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CO_2 Absorption and Desorption Simulation with Aspen HYSYS

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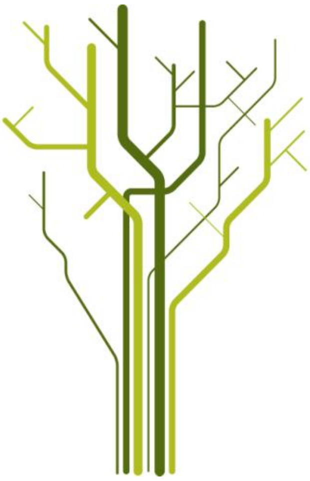

Master's thesis

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Abstract

The last years it has been an increasing global interest to reduce emissions of greenhouse gases to the atmosphere. One of the most important greenhouse gases is CO_2. To reduce CO_2 emissions carbon capture and storage (CCS) is the most realistic approach. With today's technology absorption by an amine solution is the most developed and applicable method for post-combustion CO_2 capture. But this technology is very energy demanding. To reduce the energy demand this technology must be optimized to realize this process as a beneficial method for large scale CO_2 capture.

This thesis considers three different configurations for absorption by an amine mixture aimed to reduce the energy demand. The different configurations are the standard absorption process, a vapour recompression and a lean split with vapour recompression. Aspen HYSYS has been used as the simulation tool. To compare the different models equally the CO_2 removal efficiency was kept at 85% and the minimum temperature approach in the lean/rich heat exchanger was 5K. Kent-Eisenberg was used as the thermodynamic model for the aqueous amine solution and Peng-Robinson for the vapour phase.

All configurations were evaluated due to the energy cost. The lean split with vapour recompression had the lowest energy cost with 81 MNOK/year. However, the vapour recompression had only a slightly higher cost equal to 85 MNOK/year. The standard absorption process was simulated to have an energy cost of 120 MNOK/year. At these values 1.15 M ton CO_2/year are removed.

A capital cost estimation of the configurations has also been conducted. This capital cost estimation has considered equipment, engineering and installation cost. The standard absorption process was estimated to have the lowest capital cost by 514 MNOK. The two other modifications were more expensive. The biggest difference was due to the extra compressor. The lean split with vapour recompression had a cost of 768 MNOK, while the vapour recompression had a cost of 832 MNOK.

Some sensitivity calculations have also been conducted, especially for the vapour recompression. Under these conditions the following parameter values were optimal: CO_2 removal efficiency of 84-86%, flash tank pressure at 110-120 kPa, 14-16 stages in the absorption column.

More research should be done to verify values due to uncertainties in the models and cost estimates.

Keywords	**Supervisor**
- **CO_2 Absorption, amine** - **HYSYS** - **Vapour recompression**	Associate Professor Lars Erik Øi, Telemark University College.

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Preface

This Master's thesis was done during the spring semester 2013 at the Faculty of Science and Technology at the University of Tromsø (UiT).

I want to thank my supervisor Associate Professor Lars Erik Øi from Telemark University College for guidance and reliable communication despite the long distance between the working locations.

I also want to thank my fellow graduating student Trond Vegard Sørensen for motivation and for professional and private discussions during this work.

Tromsø, 1st of June, 2013

Nomenclature, abbreviation and symbol list

CCS	Carbon capture and storage
KJ/kg	KJ for each kg CO_2 removed
DCC	Direct contact cooler
MEA	Monoethanolamine
TCM	Test Centre Mongstad
UiT	University of Tromsø
LMTD	Logarithmic mean temperature difference
U	Overall heat transfer coefficient

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1. Introduction

This master's thesis is about optimization of CO_2 removal processes from a low pressure flue gas from a natural gas combined heat and power plant simulated in Aspen HYSYS. The work is done at the University of Tromsø (UiT).

1.1. Purpose

The aim of this paper:

The purpose with this paper is to optimize the energy demand of CO_2 removal processes in the simulation tool Aspen HYSYS. It is also an objective to estimate the energy and capital cost for the different configurations. The different configurations are the standard absorption process, a vapour recompression modification and a lean split with vapour recompression modification. For the vapour recompression modification sensitivity analysis are conducted to optimize the energy consumption.

Limitations:

For a real process there is some equipment that is necessary for operation which is not considered in this paper. Auxiliary systems like pumps, fans, DCC, a water wash system, or an amine reclaimer are not considered. A short explanation of these parts is presented in section 3.4: Equipment not considered. Pressure drop and heat losses throughout the process equipment are neither considered.

1.2. Background

The last years it has been an increasing international agreement that CO_2 is a dangerous greenhouse gas and that the human made CO_2 emissions to the atmosphere must be managed to control the climate changes. The climate change meetings in Kyoto, Copenhagen, Cancun etc. has been activities to set accepted emissions and a plan of how to control the climate changes. Based on this a new area of focus has grown forth. This area is the focus of carbon capture and storage (CCS). This work is a supplement to the carbon capture part. The idea is that when CO_2 is captured it can be transported to and stored inside geological structures, e.g.

inside produced reservoirs. These geological structures must however have an impermeable layer so the CO_2 is completely isolated from the atmosphere. This storage technology is already implemented on a few existing process facilities in Norway. At the LNG production plant at Hammerfest CO_2 is captured, transported and injected back to the geologic structure beneath the seabed. This technology is also used at Sleipner. However, these capturing processes are from high pressure streams. But because of the increase of focus on CCS other big pollution objects have had an increasing interest. One of these is natural gas power plants. In Norway there are currently a few of these power plants. On some of the offshore facilities a small gas turbine is the only source of electricity. But onshore there are currently three natural gas power plants. One is at Kårstø, another is at Melkøya, and the last one is at Mongstad. The one at Mongstad is a combined power and heat plant. On the concession application Statoil estimated the plant to have a capacity to generate 280 MW electricity and 350 MW heat. And at normal production the plant stands for about 1, 3 million tons of CO_2 each year [1] [2]. Therefore, development of technology for CO_2 removal from power plants will be an important step towards reducing and controlling CO_2 emissions. Today there are several known methods to remove CO_2. Chemical and physical absorption are two different methods, some other methods are; adsorption, use of membranes or cryogenic separation. A short presentation of these possible CO_2 removal processes are presented in chapter 1.4.

When the concession for a power plant at Mongstad was accepted there was not set a requirement that a CO_2 removal process must be in place [1]. However, there were discussions on a political level that this must happen. But CO_2 removal by the known technology is very expensive and the government decided that a test center is going to optimize the known technology of how to extract CO_2 from flue gases. This test centre is called *Technology Centre Mongstad* (TCM). The test center's owners is a joint corporation between Gassnova (75,12%), Statoil (20,00%), Shell (2,44%) and Sasol (2,44%). Gassnova has the share majority and it is through this company the government is managing the research process. TCM started up in May 2012 and has a flue gas feed flow rate about 10% (100 000 ton CO_2/year) of the full scale case [3]. Currently there are two companies with a CO_2 removal technology they want to test. The first company is *Alstom.* They test a technology which is based on absorption with an aqueous ammonia mixture. The second company is *Aker Clean Carbon. They are testing a* technology based on absorption with an aqueous amine mixture. With the known technology CO_2 removal from a post combustion power plant is expected to reduce the total energy efficiency of the plant from about 58% to about 50% [13]. And this excludes transportation and storage of CO_2. Therefore it is necessary to optimize the known technology or invent new technology for this to be accepted as benefitting. Based on this, the main purpose with the technology center is to develop, test and verify technologies to reduce cost, technology, environmental and financial risk of the CO_2 removal process. TCM will be the first step towards commercializing the process as a life worthy product.

Removing CO_2 from a stream has been done for many years. But this is either in small scale or from high pressure petroleum streams. When removing from a high pressure stream the conditions are quite different. The known technology must be adapted to low pressure in big scale. TCM is a pilot plant which has a size that means that the results of this testing can be extrapolated to full scale plants all around the world. There are two different ways of applying a post-combustion CO_2 removal process based on absorption to a power plant. The first way is to include the CO_2 removal process into the design phase. The other way is to apply the process onto an existing plant. Chemical absorption post-combustion can be implemented in both ways, and this is one important factor that makes this way of CO_2 capture very interesting [4]. In addition, it is important to note that one type of technology is not always the best solution. Different operation and investment costs and the planed life-time of a process are factors that may change what is the best choice in a specific case.

It can also be mentioned that most work on this topic is likely not public information. Most companies have no interest in publishing their research on technology which may be a competitive advantage. Therefore it is expected that some scientific work is done but has not been published by companies as Aker Clean Carbon, Alstrom, Fluor, Mitsubishi, HTC Energy and other similar companies with a strong interest in this type of technology. However, there are a few institutions that have an interest in publishing their work, i.e. education institutes.

1.3. Combined heat and power plant

This work is based on a flue gas from a combined power and heat plant. The plant uses natural gas as the energy source. Figure 1 illustrates the process of a power plant. The combusted air/natural gas is first used directly on the gas turbine, and then the flue gas produce steam which is used in the steam turbine. Both turbines are used to produce electrical power.

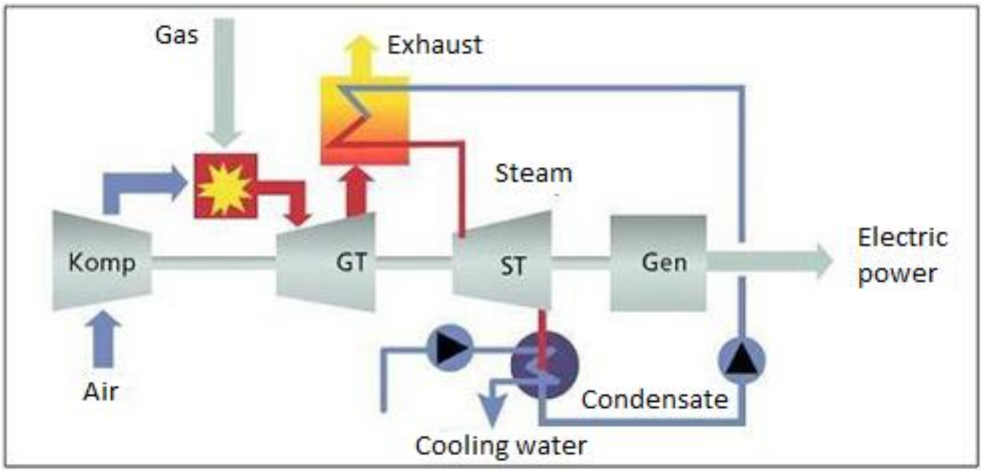

Figure 1: The principal of a combined heat and power plant [5]

1.4. CO_2 removal in general

Traditionally have CO_2 been removed from high pressure streams for many years. It is several reasons why this sour gas is removed:

- CO_2 has no heating value. Therefore removing CO_2 will increase the heating value of a combustible mixture.
- When gas is transported in pipelines to customers CO_2 will increase the load on the compressors.
- CO_2 crystallizes at low temperatures. So when natural gas is liquefied to LNG the CO_2 content must be below a certain value to not plug small channels, i.e. heat exchangers.
- In presents of water CO_2 forms an acid which corrode metal pipes.
- CO_2 is a greenhouse gas.
- Achieve sale gas specifications.

To remove CO_2 a few different technologies are available. These technologies are physical or chemical absorption, adsorption, cryogenic separation, and membranes. Each of these technologies has its field of use.

Adsorption

Adsorption is based on the principle of having a fluid to be adsorbed onto a solid surface. When this process is used there must be two adsorption lines in parallel. This is because the regeneration happens by changing pressure or temperature, and therefore one line must always be able to adsorb while the other regenerates. This process might not be suitable for large scale CO_2 removal from a natural gas based power plant. At this scale, the low adsorption capacity might be a big challenge. In addition, the flue gas that is treated must have a high CO_2 concentration because of the low selectivity of most adsorbents [6].

Physical absorption

Physical absorption is based on absorbing CO_2 into a solvent which may be described by the equation of Henry's law. Henry's law says that the relation between the concentration and the partial pressure of a component in a mixture is directly proportional. Because of this, physical absorption is only suitable if the partial pressure of CO_2 is quite high. According to [7], physical absorption is a more suitable method when CO_2 concentration is higher than 15% and at high partial pressures.

Chemical absorption

This process is based on the principle to have CO_2 from a flue gas to be chemical absorbed by a solvent. The chemical reaction needs to form a weak intermediate compound so that the absorbent may be regenerated. To apply regeneration a pressure reduction or an increase in temperature is required. The solvent can be ammonia, different amines, or a mixture of amines. Since exhaust gas from a power plant is at low pressure, the process will be very heat demanding. According to [8] amine absorption systems are considered to be the best suited technology for removing CO_2 from flue gases in the power sector.

Cryogenic separation

Cryogenic separation is the process where CO_2 is separated from the flue gas by condensing. The principle exploits the difference in the boiling point for the components. According to [6] and [9] this physical process is suitable for flue gas streams with CO_2 concentrations above 90%, and this process is more suitable to capture CO_2 from flue gases from an oxyfuel power plant.

Membranes

Membrane separation is based on two flows that are separated by a membrane. The membrane is most often a thin, nonporous, polymeric film which is semipermeable. Some species move faster through the membrane than others and in this way CO_2 is separated from the feed. However, the selectivity and the fraction CO_2 removed of this process is low. A multistage separation is required to capture a higher amount which leads to a higher investment and operation cost [6] [10].

1.5. Task description

The tasks of this Master's thesis can be found in appendix 1.

2. Literature about different CO_2 absorption processes

The idea with this chapter is to give a short presentation of some general research about CO_2 removal at low pressure conditions, and then mention some research on the different configurations used in this work.

A few years ago there was not done much research on CO_2 removal in big scale from a low pressure flue gas. But the last years the political interest in CO_2 emission management has stimulated and motivated for more extensive research. The aim of most of this research is to reduce the energy and/or cost demand of a process. This can either be done by configuring the physical process equipment or by changing process parameters for optimization of a specific modification. Based on this several possible CO_2 absorption configurations have been theoretically tested and evaluated. Because of the high cost of a large scale process much of the research done are based on work with different simulation tools. These simulation tools are software programs like Aspen HYSYS, Aspen plus, K-Spice and Pro/II. The use of these tools ease the massive calculations required to simulate a close-to-real process. Calculations like material balance, energy balance, vapour/liquid equilibrium, equations of states are solved quickly. These tools are especially practical when complex or large quantities of calculations are required.

General

During the literature review several interesting works was found [11] presents fifteen different process flow sheet modifications. The work does also have a focus on the patent information related to each modification. More interesting work found are [6] which consists of a state-of-the-art review for post-combustion CO_2 capturing, and [12] which considers removal of CO_2 from exhaust gas.

Standard absorption process

In much research found the standard absorption model has been used as a reference case. When different modifications or process parameters have been optimized the improvement has been related to this base case. In the paper [13] a presentation of a combined cycle gas power plant and the standard absorption process are given. In this work the energy consumption of the CO_2 removal process was calculated, and it was concluded that the process reduces the efficiency of the power plant from about 58 to 50%.

Vapour recompression modification

In the paper [14], [15], [16], and [17] it is concluded that a vapour recompression modification is perhaps the most interesting choice of modification because the process achieves a large energy reduction with a limited increase in complexity. Some research is done in [8] about net present value maximization on a vapour recompression model. This paper conclude that the optimum flash tank pressure is at 1,2 bar.

Split stream modification

In several papers found different split stream modifications are presented and simulated. Perhaps the most interesting one are simulated in [15]. In that paper a simulation of a lean split stream with a vapour recompression modification are accomplished. The results are interesting and gave less reboiler and compressor duty compared to the vapour recompression modification.

3. Process description

This chapter is meant to give a presentation of the three configurations used in this work. First is the standard absorption process presented, then a vapour recompression modification, and last a lean split with vapour recompression modification. Principles and the process equipment are also briefly explained. Equipment which is required in a real process but not considered in the model are also mentioned. After this, sections about column stage equilibrium in Aspen HYSYS, the property package, and the solvent are presented.

3.1. Standard absorption process

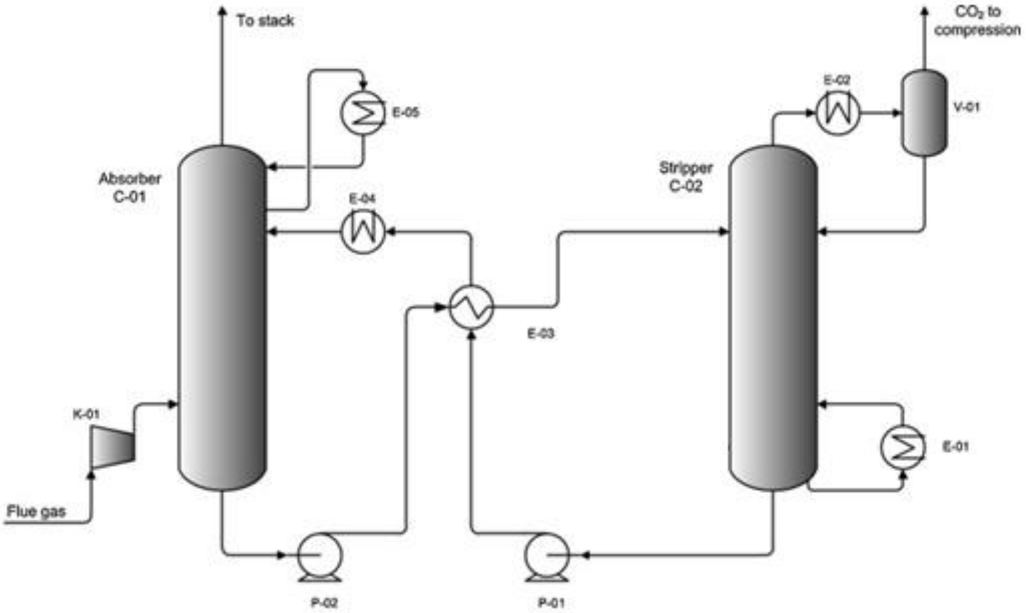

Figure 2: Simplified figure of the standard absorption process [8]

Figure 2 shows the configurations of the standard absorption process. The flue gas enters the absorption column in the bottom part. Here the exhaust is climbing upward due to buoyancy. At the same time an aqueous solution enters at the top and flows downward. This aqueous solution will mainly consist of the solvent and water, but it will also consist of some CO_2. Because of the layout inside the column the exhaust gas and the aqueous solution will have a big contact surface. During this contact CO_2 will be absorbed into the aqueous solution. In this way the exhaust will when exiting at the top of the column have a lower CO_2 content. The aqueous solution will exit the absorption column at the bottom. Inside the column there is an arrangement that optimize the liquid/vapour contact surface. This arrangement may be plates, structured or random packing. Each plate or a specific high of these may be called a stage, and the number of stages is one of the factors that decide how much CO_2 that will be removed. Theoretical you can assume chemical and vapour/liquid equilibrium over each plate. But in reality there is a deviation between the composition change to equilibrium and the actual composition change of the components. This deviation is what decides the efficiency at each plate. This efficiency may be called the Murphee efficiency. A definition of the Murphee efficiency can be found in chapter 3.5. From the bottom of the absorption column the liquid (rich amine) will be pumped through a lean/rich heat exchanger. In this side of the heat exchanger the rich amine stream will be heated. After this the rich amine will enter the desorption column/stripper. In the desorption column there is a condenser at the top and a boiler in the bottom, and here the CO_2 vaporizes from the aqueous mixture. The vapour rises and the liquid, which mostly consist of the solvent and water, flows downwards. In this way the amine can be reused, while the CO_2 can be extrapolated from the stream as a top product. Furthermore, when CO_2 is captured it is ready for transportation and storage as a link in the chain of CCS. In the desorption column the principle about Murphee efficiency is also valid. From the bottom of the desorption column the liquid part (lean amine) is pumped through the lean/rich heat exchanger. In this heat exchanger the lean amine will be cooled. After leaving this heat exchanger the temperature is still too high, therefore is the stream further cooled by another heat exchanger which uses cheap and available fluids, e.g. water. The lean amine is supposed to be cooled to the wanted/optimal absorption temperature before entering the absorber. At this point the lean amine is mixed with a make-up stream of water and amine. These make-up streams are supposed to fill in the lost amine and water from the product streams leaving the system. When the make-up steams are mixed together with the lean amine stream the mixed stream enters the absorption column to fulfill the cycle.

3.2. A vapour recompression process

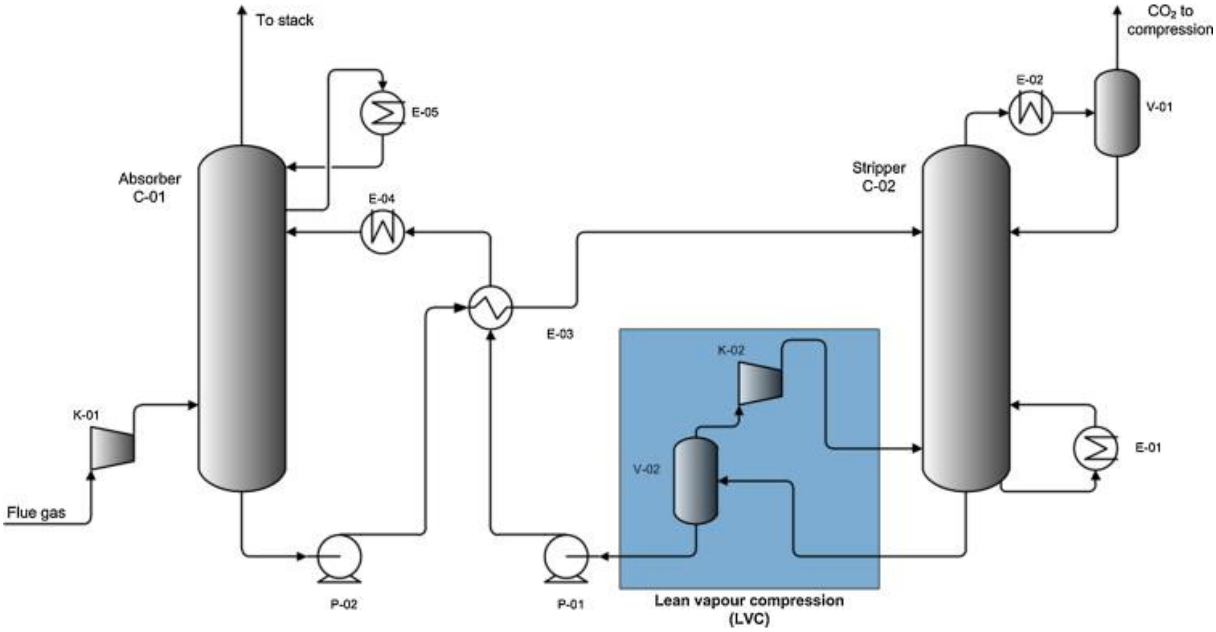

Figure 3: Simplified figure of an absorption process with a vapour recompression modification [8]

There are several differences from a vapour recompression absorption modification and the standard absorption process. The main changes are as follows:

- One extra flash tank, a compressor, a small increase in the complexity of the lean/rich heat exchanger.
- The reboiler duty will decrease due to the extra stream coming from the compressor.
- Some additional electricity is required to operate the compressor.
- Small modifications for the lean/rich heat exchanger may be required.
- The stripper need to accommodate a slightly increase in the vapour flow for a vapour recompression model [8].
- The CO_2 loading (mole CO_2/mole MEA) in the lean amine will decrease. The CO_2 loading in the rich amine stream leaving the absorber will however be on about the same value. This means that a lower lean amine flow rate is required for the same amount of CO_2 removed.

The blue square in figure 3 shows the change in the required physical equipment compared to the standard absorption process. This blue box contains the recompression part of the process.

From the bottom of the stripper the liquid goes through a valve which reduces the pressure in the stream. This pressure reduction causes some of the liquid to vaporize. The vapour/liquid mixture enters then a flash tank where the vapour and the liquid are separated. The vapour is then slightly cooled in the lean/rich heat exchanger (not illustrated in figure 3) and recompressed before it enters the desorption column. By doing this the heat in this stream causes a reduction in the reboiler duty. But while the reboiler duty reduces an extra duty for the compressor is added to the system. While the vapour part is recompressed, the liquid from the flash tank follows the same path as in the standard absorption process.

For a vapour recompression process there is only a small increase in the amount of physical equipment. This increase is only considered to slightly increase the overall acquisition cost for the process. However, due to the reduction in the reboiler duty the total energy required will in spite of the extra electricity demand decrease. In the work [18] the energy demand is considered for a few different configurations. One of these considerations is the vapour recompression process and the basic process. This work conclude that if the vapour recompression model have a temperature approach in the lean/rich heat exchanger of $\Delta 5K$ the investment cost and energy demand compared to a standard absorption process can be approximately increased and reduced by respectively 2,77% and 9,37%. From these numbers it is quite clear that it is possible to significantly reduce the cost and that it therefore is very important to optimize the process.

3.3. A lean split with vapour recompression process

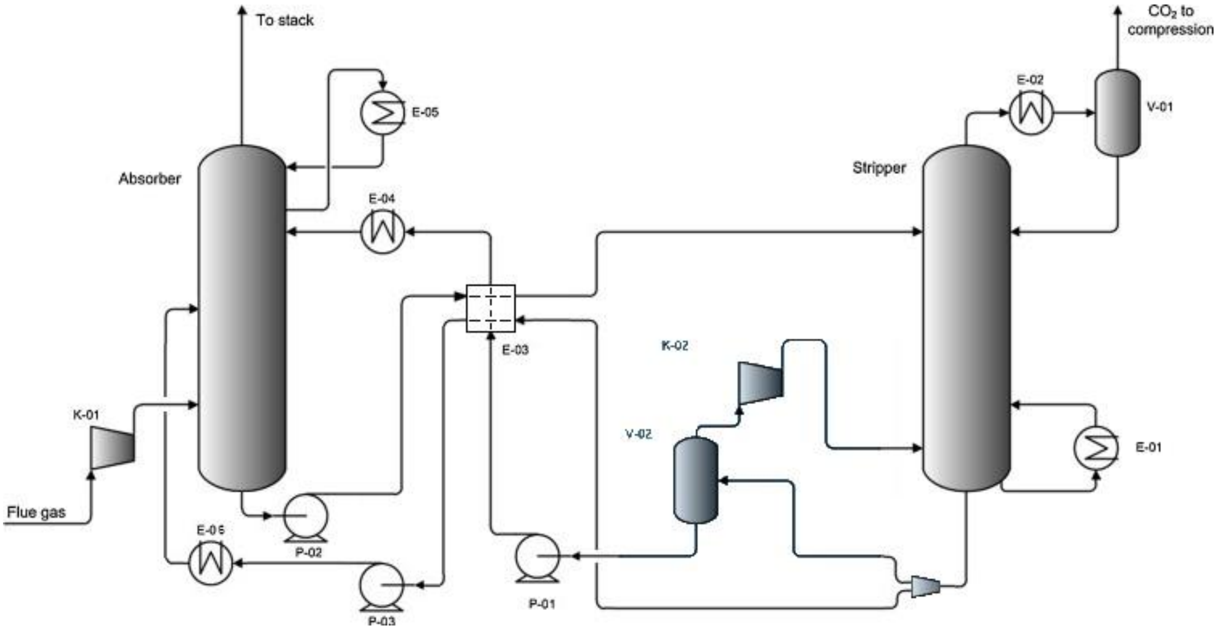

Figure 4: Simplified figure of a lean split with vapour recompression modification [8]

The difference from this modification compared to the vapour recompression modification is that the lean amine stream from the stripper is splitted into two streams. One of the streams goes through the same process as in the vapour recompression modification, but the other stream (called semi-lean) goes directly through the lean/rich heat exchanger then a pump and a cooler brings the medium to the wanted pressure and temperature condition before entering the absorption column. By doing this the high temperature (120 °C) provides additional heating in the lean/rich heat exchanger which will affect the reboiler duty.

As mentioned in chapter 2 this process has been simulated to require less reboiler and compressor duty compared to the vapour recompression modification [15]. This process does however have a more complex lean/rich heat exchanger, one more pump and cooler, more piping, and an extra inlet to the absorption column. This means that investment and operation costs should be evaluated and compared to the standard absorption process and the vapour recompression modification.

3.4. Equipment not considered

In addition to the components that are mentioned above there is some equipment that is necessary for a real process to be operational. The most important equipment is a direct contact cooler (DCC), an amine reclaimer, a fan, and a water wash system:

- DCC: The available pressure and thermal energy in the flue gas are used as the energy source in the power and heat plant, but still the temperature may be as high as 200°C. Since the wanted inlet temperature to the absorber is about 25-40°C the thermal energy need to be reduced. This means that upstream from the absorption column a direct contact cooler is required to chill the flue gas so that the temperature reaches the wanted/optimized operation temperature in the absorption column. This DCC consists of a column and a water circulation system. The column acts as the direct cooler where process water is cooling the flue gas which streams upwards. For the water circuit a pump, cooler and a splitter are required. A splitter is required because of a change in the water saturation limit in the flue gas, i.e. water condenses from the flue gas inside the column.
- Flue gas fan: If the flue gas needs a small pressure increase a fan may be used. A fan will also give the process more stability and a bigger flexibility when considering the pressure operating condition.
- Amine reclaimer: Because the amine solvent degrades over time due to oxidative and thermal reactions a system to reclaim the solvent is necessary. This amine reclaimer bleeds of some of the lean amine stream and vaporizes the solvent. The part of the stream which is not recovered is considered a waste product.
- Water wash section: The solvent in this study is MEA, and this solvent has a relatively high vapour pressure. A high vapour pressure will lead to a significant vaporization loss in the absorption column. This means that the MEA content will be quite high in the pure product stream. To greatly reduce the loss of MEA it is possible to integrate a water wash column.

3.5. Column stage equilibrium in Aspen HYSYS

In Aspen HYSYS the vapour concentration CO_2 entering and leaving each plate may be assumed to be in equilibrium with the liquid. However in a real column the concentration will not be in equilibrium. Therefore the efficiency on each place may be assumed and specified in the software simulation program. This efficiency is called Murphee efficiency, and is defined as:

$$E_M = \frac{y_{i,n+1} - y_i}{y_{i,n+1} - y*_i} \tag{3.1}$$

Where $y_{i,\, n+1}$ is the mole fraction of species i in the vapour phase leaving stage n+1, and y_i is the mole fraction of species i leaving stage n, and $y*_i$ is the mole fraction of species i in equilibrium with the liquid leaving stage n [10].

This Murphee efficiency will not be constant through the columns. In reality the efficiency is slightly different on each plate. The driving force of the absorption is based on the chemical and vapour/liquid equilibrium.

3.6. Property Package

In HYSYS there are several property packages available. A process with water/amine/oxygen/nitrogen/light hydrocarbons/CO_2 mixtures limits the accuracy of most of these models. But HYSYS has a special amine package for this type of mixtures. This Amine Package contains thermodynamic models developed by D.B. Robinson & associates. The chemical and physical property data does however have some restrictions attached to components, amine concentration, pressure and temperature. The relevant restriction ranges are as follows:

- Acid gases: CO_2, H_2S, COS, CS_2.
- Non Hydrocarbons: H_2, N_2, O_2, CO, H_2O.
- MEA: Concentration 0 - 30wt%.
- Pressure: 0,00001 – 300 psia.
- Temperature: 77-260 °F, or 25-126 °C.
- 1.0 mole acid gas/mole alkanolamine.

All these restrictions are fulfilled in the simulations. This package uses Kent-Eisenberg or Li-Mather as the thermodynamic model for the aqueous amine solution. According to [19] Kent-Eisenberg is validated as an approach to correlate the equilibrium solubility of acid gases in a MEA solution. The model chosen is Kent-Eisenberg during the simulations. But Li-Mather was tested to check the deviation between these two. For the vapour phase it is only expected a small deviation from an ideal solution. This means that the basic ideal gas law could be applied. However, the small deviation may easily be taken care of by considering the phase mixture non-ideal. Therefore the vapour phase is calculated as non-ideal. For this non-ideal vapour phase Aspen HYSYS uses the equation of state Peng-Robinson to calculate the fugacity coefficient. No other choices are available. And for calculation of enthalpy/entropy a curve fit approach is used. This amine package is also capable of simulating blended solvents made up of two of the following amines: MEA, DEA, MDEA, TEA, DGA, and DIPA. The absorption is an exothermic process and the temperature will therefore vary inside the absorption column, and since the heat effects are an important factor in amine treating processes it is worth mentioning that this is properly taken into account in the amines property package [19].

For the vapour phase several other equations of state could have been used. The small deviation expected from an ideal mixture gives a wide range of choices. However, here the most complex equation is used because it is expected to give a slightly more accurate result with no increase in effort. For the liquid phase Li-Mather could have been used as as the thermodynamic model for the aqueous amine solution.

3.7. The solvent

The amine chosen for this work is monoethanolamine (MEA). MEA is also called 2-aminoethanol or ethanolamine. The molecular formula is C_2H_7NO, and it is a primary alkanolamine and alcohol. According to [20] MEA is the preferred solvent when sweetening a stream by removing carbon dioxide (CO_2) or hydrogen sulphide (H_2S) if there are no contaminations of COS or CS_2. And this is especially true when the sour components are removed from a low pressure gas and if a maximum removal of CO_2 or H_2S is required. In similar research, concerning CO_2 removal by amine absorption, MEA has been the typically used solvent.

The advantages with MEA as solvent are that it has a high reactivity, high absorbing capacity on a mass basis, reasonable thermal stability and degradation rate [21]. But the use of MEA as the solvent does have some disadvantages. MEA has a relatively high vapour pressure which will lead to a significant vaporization loss. This can however be limited by a simple water wash system. Another disadvantage with MEA is the high heat of reaction. A high heat of reaction means that more energy must be added in the regeneration process [12]. In addition, CO_2 is corrosive if water is present.

It is not easy to find a optimized absorption temperature for MEA. In a chemical reaction a high temperature is favored, but the equilibrium in this process will favor a lower temperature. Therefore it is not easy to optimize the absorber inlet temperature. However, as mentioned does MEA have a high reactivity. This means that MEA does not need as high operation temperature compared to some other amines.

The reaction is between a weak base and a weak acid. CO_2 solved in H_2O is a weak acid, while MEA solved in H_2O is a weak base. The reaction of CO_2 and MEA is considered by [24].

Different solvents

In the work [12] different amines than MEA has been shortly evaluated in a standard absorption model. Dietanolamine (DEA) and methyldiethanolamine (MDEA) in water are two popular solvents when CO_2 are removed at high pressures, but these do not seem to give better results than MEA. Either does a mixture of MEA and MDEA. In addition, most papers found on this topic have been using an MEA, and therefore it is easier to compare different results when based on the same specifications.

4. Energy and economical estimation methods

4.1. Energy estimation method

In this process there are two types of energy demand, thermal heat and electricity. These two cannot be compared on an equal basis. Therefore the electricity and the thermal heat required will be kept separated. But in the sensitivity cases a method to estimate the combined energy demand is very practical. This combined energy is called equivalent thermodynamic work. In this method the thermal energy demand for the system will be recalculated into the amount of electricity lost due to the thermal energy used, and then the compressor and pump duties will be added.

The equivalent thermodynamic work W_E is calculated as [18]:

$$W_E = Q_H \times \left(1 - \frac{T_C}{T_H}\right) \times \eta + W_C + W_P \tag{4.1}$$

Where Q_H is the total heat used in the reboiler, the steam turbine efficiency η is assumed to be 75%, W_C is the duty for the compressor, and W_P is the summarized pump duties. To estimate the thermal energy transformation to work the factor $1 - \frac{T_C}{T_H}$ is used. This factor is the maximum efficency of a Carnot engine, where work is transformed from thermal heat. If the steam is assumed to be about 10K higher than the temperature in the reboiler, then T_H =130+273K. And if the steam is assumed to condense at 40 °C, T_C = 313K. This method for unifying the different energy values has also been used in literature by [18].

4.2. Economical estimation methods

4.2.1. Electricity and steam cost

To estimate the cost of the electricity and steam demand of the system a transformation to NOK is necessary. This means that the cost for electricity and steam must be set. The electricity cost is set to 0, 4 NOK/kWh. This cost is a typical value used in papers found, e.g. [12]. When the steam cost is estimated a comparison to the electricity cost must be considered. Using the Carnot efficiency formula [28] and [15]:

$$\eta = \left(1 - \frac{T_C}{T_H}\right) = 0{,}223 \tag{4.2}$$

This means that the low pressure steam can produce electricity for about 0,223 of the thermal energy, and therefore:

- Electricity cost: 0,4 NOK/kWh
- Steam cost: 0,089 NOK/kWh

4.2.2. Investment cost

When estimating the investment cost of the different process modifications a few methods are available. The first and most accurate method is to contact vendors for a prize. When the number of cases is big the investment cost may be extrapolated from earlier projects, or from estimation methods found in literature. Commercial software packages as *Aspen In-Plant Cost Estimator* or handbooks from *Hydrocarbon Processing* may also be used. Since not a commercial software package or handbooks are available the cost estimation will be done by scaling costs from similar research.

4.2.3. Scaling factor

If cost for earlier process plants that uses the same technology is known a scaling can be done by the following equation [22]:

$$C_2 = C_1 \times \left(\frac{S_2}{S_1}\right)^{0,65} \tag{4.3}$$

Where: C_n is the cost with capacity S_n. [22] estimates the values for these type of processes to be between 0,6 and 0,7, and therefore a mid-value of 0,65 is chosen.

4.2.4. Capital cost estimation

When costs of equipment are estimated, equation 4.4 is applied. The result will include cost of equipment, engineering, and installation.

$$C = F\ (\sum C_e) \tag{4.4}$$

The installation factor F equals 5 [22].

4.2.5. Currency index

Converting the currency from US dollar $ to NOK is done by the following equation:

$$Cost\ NOK = \frac{Cost\ \$}{Exchange\ \$/\mathrm{NOK}} \tag{4.5}$$

Exchange $\$/\mathrm{NOK}$ equals $\frac{1}{5{,}8335}$ [25].

4.2.6. Cost index

To update the cost to 2013 equation 4.6 is used [22].

$$Cost\ in\ year\ 2013 = Cost\ in\ year\ 2010\ \times \frac{Cost\ index\ in\ year\ 2013}{Cost\ index\ in\ year\ 2010} \tag{4.6}$$

Table 1: Cost index for 2010 and 2013 [26]

Year	Cost index
2010	128,8 (average)
2011	130,4 (average)
2013	133,175 (average for the first four months)

5. Aspen HYSYS simulations

This chapter starts with a presentation of the three base cases in this work. The standard absorption process, the vapour recompression modification, and the lean split with vapour recompression modification in Aspen HYSYS. After this, a parameter variation chapter and the sensitivity cases are presented as the last part.

For all the simulation cases the following parameters has been unchanged:

- Sour feed specifications to the absorption column.
- The solver is modified HYSIM Inside-Out.
- Pump efficiency.
- Compressor efficiency.
- Murphee efficiency of 15% in the absorption column.

During the simulations it was experienced that the Modified HYSIM Inside-Out gave the best convergence in both columns. The Murphee efficiency was kept at 15%. The adiabatic efficiency in the pumps and the compressor was set to 75%, this is the default value in Aspen HYSYS. Table 2 shows the feed parameters and values that were held constant in all simulations.

Table 2: Specifications for the sour feed to the absorber

Parameter	**Value**
Composition	N_2: 76,0 mole%
	CO_2: 3,3 mole%
	H_2O: 6,9 mole%
	O_2: 13,8 mole%
Temperature	40 °C
Pressure	101 kPa
Flow rate	1,09141 *10^5 kgmole/h

5.1. Base cases

For all base cases the specifications made and a figure of the model are presented. A picture of the models can be found in appendix 2, 3 and 4. Last for each base case the results are presented. For the three base cases the following parameters was kept constant:

- 85% CO_2 removed from the flue gas.
- The inlet temperature to the absorption column was set to 40 °C for all inlet streams.
- Minimum temperature approach in the lean/rich heat exchanger was set to 5K.

There are set a few general requirements for the base cases. The CO_2 removal efficiency was set to approximately 85%. The inlet temperature to the absorption column for the flue gas and all circulation streams was set to 40 °C.

5.1.1. Process description of the Aspen HYSYS standard base case

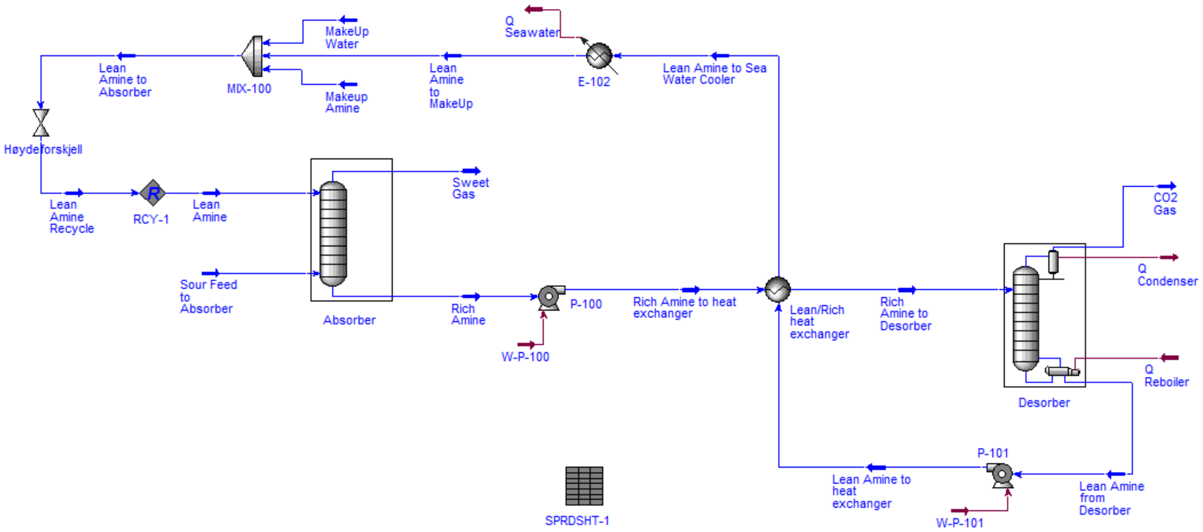

Figure 5: The user interface of the basic absorption model in Aspen HYSYS

A figure of the standard model is shown by figure 5, and a bigger picture is found in appendix 2. The model consists of the following process equipment:

- Absorption column
- Rich amine pump

- Desorption column
- Lean/Rich amine heat exchanger
- Lean amine pump
- Water cooler

Some of the elements shown in figure 5 do only have a software function. These functions are: The recycle functions, called RCY-1 and RCY-2. The mixer, called Mix-100. And the adjust function, called ADJ-1.

5.1.1.1. Specifications for the Aspen HYSYS standard base case

Table 3 shows the specifications for the lean amine feed to the absorption column. Table 4 shows the specifications and data for the rest of the model. The Aspen HYSYS simulation results may be found in appendix 5.

Table 3: Specifications for lean amine to absorber

Parameter	Value
Composition	MEA: 29,0 weight%
	CO_2:5,5 weight%
	H_2O: 65,5 weight%
Lean amine loading	0,263
Temperature	40 °C
Pressure	101 kPa
Flow rate	1,6 *10^5 kgmole/h

Table 4: Specifications and data for the rest of the model

Parameter	Value
Absorber - stages	14
Absorber - Murphree efficiency	0,15
Desorber - stages	10 + condenser + reboiler
Desorber - Murphree efficiency	1

Reboiler - temperature	120 °C
Desorber - Reflux ratio	0,1
Rich amine loading	0,434
Rich amine pump - inlet pressure	101 kPa
Rich amine pump - outlet pressure	200 kPa
Rich amine pump - inlet temperature	43,5 °C
Rich amine pump - adiabatic efficiency	75%
Heated rich amine - temperature	104,5 °C
Lean amine pump - inlet pressure	100 kPa
Lean amine pump - outlet pressure	400 kPa
Lean amine pump - adiabatic efficiency	75%
Make up Amine - Flow rate	45 kgmole/h
Make up Water - Flow rate	6150 kgmole/h

5.1.1.2. Results for the Aspen HYSYS standard base case

Results for the standard absorption process simulation are presented in table 5.

Table 5: Results for the Aspen HYSYS standard base case

Modification	Boiler duty, [MW]	Boiler duty, [MJ/kg]	Compressor, [MW]	Equivalent work [kJ/kg]
Standard base case	161	4,3	-	724

5.1.2. Process description of the Aspen HYSYS vapour recompression base case

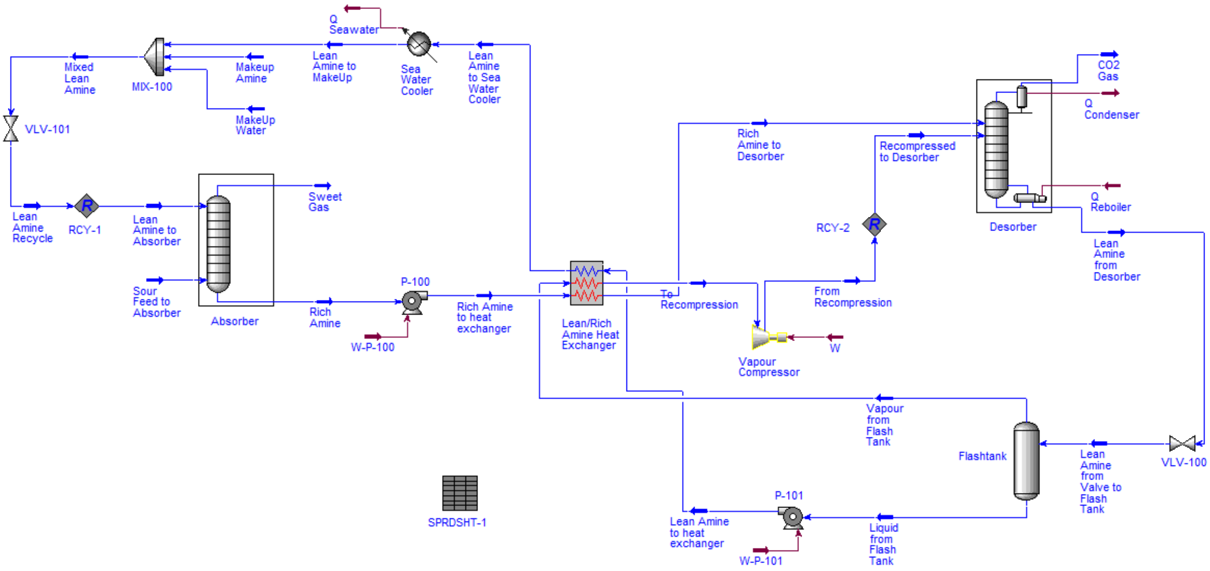

Figure 6: The user interface of the vapour recompression model in Aspen HYSYS

The model layout is presented by figure 6, and a bigger picture of the model is attached in appendix 3. The model consists of the following process equipment:

- Absorption column
- Rich amine pump
- Desorption column
- Valve
- Flash tank
- Lean vapour compressor
- Lean/Rich amine heat exchanger
- Lean amine pump
- Sea water cooler

Some of the elements shown in figure 6 do only have a software function. These functions are: The recycle functions, called RCY-1 and RCY-2. The mixer, called Mix-100. And the adjust function, called ADJ-1.

5.1.2.1. Specifications for the Aspen HYSYS vapour recompression base case

Table 6 contains the lean amine specifications. Table 7 shows the recompression stream specifications. And in table 8 contains specifications and data for the rest of the model. The Aspen HYSYS simulation results may be found in appendix 6.

Table 6: Specifications for lean amine to absorber

Parameter	Value
Composition	MEA: 29,0 weight%
	CO_2:5,1 weight%
	H_2O: 65,9 weight%
Lean amine loading	24,4
Temperature	40 °C
Pressure	101 kPa
Flow rate	1,23 *10^5 kgmole/h

Table 7: Specifications for the recompressed stream to the stripper

Parameter	Value
Composition	CO_2: 10,8 weight%
	H_2O: 86,4 weight%
	MEA: 2,8 weight%
Temperature	120 °C
Pressure	200 kPa
Flow rate	3985 kgmole/h

Table 8: Specifications and data for the rest of the model

Parameter	Value
Absorber - stages	16
Absorber - Murphree efficiency	0,15
Desorber - stages	10 + condenser + reboiler
Desorber - Murphree efficiency	1

Reboiler - temperature	120 °C
Desorber - Reflux ratio	0,3
Flash tank - pressure	115 kPa
Rich amine loading	46,8
Rich amine pump - inlet pressure	101 kPa
Rich amine pump - outlet pressure	200 kPa
Rich amine pump - inlet temperature	41,8 °C
Rich amine pump - adiabatic efficiency	75%
Lean amine pump - inlet pressure	115 kPa
Lean amine pump - outlet pressure	200 kPa
Lean amine pump - inlet temperature	105,3 °C
Lean amine pump - adiabatic efficiency	75%
Compressor - adiabatic efficiency	75%
Compressor - inlet pressure	115 kPa
Compressor - outlet pressure	200 kPa
Compressor - inlet temperature	99,4 °C
Compressor - outlet temperature	120 °C
Make up Amine - Flow rate	40 kgmole/h
Make up Water - Flow rate	4980 kgmole/h

5.1.2.2. Results for the Aspen HYSYS vapour recompression base case

Results for the vapour recompression simulation are presented in table 9.

Table 9: Results for the Aspen HYSYS vapour recompression base case

Modification	Boiler duty, [MW]	Boiler duty, [MJ/kg]	Compressor, [MW]	Equivalent work [kJ/kg]
Vapour recompression base case	102	2,7	2,7	538

5.1.3. Process description of the Aspen HYSYS lean split with vapour recompression base case

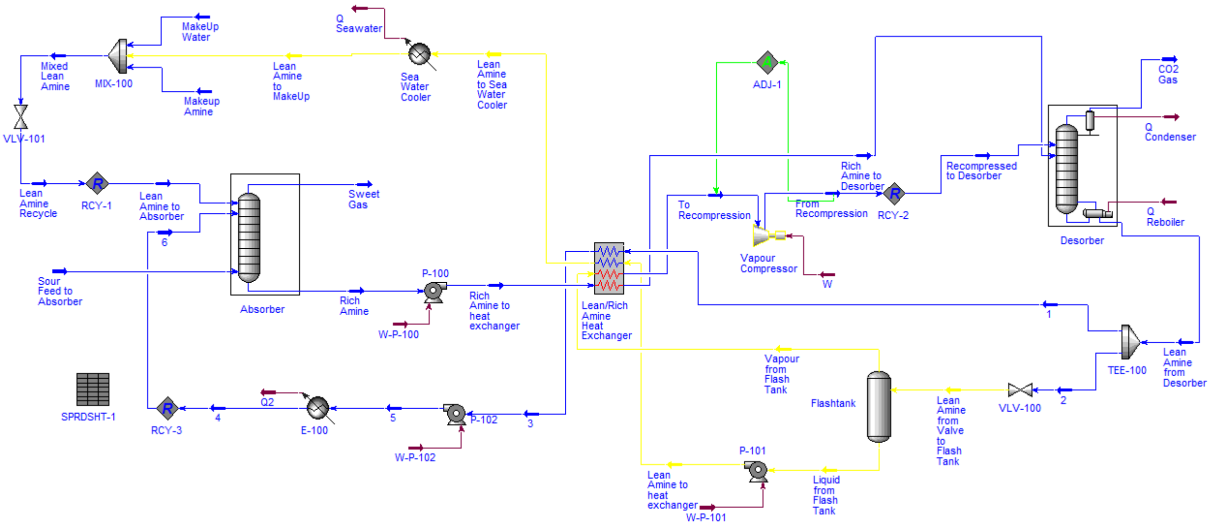

Figure 7: The user interface of the lean split with vapour recompression model in Aspen HYSYS

The model layout is shown by figure 7, and a bigger picture of the model is attached in appendix 4. The model consists of the following process equipment:

- Absorption column
- Rich amine pump
- Desorption column
- Valve
- Flash tank
- Lean vapour compressor
- Lean/Rich amine heat exchanger
- Lean amine pump
- Semi-lean pump
- Two water coolers

Some of the elements shown in figure 7 do only have a software function. These functions are: The recycle functions, called RCY-1, RCY-3, and RCY-2. The mixer and splitter, called Mix-100 and TEE-100. And the adjust function, called ADJ-1.

5.1.3.1. Specifications for the Aspen HYSYS lean split with vapour recompression base case

Table 10, 11, and 12 contains specifications for the recirculation streams. Specifications and data for the rest of the model are presented in table 13. The Aspen HYSYS simulation results may be found in appendix 7.

Table 10: Specifications for lean amine to absorber

Parameter	Value
Composition	MEA: 27,0 weight%
	CO_2:4,4 weight%
	H_2O: 68,6 weight%
Lean amine loading	
Temperature	40 °C
Pressure	101 kPa
Flow rate	4,55 *10^4 kgmole/h

Table 11: Specifications for the semi-lean stream to absorber

Parameter	Value
Composition	MEA: 29,0 weight%
	CO_2:5,1 weight%
	H_2O: 65,9 weight%
Temperature	40 °C
Pressure	101 kPa
Flow rate	5,29 *10^4 kgmole/h

Table 12: Specifications for the recompressed stream to the stripper

Parameter	Value
Composition	CO_2: 7,9 weight%
	H_2O: 89,3 weight%
	MEA: 2,8 weight%

Temperature	120 °C
Pressure	200 kPa
Flow rate	1689 kgmole/h

Table 13: Specifications and data for the rest of the model

Parameter	Value
Absorber - stages	24
Absorber - Murphree efficiency	0,15
Desorber - stages	6 + condenser + reboiler
Desorber - Murphree efficiency	1
Reboiler - temperature	120 °C
Desorber - Reflux ratio	0,3
Flash tank - pressure	100 kPa
Rich amine loading	0,537
Rich amine pump - inlet pressure	101 kPa
Rich amine pump - outlet pressure	291 kPa
Rich amine pump - inlet temperature	41,3 °C
Rich amine pump - adiabatic efficiency	75%
Lean amine pump - inlet pressure	100 kPa
Lean amine pump - outlet pressure	300 kPa
Lean amine pump - inlet temperature	101,8 °C
Lean amine pump - adiabatic efficiency	75%
Compressor - adiabatic efficiency	75%
Compressor - inlet pressure	100 kPa
Compressor - outlet pressure	200 kPa
Compressor - inlet temperature	99,4 °C
Compressor - outlet temperature	120 °C
Semi-lean amine pump - inlet pressure	100 kPa
Semi-lean amine pump - outlet pressure	111 kPa
Semi-lean amine pump - inlet temperature	46,5 °C
Semi-lean amine pump - adiabatic efficiency	75%

5.1.3.2. Results for the Aspen HYSYS lean split with vapour recompression base case

Results for the lean split with vapour recompression simulation are presented in table 14.

Table 14: Results for the Aspen HYSYS lean split with vapour recompression base case

Modification	Boiler duty, [MW]	Boiler duty, [MJ/kg]	Compressor, [MW]	Equivalent work [kJ/kg]
Lean split with vapour recompression base case	103	2,7	1,1	485

5.2. Parameter variation

Parameter variations for the base cases

Many different parameters have been varied in the base cases to fulfill the requirements for the removal efficiency and the minimum temperature approach in the lean/rich heat exchanger. The removal efficiency was kept at 85%, and the minimum temperature approach was 5K.

To fulfill these requirements there are a few parameters that are more significant than others. These ones are the recirculation flow rate and temperature, number of stages in the absorption and desorption column, Murphee efficiency, and the temperature in the rich amine feed to the stripper. But to reach the required CO_2 removal efficiency the main varied parameter was the circulation rate(s) and composition(s).

Parameter variation for the sensitivity cases

For the sensitivity cases the parameter changes are explained in each sensitivity case chapter. However, the parameter variation was continued until convergence problems occurred or as long as it had a practical/theoretical purpose.

5.3. Sensitivity calculation in the Aspen HYSYS standard absorption model

In each subchapter is the purpose of the case presented. The chapter also contains something about the methodology used.

5.3.1. Variation of lean amine circulation rate in the Aspen HYSYS standard absorption model

For the standard absorption process it has been of interest to simulate the effect of a change in lean amine circulation rate to verify the effect on the energy demand and CO_2 removal efficiency. This simulation may give a better understanding of which circulation rate that will give the optimal CO_2 removal efficiency based on the energy demand.

The lean amine circulation rate was varied from 1,3 *10^5 kgmole/h to 2,9 *10^5 kgmole/h with a 0,1 *10^5 kgmole/h step size.

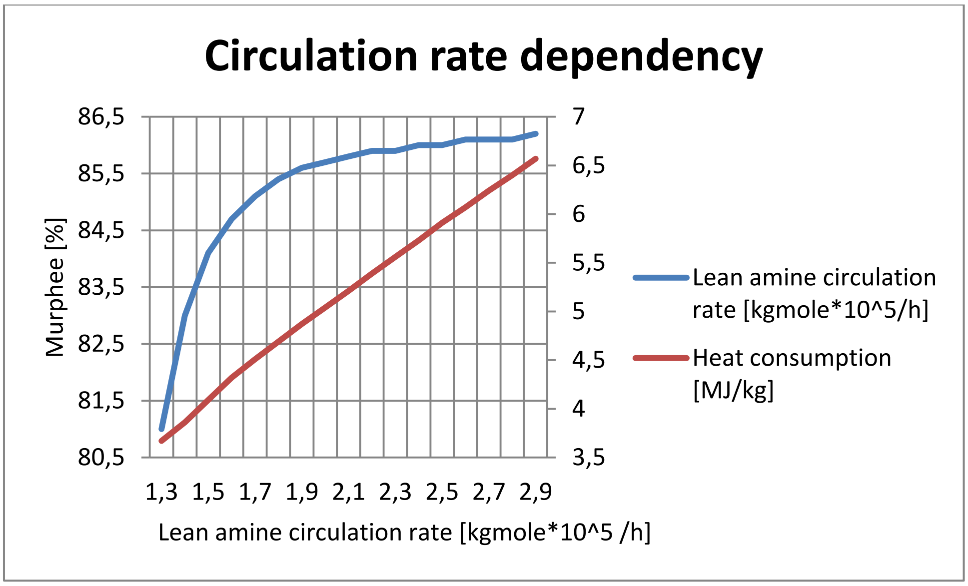

Figure 8: Lean amine circulation rate, CO_2 removal efficiency and heat demand for the Aspen HYSYS standard absorption model

5.4. Sensitivity calculation for the Aspen HYSYS vapour recompression model

In each subchapter is the purpose of the case presented. The chapter also contains something about the methodology used.

5.4.1. Variation of the lean amine circulation rate in the Aspen HYSYS vapour recompression model

For the vapour recompression model it was interesting to vary the lean amine circulation flow rate to the absorption column to find the optimal CO_2 removal efficiency compared to the equivalent thermodynamic work.

The circulation flow rate was varied from 1,10 *10^5 kgmole/h to 1,55 *10^5 kgmole/h with 0,05 *10^5 kgmole/h as the step size. The minimum temperature approach in the lean/rich heat exchanger was kept constant at 5K. The equivalent work and CO_2 efficiency was calculated and noted.

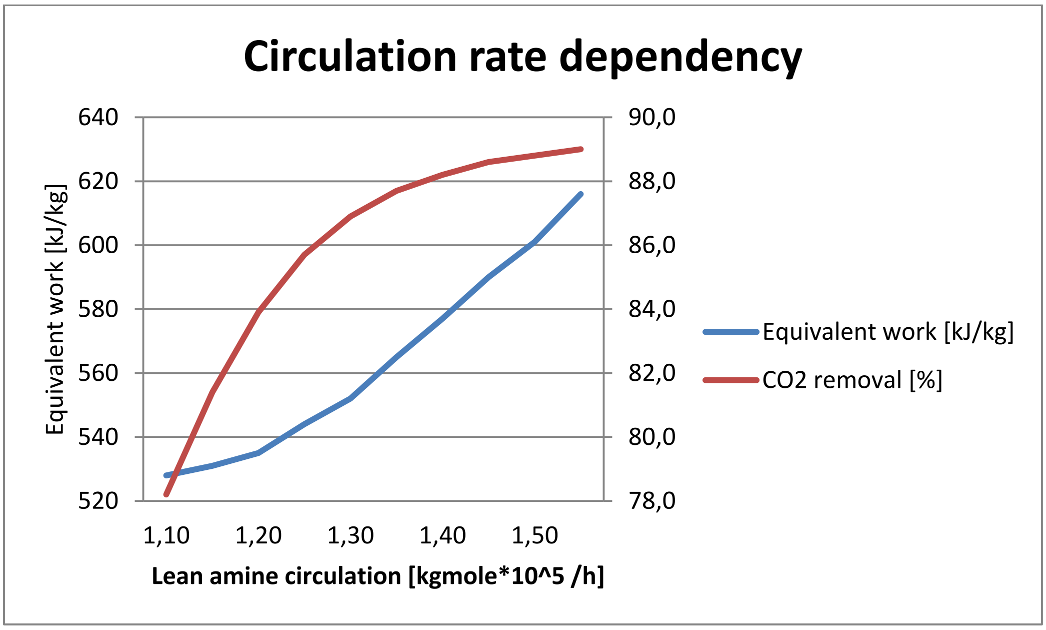

Figure 9: Lean amine circulation rate, CO_2 removal efficiency and heat demand for the Aspen HYSYS vapour recompression model

5.4.2. Variation of number plates in the absorption column in the Aspen HYSYS vapour recompression model

This case is supposed to give a understanding of how the number of plates in the absorption column affect the lean amine circulation rate and the equivalent thermodynamic work demand. This might also give some knowledge about the investment cost (number of plates) compared to operation cost (energy demand).

In this simulation the lean amine circulation rate to the absorption column was varied while the CO_2 removal efficient was kept constant at 85%, and the minimum temperature approach in the lean/rich heat exchanger was kept at 5K. The simulation was done by changing the number of plates from 13 to 21. Below 13 and above 21 the absorption column did not converge.

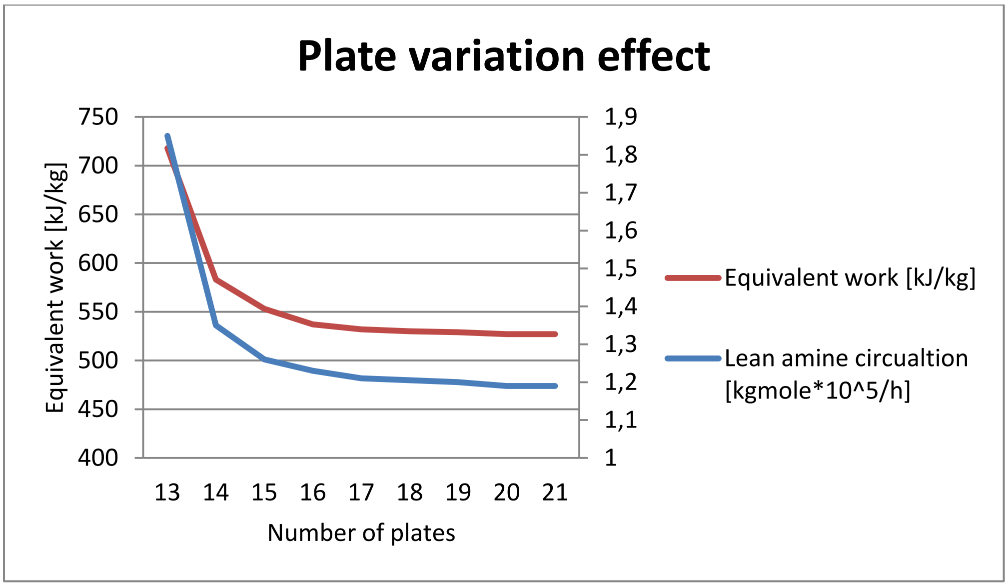

Figure 10: Effect of variation on the number of plates in the absorption column for the Aspen HYSYS vapour recompression model

5.4.3. Variation of the flash tank pressure in the Aspen HYSYS vapour recompression model

The purpose with this case is to verify how a change in the flash tank pressure affects the equivalent thermodynamic work of the process. When the flash tank pressure is changed the potential of heating in the lean/rich heat exchanger will be affected due to a change in flow rate. By keeping the minimum temperature approach constant the temperature to the stripper will be affected.

The valve before the flash tank was used to vary the pressure from 90 to 150 kPa with a 5 kPa step length while the minimum temperature approach was kept constant and the equivalent thermodynamic work was recorded.

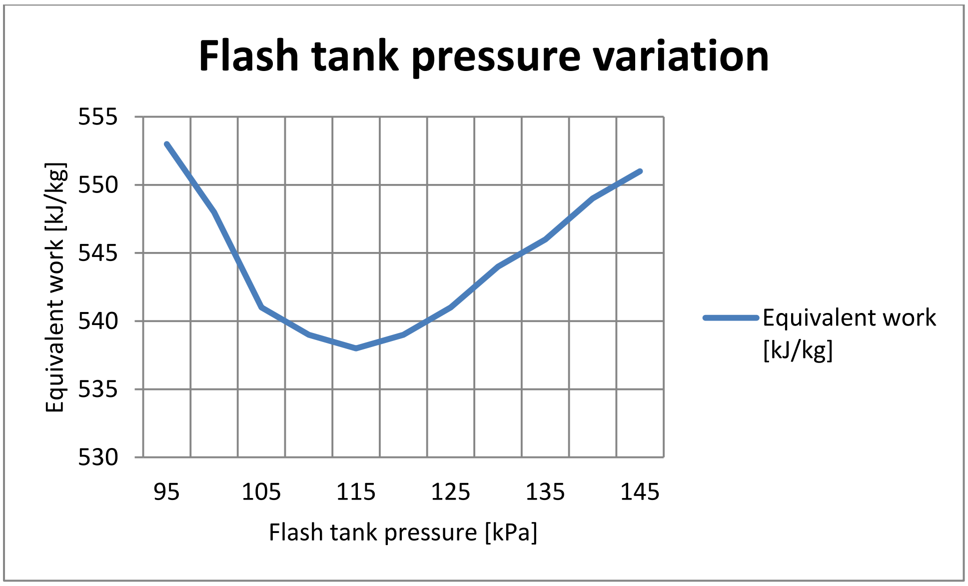

Figure 11: Effect of flash tank pressure variation on the equivalent work for the Aspen HYSYS vapour recompression model

6. Simulation strategy and calculation sequence in Aspen HYSYS

The calculation sequence in these Aspen HYSYS models was based on specified/guessed composition, flow rate, pressure and temperature to the absorption column and to the recompressed stream to the desorption column.

In the calculation sequence for the vapour recompression modification the absorption column was calculated first. The following calculations were on the rich amine pump and then the rich amine side of the heat exchanger. After this, the desorption column was solved, then the pressure reduction in the valve. From here the recycle loop was calculated: Meaning first the compressor and then checking the parameter values to the existing ones. If the aberration was outside the accepted deviation manually iterations was done until the requirement was met (recycle function was on ignore). When a solution is found the lean amine pump was calculated. Then the lean side of the heat exchanger was solved. After this, the cooler was solved, then the mixer and the valve. The last recycle function was also put on ignored while modeling. This means that the composition was manually compared to the specified composition in the lean amine feed to the absorption column.

As mentioned, the adjust functions to the absorption/desorption column was set to ignored. This was basically done because the convergence of the process was eased. The specifications were manually changed in the system until the deviation was within the accepted limits. The sensitivity of these adjust functions was set as default. Furthermore, the number of plates in the absorption and desorption column was based on earlier works and on the try-and-failure method. For both columns the used solver was the Modified HYSIM Inside-Out. This solver method was experienced to give the best column convergence. The amine flow rate to the absorption column was adjusted to achieve the requirement of 85% CO_2 removal. Efficiency in pumps and the compressor was set to 75%. The compositions in the make-up streams are pure water and amine. The mole flow specifications for the two make up streams are imported from the spreadsheet in the model. This spreadsheet sums all the lost amine and water from the system, and from this spreadsheet the values are manually exported to the stream specifications. For the mixer the outlet pressure is set to lowest inlet.

The simulation strategy concerning the lean split with vapour recompression modification was based on the method of try-and-failure. To get a converged model for both the columns and all recycle functions was very demanding. The specifications connected to the recycle functions were manually updated. The three recycle functions increase the complexity of the model dramatically compared to two recycle functions. The model is converged for all columns and recycle functions. However, the complexity and low flexibility of the model makes any reliable sensitivity analysis hard to achieve.

7. Evaluation of the Aspen HYSYS simulation results

In this chapter the energy demands of the simulation results are evaluated by qualitative and quantitative methods.

7.1. Evaluation of the base cases

Results from the base case simulations are presented in table 15. The boiler duty given by MJ/kg is the energy consumption in the reboiler for each kg removed CO_2. The cost calculation is done as described in chapter 4 with expected operation of 8400 hours/year.

Table 15: The Aspen HYSYS base case simulation results

Modification/ base case	Boiler duty, [MW]	Boiler duty, [MJ/kg]	Compressor, [MW]	Equivalent work [kJ/kg]	Energy cost [MNOK/year]
Standard	161	4,3	-	724	120,36
Vapour recompression	102	2,7	2,7	538	85,33
Lean split with vapour recompression	103	2,7	1,1	485	80,70

The boiler duty for each kg CO2 removed is calculated to 4,3 MJ/kg for the standard base case, and 2,7 MJ/kg for both the vapour recompression and lean split with vapour recompression base case. Compared to other research done as [15] and [14] these values are approximately the same and is considered typical values for these types of modifications based on flue gas from a natural gas power and heat plant. By comparing the compressor duty for the base cases it is clear to see that the standard process is the best since it has none. But for the other two modifications the lean split with vapour recompression is the best. It has only about 40% of the compressor duty of the vapour recompression model. When comparing the equivalent work for these modifications it is clear that the lean split with vapour recompression modification is less energy demanding than the other two models. The two modifications with the lowest equivalent work demand have an increase in the electricity demand because of the compressor. However, the overall efficiency of the system will increase because of the much lower reboiler duty consumption. The boiler uses stream from the combined power and heat plant.

From table 15 it is clear that the energy cost is lowest for the lean split with vapour recompression modification. This modification has 80,70 MNOK per year compared to 85,33 MNOK for the vapour recompression modification, and 120,36 MNOK each year for the standard CO_2 removal process. For these values the amount of CO_2 removed is about 1,15 M ton/year.

7.2. Evaluation of the sensitivity cases

When reading the evaluations and remarks for the sensitivity cases it should be noted that these values are restricted to similar operational conditions and feed values.

7.2.1. Evaluation of the sensitivity calculations for the Aspen HYSYS standard absorption model

7.2.1.1. Evaluation of the case: Variation of lean amine circulation in the Aspen HYSYS standard absorption model

For the lean amine circulation rate in the standard process figure 8 shows that the CO_2 removal efficiency is not increasing much after 85% with increasing circulation rate. At the same time the thermal energy demand is increasing linear with increasing circulation rate. This means that the simulation result indicates that the optimal CO_2 removal efficiency will be about 85% by considering the thermal energy demand in the reboiler.

7.2.2. Evaluation of the sensitivity calculations for the Aspen HYSYS vapour recompression model

7.2.2.1. Evaluation of the case: Variation of the lean amine circulation rate in the Aspen HYSYS vapour recompression model

The effect of vary the lean amine circulation rate in the vapour recompression model is presented in figure 9. The CO_2 removal efficiency does have the same trend as for the standard model; the slope reduces with increasing lean amine circulation rate. The equivalent thermodynamic work does however not follow a linear line, but increases potentially with increasing circulation rate. According to the figure the optimal CO_2 removal efficiency will be around 84-86%. At this efficiency the circulation rate will be about 1,20 – 1,25 * 10^5 kgmole/h, and the equivalent thermodynamic work will be at 580-600 kJ/kg.

7.2.2.2. Evaluation of the case: Variation of number plates in the absorption column in the Aspen HYSYS vapour recompression model

Figure 10 shows the lean amine circulation rate and equivalent work for each number of plate simulated. In this simulation the circulation rate CO_2 removal efficiency was kept constant at 85%. From the lowest amount of plates (13) the equivalent work and circulation rate decreased a lot to the simulation result with 14 plates. From 14 to 16 plates the equivalent work and circulation rate was reduced from respectively 583 kJ/kg and 1,35 *10^5 kgmole/h to 537 kJ/kg and 1,23 *10^5 kgmole/h. This is a 7,9% reduction in the equivalent work. The simulation results with more than 16 plates shows that the reduction in circulation rate and equivalent work will wane. From the values in figure 10 the optimal number of plates will be from 14 to 16. This will be a trade-off between investment and operation cost. It should however be mentioned that these values are restricted to similar operational conditions.

7.2.2.3. Evaluation of the case: Variation of the flash tank pressure in the Aspen HYSYS vapour recompression model

The effect of variation in the flash tank pressure on the equivalent work demand is shown in figure 11. The minimum temperature approach in the lean/rich heat exchanger is kept constant at about 5K for all simulations. The figure shows that the optimal flash tank pressure will be about 110-120 kPa when considering the energy saving. With increasing or decreasing flash tank pressure from this range the equivalent work demand will increase. This illustrate that the flash tank pressure should be at this value range to minimize the energy cost. However, it should be mentioned that a minimization of the temperature approach will increase the purchase/investment cost of the heat exchanger. In addition, a different temperature approach may change the optimal flash tank pressure.

In paper [8] the optimum flash tank pressure has been evaluated to be at 1,2 bar. This value is in line with the estimated value in this work.

8. Uncertainties in the simulations

Accuracy

When simulations were repeated small deviations in values occurs. This deviation is about 0,5%. This is expected to be because of starting values in the model and the accepted sensitivity deviations in the software functions. This deviation may be reduced if the sensitivities are reduced, i.e. tighter convergence limits.

The simulations were done with Kent-Eisenberg as the model for the aqueous solution. But a test was conducted with Li-Mather to check the difference in calculation results. A change between these two models gave an aberration of more than 2% change in the CO_2 efficiency.

Simplified model

The three simulated models are only simplified processes. Heat losses from equipment are neglected, and so are the pressure drops throughout the process. A real process will consist of more equipment and components which will generate a higher pressure drop and even more heat loss. As mentioned in chapter 3.4 a real process will have more auxiliary systems that will increase the complexity and the electricity demand of the total system, but these are not considered in this work.

One of the important discussions around these kinds of simulations is the complexity versus the simplicity of different process/modification models. A complex model might be slightly more accurate compared to a simplified model, but it will however be more information and detail demanding, time consuming, and more column convergence problems will occur.

Adiabatic efficiencies

The adiabatic efficiency in the pumps was set to 75 %. This is the default value in Aspen HYSYS. This value might not be accurate enough for a detailed pump power study. However, the pump duty is relatively small compared to the compressor duty and the thermal heat demand of the system, and will therefore not be important in this study. The adiabatic efficiency for the compressor was also set to 75%, which is the default value in Aspen HYSYS.

Property package limitation

The parameter value range limits for the amine package was fulfilled for all calculations except for the lean split with vapour recompression modification. In this simulation some of the streams between the columns were giving a warning. However, the streams connected to the columns were within the amine package range.

9. Capital cost estimation of the Aspen HYSYS base cases

The capital cost is defined as the total cost of equipment, engineering, and installing. The equipment cost estimations made in this chapter are scaled and cost converted by equation 4.3 and 4.6 from table 16. Data not available there are from [27] or [15]. When the costs of the equipment are estimated equation 4.4 are used to estimate the capital cost. All calculation methods used are described in chapter 4. It is used three significant digits in this estimation.

9.1. Pumps, coolers, condenser, reboiler and separator cost

Table 16 contains equipment cost before the cash index converting and scaling are applied.

Table 16: Equipment cost in 2010 currency [23]

List of equipment	Equipment cost, [NOK]
Rich pump	2890000
Reboiler	6120000
Lean pump	1330000
Lean cooler	1430000
Condenser	264000
Separator	1020000
Semi-lean pump	1330000
Semi-lean cooler	1430000

9.2. Compressor costs

The compressor costs for the two relevant cases are estimated by power demand and presented in table 17. The material is assumed to be stainless steel. Currency converting was done by equation 4.5.

Table 17: Compressor cost [27]

Modification	Cost [$]	Cost [NOK]
Standard	-	-
Vapour recompression	9770000	57000000
Lean split with vapour recompression	4520000	26400000

9.3. Absorption column cost

The method and values of absorption column dimensioning is referred to [15]. That work has close to the same specifications and equal number of stages in the column.

The absorber dimensions and cost for packing and skirt are presented in table 18 and 19.

Table 18: Absorber dimensions

Modification	Packing height [m]	Column height [m]	Column diameter [m]
Standard	14	16	17,3
Vapour recompression	16	28	17,3
Lean split with vapour recompression	24	35	17,3

Table 19: Absorber cost

Modification	Absorber packing cost [NOK]	Absorber skirt cost [NOK]
Standard	21800000	2430000
Vapour recompression	23800000	2520000
Lean split with vapour recompression	34200000	2980000

9.4. Desorption column cost

Costs for the desorption column are scaled and the cost updated from [23].

The desorber packing and skirt costs are presented in table 20.

Table 20: Desorber cost

Modification	Desorber packing cost [NOK]	Desorber skirt cost [NOK]
Standard	7900000	5490000
Vapour recompression	7900000	5490000
Lean split with vapour recompression	5660000	3940000

9.5. Lean/rich heat exchanger cost

The lean/rich heat exchanger is scaled with heat transfer area. Heat transfer area is calculated by the following equation:

$$A = \frac{Q}{U \times \Delta T_{LM} \times f} \tag{9.1}$$

- Logarithmic mean temperature difference ΔT_{LM} [K] and Q [kW] is calculated by Aspen HYSYS.
- Temperature correction factor f is set to 1.
- Heat transfer coefficient U is set to 0,5 $\frac{kW}{m^2K}$.

Table 21 contains the lean/rich heat exchanger costs for the different configurations.

Table 21: Lean/rich heat exchanger cost

Modification	**Cost [NOK]**
Standard	70700000
Vapour recompression	62100000
Lean split with vapour recompression	46600000

9.6. Comparison of capital cost

Table 22 contains the scaled capital costs for each configuration in 2013 currency.

Table 22: Capital cost

	Standard absorption	**Vapour recompression**	**Lean split with vapour recompression**
Absorber packing	109000000	119000000	171000000
Absorber skirt	12150000	12600000	14900000
Desorber packing	39500000	39500000	28300000
Desorber skirt	27400000	27400000	19700000
Lean pump	9170000	7710000	3730000
Lean cooler	14000000	6200000	3200000
Rich pump	13300000	11200000	9670000
Semi-lean pump	-	-	4470000
Semi-lean cooler	-	-	3730000
Separator	-	5270000	5270000
Compressor	-	284000000	131000000
Lean/rich heat exchanger	254000000	290000000	345000000
Reboiler	34800000	25800000	26000000
Condenser	1510000	2430000	1370000
SUM	**515000000**	**832000000**	**768000000**

10. Evaluation of the capital cost estimation

The capital costs are presented in table 23. These costs include equipment, engineering, and installation costs. In addition, [23] are based on assumed realistic types of materials. This means that the different material costs are included in the capital costs.

It is quite clear that the standard process has the lowest capital cost with 515 MNOK. This is because this process is the simplest with lowest amount of equipment. For the other two cases the compressor cost are the most significant single major equipment which increase the cost dramatically. Since the flow rate in the lean split with vapour recompression modification does have a significant lower rate than the vapour recompression modification the compressor cost is very different. This difference alone makes the vapour recompression modification the most expensive with 832 MNOK, compared to 768 MNOK for the lean split with vapour recompression modification.

The capital cost estimations is based on several methods and sources which has a latent uncertainty attached. According to [22] do some of the methods used expect to have an accuracy of ±50%.

In this work there are a few components which are not considered, e.g. a fan, fan motor, DCC and some auxiliary equipment. This means that the capital cost estimation should be lower than similar work. However, these costs will be approximately the same for all the different base cases simulated in this work. And therefore, the costs can still be compared relative to each other.

11. Recommendations for further research

It is of interest to verify results from this work. Therefore more research on the capital and energy cost for these configurations are recommended. However, more simulations and cost analysis for different modifications are also interesting.

The calculations in the lean split with vapour recompression model gave low energy and cost results. Sensitivity calculation cases on this model may be very interesting for verifying and optimize the modification. But to do this an improvement of the robustness/flexibility of the model is necessary.

It is also strongly recommended that future capital cost analyses are done by commercial software programs or handbooks to reduce the uncertainty of calculations as much as possible.

In the future when some real data from a big scale CO_2 removal plant are published verifications of simulation tools and calculations would be very interesting.

12. Conclusion

In this work three different flow sheet configurations have been evaluated for post combustion CO_2 capture from a combined heat and power plant by the use of chemical absorption. The simulations have been conducted in the simulation tool Aspen HYSYS. The configurations evaluated are a standard absorption process, a vapour recompression modification, and a lean split with vapour recompression modification. For all three configurations the energy consumption and the capital cost have been evaluated. In addition, sensitivity cases have been conducted for optimization, especially in the vapour recompression modification. The lean split with vapour recompression was too complex and had too low flexibility to achieve converged calculations in sensitivity cases.

For comparison of all three modifications the CO_2 removal efficiency of 85%, feed parameters, and the minimum temperature approach in the lean/rich heat exchanger of 5K was kept constant. The energy consumption for steam and electricity was converted to energy cost per year.

For all three configurations the lean split with vapour recompression modification had the lowest energy cost with 81 MNOK/year when removing about 1,15 M ton CO_2/year. However, the vapour recompression modification had only a slightly higher cost equal to 85 MNOK/year. The standard absorption process had an energy cost of 120 MNOK/year.

The capital costs estimations for the three configurations gave the lowest cost for the standard process with about 514 MNOK. The two other modifications were more expensive. The biggest difference was due to the extra compressor. The lean split with vapour recompression had a cost of 768 MNOK, while the vapour recompression modification had a cost of 832 MNOK.

Sensitivity calculations for the vapour recompression modification was analyzed to have the following optimal values: CO_2 removal efficiency of 84-86%, flash tank pressure at 110-120 kPa, 14-16 stages in the absorption column. It should however be noted that these values are restricted to similar operational conditions and feed values.

The uncertainties are very high for the capital and energy cost estimations. More accurate estimations are probably necessary to conclude which modification and parameters are the most optimum.

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14. Appendices

Appendix 1	Master’s thesis task description
Appendix 2	Figure of the standard absorption base case in Aspen HYSYS
Appendix 3	Figure of the vapour recompression base case in Aspen HYSYS
Appendix 4	Figure of the lean split with vapour recompression base case in Aspen HYSYS
Appendix 5	Aspen HYSYS report for the standard absorption base case
Appendix 6	Aspen HYSYS report for the vapour recompression base case
Appendix 7	Aspen HYSYS report for the lean split with vapour recompression base case

UiT Master's Thesis

Title: CO_2 absorption and desorption simulation with Aspen HYSYS

Supervisor: Associate Professor Lars Erik Øi, Telemark University College

Task Description:

1. Evaluation of earlier projects on process simulation of CO_2 capture with emphasis on different process configurations aiming at reduction of energy consumption.

2. Simulations of CO_2 capture with Aspen HYSYS absorption and desorption in an amine solution. Evaluation of different options for reducing the energy consumption, especially by using vapour recompression.

3. Calculate energy optimum and possibly cost optimum conditions for processes, especially based on vapour recompression.

4. Evaluation of uncertainties in the calculations.

Background:

The most studied method for removal of CO_2 from atmospheric exhaust is by the help of amine solutions. HYSYS has been much used in projects for process simulation of CO_2 removal. There are several possibilities to improve the existing models. Vapour recompression is one of the most promising configurations for reducing the energy consumption.

References:

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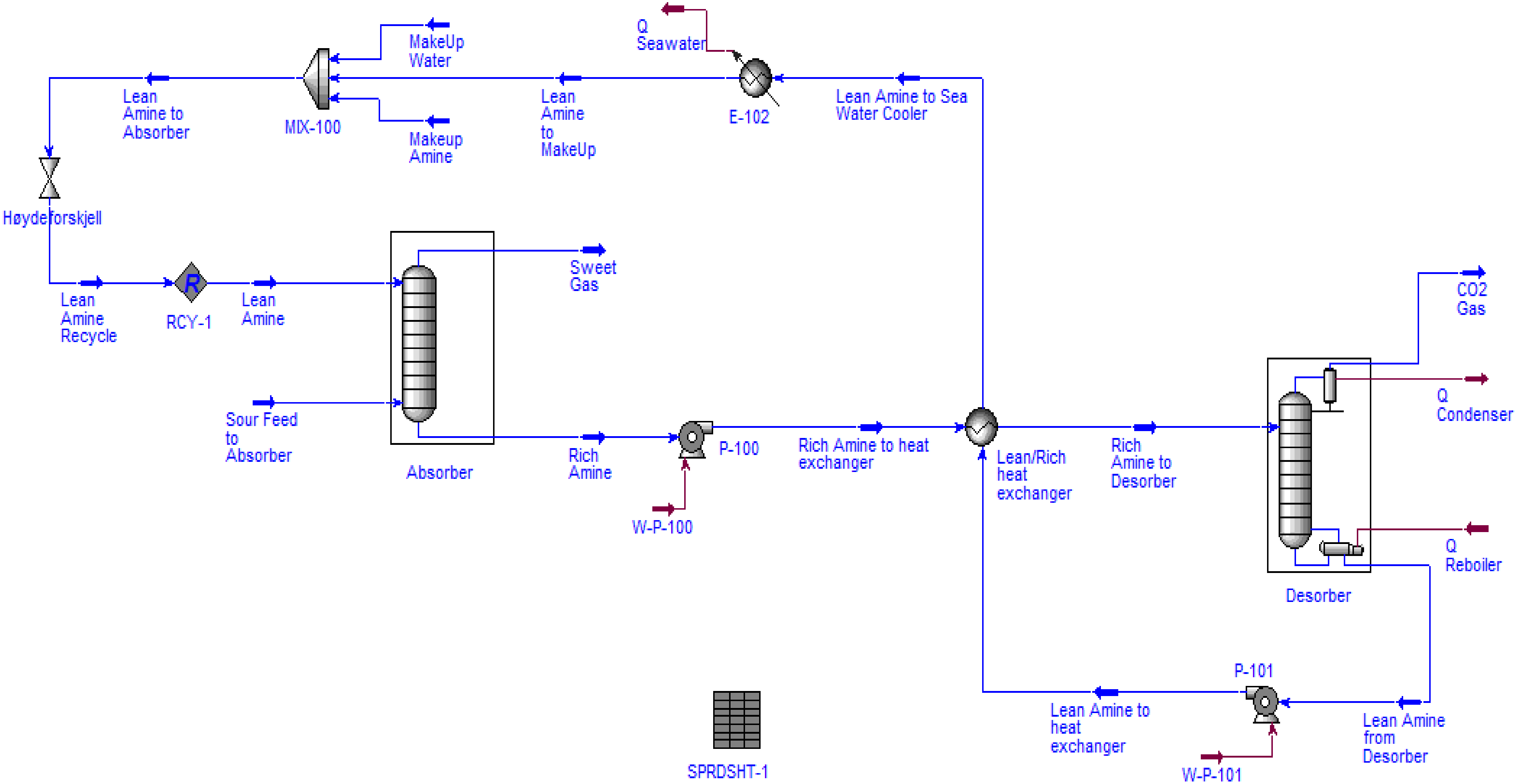
Student: Even Birkelund

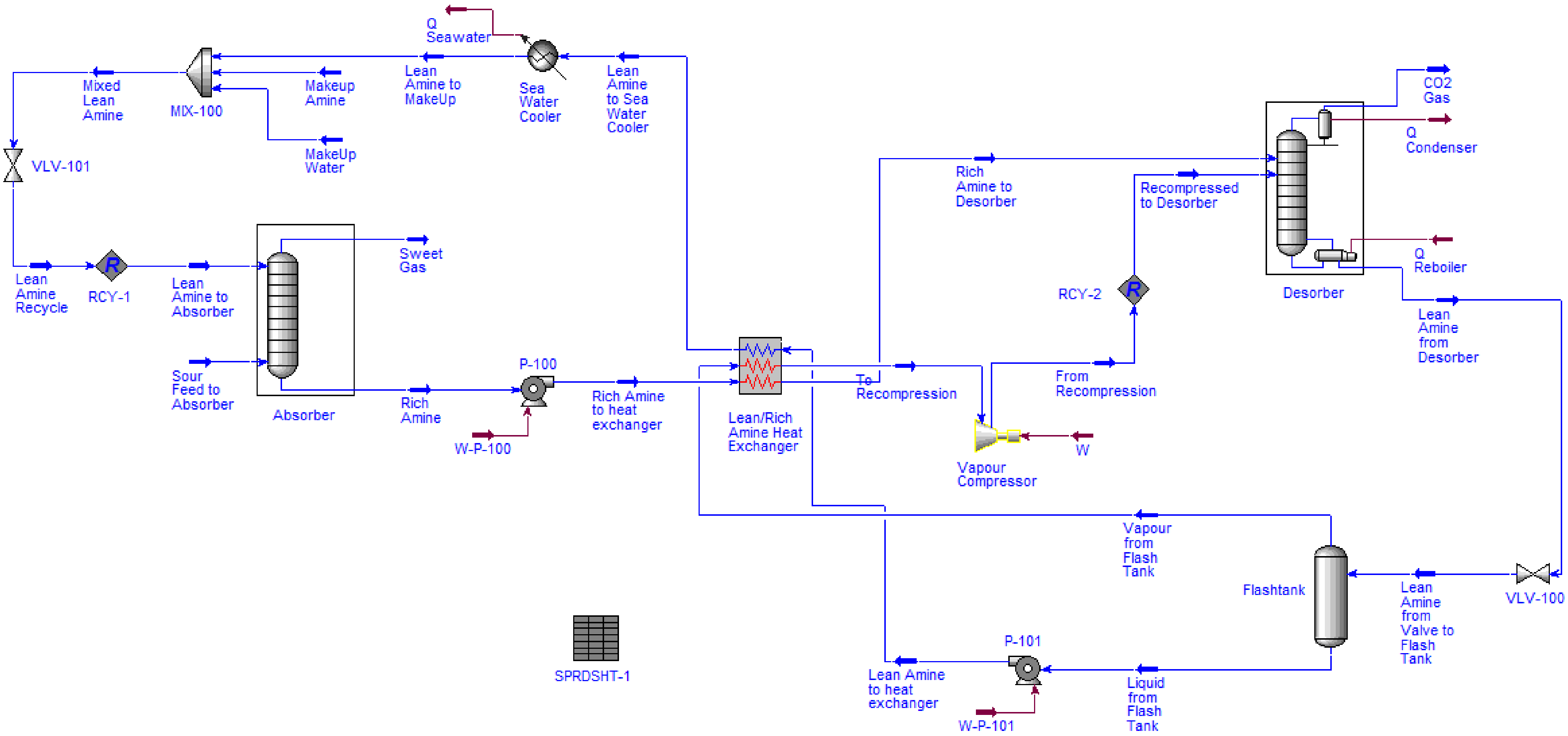
Practical arrangements:

The work will mainly be carried out at the University of Tromsø, with a possible visit at the TCM facility at Mongstad.

Appendix 2 Figure of the standard absorption base case in Aspen HYSYS



Appendix 3 Figure of the vapour recompression base case in Aspen HYSYS



Appendix 4 Figure of the lean split with vapour recompression base case in Aspen HYSYS

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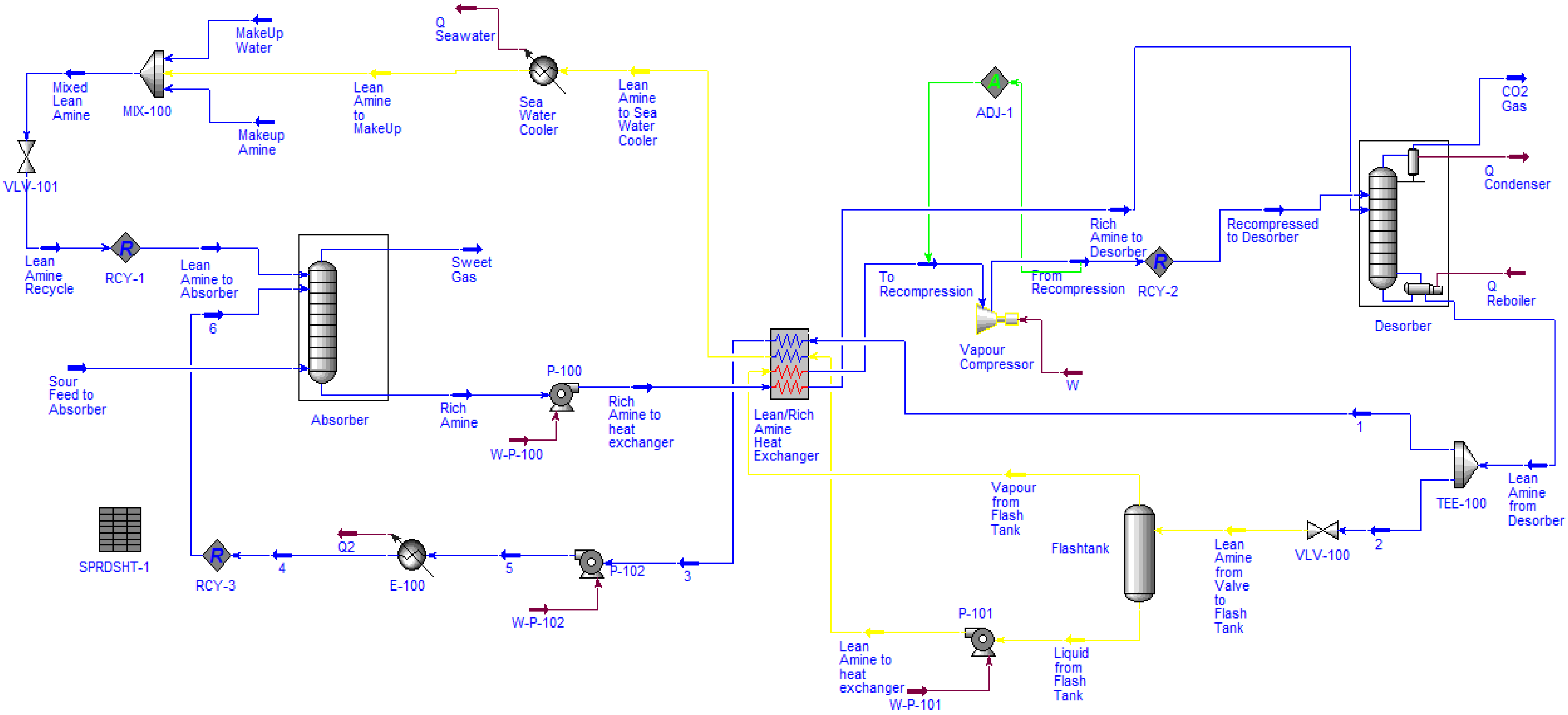

aspentech
UNIVERSITY OF TROMSO
Burlington, MA
USA

Case Name: STANDARD ABSORPTION PROCESS.HSC
Unit Set: SI1
Date/Time: Fri May 31 13:26:08 2013

Material Stream: Sour Feed

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	194.0 *	194.0			
Pressure:	(kPa)	110.0 *	110.0			
Molar Flow	(kgmole/h)	1.091e+005 *	1.091e+005			
Mass Flow	(kg/h)	3.100e+006	3.100e+006			
Std Ideal Liq Vol Flow	(m3/h)	3633	3633			
Molar Enthalpy	(kJ/kgmole)	1.383e+004	1.383e+004			
Molar Entropy	(kJ/kgmole-C)	208.0	208.0			
Heat Flow	(MW)	419.3	419.3			
Liq Vol Flow @Std Cond	(m3/h)	---	---			

Material Stream: Sour Feed to Absorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	40.00 *	40.00			
Pressure:	(kPa)	101.0 *	101.0			
Molar Flow	(kgmole/h)	1.091e+005	1.091e+005			
Mass Flow	(kg/h)	3.100e+006	3.100e+006			
Std Ideal Liq Vol Flow	(m3/h)	3633	3633			
Molar Enthalpy	(kJ/kgmole)	9211	9211			
Molar Entropy	(kJ/kgmole-C)	196.6	196.6			
Heat Flow	(MW)	279.3	279.3			
Liq Vol Flow @Std Cond	(m3/h)	---	---			

Material Stream: Sweet Gas

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	47.93	47.93			
Pressure:	(kPa)	101.0	101.0			
Molar Flow	(kgmole/h)	1.093e+005	1.093e+005			
Mass Flow	(kg/h)	3.025e+006	3.025e+006			
Std Ideal Liq Vol Flow	(m3/h)	3530	3530			
Molar Enthalpy	(kJ/kgmole)	9483	9483			
Molar Entropy	(kJ/kgmole-C)	197.1	197.1			
Heat Flow	(MW)	287.9	287.9			
Liq Vol Flow @Std Cond	(m3/h)	---	---			

Material Stream: Rich Amine

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	43.45	43.45			
Pressure:	(kPa)	101.0	101.0			
Molar Flow	(kgmole/h)	1.598e+005	1.598e+005			
Mass Flow	(kg/h)	3.852e+006	3.852e+006			
Std Ideal Liq Vol Flow	(m3/h)	3911	3911			
Molar Enthalpy	(kJ/kgmole)	-2.805e+004	-2.805e+004			
Molar Entropy	(kJ/kgmole-C)	85.83	85.83			
Heat Flow	(MW)	-1246	-1246			
Liq Vol Flow @Std Cond	(m3/h)	3648 *	3648			

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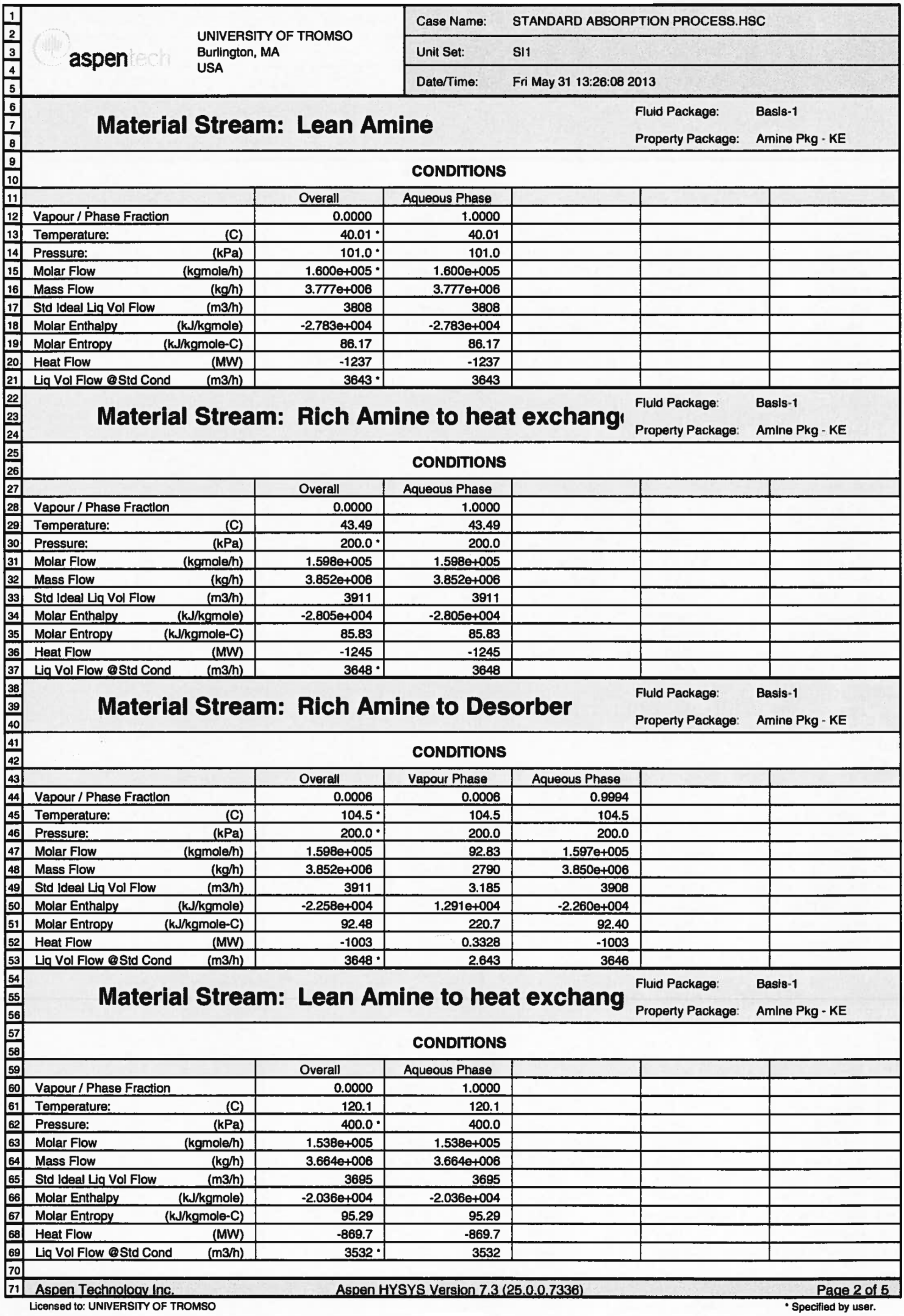
* Specified by user.



aspentech

UNIVERSITY OF TROMSO
Burlington, MA
USA

Case Name:	STANDARD ABSORPTION PROCESS.HSC
Unit Set:	SI1
Date/Time:	Fri May 31 13:26:08 2013

Material Stream: Lean Amine

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	40.01 *	40.01			
Pressure: (kPa)	101.0 *	101.0			
Molar Flow (kgmole/h)	1.600e+005 *	1.600e+005			
Mass Flow (kg/h)	3.777e+006	3.777e+006			
Std Ideal Liq Vol Flow (m3/h)	3808	3808			
Molar Enthalpy (kJ/kgmole)	-2.783e+004	-2.783e+004			
Molar Entropy (kJ/kgmole-C)	86.17	86.17			
Heat Flow (MW)	-1237	-1237			
Liq Vol Flow @Std Cond (m3/h)	3643 *	3643			

Material Stream: Rich Amine to heat exchang

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	43.49	43.49			
Pressure: (kPa)	200.0 *	200.0			
Molar Flow (kgmole/h)	1.598e+005	1.598e+005			
Mass Flow (kg/h)	3.852e+006	3.852e+006			
Std Ideal Liq Vol Flow (m3/h)	3911	3911			
Molar Enthalpy (kJ/kgmole)	-2.805e+004	-2.805e+004			
Molar Entropy (kJ/kgmole-C)	85.83	85.83			
Heat Flow (MW)	-1245	-1245			
Liq Vol Flow @Std Cond (m3/h)	3648 *	3648			

Material Stream: Rich Amine to Desorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.0006	0.0006	0.9994		
Temperature: (C)	104.5 *	104.5	104.5		
Pressure: (kPa)	200.0 *	200.0	200.0		
Molar Flow (kgmole/h)	1.598e+005	92.83	1.597e+005		
Mass Flow (kg/h)	3.852e+006	2790	3.850e+006		
Std Ideal Liq Vol Flow (m3/h)	3911	3.185	3908		
Molar Enthalpy (kJ/kgmole)	-2.258e+004	1.291e+004	-2.260e+004		
Molar Entropy (kJ/kgmole-C)	92.48	220.7	92.40		
Heat Flow (MW)	-1003	0.3328	-1003		
Liq Vol Flow @Std Cond (m3/h)	3648 *	2.643	3646		

Material Stream: Lean Amine to heat exchang

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	120.1	120.1			
Pressure: (kPa)	400.0 *	400.0			
Molar Flow (kgmole/h)	1.538e+005	1.538e+005			
Mass Flow (kg/h)	3.664e+006	3.664e+006			
Std Ideal Liq Vol Flow (m3/h)	3695	3695			
Molar Enthalpy (kJ/kgmole)	-2.036e+004	-2.036e+004			
Molar Entropy (kJ/kgmole-C)	95.29	95.29			
Heat Flow (MW)	-869.7	-869.7			
Liq Vol Flow @Std Cond (m3/h)	3532 *	3532			

Aspen Technology Inc. Aspen HYSYS Version 7.3 (25.0.0.7336) Page 2 of 5

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* Specified by user.

Material Stream: Lean Amine to Sea Water Co

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	58.28	58.28			
Pressure:	(kPa)	400.0 *	400.0			
Molar Flow	(kgmole/h)	1.538e+005	1.538e+005			
Mass Flow	(kg/h)	3.664e+006	3.664e+006			
Std Ideal Liq Vol Flow	(m3/h)	3695	3695			
Molar Enthalpy	(kJ/kgmole)	-2.604e+004	-2.604e+004			
Molar Entropy	(kJ/kgmole-C)	88.57	88.57			
Heat Flow	(MW)	-1112	-1112			
Liq Vol Flow @Std Cond	(m3/h)	3532 *	3532			

Material Stream: Lean Amine from Desorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	120.0	120.0			
Pressure:	(kPa)	200.0	200.0			
Molar Flow	(kgmole/h)	1.538e+005	1.538e+005			
Mass Flow	(kg/h)	3.664e+006	3.664e+006			
Std Ideal Liq Vol Flow	(m3/h)	3695	3695			
Molar Enthalpy	(kJ/kgmole)	-2.036e+004	-2.036e+004			
Molar Entropy	(kJ/kgmole-C)	95.29	95.29			
Heat Flow	(MW)	-869.9	-869.9			
Liq Vol Flow @Std Cond	(m3/h)	3532 *	3532			

Material Stream: CO2 Gas

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	100.0	100.0			
Pressure:	(kPa)	200.0	200.0			
Molar Flow	(kgmole/h)	6035	6035			
Mass Flow	(kg/h)	1.883e+005	1.883e+005			
Std Ideal Liq Vol Flow	(m3/h)	216.8	216.8			
Molar Enthalpy	(kJ/kgmole)	1.248e+004	1.248e+004			
Molar Entropy	(kJ/kgmole-C)	219.9	219.9			
Heat Flow	(MW)	20.92	20.92			
Liq Vol Flow @Std Cond	(m3/h)	178.5 *	178.5			

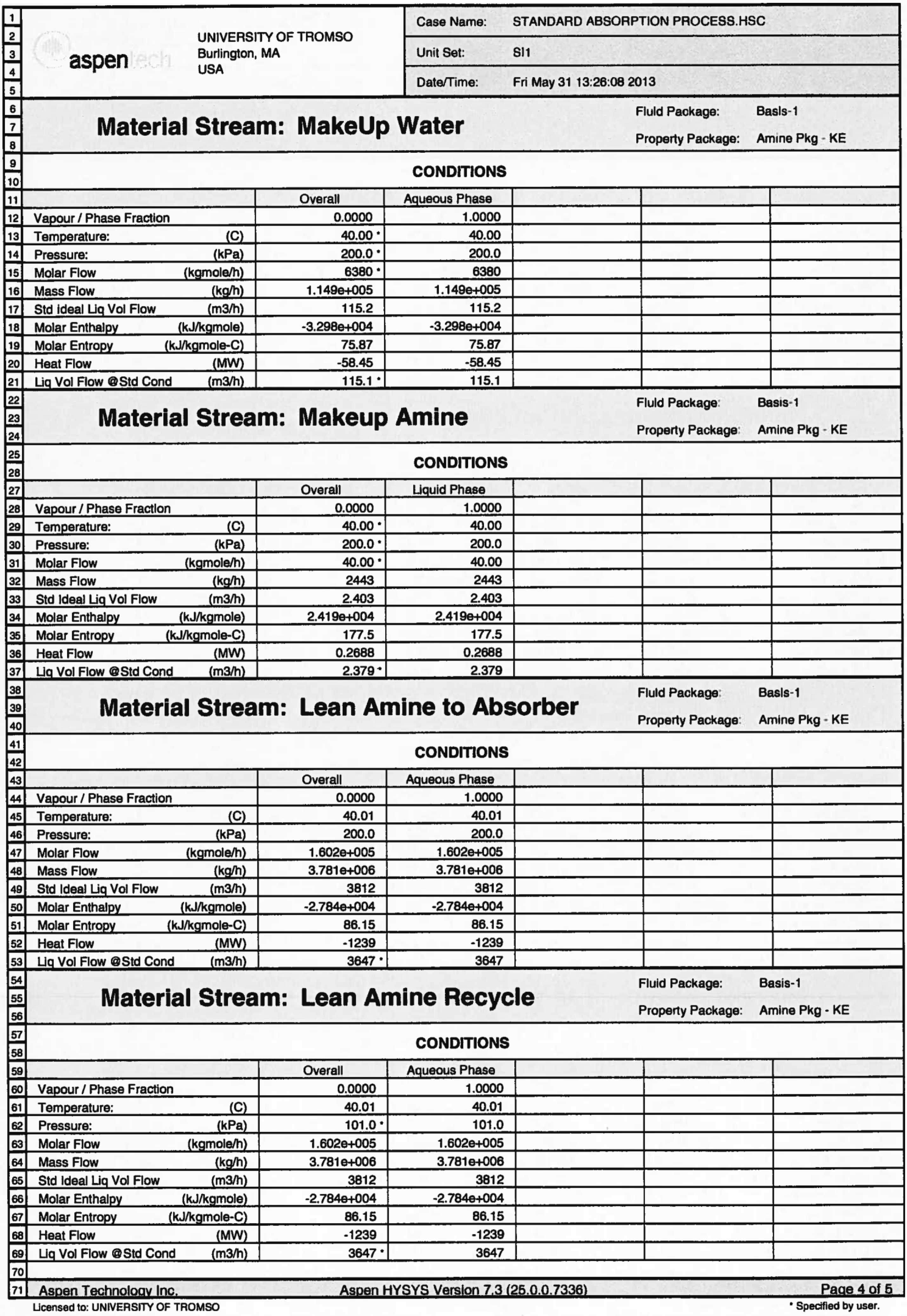
Material Stream: Lean Amine to MakeUp

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	40.00 *	40.00			
Pressure:	(kPa)	400.0 *	400.0			
Molar Flow	(kgmole/h)	1.538e+005	1.538e+005			
Mass Flow	(kg/h)	3.664e+006	3.664e+006			
Std Ideal Liq Vol Flow	(m3/h)	3695	3695			
Molar Enthalpy	(kJ/kgmole)	-2.764e+004	-2.764e+004			
Molar Entropy	(kJ/kgmole-C)	86.55	86.55			
Heat Flow	(MW)	-1181	-1181			
Liq Vol Flow @Std Cond	(m3/h)	3532 *	3532			

* Specified by user.



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Case Name: STANDARD ABSORPTION PROCESS.HSC
Unit Set: SI1
Date/Time: Fri May 31 13:26:08 2013

Material Stream: MakeUp Water

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	40.00 *	40.00			
Pressure: (kPa)	200.0 *	200.0			
Molar Flow (kgmole/h)	6380 *	6380			
Mass Flow (kg/h)	1.149e+005	1.149e+005			
Std Ideal Liq Vol Flow (m3/h)	115.2	115.2			
Molar Enthalpy (kJ/kgmole)	-3.298e+004	-3.298e+004			
Molar Entropy (kJ/kgmole-C)	75.87	75.87			
Heat Flow (MW)	-58.45	-58.45			
Liq Vol Flow @Std Cond (m3/h)	115.1 *	115.1			

Material Stream: Makeup Amine

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Liquid Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	40.00 *	40.00			
Pressure: (kPa)	200.0 *	200.0			
Molar Flow (kgmole/h)	40.00 *	40.00			
Mass Flow (kg/h)	2443	2443			
Std Ideal Liq Vol Flow (m3/h)	2.403	2.403			
Molar Enthalpy (kJ/kgmole)	2.419e+004	2.419e+004			
Molar Entropy (kJ/kgmole-C)	177.5	177.5			
Heat Flow (MW)	0.2688	0.2688			
Liq Vol Flow @Std Cond (m3/h)	2.379 *	2.379			

Material Stream: Lean Amine to Absorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	40.01	40.01			
Pressure: (kPa)	200.0	200.0			
Molar Flow (kgmole/h)	1.602e+005	1.602e+005			
Mass Flow (kg/h)	3.781e+006	3.781e+006			
Std Ideal Liq Vol Flow (m3/h)	3812	3812			
Molar Enthalpy (kJ/kgmole)	-2.784e+004	-2.784e+004			
Molar Entropy (kJ/kgmole-C)	86.15	86.15			
Heat Flow (MW)	-1239	-1239			
Liq Vol Flow @Std Cond (m3/h)	3647 *	3647			

Material Stream: Lean Amine Recycle

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	40.01	40.01			
Pressure: (kPa)	101.0 *	101.0			
Molar Flow (kgmole/h)	1.602e+005	1.602e+005			
Mass Flow (kg/h)	3.781e+006	3.781e+006			
Std Ideal Liq Vol Flow (m3/h)	3812	3812			
Molar Enthalpy (kJ/kgmole)	-2.784e+004	-2.784e+004			
Molar Entropy (kJ/kgmole-C)	86.15	86.15			
Heat Flow (MW)	-1239	-1239			
Liq Vol Flow @Std Cond (m3/h)	3647 *	3647			

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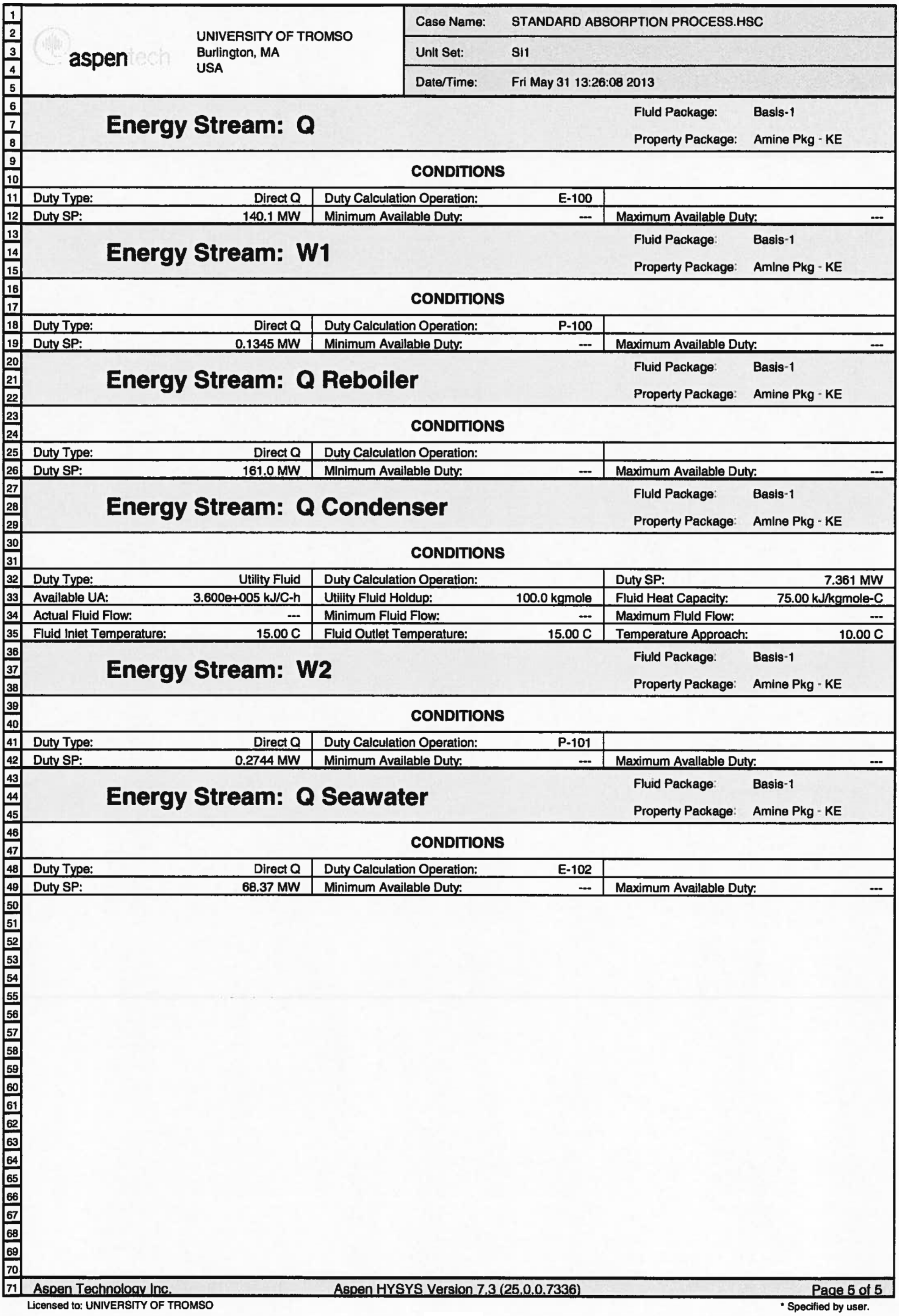

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Case Name:	STANDARD ABSORPTION PROCESS.HSC
Unit Set:	SI1
Date/Time:	Fri May 31 13:26:08 2013

Energy Stream: Q

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	E-100		
Duty SP:	140.1 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: W1

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	P-100		
Duty SP:	0.1345 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: Q Reboiler

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:			
Duty SP:	161.0 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: Q Condenser

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Utility Fluid	Duty Calculation Operation:		Duty SP:	7.361 MW
Available UA:	3.600e+005 kJ/C-h	Utility Fluid Holdup:	100.0 kgmole	Fluid Heat Capacity:	75.00 kJ/kgmole-C
Actual Fluid Flow:	---	Minimum Fluid Flow:	---	Maximum Fluid Flow:	---
Fluid Inlet Temperature:	15.00 C	Fluid Outlet Temperature:	15.00 C	Temperature Approach:	10.00 C

Energy Stream: W2

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	P-101		
Duty SP:	0.2744 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: Q Seawater

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	E-102		
Duty SP:	68.37 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

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Case Name:	VAPOUR RECOMPRESSION.HSC
Unit Set:	SI1
Date/Time:	Fri May 31 13:28:02 2013

Material Stream: Sour Feed to Absorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase			
Vapour / Phase Fraction	1.0000	1.0000			
Temperature: (C)	40.00 *	40.00			
Pressure: (kPa)	101.0 *	101.0			
Molar Flow (kgmole/h)	1.092e+005	1.092e+005			
Mass Flow (kg/h)	3.100e+006 *	3.100e+006			
Std Ideal Liq Vol Flow (m3/h)	3634	3634			
Molar Enthalpy (kJ/kgmole)	9211	9211			
Molar Entropy (kJ/kgmole-C)	196.6	196.6			
Heat Flow (MW)	279.3	279.3			
Liq Vol Flow @Std Cond (m3/h)	---	---			

Material Stream: Sweet Gas

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase			
Vapour / Phase Fraction	1.0000	1.0000			
Temperature: (C)	48.94	48.94			
Pressure: (kPa)	101.0	101.0			
Molar Flow (kgmole/h)	1.099e+005	1.099e+005			
Mass Flow (kg/h)	3.036e+006	3.036e+006			
Std Ideal Liq Vol Flow (m3/h)	3541	3541			
Molar Enthalpy (kJ/kgmole)	9521	9521			
Molar Entropy (kJ/kgmole-C)	197.4	197.4			
Heat Flow (MW)	290.8	290.8			
Liq Vol Flow @Std Cond (m3/h)	---	---			

Material Stream: Rich Amine

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	41.65	41.65			
Pressure: (kPa)	101.0	101.0			
Molar Flow (kgmole/h)	1.222e+005	1.222e+005			
Mass Flow (kg/h)	2.959e+006	2.959e+006			
Std Ideal Liq Vol Flow (m3/h)	3009	3009			
Molar Enthalpy (kJ/kgmole)	-2.827e+004	-2.827e+004			
Molar Entropy (kJ/kgmole-C)	85.50	85.50			
Heat Flow (MW)	-959.9	-959.9			
Liq Vol Flow @Std Cond (m3/h)	2791 *	2791			

Material Stream: Lean Amine to Absorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	40.00 *	40.00			
Pressure: (kPa)	101.0 *	101.0			
Molar Flow (kgmole/h)	1.230e+005 *	1.230e+005			
Mass Flow (kg/h)	2.895e+006	2.895e+006			
Std Ideal Liq Vol Flow (m3/h)	2916	2916			
Molar Enthalpy (kJ/kgmole)	-2.777e+004	-2.777e+004			
Molar Entropy (kJ/kgmole-C)	86.22	86.22			
Heat Flow (MW)	-948.7	-948.7			
Liq Vol Flow @Std Cond (m3/h)	2798 *	2798			

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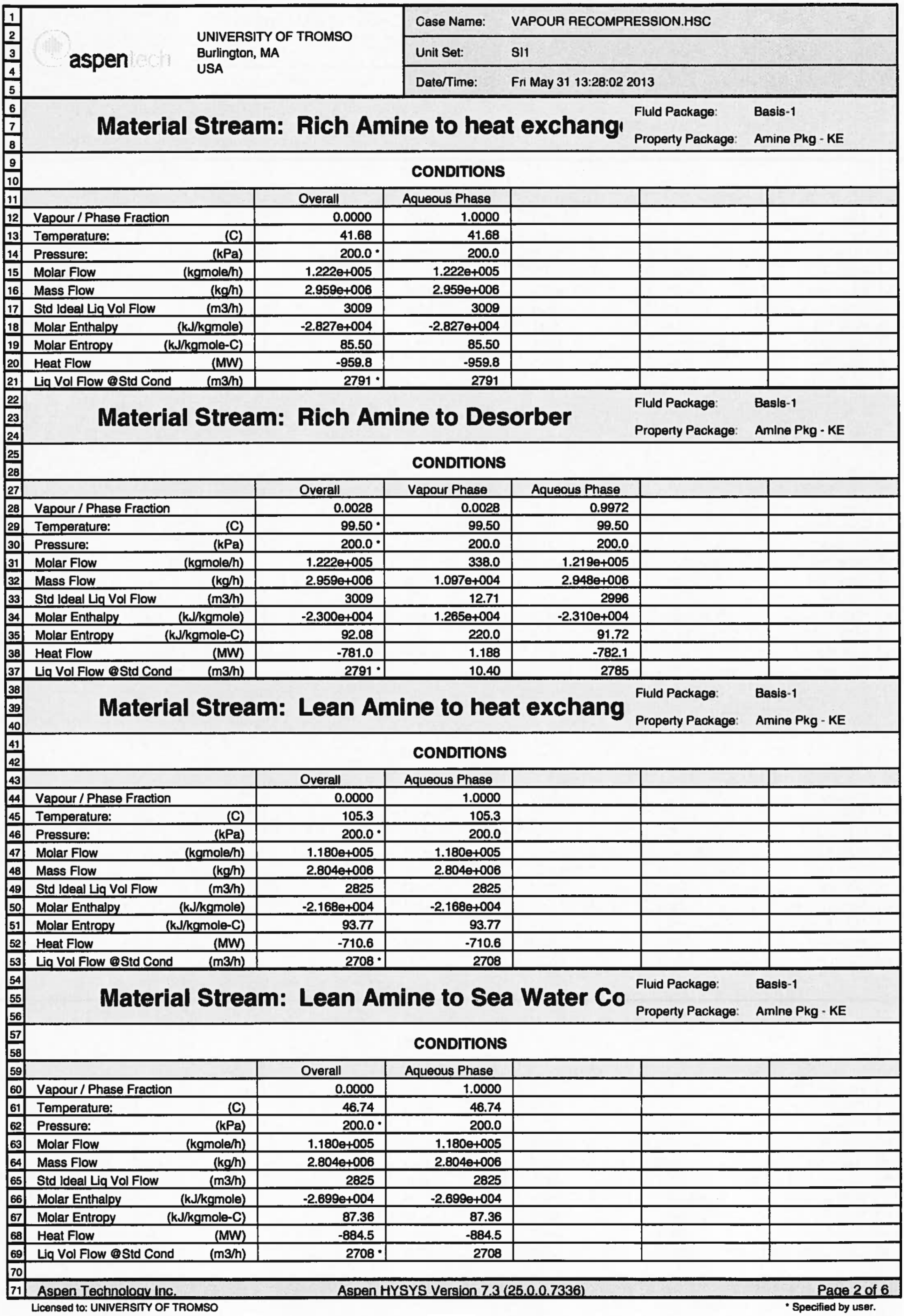

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Case Name: VAPOUR RECOMPRESSION.HSC
Unit Set: SI1
Date/Time: Fri May 31 13:28:02 2013

Material Stream: Rich Amine to heat exchang

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	41.68	41.68			
Pressure: (kPa)	200.0 *	200.0			
Molar Flow (kgmole/h)	1.222e+005	1.222e+005			
Mass Flow (kg/h)	2.959e+006	2.959e+006			
Std Ideal Liq Vol Flow (m3/h)	3009	3009			
Molar Enthalpy (kJ/kgmole)	-2.827e+004	-2.827e+004			
Molar Entropy (kJ/kgmole-C)	85.50	85.50			
Heat Flow (MW)	-959.8	-959.8			
Liq Vol Flow @Std Cond (m3/h)	2791 *	2791			

Material Stream: Rich Amine to Desorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.0028	0.0028	0.9972		
Temperature: (C)	99.50 *	99.50	99.50		
Pressure: (kPa)	200.0 *	200.0	200.0		
Molar Flow (kgmole/h)	1.222e+005	338.0	1.219e+005		
Mass Flow (kg/h)	2.959e+006	1.097e+004	2.948e+006		
Std Ideal Liq Vol Flow (m3/h)	3009	12.71	2996		
Molar Enthalpy (kJ/kgmole)	-2.300e+004	1.265e+004	-2.310e+004		
Molar Entropy (kJ/kgmole-C)	92.08	220.0	91.72		
Heat Flow (MW)	-781.0	1.188	-782.1		
Liq Vol Flow @Std Cond (m3/h)	2791 *	10.40	2785		

Material Stream: Lean Amine to heat exchang

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	105.3	105.3			
Pressure: (kPa)	200.0 *	200.0			
Molar Flow (kgmole/h)	1.180e+005	1.180e+005			
Mass Flow (kg/h)	2.804e+006	2.804e+006			
Std Ideal Liq Vol Flow (m3/h)	2825	2825			
Molar Enthalpy (kJ/kgmole)	-2.168e+004	-2.168e+004			
Molar Entropy (kJ/kgmole-C)	93.77	93.77			
Heat Flow (MW)	-710.6	-710.6			
Liq Vol Flow @Std Cond (m3/h)	2708 *	2708			

Material Stream: Lean Amine to Sea Water Co

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	46.74	46.74			
Pressure: (kPa)	200.0 *	200.0			
Molar Flow (kgmole/h)	1.180e+005	1.180e+005			
Mass Flow (kg/h)	2.804e+006	2.804e+006			
Std Ideal Liq Vol Flow (m3/h)	2825	2825			
Molar Enthalpy (kJ/kgmole)	-2.699e+004	-2.699e+004			
Molar Entropy (kJ/kgmole-C)	87.36	87.36			
Heat Flow (MW)	-884.5	-884.5			
Liq Vol Flow @Std Cond (m3/h)	2708 *	2708			

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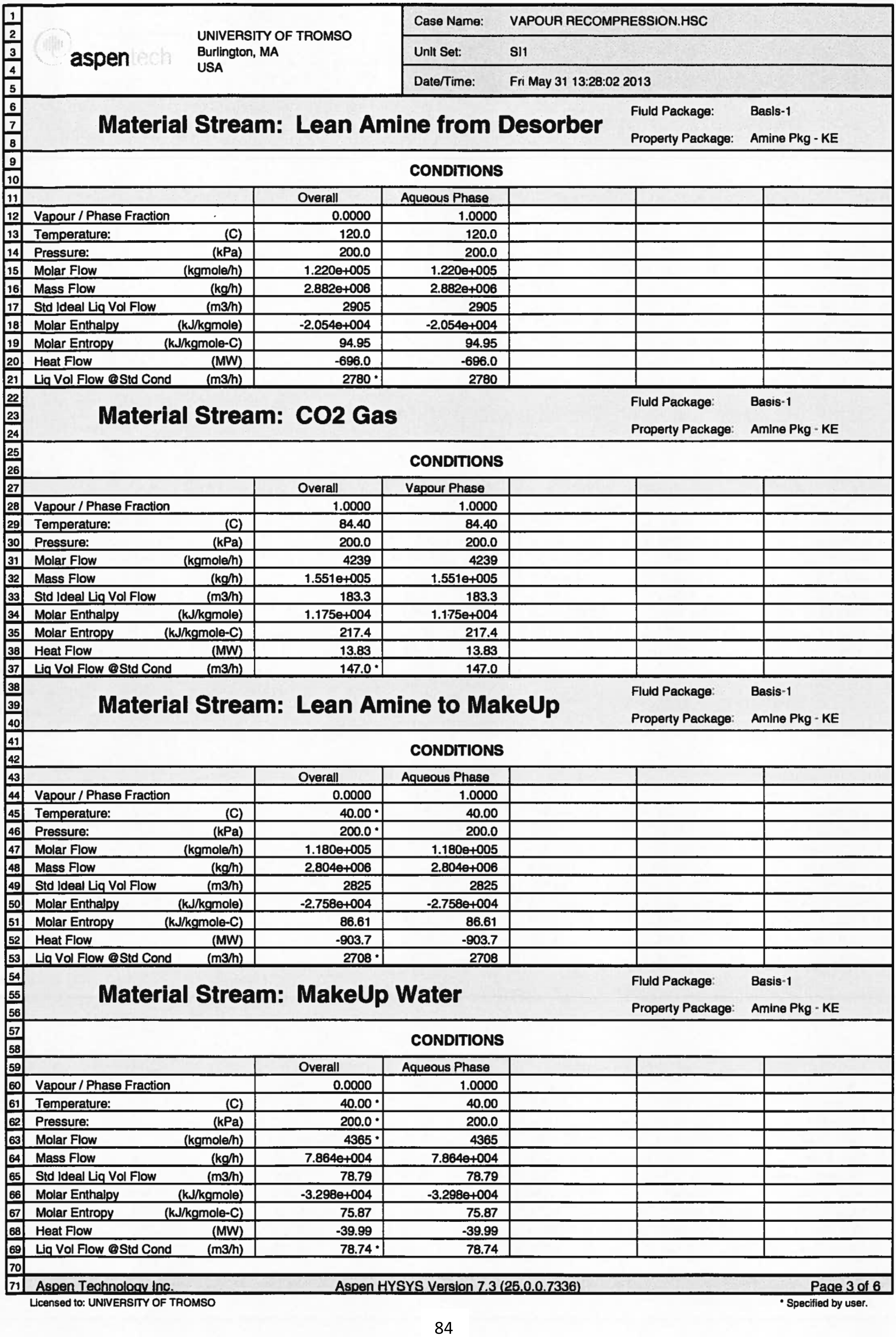

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Case Name:	VAPOUR RECOMPRESSION.HSC
Unit Set:	SI1
Date/Time:	Fri May 31 13:28:02 2013

Material Stream: Lean Amine from Desorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	120.0	120.0			
Pressure:	(kPa)	200.0	200.0			
Molar Flow	(kgmole/h)	1.220e+005	1.220e+005			
Mass Flow	(kg/h)	2.882e+006	2.882e+006			
Std Ideal Liq Vol Flow	(m3/h)	2905	2905			
Molar Enthalpy	(kJ/kgmole)	-2.054e+004	-2.054e+004			
Molar Entropy	(kJ/kgmole-C)	94.95	94.95			
Heat Flow	(MW)	-696.0	-696.0			
Liq Vol Flow @Std Cond	(m3/h)	2780 *	2780			

Material Stream: CO2 Gas

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	84.40	84.40			
Pressure:	(kPa)	200.0	200.0			
Molar Flow	(kgmole/h)	4239	4239			
Mass Flow	(kg/h)	1.551e+005	1.551e+005			
Std Ideal Liq Vol Flow	(m3/h)	183.3	183.3			
Molar Enthalpy	(kJ/kgmole)	1.175e+004	1.175e+004			
Molar Entropy	(kJ/kgmole-C)	217.4	217.4			
Heat Flow	(MW)	13.83	13.83			
Liq Vol Flow @Std Cond	(m3/h)	147.0 *	147.0			

Material Stream: Lean Amine to MakeUp

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	40.00 *	40.00			
Pressure:	(kPa)	200.0 *	200.0			
Molar Flow	(kgmole/h)	1.180e+005	1.180e+005			
Mass Flow	(kg/h)	2.804e+006	2.804e+006			
Std Ideal Liq Vol Flow	(m3/h)	2825	2825			
Molar Enthalpy	(kJ/kgmole)	-2.758e+004	-2.758e+004			
Molar Entropy	(kJ/kgmole-C)	86.61	86.61			
Heat Flow	(MW)	-903.7	-903.7			
Liq Vol Flow @Std Cond	(m3/h)	2708 *	2708			

Material Stream: MakeUp Water

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	40.00 *	40.00			
Pressure:	(kPa)	200.0 *	200.0			
Molar Flow	(kgmole/h)	4365 *	4365			
Mass Flow	(kg/h)	7.864e+004	7.864e+004			
Std Ideal Liq Vol Flow	(m3/h)	78.79	78.79			
Molar Enthalpy	(kJ/kgmole)	-3.298e+004	-3.298e+004			
Molar Entropy	(kJ/kgmole-C)	75.87	75.87			
Heat Flow	(MW)	-39.99	-39.99			
Liq Vol Flow @Std Cond	(m3/h)	78.74 *	78.74			

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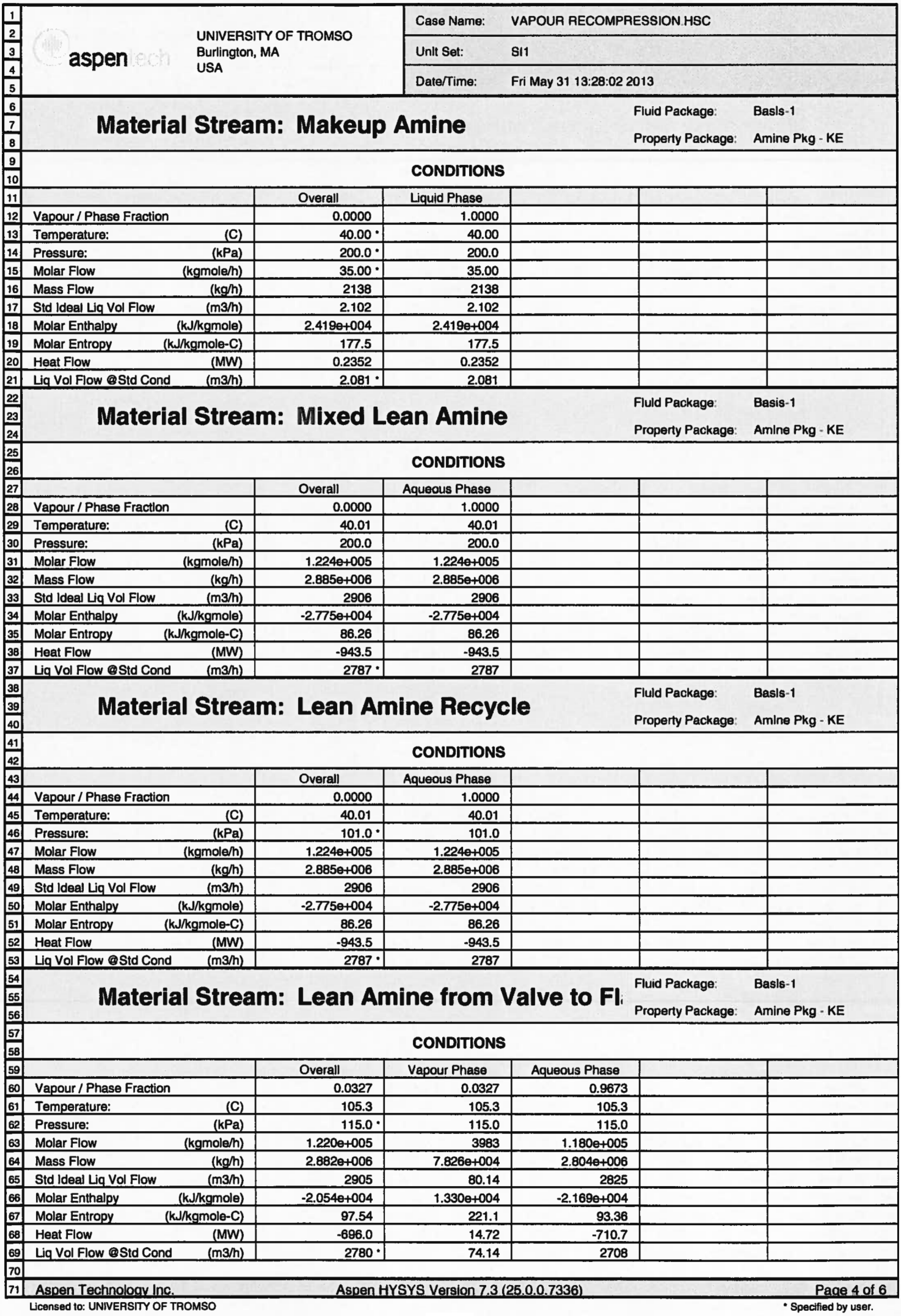

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Case Name: VAPOUR RECOMPRESSION.HSC
Unit Set: SI1
Date/Time: Fri May 31 13:28:02 2013

Material Stream: Makeup Amine

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Liquid Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	40.00 *	40.00			
Pressure:	(kPa)	200.0 *	200.0			
Molar Flow	(kgmole/h)	35.00 *	35.00			
Mass Flow	(kg/h)	2138	2138			
Std Ideal Liq Vol Flow	(m3/h)	2.102	2.102			
Molar Enthalpy	(kJ/kgmole)	2.419e+004	2.419e+004			
Molar Entropy	(kJ/kgmole-C)	177.5	177.5			
Heat Flow	(MW)	0.2352	0.2352			
Liq Vol Flow @Std Cond	(m3/h)	2.081 *	2.081			

Material Stream: Mixed Lean Amine

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	40.01	40.01			
Pressure:	(kPa)	200.0	200.0			
Molar Flow	(kgmole/h)	1.224e+005	1.224e+005			
Mass Flow	(kg/h)	2.885e+006	2.885e+006			
Std Ideal Liq Vol Flow	(m3/h)	2906	2906			
Molar Enthalpy	(kJ/kgmole)	-2.775e+004	-2.775e+004			
Molar Entropy	(kJ/kgmole-C)	86.26	86.26			
Heat Flow	(MW)	-943.5	-943.5			
Liq Vol Flow @Std Cond	(m3/h)	2787 *	2787			

Material Stream: Lean Amine Recycle

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	40.01	40.01			
Pressure:	(kPa)	101.0 *	101.0			
Molar Flow	(kgmole/h)	1.224e+005	1.224e+005			
Mass Flow	(kg/h)	2.885e+006	2.885e+006			
Std Ideal Liq Vol Flow	(m3/h)	2906	2906			
Molar Enthalpy	(kJ/kgmole)	-2.775e+004	-2.775e+004			
Molar Entropy	(kJ/kgmole-C)	86.26	86.26			
Heat Flow	(MW)	-943.5	-943.5			
Liq Vol Flow @Std Cond	(m3/h)	2787 *	2787			

Material Stream: Lean Amine from Valve to Fl

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction		0.0327	0.0327	0.9673		
Temperature:	(C)	105.3	105.3	105.3		
Pressure:	(kPa)	115.0 *	115.0	115.0		
Molar Flow	(kgmole/h)	1.220e+005	3983	1.180e+005		
Mass Flow	(kg/h)	2.882e+006	7.826e+004	2.804e+006		
Std Ideal Liq Vol Flow	(m3/h)	2905	80.14	2825		
Molar Enthalpy	(kJ/kgmole)	-2.054e+004	1.330e+004	-2.169e+004		
Molar Entropy	(kJ/kgmole-C)	97.54	221.1	93.36		
Heat Flow	(MW)	-696.0	14.72	-710.7		
Liq Vol Flow @Std Cond	(m3/h)	2780 *	74.14	2708		

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Case Name: VAPOUR RECOMPRESSION.HSC
Unit Set: SI1
Date/Time: Fri May 31 13:28:02 2013

Material Stream: Vapour from Flash Tank

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	1.0000	1.0000	0.0000		
Temperature: (C)	105.3	105.3	105.3		
Pressure: (kPa)	115.0	115.0	115.0		
Molar Flow (kgmole/h)	3983	3983	0.0000		
Mass Flow (kg/h)	7.826e+004	7.826e+004	0.0000		
Std Ideal Liq Vol Flow (m3/h)	80.14	80.14	0.0000		
Molar Enthalpy (kJ/kgmole)	1.330e+004	1.330e+004	-2.169e+004		
Molar Entropy (kJ/kgmole-C)	221.1	221.1	93.36		
Heat Flow (MW)	14.72	14.72	0.0000		
Liq Vol Flow @Std Cond (m3/h)	74.14 *	74.14	0.0000		

Material Stream: Liquid from Flash Tank

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.0000	0.0000	1.0000		
Temperature: (C)	105.3	105.3	105.3		
Pressure: (kPa)	115.0	115.0	115.0		
Molar Flow (kgmole/h)	1.180e+005	0.0000	1.180e+005		
Mass Flow (kg/h)	2.804e+006	0.0000	2.804e+006		
Std Ideal Liq Vol Flow (m3/h)	2825	0.0000	2825		
Molar Enthalpy (kJ/kgmole)	-2.169e+004	1.330e+004	-2.169e+004		
Molar Entropy (kJ/kgmole-C)	93.36	221.1	93.36		
Heat Flow (MW)	-710.7	0.0000	-710.7		
Liq Vol Flow @Std Cond (m3/h)	2708 *	0.0000	2708		

Material Stream: To Recompression

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.8999	0.8999	0.1001		
Temperature: (C)	99.45 *	99.45	99.45		
Pressure: (kPa)	100.0 *	100.0	100.0		
Molar Flow (kgmole/h)	3983	3584	398.9		
Mass Flow (kg/h)	7.826e+004	6.995e+004	8316		
Std Ideal Liq Vol Flow (m3/h)	80.14	71.78	8.365		
Molar Enthalpy (kJ/kgmole)	8865	1.268e+004	-2.543e+004		
Molar Entropy (kJ/kgmole-C)	207.5	221.6	80.90		
Heat Flow (MW)	9.809	12.63	-2.818		
Liq Vol Flow @Std Cond (m3/h)	74.14 *	66.30	8.033		

Material Stream: From Recompression

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.9390	0.9390	0.0610		
Temperature: (C)	120.0	120.0	120.0		
Pressure: (kPa)	200.0 *	200.0	200.0		
Molar Flow (kgmole/h)	3983	3740	242.8		
Mass Flow (kg/h)	7.826e+004	7.314e+004	5120		
Std Ideal Liq Vol Flow (m3/h)	80.14	75.00	5.143		
Molar Enthalpy (kJ/kgmole)	1.131e+004	1.354e+004	-2.305e+004		
Molar Entropy (kJ/kgmole-C)	209.5	217.8	82.91		
Heat Flow (MW)	12.51	14.06	-1.555		
Liq Vol Flow @Std Cond (m3/h)	74.14 *	69.32	4.984		

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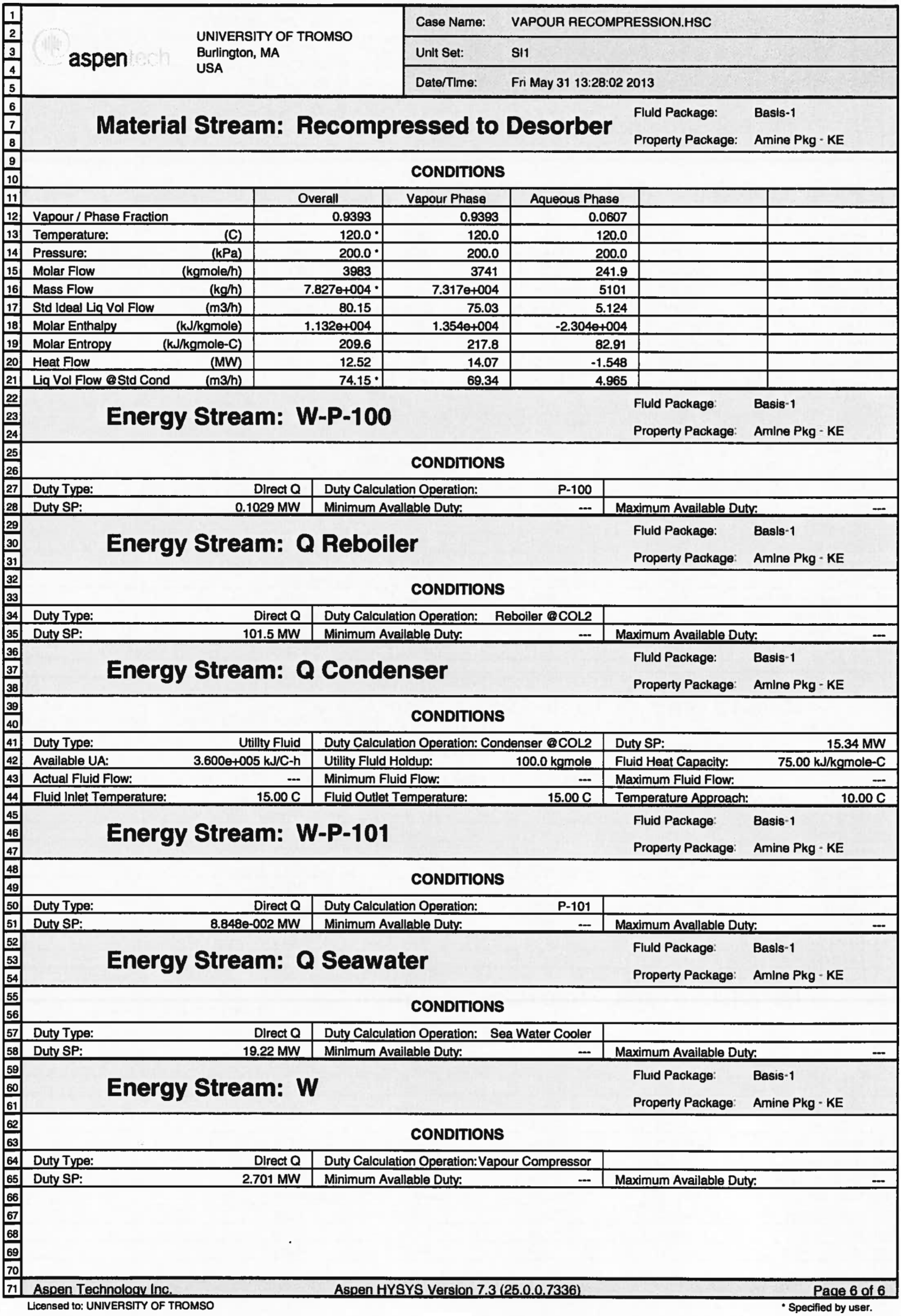

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UNIVERSITY OF TROMSO
Burlington, MA
USA

Case Name: VAPOUR RECOMPRESSION.HSC
Unit Set: SI1
Date/Time: Fri May 31 13:28:02 2013

Material Stream: Recompressed to Desorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.9393	0.9393	0.0607		
Temperature: (C)	120.0 *	120.0	120.0		
Pressure: (kPa)	200.0 *	200.0	200.0		
Molar Flow (kgmole/h)	3983	3741	241.9		
Mass Flow (kg/h)	7.827e+004 *	7.317e+004	5101		
Std Ideal Liq Vol Flow (m3/h)	80.15	75.03	5.124		
Molar Enthalpy (kJ/kgmole)	1.132e+004	1.354e+004	-2.304e+004		
Molar Entropy (kJ/kgmole-C)	209.6	217.8	82.91		
Heat Flow (MW)	12.52	14.07	-1.548		
Liq Vol Flow @Std Cond (m3/h)	74.15 *	69.34	4.965		

Energy Stream: W-P-100

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	P-100		
Duty SP:	0.1029 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: Q Reboiler

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Reboiler @COL2		
Duty SP:	101.5 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: Q Condenser

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Utility Fluid	Duty Calculation Operation:	Condenser @COL2	Duty SP:	15.34 MW
Available UA:	3.600e+005 kJ/C-h	Utility Fluid Holdup:	100.0 kgmole	Fluid Heat Capacity:	75.00 kJ/kgmole-C
Actual Fluid Flow:	---	Minimum Fluid Flow:	---	Maximum Fluid Flow:	---
Fluid Inlet Temperature:	15.00 C	Fluid Outlet Temperature:	15.00 C	Temperature Approach:	10.00 C

Energy Stream: W-P-101

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	P-101		
Duty SP:	8.848e-002 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: Q Seawater

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Sea Water Cooler		
Duty SP:	19.22 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: W

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Vapour Compressor		
Duty SP:	2.701 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

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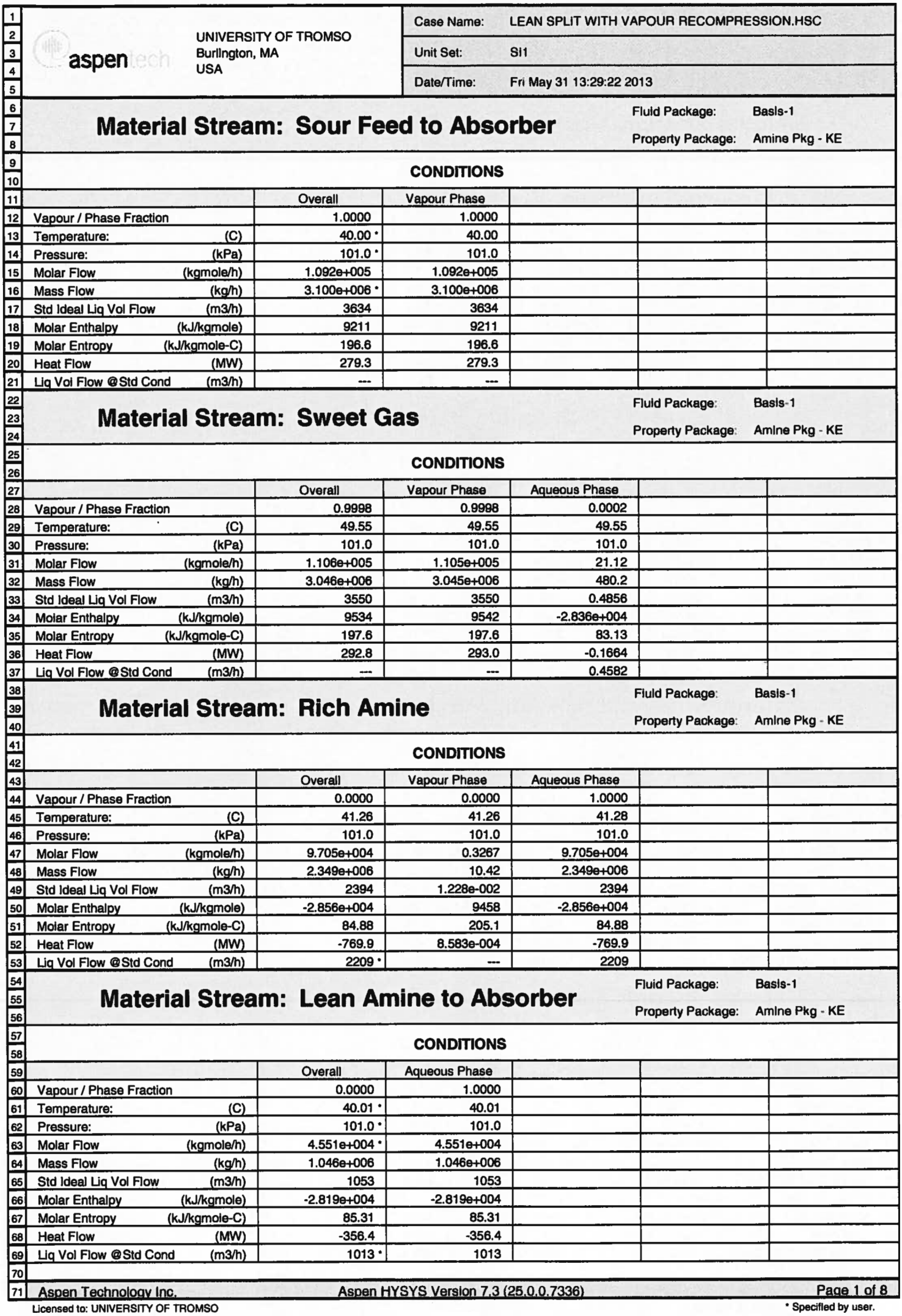

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USA

Case Name: LEAN SPLIT WITH VAPOUR RECOMPRESSION.HSC

Unit Set: SI1

Date/Time: Fri May 31 13:29:22 2013

Material Stream: Sour Feed to Absorber

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase			
Vapour / Phase Fraction	1.0000	1.0000			
Temperature: (C)	40.00 *	40.00			
Pressure: (kPa)	101.0 *	101.0			
Molar Flow (kgmole/h)	1.092e+005	1.092e+005			
Mass Flow (kg/h)	3.100e+006 *	3.100e+006			
Std Ideal Liq Vol Flow (m3/h)	3634	3634			
Molar Enthalpy (kJ/kgmole)	9211	9211			
Molar Entropy (kJ/kgmole-C)	196.6	196.6			
Heat Flow (MW)	279.3	279.3			
Liq Vol Flow @Std Cond (m3/h)	---	---			

Material Stream: Sweet Gas

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.9998	0.9998	0.0002		
Temperature: (C)	49.55	49.55	49.55		
Pressure: (kPa)	101.0	101.0	101.0		
Molar Flow (kgmole/h)	1.106e+005	1.105e+005	21.12		
Mass Flow (kg/h)	3.046e+006	3.045e+006	480.2		
Std Ideal Liq Vol Flow (m3/h)	3550	3550	0.4856		
Molar Enthalpy (kJ/kgmole)	9534	9542	-2.836e+004		
Molar Entropy (kJ/kgmole-C)	197.6	197.6	83.13		
Heat Flow (MW)	292.8	293.0	-0.1664		
Liq Vol Flow @Std Cond (m3/h)	---	---	0.4582		

Material Stream: Rich Amine

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.0000	0.0000	1.0000		
Temperature: (C)	41.26	41.26	41.28		
Pressure: (kPa)	101.0	101.0	101.0		
Molar Flow (kgmole/h)	9.705e+004	0.3267	9.705e+004		
Mass Flow (kg/h)	2.349e+006	10.42	2.349e+006		
Std Ideal Liq Vol Flow (m3/h)	2394	1.228e-002	2394		
Molar Enthalpy (kJ/kgmole)	-2.856e+004	9458	-2.856e+004		
Molar Entropy (kJ/kgmole-C)	84.88	205.1	84.88		
Heat Flow (MW)	-769.9	8.583e-004	-769.9		
Liq Vol Flow @Std Cond (m3/h)	2209 *	---	2209		

Material Stream: Lean Amine to Absorber

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	40.01 *	40.01			
Pressure: (kPa)	101.0 *	101.0			
Molar Flow (kgmole/h)	4.551e+004 *	4.551e+004			
Mass Flow (kg/h)	1.046e+006	1.046e+006			
Std Ideal Liq Vol Flow (m3/h)	1053	1053			
Molar Enthalpy (kJ/kgmole)	-2.819e+004	-2.819e+004			
Molar Entropy (kJ/kgmole-C)	85.31	85.31			
Heat Flow (MW)	-356.4	-356.4			
Liq Vol Flow @Std Cond (m3/h)	1013 *	1013			

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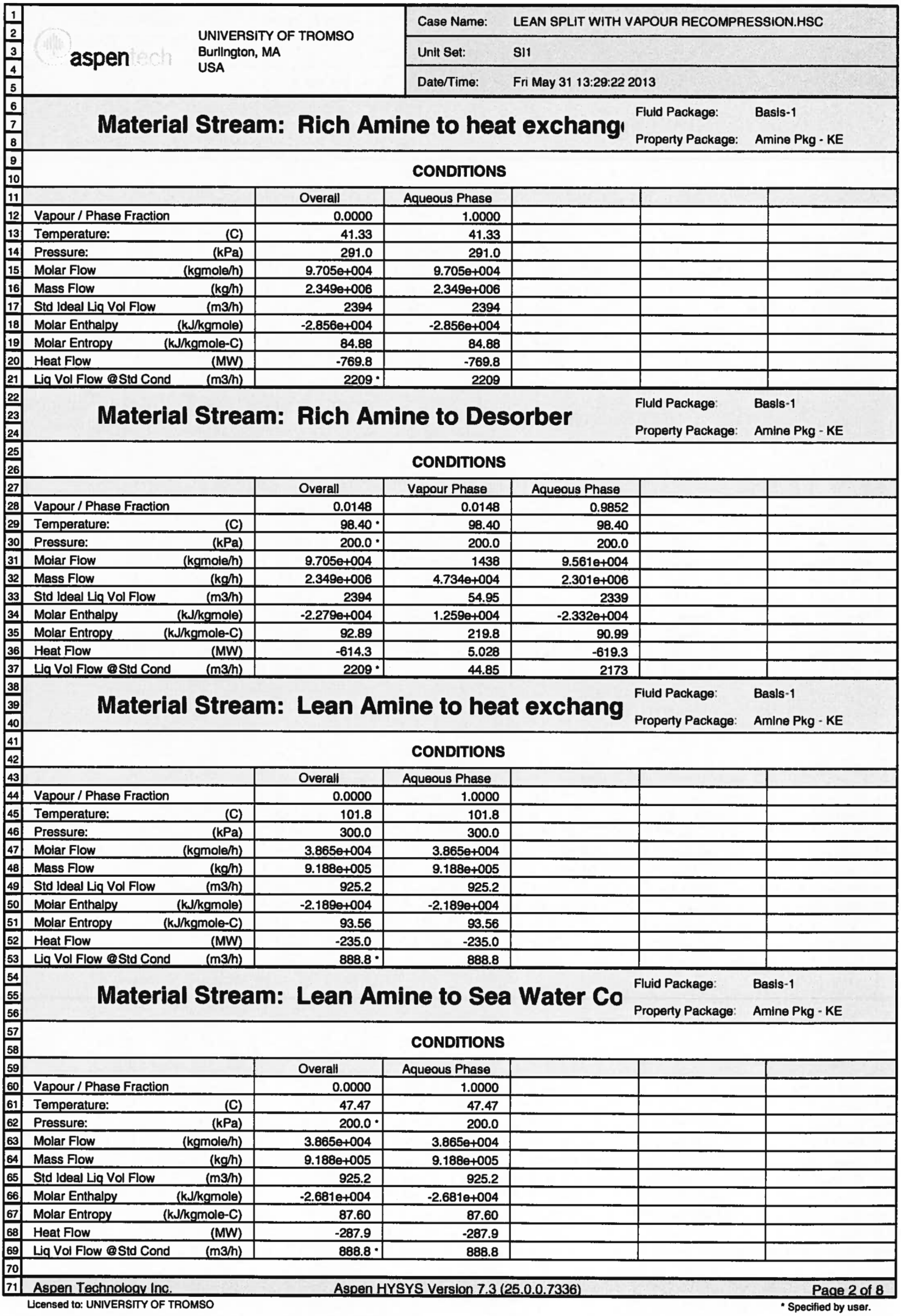

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Burlington, MA
USA

Case Name:	LEAN SPLIT WITH VAPOUR RECOMPRESSION.HSC
Unit Set:	SI1
Date/Time:	Fri May 31 13:29:22 2013

Material Stream: Rich Amine to heat exchang

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	41.33	41.33			
Pressure:	(kPa)	291.0	291.0			
Molar Flow	(kgmole/h)	9.705e+004	9.705e+004			
Mass Flow	(kg/h)	2.349e+006	2.349e+006			
Std Ideal Liq Vol Flow	(m3/h)	2394	2394			
Molar Enthalpy	(kJ/kgmole)	-2.856e+004	-2.856e+004			
Molar Entropy	(kJ/kgmole-C)	84.88	84.88			
Heat Flow	(MW)	-769.8	-769.8			
Liq Vol Flow @Std Cond	(m3/h)	2209 *	2209			

Material Stream: Rich Amine to Desorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction		0.0148	0.0148	0.9852		
Temperature:	(C)	98.40 *	98.40	98.40		
Pressure:	(kPa)	200.0 *	200.0	200.0		
Molar Flow	(kgmole/h)	9.705e+004	1438	9.561e+004		
Mass Flow	(kg/h)	2.349e+006	4.734e+004	2.301e+006		
Std Ideal Liq Vol Flow	(m3/h)	2394	54.95	2339		
Molar Enthalpy	(kJ/kgmole)	-2.279e+004	1.259e+004	-2.332e+004		
Molar Entropy	(kJ/kgmole-C)	92.89	219.8	90.99		
Heat Flow	(MW)	-614.3	5.028	-619.3		
Liq Vol Flow @Std Cond	(m3/h)	2209 *	44.85	2173		

Material Stream: Lean Amine to heat exchang

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	101.8	101.8			
Pressure:	(kPa)	300.0	300.0			
Molar Flow	(kgmole/h)	3.865e+004	3.865e+004			
Mass Flow	(kg/h)	9.188e+005	9.188e+005			
Std Ideal Liq Vol Flow	(m3/h)	925.2	925.2			
Molar Enthalpy	(kJ/kgmole)	-2.189e+004	-2.189e+004			
Molar Entropy	(kJ/kgmole-C)	93.56	93.56			
Heat Flow	(MW)	-235.0	-235.0			
Liq Vol Flow @Std Cond	(m3/h)	888.8 *	888.8			

Material Stream: Lean Amine to Sea Water Co

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	47.47	47.47			
Pressure:	(kPa)	200.0 *	200.0			
Molar Flow	(kgmole/h)	3.865e+004	3.865e+004			
Mass Flow	(kg/h)	9.188e+005	9.188e+005			
Std Ideal Liq Vol Flow	(m3/h)	925.2	925.2			
Molar Enthalpy	(kJ/kgmole)	-2.681e+004	-2.681e+004			
Molar Entropy	(kJ/kgmole-C)	87.60	87.60			
Heat Flow	(MW)	-287.9	-287.9			
Liq Vol Flow @Std Cond	(m3/h)	888.8 *	888.8			

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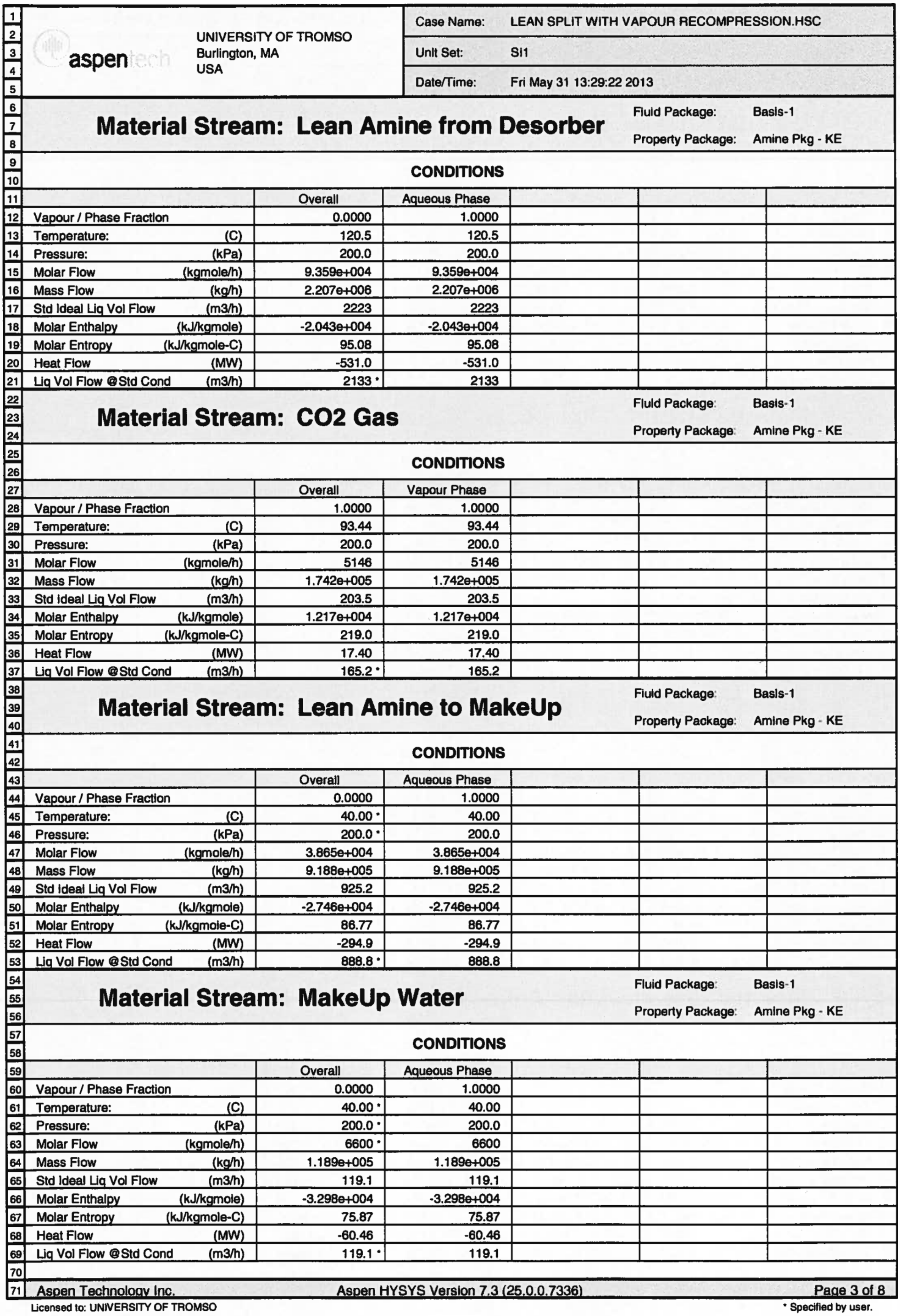

UNIVERSITY OF TROMSO
Burlington, MA
USA

Case Name: LEAN SPLIT WITH VAPOUR RECOMPRESSION.HSC

Unit Set: SI1

Date/Time: Fri May 31 13:29:22 2013

Material Stream: Lean Amine from Desorber

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	120.5	120.5			
Pressure:	(kPa)	200.0	200.0			
Molar Flow	(kgmole/h)	9.359e+004	9.359e+004			
Mass Flow	(kg/h)	2.207e+006	2.207e+006			
Std Ideal Liq Vol Flow	(m3/h)	2223	2223			
Molar Enthalpy	(kJ/kgmole)	-2.043e+004	-2.043e+004			
Molar Entropy	(kJ/kgmole-C)	95.08	95.08			
Heat Flow	(MW)	-531.0	-531.0			
Liq Vol Flow @Std Cond	(m3/h)	2133 *	2133			

Material Stream: CO2 Gas

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	93.44	93.44			
Pressure:	(kPa)	200.0	200.0			
Molar Flow	(kgmole/h)	5146	5146			
Mass Flow	(kg/h)	1.742e+005	1.742e+005			
Std Ideal Liq Vol Flow	(m3/h)	203.5	203.5			
Molar Enthalpy	(kJ/kgmole)	1.217e+004	1.217e+004			
Molar Entropy	(kJ/kgmole-C)	219.0	219.0			
Heat Flow	(MW)	17.40	17.40			
Liq Vol Flow @Std Cond	(m3/h)	165.2 *	165.2			

Material Stream: Lean Amine to MakeUp

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	40.00 *	40.00			
Pressure:	(kPa)	200.0 *	200.0			
Molar Flow	(kgmole/h)	3.865e+004	3.865e+004			
Mass Flow	(kg/h)	9.188e+005	9.188e+005			
Std Ideal Liq Vol Flow	(m3/h)	925.2	925.2			
Molar Enthalpy	(kJ/kgmole)	-2.746e+004	-2.746e+004			
Molar Entropy	(kJ/kgmole-C)	86.77	86.77			
Heat Flow	(MW)	-294.9	-294.9			
Liq Vol Flow @Std Cond	(m3/h)	888.8 *	888.8			

Material Stream: MakeUp Water

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	40.00 *	40.00			
Pressure:	(kPa)	200.0 *	200.0			
Molar Flow	(kgmole/h)	6600 *	6600			
Mass Flow	(kg/h)	1.189e+005	1.189e+005			
Std Ideal Liq Vol Flow	(m3/h)	119.1	119.1			
Molar Enthalpy	(kJ/kgmole)	-3.298e+004	-3.298e+004			
Molar Entropy	(kJ/kgmole-C)	75.87	75.87			
Heat Flow	(MW)	-60.46	-60.46			
Liq Vol Flow @Std Cond	(m3/h)	119.1 *	119.1			

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Case Name:	LEAN SPLIT WITH VAPOUR RECOMPRESSION.HSC
Unit Set:	SI1
Date/Time:	Fri May 31 13:29:22 2013

Material Stream: Makeup Amine

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Liquid Phase
Vapour / Phase Fraction		0.0000	1.0000
Temperature:	(C)	40.00 *	40.00
Pressure:	(kPa)	200.0 *	200.0
Molar Flow	(kgmole/h)	44.00 *	44.00
Mass Flow	(kg/h)	2688	2688
Std Ideal Liq Vol Flow	(m3/h)	2.643	2.643
Molar Enthalpy	(kJ/kgmole)	2.419e+004	2.419e+004
Molar Entropy	(kJ/kgmole-C)	177.5	177.5
Heat Flow	(MW)	0.2956	0.2956
Liq Vol Flow @Std Cond	(m3/h)	2.617 *	2.617

Material Stream: Mixed Lean Amine

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase
Vapour / Phase Fraction		0.0000	1.0000
Temperature:	(C)	40.01	40.01
Pressure:	(kPa)	200.0	200.0
Molar Flow	(kgmole/h)	4.530e+004	4.530e+004
Mass Flow	(kg/h)	1.040e+006	1.040e+006
Std Ideal Liq Vol Flow	(m3/h)	1047	1047
Molar Enthalpy	(kJ/kgmole)	-2.822e+004	-2.822e+004
Molar Entropy	(kJ/kgmole-C)	85.27	85.27
Heat Flow	(MW)	-355.0	-355.0
Liq Vol Flow @Std Cond	(m3/h)	1008 *	1008

Material Stream: Lean Amine Recycle

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase
Vapour / Phase Fraction		0.0000	1.0000
Temperature:	(C)	40.01	40.01
Pressure:	(kPa)	101.0 *	101.0
Molar Flow	(kgmole/h)	4.530e+004	4.530e+004
Mass Flow	(kg/h)	1.040e+006	1.040e+006
Std Ideal Liq Vol Flow	(m3/h)	1047	1047
Molar Enthalpy	(kJ/kgmole)	-2.822e+004	-2.822e+004
Molar Entropy	(kJ/kgmole-C)	85.27	85.27
Heat Flow	(MW)	-355.0	-355.0
Liq Vol Flow @Std Cond	(m3/h)	1008 *	1008

Material Stream: Lean Amine from Valve to Fl

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Vapour Phase	Aqueous Phase
Vapour / Phase Fraction		0.0419	0.0419	0.9581
Temperature:	(C)	101.8	101.8	101.8
Pressure:	(kPa)	100.0 *	100.0	100.0
Molar Flow	(kgmole/h)	4.034e+004	1689	3.865e+004
Mass Flow	(kg/h)	9.514e+005	3.260e+004	9.188e+005
Std Ideal Liq Vol Flow	(m3/h)	958.4	33.19	925.2
Molar Enthalpy	(kJ/kgmole)	-2.043e+004	1.316e+004	-2.189e+004
Molar Entropy	(kJ/kgmole-C)	98.44	221.6	93.05
Heat Flow	(MW)	-228.9	6.177	-235.1
Liq Vol Flow @Std Cond	(m3/h)	919.3 *	30.88	888.8

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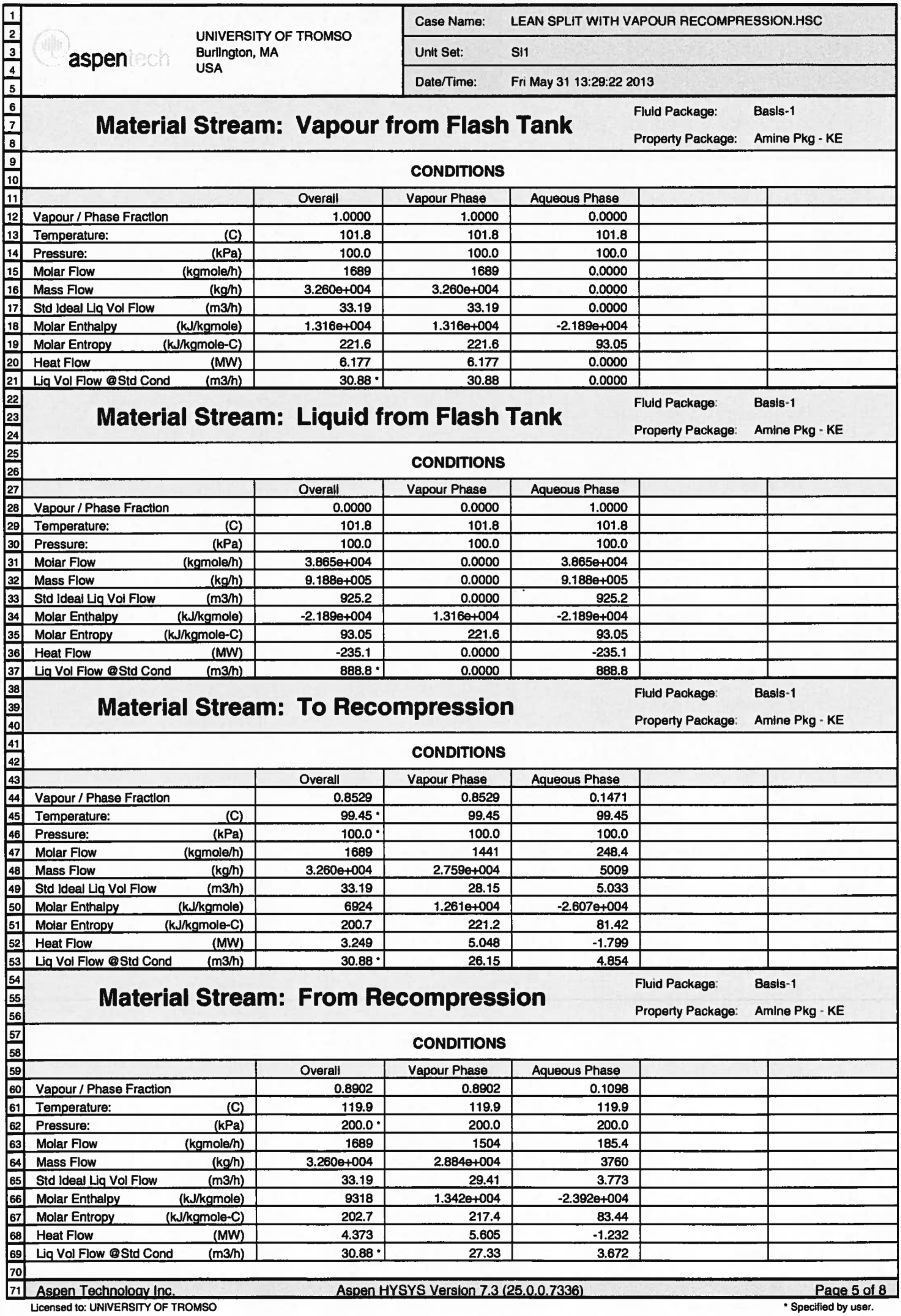

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Burlington, MA
USA

Case Name: LEAN SPLIT WITH VAPOUR RECOMPRESSION.HSC
Unit Set: SI1
Date/Time: Fri May 31 13:29:22 2013

Material Stream: Vapour from Flash Tank

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	1.0000	1.0000	0.0000		
Temperature: (C)	101.8	101.8	101.8		
Pressure: (kPa)	100.0	100.0	100.0		
Molar Flow (kgmole/h)	1689	1689	0.0000		
Mass Flow (kg/h)	3.260e+004	3.260e+004	0.0000		
Std Ideal Liq Vol Flow (m3/h)	33.19	33.19	0.0000		
Molar Enthalpy (kJ/kgmole)	1.316e+004	1.316e+004	-2.189e+004		
Molar Entropy (kJ/kgmole-C)	221.6	221.6	93.05		
Heat Flow (MW)	6.177	6.177	0.0000		
Liq Vol Flow @Std Cond (m3/h)	30.88 *	30.88	0.0000		

Material Stream: Liquid from Flash Tank

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.0000	0.0000	1.0000		
Temperature: (C)	101.8	101.8	101.8		
Pressure: (kPa)	100.0	100.0	100.0		
Molar Flow (kgmole/h)	3.865e+004	0.0000	3.865e+004		
Mass Flow (kg/h)	9.188e+005	0.0000	9.188e+005		
Std Ideal Liq Vol Flow (m3/h)	925.2	0.0000	925.2		
Molar Enthalpy (kJ/kgmole)	-2.189e+004	1.316e+004	-2.189e+004		
Molar Entropy (kJ/kgmole-C)	93.05	221.6	93.05		
Heat Flow (MW)	-235.1	0.0000	-235.1		
Liq Vol Flow @Std Cond (m3/h)	888.8 *	0.0000	888.8		

Material Stream: To Recompression

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.8529	0.8529	0.1471		
Temperature: (C)	99.45 *	99.45	99.45		
Pressure: (kPa)	100.0 *	100.0	100.0		
Molar Flow (kgmole/h)	1689	1441	248.4		
Mass Flow (kg/h)	3.260e+004	2.759e+004	5009		
Std Ideal Liq Vol Flow (m3/h)	33.19	28.15	5.033		
Molar Enthalpy (kJ/kgmole)	6924	1.261e+004	-2.607e+004		
Molar Entropy (kJ/kgmole-C)	200.7	221.2	81.42		
Heat Flow (MW)	3.249	5.048	-1.799		
Liq Vol Flow @Std Cond (m3/h)	30.88 *	26.15	4.854		

Material Stream: From Recompression

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction	0.8902	0.8902	0.1098		
Temperature: (C)	119.9	119.9	119.9		
Pressure: (kPa)	200.0 *	200.0	200.0		
Molar Flow (kgmole/h)	1689	1504	185.4		
Mass Flow (kg/h)	3.260e+004	2.884e+004	3760		
Std Ideal Liq Vol Flow (m3/h)	33.19	29.41	3.773		
Molar Enthalpy (kJ/kgmole)	9318	1.342e+004	-2.392e+004		
Molar Entropy (kJ/kgmole-C)	202.7	217.4	83.44		
Heat Flow (MW)	4.373	5.605	-1.232		
Liq Vol Flow @Std Cond (m3/h)	30.88 *	27.33	3.672		

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* Specified by user.

Material Stream: Recompressed to Desorber

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Vapour Phase	Aqueous Phase
Vapour / Phase Fraction	0.8904	0.8904	0.1096
Temperature: (C)	119.9 *	119.9	119.9
Pressure: (kPa)	200.0 *	200.0	200.0
Molar Flow (kgmole/h)	1689 *	1504	185.2
Mass Flow (kg/h)	3.260e+004	2.884e+004	3755
Std Ideal Liq Vol Flow (m3/h)	33.19	29.42	3.768
Molar Enthalpy (kJ/kgmole)	9324	1.342e+004	-2.392e+004
Molar Entropy (kJ/kgmole-C)	202.7	217.4	83.44
Heat Flow (MW)	4.375	5.606	-1.230
Liq Vol Flow @Std Cond (m3/h)	30.88 *	27.34	3.668

Material Stream: 1

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase
Vapour / Phase Fraction	0.0000	1.0000
Temperature: (C)	120.5	120.5
Pressure: (kPa)	200.0	200.0
Molar Flow (kgmole/h)	5.325e+004	5.325e+004
Mass Flow (kg/h)	1.256e+006	1.256e+006
Std Ideal Liq Vol Flow (m3/h)	1265	1265
Molar Enthalpy (kJ/kgmole)	-2.043e+004	-2.043e+004
Molar Entropy (kJ/kgmole-C)	95.08	95.08
Heat Flow (MW)	-302.1	-302.1
Liq Vol Flow @Std Cond (m3/h)	1213 *	1213

Material Stream: 2

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase
Vapour / Phase Fraction	0.0000	1.0000
Temperature: (C)	120.5	120.5
Pressure: (kPa)	200.0	200.0
Molar Flow (kgmole/h)	4.034e+004	4.034e+004
Mass Flow (kg/h)	9.514e+005	9.514e+005
Std Ideal Liq Vol Flow (m3/h)	958.4	958.4
Molar Enthalpy (kJ/kgmole)	-2.043e+004	-2.043e+004
Molar Entropy (kJ/kgmole-C)	95.08	95.08
Heat Flow (MW)	-228.9	-228.9
Liq Vol Flow @Std Cond (m3/h)	919.3 *	919.3

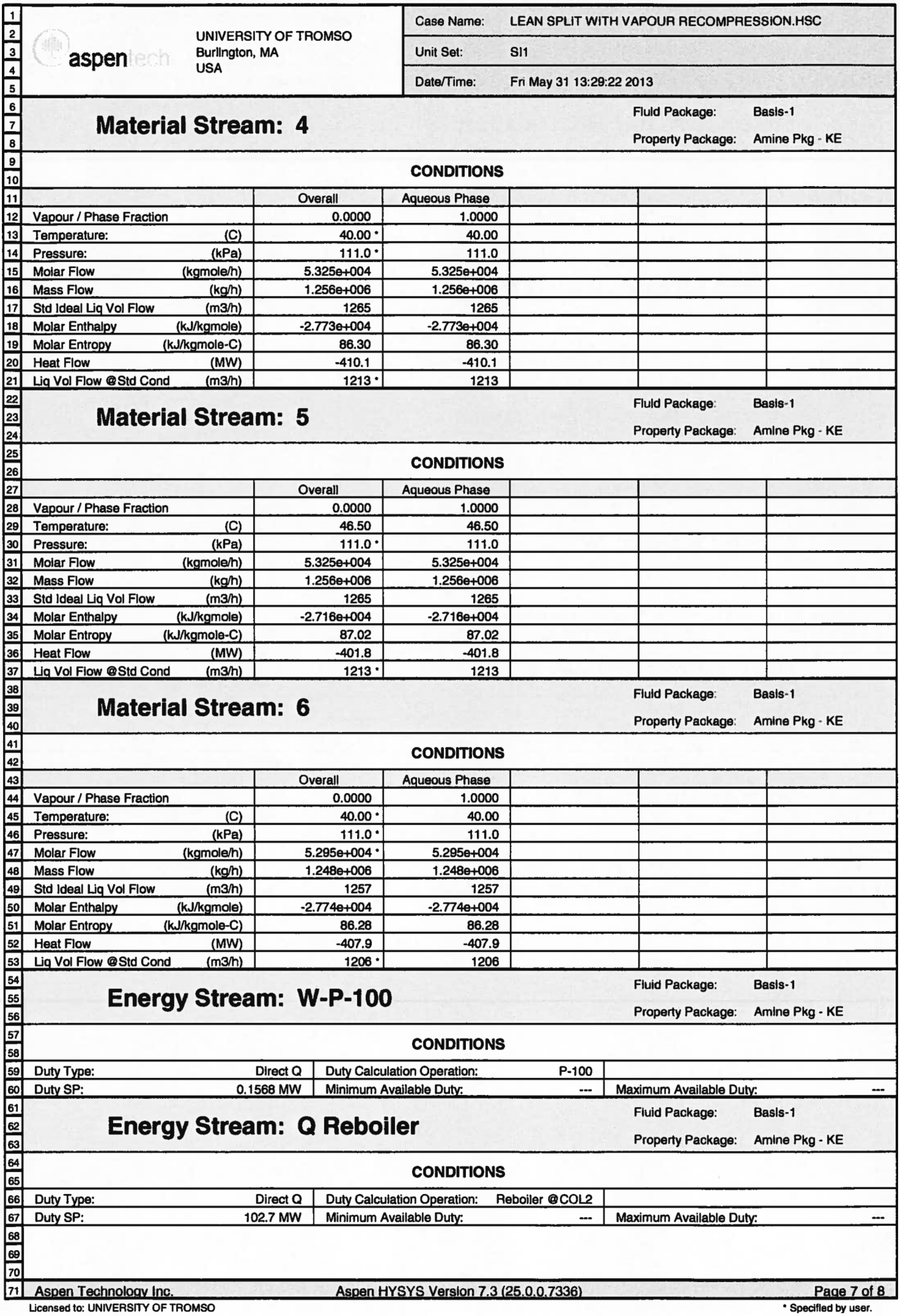
Material Stream: 3

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

	Overall	Aqueous Phase
Vapour / Phase Fraction	0.0000	1.0000
Temperature: (C)	46.50 *	46.50
Pressure: (kPa)	100.0 *	100.0
Molar Flow (kgmole/h)	5.325e+004	5.325e+004
Mass Flow (kg/h)	1.256e+006	1.256e+006
Std Ideal Liq Vol Flow (m3/h)	1265	1265
Molar Enthalpy (kJ/kgmole)	-2.716e+004	-2.716e+004
Molar Entropy (kJ/kgmole-C)	87.02	87.02
Heat Flow (MW)	-401.8	-401.8
Liq Vol Flow @Std Cond (m3/h)	1213 *	1213

* Specified by user.



aspentech	UNIVERSITY OF TROMSO Burlington, MA USA	Case Name:	LEAN SPLIT WITH VAPOUR RECOMPRESSION.HSC
		Unit Set:	SI1
		Date/Time:	Fri May 31 13:29:22 2013

Material Stream: 4

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase
Vapour / Phase Fraction		0.0000	1.0000
Temperature:	(C)	40.00 *	40.00
Pressure:	(kPa)	111.0 *	111.0
Molar Flow	(kgmole/h)	5.325e+004	5.325e+004
Mass Flow	(kg/h)	1.256e+006	1.256e+006
Std Ideal Liq Vol Flow	(m3/h)	1265	1265
Molar Enthalpy	(kJ/kgmole)	-2.773e+004	-2.773e+004
Molar Entropy	(kJ/kgmole-C)	86.30	86.30
Heat Flow	(MW)	-410.1	-410.1
Liq Vol Flow @Std Cond	(m3/h)	1213 *	1213

Material Stream: 5

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase
Vapour / Phase Fraction		0.0000	1.0000
Temperature:	(C)	46.50	46.50
Pressure:	(kPa)	111.0 *	111.0
Molar Flow	(kgmole/h)	5.325e+004	5.325e+004
Mass Flow	(kg/h)	1.256e+006	1.256e+006
Std Ideal Liq Vol Flow	(m3/h)	1265	1265
Molar Enthalpy	(kJ/kgmole)	-2.716e+004	-2.716e+004
Molar Entropy	(kJ/kgmole-C)	87.02	87.02
Heat Flow	(MW)	-401.8	-401.8
Liq Vol Flow @Std Cond	(m3/h)	1213 *	1213

Material Stream: 6

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

		Overall	Aqueous Phase
Vapour / Phase Fraction		0.0000	1.0000
Temperature:	(C)	40.00 *	40.00
Pressure:	(kPa)	111.0 *	111.0
Molar Flow	(kgmole/h)	5.295e+004 *	5.295e+004
Mass Flow	(kg/h)	1.248e+006	1.248e+006
Std Ideal Liq Vol Flow	(m3/h)	1257	1257
Molar Enthalpy	(kJ/kgmole)	-2.774e+004	-2.774e+004
Molar Entropy	(kJ/kgmole-C)	86.28	86.28
Heat Flow	(MW)	-407.9	-407.9
Liq Vol Flow @Std Cond	(m3/h)	1206 *	1206

Energy Stream: W-P-100

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	P-100		
Duty SP:	0.1568 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: Q Reboiler

Fluid Package: Basis-1

Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Reboiler @COL2		
Duty SP:	102.7 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

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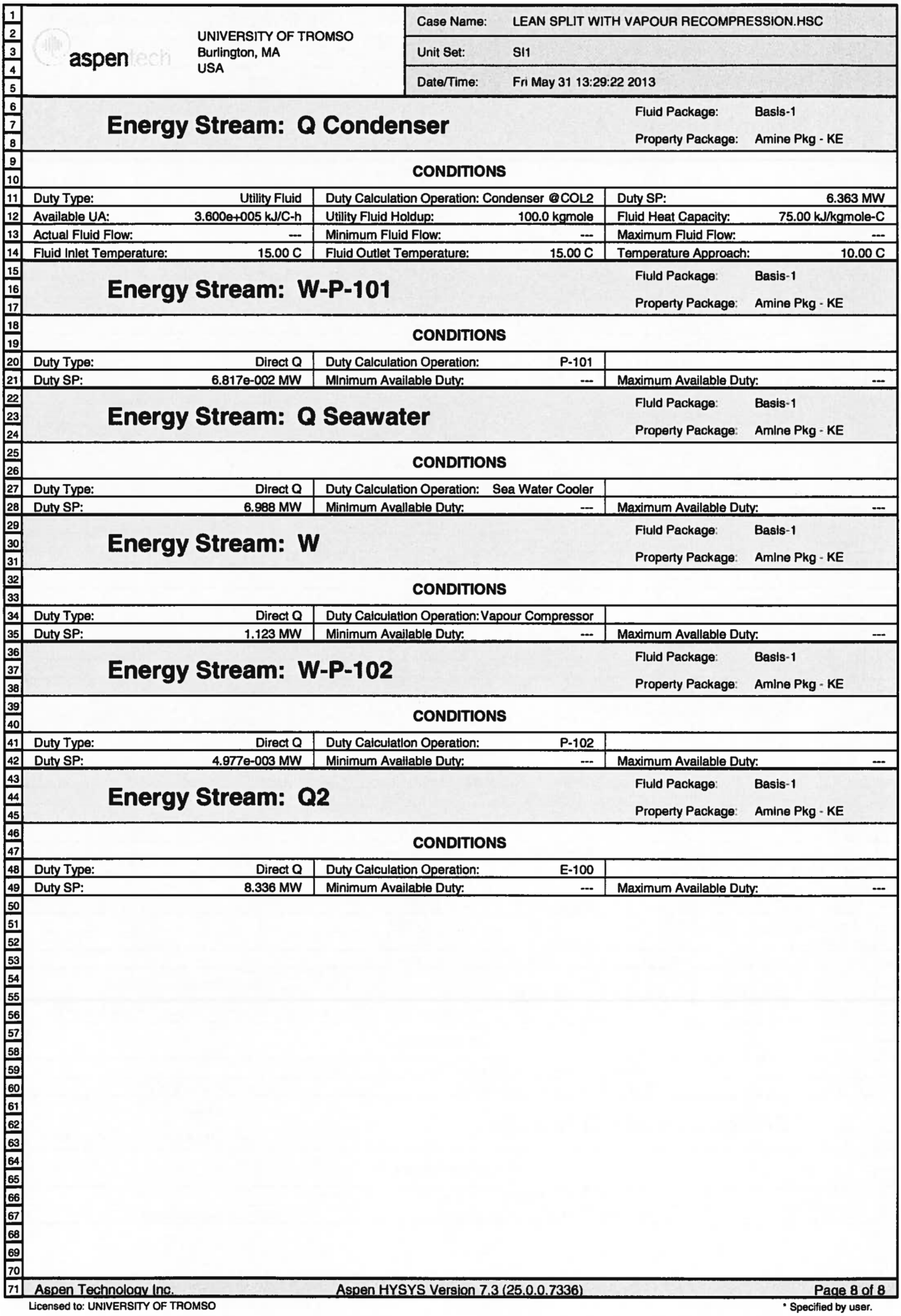

UNIVERSITY OF TROMSO
Burlington, MA
USA

Case Name:	LEAN SPLIT WITH VAPOUR RECOMPRESSION.HSC
Unit Set:	SI1
Date/Time:	Fri May 31 13:29:22 2013

Energy Stream: Q Condenser

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Utility Fluid	Duty Calculation Operation:	Condenser @COL2	Duty SP:	6.363 MW
Available UA:	3.600e+005 kJ/C-h	Utility Fluid Holdup:	100.0 kgmole	Fluid Heat Capacity:	75.00 kJ/kgmole-C
Actual Fluid Flow:	---	Minimum Fluid Flow:	---	Maximum Fluid Flow:	---
Fluid Inlet Temperature:	15.00 C	Fluid Outlet Temperature:	15.00 C	Temperature Approach:	10.00 C

Energy Stream: W-P-101

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	P-101		
Duty SP:	6.817e-002 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: Q Seawater

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Sea Water Cooler		
Duty SP:	6.988 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: W

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Vapour Compressor		
Duty SP:	1.123 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: W-P-102

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	P-102		
Duty SP:	4.977e-003 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

Energy Stream: Q2

Fluid Package: Basis-1
Property Package: Amine Pkg - KE

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	E-100		
Duty SP:	8.336 MW	Minimum Available Duty:	---	Maximum Available Duty:	---

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