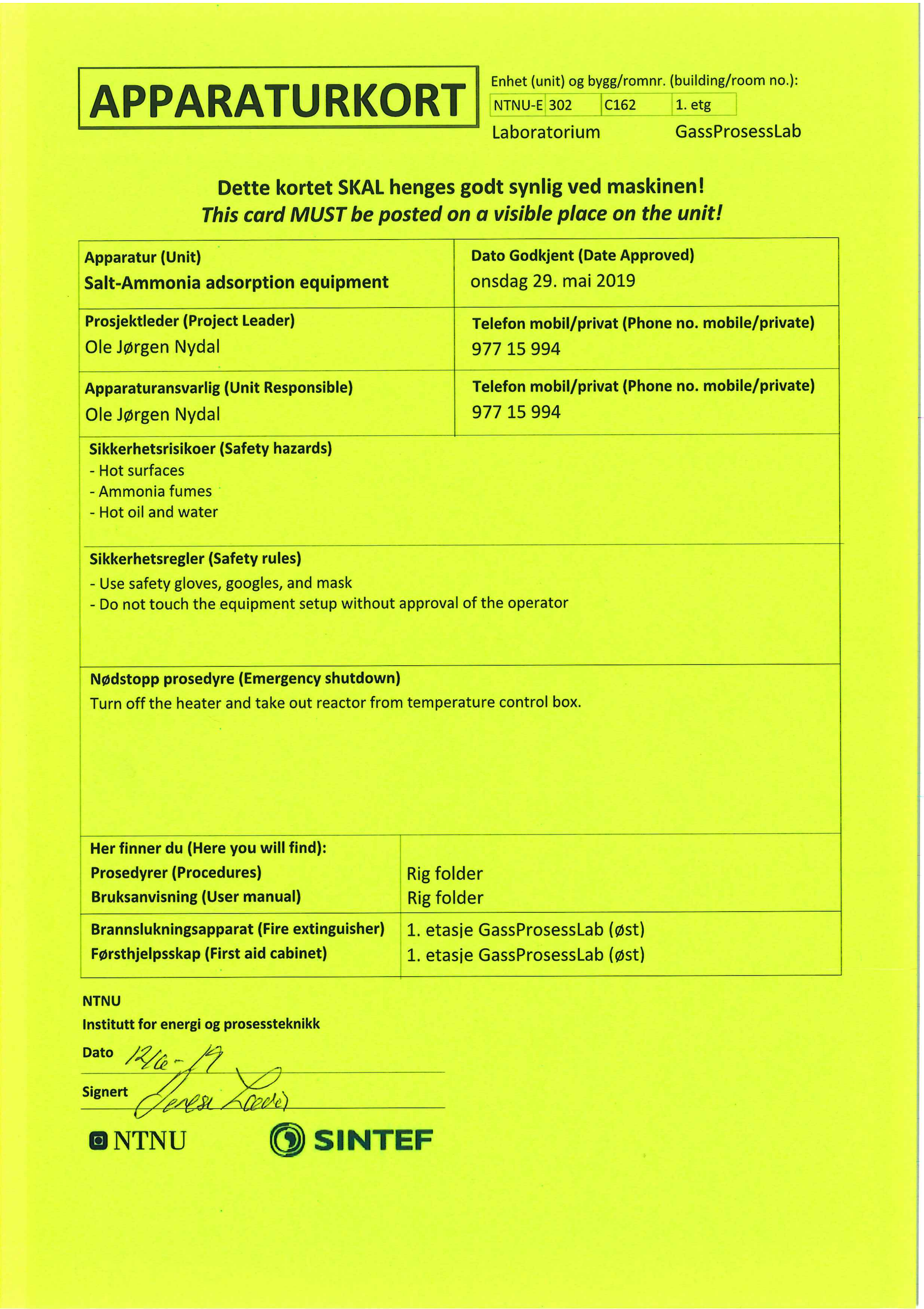
Prosjekt Adsorption-based Heat Storage for Cooking		
Apparatur Salt-Ammonia adsorption equipment	**Dato**	**Signatur**
Prosjektleder Ole Jørgen Nydal	3/6/19	

	Knowledge about EPT LAB in general	
	Lab • Access • routines and rules • working hour	
	Knowledge about the evacuation procedures.	
	Activity calendar for the Lab	
	Early warning, iept-experiments@ivt.ntnu.no	
	Knowledge about the experiments	
	Procedures for the experiments	
	Emergency shutdown.	
	Nearest fire and first aid station.	

I hereby declare that I have read and understood the regulatory requirements has received appropriate training to run this experiment and are aware of my personal responsibility by working in EPT laboratories.

Operator(s):

Navn	Dato	Signatur
Pomto Jaya	03/06 2019	



APPARATURKORT

Enhet (unit) og bygg/romnr. (building/room no.):

NTNU-E	302	C162	1. etg

Laboratorium GassProsessLab

Dette kortet SKAL henges godt synlig ved maskinen!
This card MUST be posted on a visible place on the unit!

Apparatur (Unit) **Salt-Ammonia adsorption equipment**	**Dato Godkjent (Date Approved)** onsdag 29. mai 2019
Prosjektleder (Project Leader) Ole Jørgen Nydal	**Telefon mobil/privat (Phone no. mobile/private)** 977 15 994
Apparaturansvarlig (Unit Responsible) Ole Jørgen Nydal	**Telefon mobil/privat (Phone no. mobile/private)** 977 15 994

Sikkerhetsrisikoer (Safety hazards)

- Hot surfaces
- Ammonia fumes
- Hot oil and water

Sikkerhetsregler (Safety rules)

- Use safety gloves, googles, and mask
- Do not touch the equipment setup without approval of the operator

Nødstopp prosedyre (Emergency shutdown)

Turn off the heater and take out reactor from temperature control box.

Her finner du (Here you will find):	
Prosedyrer (Procedures)	Rig folder
Bruksanvisning (User manual)	Rig folder
Brannslukningsapparat (Fire extinguisher)	1. etasje GassProsessLab (øst)
Førsthjelpsskap (First aid cabinet)	1. etasje GassProsessLab (øst)

NTNU
Institutt for energi og prosessteknikk

Dato 12/6-19

Signert Terese Løvås

NTNU SINTEF

FORSØK PÅGÅR

Enhet (unit) og bygg/romnr. (building/room no.):

NTNU-E	302	C162	1. etg

Laboratorium GassProsessLab

Dette kortet SKAL henges opp før forsøk kan starte!
This card MUST be posted on the unit before the experiment startup!

Apparatur (Unit) **Salt-Ammonia adsorption equipment**	**Dato godkjent (Date Approved)** onsdag 29. mai 2019
Prosjektleder (Project Leader) Ole Jørgen Nydal	**Telefon mobil/privat (Phone no. mobile/private)** 977 15 994
Apparaturansvarlig (Unit Responsible) Ole Jørgen Nydal	**Telefon mobil/privat (Phone no. mobile/private)** 977 15 994

Godkjente operatører (Approved Operators)

Navn/Name	**Telefon/Phone**	**Mobil**
Jaya, Pomto		

Prosjekt (Project)
Adsorption-based Heat Storage for Cooking

Forsøkstid / Experimental time (start - stop)
29.05.2019 - 29.05.2020

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

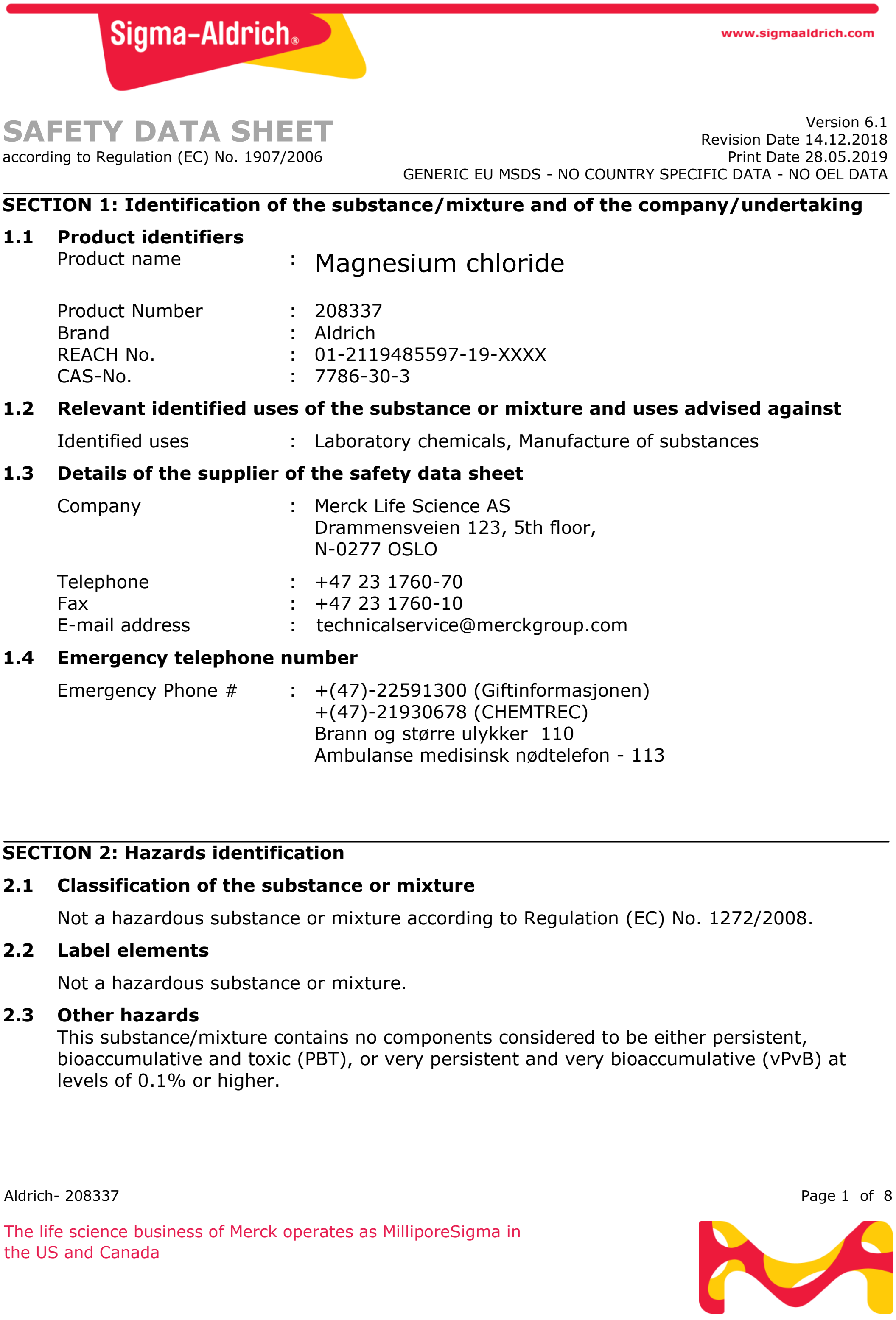
- Adsorption of ammonia gas between 2 salts through steel pipes and reactors.
- Maximum operating temperature 215 Celsius and pressure 22 bar.
- Potential hazards: ammonia fumes, hot surface, hot oil and water.

NTNU
Institutt for energi og prosessteknikk

Dato 12/6-19

Signert

NTNU SINTEF



Sigma-Aldrich® www.sigmaaldrich.com

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Version 6.1
Revision Date 14.12.2018
Print Date 28.05.2019
GENERIC EU MSDS - NO COUNTRY SPECIFIC DATA - NO OEL DATA

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifiers

Product name : Magnesium chloride

Product Number : 208337
Brand : Aldrich
REACH No. : 01-2119485597-19-XXXX
CAS-No. : 7786-30-3

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Merck Life Science AS
Drammensveien 123, 5th floor,
N-0277 OSLO

Telephone : +47 23 1760-70
Fax : +47 23 1760-10
E-mail address : technicalservice@merckgroup.com

1.4 Emergency telephone number

Emergency Phone # : +(47)-22591300 (Giftinformasjonen)
+(47)-21930678 (CHEMTREC)
Brann og større ulykker 110
Ambulanse medisinsk nødtelefon - 113

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture according to Regulation (EC) No. 1272/2008.

2.2 Label elements

Not a hazardous substance or mixture.

2.3 Other hazards

This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

SECTION 3: Composition/information on ingredients

3.1 Substances

Formula : Cl_2Mg
Molecular weight : 95,21 g/mol
CAS-No. : 7786-30-3
EC-No. : 232-094-6

No components need to be disclosed according to the applicable regulations.

SECTION 4: First aid measures

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

SECTION 5: Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

Hydrogen chloride gas, Magnesium oxide

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

No data available

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures

Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions

No special environmental precautions required.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

SECTION 7: Handling and storage

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Store in cool place. Keep container tightly closed in a dry and well-ventilated place.

Store under inert gas. Hygroscopic. Keep in a dry place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

---

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

Components with workplace control parameters

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

The selected protective gloves have to satisfy the specifications of EU Directive 89/686/EEC and the standard EN 374 derived from it.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0,11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0,11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This

recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
No special environmental precautions required.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder Colour: white
b)	Odour	odourless
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 714 °C
f)	Initial boiling point and boiling range	No data available
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	2,32 g/mL at 25 °C
n)	Water solubility	468,7 g/l at 20 °C - soluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available

q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

No data available

SECTION 10: Stability and reactivity

10.1 Reactivity

No data available

10.2 Chemical stability

Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions

No data available

10.4 Conditions to avoid

When mixed with limited amount of water enough heat may be generated to cause frothing. Exposure to moisture

10.5 Incompatible materials

Strong oxidizing agents

10.6 Hazardous decomposition products

Hazardous decomposition products formed under fire conditions. - Hydrogen chloride gas, Magnesium oxide
Other decomposition products - No data available
In the event of fire: see section 5

SECTION 11: Toxicological information

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - female - > 5.000 mg/kg
(OECD Test Guideline 423)
LD50 Dermal - Rat - male and female - > 2.000 mg/kg
(OECD Test Guideline 402)

Skin corrosion/irritation
Skin - In vitro study
Result: No skin irritation - 15 min
(Human Skin Model Test)
Remarks: (for the hexahydrate)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation - 72 h
(OECD Test Guideline 405)
Remarks: (for the hexahydrate)

Respiratory or skin sensitisation
Maximisation Test - Guinea pig

Result: negative
(OECD Test Guideline 406)

Germ cell mutagenicity
No data available
Human
lymphocyte
Result: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

Reproductive toxicity
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information

Repeated dose toxicity - Rat - male and female - Oral - No observed adverse effect level - > 1.000 mg/kg
RTECS: OM2800000

Central nervous system depression, Vomiting, Diarrhoea, Abdominal pain, To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

SECTION 12: Ecological information

12.1 Toxicity

Toxicity to fish	static test LC50 - Pimephales promelas (fathead minnow) - 2.119,3 mg/l - 96 h (US-EPA)
Toxicity to daphnia and other aquatic invertebrates	static test LC50 - Daphnia magna (Water flea) - 548,4 mg/l - 48 h
Toxicity to algae	Growth rate EC50 - Desmodesmus subspicatus (green algae) - > 100 mg/l - 72 h (OECD Test Guideline 201)
Toxicity to bacteria	static test EC50 - Activated Sludge - > 900 mg/l - 3 h (OECD Test Guideline 209)

12.2 Persistence and degradability

The methods for determining the biological degradability are not applicable to inorganic substances.

12.3 Bioaccumulative potential

No data available

12.4 Mobility in soil

No data available

12.5 Results of PBT and vPvB assessment

This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

12.6 Other adverse effects

No data available

SECTION 13: Disposal considerations

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

SECTION 14: Transport information

14.1 UN number

ADR/RID: - IMDG: - IATA: -

14.2 UN proper shipping name

ADR/RID: Not dangerous goods
IMDG: Not dangerous goods
IATA: Not dangerous goods

14.3 Transport hazard class(es)

ADR/RID: - IMDG: - IATA: -

14.4 Packaging group

ADR/RID: - IMDG: - IATA: -

14.5 Environmental hazards

ADR/RID: no IMDG Marine pollutant: no IATA: no

14.6 Special precautions for user

No data available

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

This safety datasheet complies with the requirements of Regulation (EC) No. 1907/2006.

15.2 Chemical safety assessment

For this product a chemical safety assessment was not carried out

SECTION 16: Other information

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

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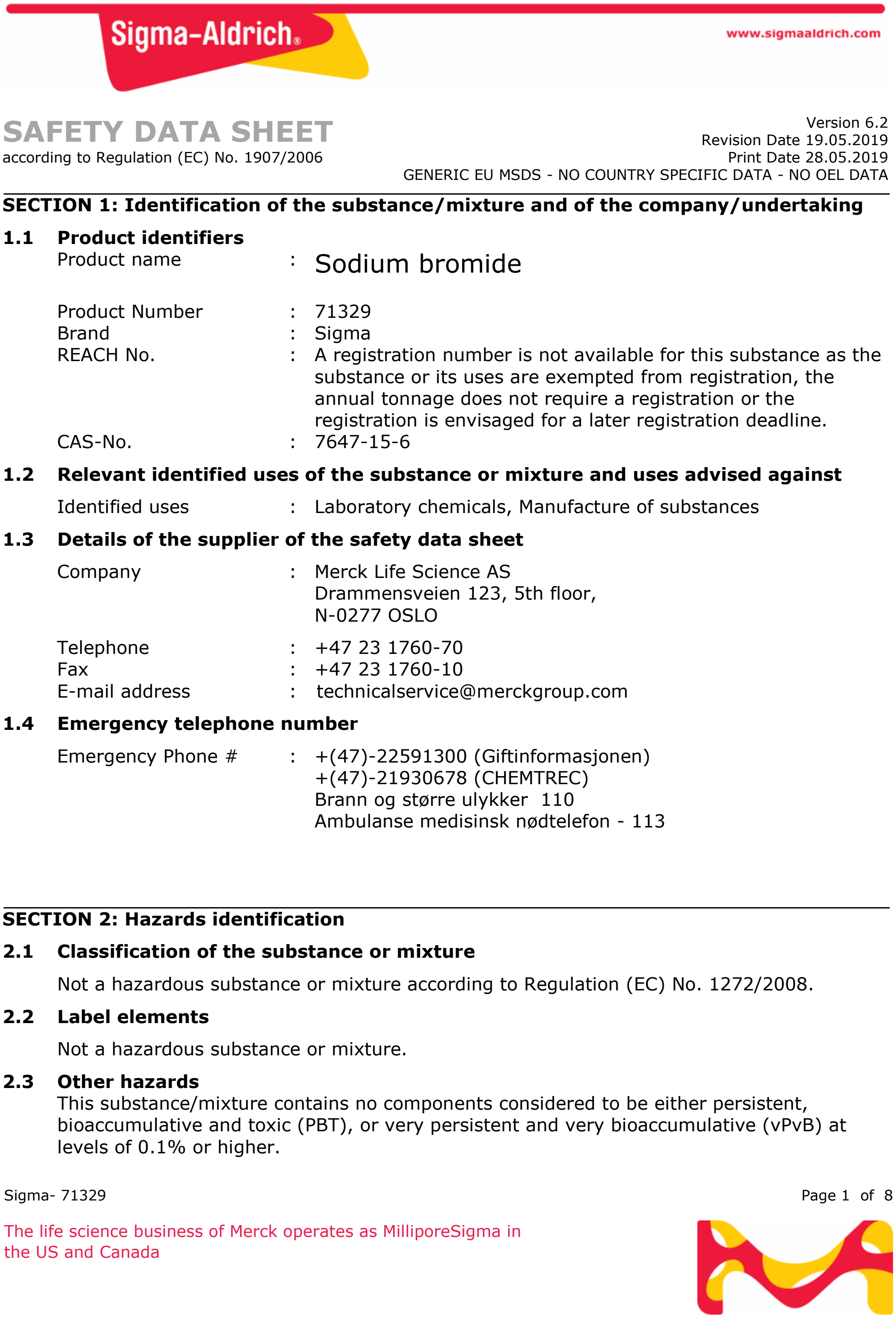

www.sigmaaldrich.com

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Version 6.2
Revision Date 19.05.2019
Print Date 28.05.2019
GENERIC EU MSDS - NO COUNTRY SPECIFIC DATA - NO OEL DATA

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifiers

Product name : Sodium bromide

Product Number : 71329
Brand : Sigma
REACH No. : A registration number is not available for this substance as the substance or its uses are exempted from registration, the annual tonnage does not require a registration or the registration is envisaged for a later registration deadline.
CAS-No. : 7647-15-6

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Merck Life Science AS
Drammensveien 123, 5th floor,
N-0277 OSLO

Telephone : +47 23 1760-70
Fax : +47 23 1760-10
E-mail address : technicalservice@merckgroup.com

1.4 Emergency telephone number

Emergency Phone # : +(47)-22591300 (Giftinformasjonen)
+(47)-21930678 (CHEMTREC)
Brann og større ulykker 110
Ambulanse medisinsk nødtelefon - 113

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture according to Regulation (EC) No. 1272/2008.

2.2 Label elements

Not a hazardous substance or mixture.

2.3 Other hazards

This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

SECTION 3: Composition/information on ingredients

3.1 Substances

Formula	:	BrNa
Molecular weight	:	102,89 g/mol
CAS-No.	:	7647-15-6
EC-No.	:	231-599-9

No components need to be disclosed according to the applicable regulations.

SECTION 4: First aid measures

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

SECTION 5: Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

Hydrogen bromide gas, Sodium oxides

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

No data available

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions

No special environmental precautions required.

6.3 Methods and materials for containment and cleaning up

Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections

For disposal see section 13.

SECTION 7: Handling and storage

7.1 Precautions for safe handling

Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Store in cool place. Keep container tightly closed in a dry and well-ventilated place.

Hygroscopic.

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

Components with workplace control parameters

8.2 Exposure controls

Appropriate engineering controls

Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection

Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection

Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

The selected protective gloves have to satisfy the specifications of Regulation (EU) 2016/425 and the standard EN 374 derived from it.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0,11 mm
Break through time: 480 min

Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0,11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
No special environmental precautions required.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: crystalline Colour: colourless
b)	Odour	odourless
c)	Odour Threshold	No data available
d)	pH	5,4 at 50 g/l at 20 °C
e)	Melting point/freezing point	Melting point/range: 755 °C - lit.
f)	Initial boiling point and boiling range	1.393 °C at 1013 hPa
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or	No data available

	explosive limits	
k)	Vapour pressure	1 hPa at 806 °C
l)	Vapour density	No data available
m)	Relative density	No data available
n)	Water solubility	soluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

No data available

SECTION 10: Stability and reactivity

10.1 Reactivity

No data available

10.2 Chemical stability

Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions

No data available

10.4 Conditions to avoid

Avoid moisture. Heat

10.5 Incompatible materials

Strong acids, Strong oxidizing agents, Alkali metals, Halogens

10.6 Hazardous decomposition products

Hazardous decomposition products formed under fire conditions. - Hydrogen bromide gas, Sodium oxides
Other decomposition products - No data available
In the event of fire: see section 5

SECTION 11: Toxicological information

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - 3.500 mg/kg
LD50 Dermal - Rabbit - > 2.000 mg/kg

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Mild eye irritation

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity
No data available

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

Reproductive toxicity

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: VZ3150000

Effects due to ingestion may include:, sedation
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

SECTION 12: Ecological information

12.1 Toxicity

Toxicity to fish	mortality NOEC - Oryzias latipes - 7.800 mg/l - 96 h
	LC50 - Poecilia reticulata (guppy) - 160.000 mg/l - 96 h
Toxicity to daphnia and other aquatic invertebrates	mortality NOEC - Daphnia magna (Water flea) - 7.800 mg/l - 48 h
	EC50 - Daphnia magna (Water flea) - 5.800 mg/l - 48 h

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

12.6 Other adverse effects

No data available

SECTION 13: Disposal considerations

13.1 Waste treatment methods

Product

Offer surplus and non-recyclable solutions to a licensed disposal company. Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging

Dispose of as unused product.

SECTION 14: Transport information

14.1 UN number

ADR/RID: - IMDG: - IATA: -

14.2 UN proper shipping name

ADR/RID: Not dangerous goods
IMDG: Not dangerous goods
IATA: Not dangerous goods

14.3 Transport hazard class(es)

ADR/RID: - IMDG: - IATA: -

14.4 Packaging group

ADR/RID: - IMDG: - IATA: -

14.5 Environmental hazards

ADR/RID: no IMDG Marine pollutant: no IATA: no

14.6 Special precautions for user

No data available

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

This safety datasheet complies with the requirements of Regulation (EC) No. 1907/2006.

15.2 Chemical safety assessment

For this product a chemical safety assessment was not carried out

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SECTION 16: Other information

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the

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SAFETY DATA SHEET
Ammonia, anhydrous

Issue Date:	16.01.2013	Version: 1.1	SDS No.: 000010021772
Last revised date:	29.01.2018		1/16

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifier

Product name:	Ammonia, anhydrous
Trade name:	Ammonia 3.0, Ammonia 3.6 Detector, Ammonia 3.8, Ammonia 4.5, Ammonia 5.0, Ammonia 6.0

Additional identification

Chemical name:	Ammonia, anhydrous
Chemical formula:	NH_3
INDEX No.	007-001-00-5
CAS-No.	7664-41-7
EC No.	231-635-3
REACH Registration No.	01-2119488876-14

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses:	Industrial and professional. Perform risk assessment prior to use. Casting operations Explosives manufacture & use Freezing, chilling, and packaging of foodstuffs. Manufacturing of fertilisers and nitric acid. Production of plastics. Refrigerant. Use for electronic component manufacture. Use of gas to manufacture pharmaceutical products. Using gas alone or in mixtures for the calibration of analysis equipment. Using gas as feedstock in chemical processes. Using gas for metal treatment. Washing of textiles or metal parts Water treatment. Use in laboratories
Uses advised against	Consumer use.

1.3 Details of the supplier of the safety data sheet

Supplier
AGA AS
Postboks 13 Nydalen
N-0409 Oslo Norway

Telephone: +4723177200

E-mail: kundeservice@no.aga.com

1.4 Emergency telephone number: +47 22 59 13 00 (24h - Giftinformasjonssentralen)

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Classification according to Regulation (EC) No 1272/2008 as amended.

Physical Hazards

Flammable gas	Category 2	H221: Flammable gas.
Gases under pressure	Liquefied gas	H280: Contains gas under pressure; may explode if heated.

Health Hazards

Acute toxicity (Inhalation - gas)	Category 3	H331: Toxic if inhaled.
Skin corrosion	Category 1B	H314: Causes severe skin burns and eye damage.
Serious eye damage	Category 1	H318: Causes serious eye damage.

Environmental Hazards

Acute hazards to the aquatic environment	Category 1	H400: Very toxic to aquatic life.
Chronic hazards to the aquatic environment	Category 2	H411: Toxic to aquatic life with long lasting effects.

2.2 Label Elements

Contains: Ammonia, anhydrous

Signal Words: Danger

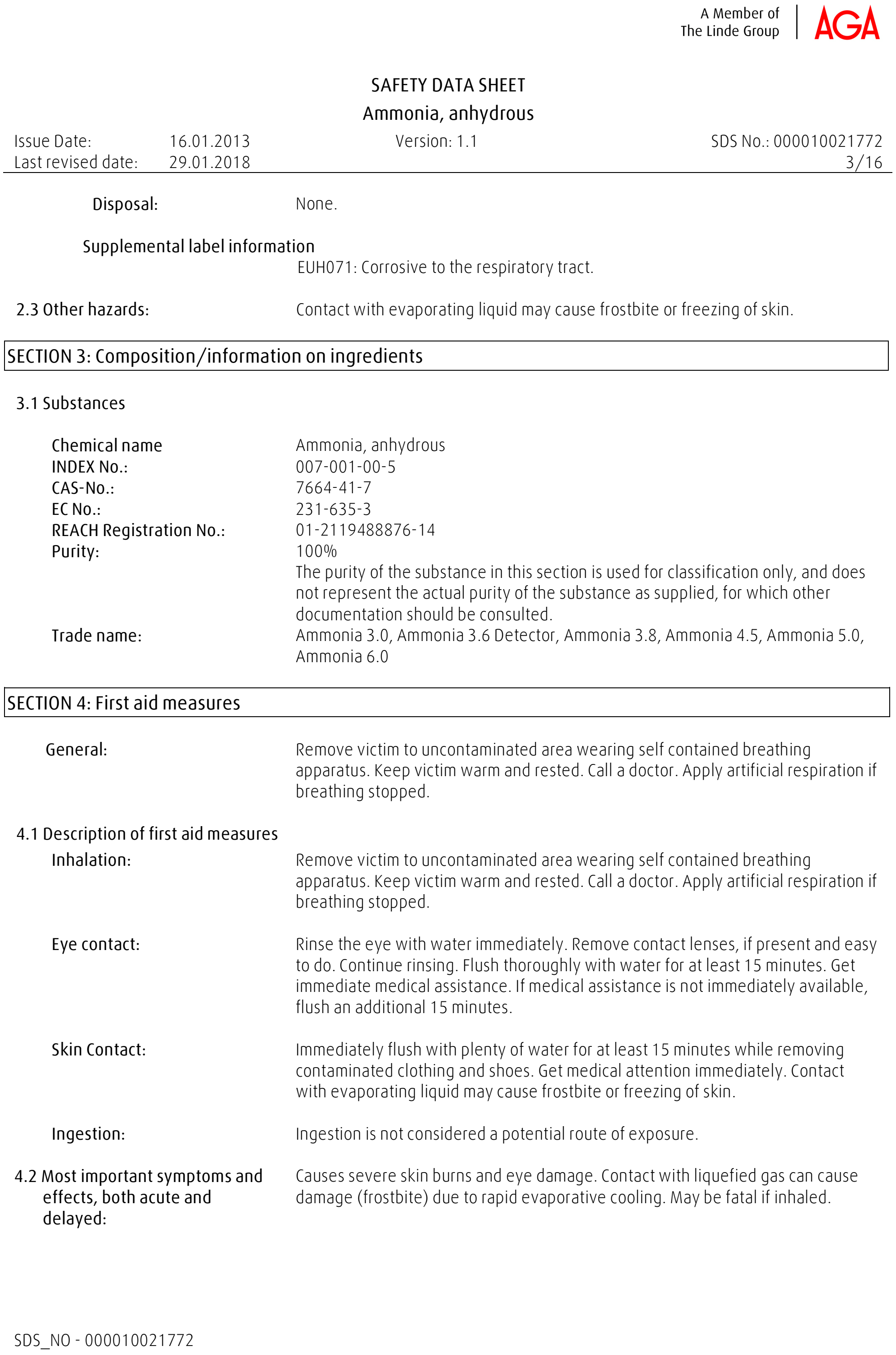
Hazard Statement(s):
H221: Flammable gas.
H280: Contains gas under pressure; may explode if heated.
H331: Toxic if inhaled.
H314: Causes severe skin burns and eye damage.
H410: Very toxic to aquatic life with long lasting effects.

Precautionary Statements

Prevention:
P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P260: Do not breathe gas/vapors.
P273: Avoid release to the environment.
P280: Wear protective gloves/protective clothing/eye protection/face protection.

Response:
P303+P361+P353+P315: IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/ shower. Get immediate medical advice/attention.
P304+P340+P315: IF INHALED: Remove person to fresh air and keep comfortable for breathing. Get immediate medical advice/attention.
P305+P351+P338+P315: IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Get immediate medical advice/attention.
P377: Leaking gas fire: Do not extinguish, unless leak can be stopped safely.
P381: In case of leakage, eliminate all ignition sources.

Storage:
P403: Store in a well-ventilated place.
P405: Store locked up.



Disposal:	None.

Supplemental label information

EUH071: Corrosive to the respiratory tract.

2.3 Other hazards:	Contact with evaporating liquid may cause frostbite or freezing of skin.

SECTION 3: Composition/information on ingredients

3.1 Substances

Chemical name	Ammonia, anhydrous
INDEX No.:	007-001-00-5
CAS-No.:	7664-41-7
EC No.:	231-635-3
REACH Registration No.:	01-2119488876-14
Purity:	100% The purity of the substance in this section is used for classification only, and does not represent the actual purity of the substance as supplied, for which other documentation should be consulted.
Trade name:	Ammonia 3.0, Ammonia 3.6 Detector, Ammonia 3.8, Ammonia 4.5, Ammonia 5.0, Ammonia 6.0

SECTION 4: First aid measures

General:	Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

4.1 Description of first aid measures

Inhalation:	Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Eye contact:	Rinse the eye with water immediately. Remove contact lenses, if present and easy to do. Continue rinsing. Flush thoroughly with water for at least 15 minutes. Get immediate medical assistance. If medical assistance is not immediately available, flush an additional 15 minutes.
Skin Contact:	Immediately flush with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical attention immediately. Contact with evaporating liquid may cause frostbite or freezing of skin.
Ingestion:	Ingestion is not considered a potential route of exposure.
4.2 Most important symptoms and effects, both acute and delayed:	Causes severe skin burns and eye damage. Contact with liquefied gas can cause damage (frostbite) due to rapid evaporative cooling. May be fatal if inhaled.

4.3 Indication of any immediate medical attention and special treatment needed

Hazards:	Causes severe skin burns and eye damage. Contact with liquefied gas can cause damage (frostbite) due to rapid evaporative cooling. May be fatal if inhaled.
Treatment:	Thaw frosted parts with lukewarm water. Do not rub affected area. Get immediate medical advice/attention. Treat with a corticosteroid spray as soon as possible after inhalation.

SECTION 5: Firefighting measures

General Fire Hazards:	Heat may cause the containers to explode.

5.1 Extinguishing media

Suitable extinguishing media:	Use water spray to reduce vapors or divert vapor cloud drift. Water Spray or Fog. Dry powder. Foam.
Unsuitable extinguishing media:	Carbon Dioxide. Do not use water jet, as this may cause corrosive liquid to splash.
5.2 Special hazards arising from the substance or mixture:	Fire or excessive heat may produce hazardous decomposition products.
Hazardous Combustion Products:	If involved in a fire the following toxic and/or corrosive fumes may be produced by thermal decomposition: Nitrogen monoxide ; Nitrogen dioxide

5.3 Advice for firefighters

Special fire fighting procedures:	In case of fire: Stop leak if safe to do so. Use of water may result in the formation of very toxic aqueous solutions. Keep run-off water out of sewers and water sources. Dike for water control. Continue water spray from protected position until container stays cool. Use extinguishants to contain the fire. Isolate the source of the fire or let it burn out.
Special protective equipment for fire-fighters:	Gas tight chemically protective clothing (Type 1) in combination with self contained breathing apparatus. Guideline: EN 943-2 Protective clothing against liquid and gaseous chemicals, aerosols and solid particles. Performance requirements for gas-tight (Type 1) chemical protective suits for emergency teams (ET)

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures:	Evacuate area. Provide adequate ventilation. Consider the risk of potentially explosive atmospheres . In case of leakage, eliminate all ignition sources. Monitor the concentration of the released product. Prevent from entering sewers, basements and workpits, or any place where its accumulation can be dangerous. Wear self-contained breathing apparatus when entering area unless atmosphere is proved to be safe. EN 137 Respiratory protective devices - Self-contained open-circuit compressed air breathing apparatus with full face mask - Requirements, testing, marking.

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6.2 Environmental Precautions:	Prevent further leakage or spillage if safe to do so. Reduce vapour with fog or fine water spray. Keep run-off water out of sewers and water sources. Dike for water control.
6.3 Methods and material for containment and cleaning up:	Provide adequate ventilation. Eliminate sources of ignition. Wash contaminated equipment or sites of leaks with copious quantities of water.
6.4 Reference to other sections:	Refer to sections 8 and 13.

SECTION 7: Handling and storage:

7.1 Precautions for safe handling:	Only experienced and properly instructed persons should handle gases under pressure. Avoid exposure - obtain special instructions before use. Use only properly specified equipment which is suitable for this product, its supply pressure and temperature. Purge system with dry inert gas (e.g. helium or nitrogen) before gas is introduced and when system is placed out of service. Purge air from system before introducing gas. Containers, which contain or have contained flammable or explosive substances, must not be inerted with liquid carbon dioxide. Assess the risk of a potentially explosive atmosphere and the need for suitable equipment i.e. explosion-proof. Take precautionary measures against static discharges. Keep away from ignition sources (including static discharges). Provide electrical earthing of equipment and electrical equipment usable in explosive atmospheres. Use non-sparking tools. Installation of a cross purge assembly between the container and the regulator is recommended. Excess pressure must be vented through an appropriate scrubber system. Refer to supplier's handling instructions. The substance must be handled in accordance with good industrial hygiene and safety procedures. Ensure the complete system has been (or is regularly) checked for leaks before use. Protect containers from physical damage; do not drag, roll, slide or drop. Do not remove or deface labels provided by the supplier for the identification of the container contents. When moving containers, even for short distances, use appropriate equipment eg. trolley, hand truck, fork truck etc. Secure cylinders in an upright position at all times, close all valves when not in use. Provide adequate ventilation. Suck back of water into the container must be prevented. Do not allow backfeed into the container. Avoid suckback of water, acid and alkalis. Keep container below 50°C in a well ventilated place. Observe all regulations and local requirements regarding storage of containers. When using do not eat, drink or smoke. Store in accordance with. Never use direct flame or electrical heating devices to raise the pressure of a container. Leave valve protection caps in place until the container has been secured against either a wall or bench or placed in a container stand and is ready for use. Damaged valves should be reported immediately to the supplier Close container valve after each use and when empty, even if still connected to equipment. Never attempt to repair or modify container valves or safety relief devices. Replace valve outlet caps or plugs and container caps where supplied as soon as container is disconnected from equipment. Keep container valve outlets clean and free from contaminates particularly oil and water. If user experiences any difficulty operating container valve discontinue use and contact supplier. Never attempt to transfer gases from one container to another. Container valve guards or caps should be in place.

7.2 Conditions for safe storage, including any incompatibilities:	All electrical equipment in the storage areas should be compatible with the risk of a potentially explosive atmosphere. Segregate from oxidant gases and other oxidants being stored. Containers should not be stored in conditions likely to encourage corrosion. Stored containers should be periodically checked for general conditions and leakage. Keep away from food, drink and animal feeding stuffs. Container valve guards or caps should be in place. Store containers in location free from fire risk and away from sources of heat and ignition. Keep away from combustible material.
7.3 Specific end use(s):	None.

SECTION 8: Exposure controls/personal protection

8.1 Control Parameters

Occupational Exposure Limits

Chemical name	Type	Exposure Limit Values		Source
Ammonia, anhydrous	NORMEN	15 ppm	11 mg/m3	Norway. Regulation No. 1358 on Measures and Limit Values for Physical and Chemical Factors in Work Environment and Infection Groups for Biological Factors (12 2014)
	STEL	50 ppm	36 mg/m3	Norway. Regulation No. 1358 on Measures and Limit Values for Physical and Chemical Factors in Work Environment and Infection Groups for Biological Factors (12 2014)
	TWA	20 ppm	14 mg/m3	EU. Indicative Exposure Limit Values in Directives 91/322/EEC, 2000/39/EC, 2006/15/EC, 2009/161/EU (12 2009)
	STEL	50 ppm	36 mg/m3	EU. Indicative Exposure Limit Values in Directives 91/322/EEC, 2000/39/EC, 2006/15/EC, 2009/161/EU (12 2009)

DNEL-Values

Critical component	Type	Value	Remarks
Ammonia, anhydrous	Worker - dermal, short-term - systemic	6,8 mg/kg bw/day	-
	Worker - inhalative, short-term - local	36 mg/m3	-
	Worker - inhalative, long-term - local	14 mg/m3	-
	Worker - inhalative, long-term - systemic	47,6 mg/m3	-
	Worker - inhalative, short-term - systemic	47,6 mg/m3	-
	Worker - dermal, long-term - systemic	6,8 mg/kg bw/day	-

PNEC-Values

Critical component	Type	Value	Remarks
Ammonia, anhydrous	Aquatic (intermit. releases)	0,0068 mg/l	-
	Aquatic (marine water)	0,0011 mg/l	-
	Aquatic (freshwater)	0,0011 mg/l	-

8.2 Exposure controls

Appropriate engineering controls:	Consider a work permit system e.g. for maintenance activities. Ensure adequate air ventilation. Provide adequate general and local exhaust ventilation. Keep concentrations well below occupational exposure limits. Gas detectors should be used when toxic quantities may be released. Gas detectors should be used when quantities of flammable gases or vapours may be released. Systems under pressure should be regularly checked for leakages. Product to be handled in a closed system and under strictly controlled conditions. Only use permanent leak tight installations (e.g. welded pipes). Take precautionary measures against static discharges. Do not eat, drink or smoke when using the product.

Individual protection measures, such as personal protective equipment

General information:	A risk assessment should be conducted and documented in each work area to assess the risks related to the use of the product and to select the PPE that matches the relevant risk. The following recommendations should be considered. Keep self contained breathing apparatus readily available for emergency use. Personal protective equipment for the body should be selected based on the task being performed and the risks involved. Protect eyes, face and skin from contact with product. Refer to local regulations for restriction of emissions to the atmosphere. See section 13 for specific methods for waste gas treatment.
Eye/face protection:	Safety eyewear, goggles or face-shield to EN166 should be used to avoid exposure to liquid splashes. Wear eye protection to EN 166 when using gases. Guideline: EN 166 Personal Eye Protection.
Skin protection	
Hand Protection:	Wear working gloves while handling containers Guideline: EN 388 Protective gloves against mechanical risks. Chemically resistant gloves complying with EN 374 should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Material: Chloroprene rubber. Break-through time: 30 min Glove thickness: 0,5 mm Guideline: EN 374-1/2/3 Protective gloves against chemicals and micro-organisms. Chemically resistant gloves complying with EN 374 should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Material: Butyl rubber. Break-through time: 480 min Glove thickness: 0,7 mm Guideline: EN 374-1/2/3 Protective gloves against chemicals and micro-organisms.

Body protection:	Wear fire resistant or flame retardant clothing. Keep suitable chemically resistant protective clothing readily available for emergency use. Guideline: ISO/TR 2801:2007 Clothing for protection against heat and flame -- General recommendations for selection, care and use of protective clothing.Guideline: EN 943 Protective clothing against liquid and gaseous chemicals, including liquid aerosols and solid particles.
Other:	Wear safety shoes while handling containers Guideline: ISO 20345 Personal protective equipment - Safety footwear.
Respiratory Protection:	Reference should be made to European Standard EN 689 for methods for the assessment of exposure by inhalation to chemical agents and national guidance documents for methods for the determination of hazardous substances. The selection of the Respiratory Protective Device (RPD) must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected RPD. Material: Filter K Guideline: EN 14387 Respiratory protective devices. Gas filter(s) and combined filter(s). Requirements, testing, marking. Guideline: EN 136 Respiratory protective devices. Full face masks. Requirements, testing, marking.
Thermal hazards:	No precautionary measures are necessary.
Hygiene measures:	Obtain special instructions before use. Specific risk management measures are not required beyond good industrial hygiene and safety procedures. Do not eat, drink or smoke when using the product.
Environmental exposure controls:	For waste disposal, see section 13 of the SDS.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

Appearance	
Physical state:	Gas
Form:	Liquefied gas
Color:	Colorless
Odor:	Very pungent odor, characteristic of drying urine
Odor Threshold:	Odor threshold is subjective and is inadequate to warn of over exposure.
pH:	If dissolved in water pH-value will be affected.
Melting Point:	-77,7 °C Experimental result, Key study
Boiling Point:	-33 °C
Sublimation Point:	not applicable.
Critical Temp. (°C):	132,0 °C
Flash Point:	Not applicable to gases and gas mixtures.
Evaporation Rate:	Not applicable to gases and gas mixtures.
Flammability (solid, gas):	Flammable Gas

Flammability Limit - Upper (%):	33,6 %(V) Experimental result, Key study
Flammability Limit - Lower (%):	15,4 %(V)
Vapor pressure:	8,5737 bar (20 °C) Experimental result, Key study
Vapor density (air=1):	0,59 AIR=1
Relative density:	0,8
Solubility(ies)	
Solubility in Water:	531 g/l (20 °C)
Partition coefficient (n-octanol/water):	< 1
Autoignition Temperature:	651 °C Experimental result, Key study 630 °C
Decomposition Temperature:	> 450 °C
Viscosity	
Kinematic viscosity:	No data available.
Dynamic viscosity:	0,7 mPa.s (48,9 °C)
Explosive properties:	Not applicable.
Oxidizing properties:	not applicable.

9.2 Other information:	None.
Molecular weight:	17,03 g/mol (NH3)
Minimum ignition energy:	680 mJ

SECTION 10: Stability and reactivity

10.1 Reactivity:	No reactivity hazard other than the effects described in sub-section below.
10.2 Chemical Stability:	Stable under normal conditions.
10.3 Possibility of hazardous reactions:	Can form a potentially explosive atmosphere in air. May react violently with oxidants.
10.4 Conditions to avoid:	Avoid moisture in the installation. Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
10.5 Incompatible Materials:	Air and oxidizers. Moisture. For material compatibility see latest version of ISO-11114. Reacts with water to form corrosive alkalis. May react violently with acids.
10.6 Hazardous Decomposition Products:	Under normal conditions of storage and use, hazardous decomposition products should not be produced. If involved in a fire the following toxic and/or corrosive fumes may be produced by thermal decomposition: The following decomposition products may be produced: Nitrogen monoxide ; Nitrogen dioxide

SECTION 11: Toxicological information

General information:	Inhalation of large amounts leads to bronchospasm, laryngeal oedema and pseudomembrane formation.

11.1 Information on toxicological effects

Acute toxicity - Oral	
Product	Based on available data, the classification criteria are not met.
Ammonia, anhydrous	LD 50 (Rat): 350 mg/kg Remarks: Experimental result, Key study
Acute toxicity - Dermal	
Product	Based on available data, the classification criteria are not met.
Acute toxicity - Inhalation	
Product	Toxic if inhaled.
Ammonia, anhydrous	LC 50 (Rat, 4 h): 2000 ppm
Repeated dose toxicity	
Ammonia, anhydrous	NOAEL (Rat(Female, Male), Oral, 28 - 53 d): 250 mg/kg Oral Read-across from supporting substance (structural analogue or surrogate), Key study LOAEL (Rat, Inhalation, 35 - 75 d): 175 mg/m3 Inhalation Experimental result, Weight of Evidence study
Skin Corrosion/Irritation	
Product	Causes severe burns.
Serious Eye Damage/Eye Irritation	
Product	Causes serious eye damage.
Respiratory or Skin Sensitization	
Product	Based on available data, the classification criteria are not met.
Germ Cell Mutagenicity	
Product	Based on available data, the classification criteria are not met.
Carcinogenicity	
Product	Based on available data, the classification criteria are not met.
Reproductive toxicity	
Product	Based on available data, the classification criteria are not met.
Specific Target Organ Toxicity - Single Exposure	
Product	Based on available data, the classification criteria are not met.

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Ammonia, anhydrous

Specific Target Organ Toxicity - Repeated Exposure	
Product	Based on available data, the classification criteria are not met.
Aspiration Hazard	
Product	Not applicable to gases and gas mixtures..

SECTION 12: Ecological information

General information:	Avoid release to the environment. Product is not allowed to be discharged into ground water or the aquatic environment.

12.1 Toxicity

Acute toxicity	
Product	Very toxic to aquatic life with long lasting effects.
Acute toxicity - Fish	
Ammonia, anhydrous	LC 50 (Oncorhynchus mykiss, 96 h): 0,44 mg/l (semi-continuous flow) Remarks: Read-across from supporting substance (structural analogue or surrogate), Supporting study
Acute toxicity - Aquatic Invertebrates	
Ammonia, anhydrous	LC 50 (48 h): 101 mg/l Remarks: Experimental result, Key study
Toxicity to microorganisms	
Ammonia, anhydrous	Depending on local conditions and existing concentrations, disturbances in the biodegradation process of activated sludge are possible.
Toxicity to terrestrial organisms	
Ammonia, anhydrous	Study not necessary due to exposure considerations.
Chronic Toxicity - Fish	
Ammonia, anhydrous	LOEC (Fish, 73 Days): 0,022 mg/l
Chronic Toxicity - Aquatic Invertebrates	
Ammonia, anhydrous	LC 50 (Daphnia magna, 96 h): 4,07 mg/l (flow-through) Read-across from supporting substance (structural analogue or surrogate), Key study
Toxicity to Aquatic Plants	
Ammonia, anhydrous	LC 50 (Algae, algal mat (Algae), 18 Days): 2.700 mg/l

12.2 Persistence and Degradability

Product	Not applicable to gases and gas mixtures..

Biodegradation	Inorganic The product is not readily biodegradable.
12.3 Bioaccumulative potential	
Product	The substance has no potential for bioaccumulation.
12.4 Mobility in soil	
Product	The substance has low mobility in soil.
Ammonia, anhydrous	Henry's Law Constant: 0,09028 MPa (25 °C)
12.5 Results of PBT and vPvB assessment	
Product	Not classified as PBT or vPvB.
12.6 Other adverse effects:	
Other Ecological Information	May cause pH changes in aqueous ecological systems. Depending on local conditions and existing concentrations, disturbances in the biodegradation process of activated sludge are possible.

SECTION 13: Disposal considerations

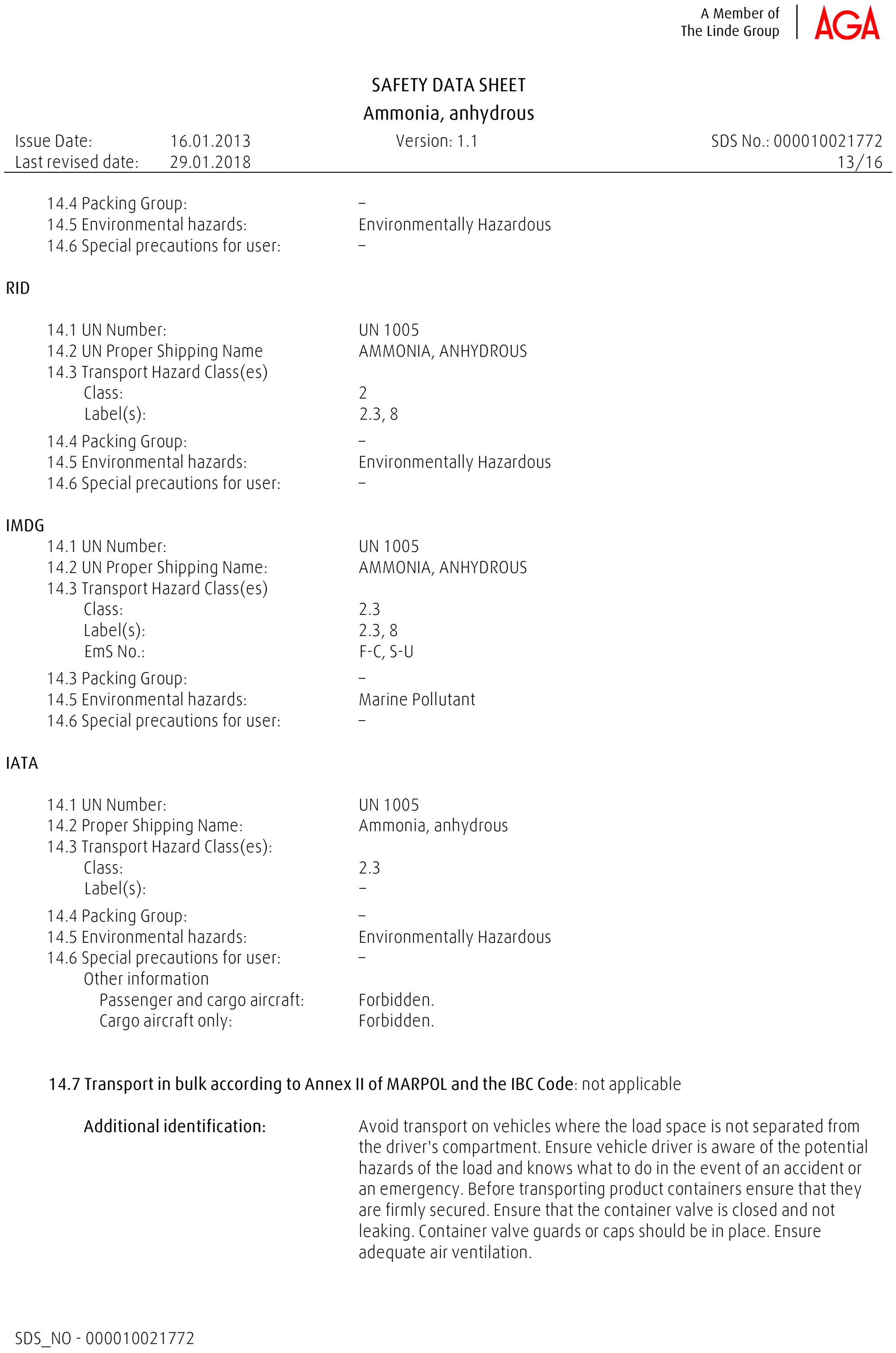
13.1 Waste treatment methods

General information:	Must not be discharged to atmosphere. Consult supplier for specific recommendations.
Disposal methods:	Refer to the EIGA code of practice (Doc.30 "Disposal of Gases", downloadable at http://www.eiga.org) for more guidance on suitable disposal methods. Dispose of container via supplier only. Discharge, treatment, or disposal may be subject to national, state, or local laws. Toxic and corrosive gases formed during combustion should be scrubbed before discharge to atmosphere. Gas may be scrubbed in water. Gas may be scrubbed in sulphuric acid solution.
European Waste Codes Container:	16 05 04*: Gases in pressure containers (including halons) containing dangerous substances.

SECTION 14: Transport information

ADR

14.1 UN Number:	UN 1005
14.2 UN Proper Shipping Name:	AMMONIA, ANHYDROUS
14.3 Transport Hazard Class(es)	
Class:	2
Label(s):	2.3, 8
Hazard No. (ADR):	268
Tunnel restriction code:	(C/D)



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14.4 Packing Group:	–
14.5 Environmental hazards:	Environmentally Hazardous
14.6 Special precautions for user:	–

RID

14.1 UN Number:	UN 1005
14.2 UN Proper Shipping Name	AMMONIA, ANHYDROUS
14.3 Transport Hazard Class(es)	
Class:	2
Label(s):	2.3, 8
14.4 Packing Group:	–
14.5 Environmental hazards:	Environmentally Hazardous
14.6 Special precautions for user:	–

IMDG

14.1 UN Number:	UN 1005
14.2 UN Proper Shipping Name:	AMMONIA, ANHYDROUS
14.3 Transport Hazard Class(es)	
Class:	2.3
Label(s):	2.3, 8
EmS No.:	F-C, S-U
14.3 Packing Group:	–
14.5 Environmental hazards:	Marine Pollutant
14.6 Special precautions for user:	–

IATA

14.1 UN Number:	UN 1005
14.2 Proper Shipping Name:	Ammonia, anhydrous
14.3 Transport Hazard Class(es):	
Class:	2.3
Label(s):	–
14.4 Packing Group:	–
14.5 Environmental hazards:	Environmentally Hazardous
14.6 Special precautions for user:	–
Other information	
Passenger and cargo aircraft:	Forbidden.
Cargo aircraft only:	Forbidden.

14.7 Transport in bulk according to Annex II of MARPOL and the IBC Code: not applicable

Additional identification: Avoid transport on vehicles where the load space is not separated from the driver's compartment. Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency. Before transporting product containers ensure that they are firmly secured. Ensure that the container valve is closed and not leaking. Container valve guards or caps should be in place. Ensure adequate air ventilation.

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture:

EU Regulations

Directive 96/82/EC (Seveso III): on the control of major accident hazards involving dangerous substances:

Chemical name	CAS-No.	Concentration
Ammonia, anhydrous	7664-41-7	100%

Directive 98/24/EC on the protection of workers from the risks related to chemical agents at work:

Chemical name	CAS-No.	Concentration
Ammonia, anhydrous	7664-41-7	100%

National Regulations

Council Directive 89/391/EEC on the introduction of measures to encourage improvements in the safety and health of workers at work Directive 89/686/EEC on personal protective equipment Directive 94/9/EC on equipment and protective systems intended for use in potentially explosive atmospheres (ATEX) Only products that comply with the food regulations (EC) No. 1333/2008 and (EU) No. 231/2012 and are labelled as such may be used as food additives.
This Safety Data Sheet has been produced to comply with Regulation (EU) 2015/830.

15.2 Chemical safety assessment: CSA has been carried out.

SECTION 16: Other information

Revision Information: Not relevant.

Key literature references and sources for data:

Various sources of data have been used in the compilation of this SDS, they include but are not exclusive to:
Agency for Toxic Substances and Diseases Registry (ATSDR) (http://www.atsdr.cdc.gov/).
European Chemical Agency: Guidance on the Compilation of Safety Data Sheets.
European Chemical Agency: Information on Registered Substances http://apps.echa.europa.eu/registered/registered-sub.aspx#search
European Industrial Gases Association (EIGA) Doc. 169 Classification and Labelling guide.
International Programme on Chemical Safety (http://www.inchem.org/)
ISO 10156:2010 Gases and gas mixtures - Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets.
Matheson Gas Data Book, 7th Edition.
National Institute for Standards and Technology (NIST) Standard Reference Database Number 69.
The ESIS (European chemical Substances 5 Information System) platform of the former European Chemicals Bureau (ECB) ESIS (http://ecb.jrc.ec.europa.eu/esis/).
The European Chemical Industry Council (CEFIC) ERICards.
United States of America's National Library of Medicine's toxicology data network TOXNET (http://toxnet.nlm.nih.gov/index.html)
Threshold Limit Values (TLV) from the American Conference of Governmental Industrial Hygienists (ACGIH).
Substance specific information from suppliers.
Details given in this document are believed to be correct at the time of publication.

Wording of the H-statements in section 2 and 3

H221	Flammable gas.
H280	Contains gas under pressure; may explode if heated.
H314	Causes severe skin burns and eye damage.
H318	Causes serious eye damage.
H331	Toxic if inhaled.
H400	Very toxic to aquatic life.
H411	Toxic to aquatic life with long lasting effects.

Training information: Users of breathing apparatus must be trained. Ensure operators understand the toxicity hazard.

Classification according to Regulation (EC) No 1272/2008 as amended.

Flam. Gas 2, H221
Press. Gas Liq. Gas, H280
Acute Tox. 3, H331
Skin Corr. 1B, H314
Eye Dam. 1, H318
Aquatic Acute 1, H400
Aquatic Chronic 2, H411

Other information: Before using this product in any new process or experiment, a thorough material compatibility and safety study should be carried out. Ensure adequate air ventilation. Ensure all national/local regulations are observed. Whilst proper care has been taken in the preparation of this document, no liability for injury or damage resulting from its use can be accepted.

Last revised date:	29.01.2018
Disclaimer:	This information is provided without warranty. The information is believed to be correct. This information should be used to make an independent determination of the methods to safeguard workers and the environment.