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# Heat recovery making use of compression resorption heat pumps

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## Abstract

This paper identifies the advantages of compression resorption heat pumps for the recovery of waste heat and its upgrading to temperatures significantly above 100 oC. Experimental work illustrates the operation of the heat rejection side of the heat pump which indicates the feasibility of operation under such conditions. The experiments are mainly executed with ammonia-water as the working fluid but additionally experiments are reported with ammonia-water-carbon dioxide as the working fluid. These last experiments indicate that the ternary mixture leads to increased performance of the heat pump. It is concluded that the relative simplicity of compression resorption heat pumps and higher performance in comparison to alternative heat pump concepts makes this heat pump type very attractive for heat recovery purposes.

## 1. Introduction

Lee et al. (2017) make use of the data reported by Bobelin et al. (2012) to illustrate the distribution of heat demand in the different industrial sectors in a European country. Table 1 illustrates the largest heat demands in the range 100 to 139 oC.

Table 1 makes clear that large amounts of heat are needed in this temperature range. As reported by van de Bor et al. (2015) a significant amount of low grade waste heat is available as spent water from cooling towers with tem-

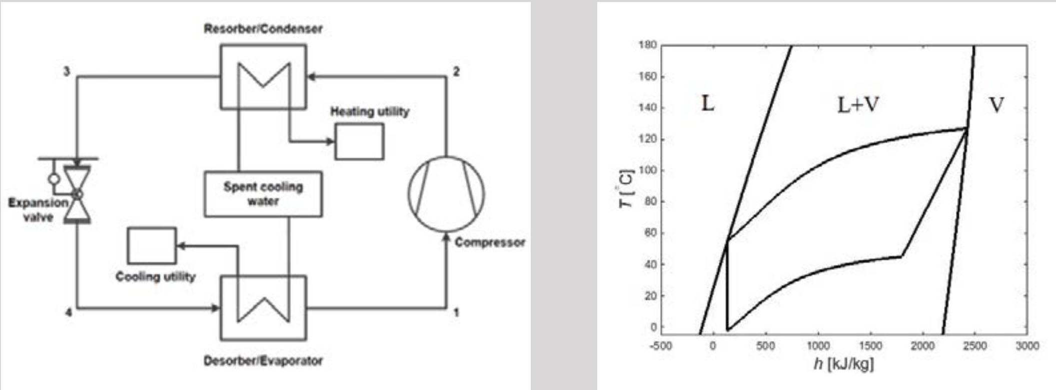


*Fig. 1 – Left: schematic of the CRHP for heat recovery from spent cooling water. Right the operating conditions of the CRHP in a T-h diagram of ammonia-water with 35 wt% ammonia. Spent cooling water is, for instance, partly heated from 50 oC to 120 oC in the resorber and partly cooled down from 50 oC to 20 oC in the desorber. This operating conditions of the CRHP lead to a COP of 3.7.*

peratures in the range of 45 to 60 oC. These authors indicate that about 17 PJ exergy is emitted at 60 oC as cooling water only from a specific plant in The Netherlands. Heat pumps can be used to upgrade these cooling tower flows to valuable thermal energy which can be used to operate processes as listed in Table 1. Van de Bor et al. (2015) have compared several heat pump types; dry and wet compression resorption heat pumps (CRHP), transcritical carbon dioxide heat pump (TCHP), and vapor compression heat pump (VCHP). These heat pumps can be used to upgrade cooling tower water flows to temperature levels above 100 oC, see Table 2 for an example. Assuming a compressor efficiency of 70 %, the wet CRHP is the most attractive option. Compared to the traditionally used VCHP almost 15 % improvement in performance is expected. In their study the working fluid for the CRHP is an ammonia water mixture. A recent study by Gudjonsdottir et al. (2017) indicates that for many applications even better performance can be achieved with wet CRHP by using NH3-CO2-H2O as a working fluid instead of the traditionally used ammonia water.

## 2. Experimental performance of the heat delivery side of the CRHP

Experimental data was collected making use of a mini-channel heat exchanger which consisted of 116 tubes with internal diameter of 0.5 mm in a shell with external diameter of 25 mm. The heat exchanging length was 0.80 m. The heat exchanger was equipped with a fractal distribution system making the flows of the heat pump working fluid (ammonia-water, which circulated through the tubes from top to bottom) and water that needed to be heated (which circulated through the shell side) pure counter currently. The operating regime is similar to what could be expected in a plate heat exchanger where also pure countercurrent flow dominates. Fig. 1 illustrates the operating conditions of the CRHP considered during the experiments with left the schematic of the heat pump and right the operating conditions in a T-h diagram of ammonia-water with an ammonia concentration of 35 wt %.

### 2.1 Ammonia-water experiments

Fig. 2 shows how the temperature of the shell of the heat exchanger varies along the absorption process. In this case the spent water flows from bottom to top of the heat exchanger while its mass flow is maintained at 15 kg/h. The water enters the heat exchanger with 50 oC and is heated to 128, 130 and 132 oC respectively for ammo-

| Sector | Temperature range 100 – 119 oC | Temperature range 120 – 139 oC |
|---|---|---|
| Drying | 3.6 PJ | 24.1 PJ |
| Evaporation, crystallization, concentration | 11.9 PJ | 8.3 PJ |
| Liquid & gas heating | 2.9 PJ | 6.1 PJ |
| Distillation | 5.0 PJ | 6.1 PJ |
| Thermal treatment | 2.2 PJ | 1.8 PJ |

*Table 1 – Yearly heat demand in some industrial sectors of France (Lee et al., 2017).*

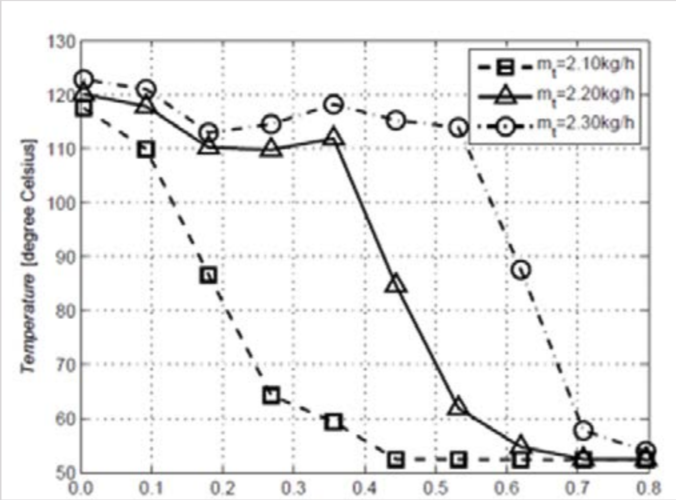


*Fig. 2 – Shell outside temperature along the length of the resorber. The shell temperature is slightly lower than the water temperature. Larger ammonia-water flows displace the absorption process to positions further downstream in the heat exchanger.*

nia-water flows from the top of 2.10, 2.20 and 2.30 kg/h.

Fig. 2 makes clear that, depending on the ammonia-water mass flow, a superheating zone may exist at the resorber inlet and generally also a subcooling region will develop in the outlet region of the resorber. This is similar to what Sarraf et al. (2015) have reported for the condensation process in plate heat exchangers in which the temperatures of the two fluids have a very small approach. The water outlet temperature for these experiments approaches the ammonia-water inlet temperature with less than 3 K. The ammonia-water outlet temperature approaches the water inlet temperature with 0.1 K for the lowest flows and with 3 K for the largest flow. Fig. 3 shows the temperature profiles along the heat exchanger as predicted by Shi et al. (2017) for the conditions of the experiments illustrated in Fig. 2. It makes clear that the water temperature closely follows the ammonia-water solution temperature. It is evident that the ammonia-water absorption process is ideal to raise the temperature of cooling tower water flows to elevated temperatures so that its heat can be recovered for heating purposes.

## 2.2 Ammonia-water-carbon dioxide experiments

Experiments have also been performed for which carbon dioxide has been added to the ammonia-water solution. Table 3 illustrates the impact of the addition of CO2 (2% by weight) for three different operating conditions.

Interesting is to see that the water side outlet temperature is significantly increased when CO2 has been added. These results indicate the performance of the system can be significantly improved when CO2 is added. Since the kinetics of the absorption of carbon dioxide are relatively slow, the addition of CO2 requires longer residence times for the absorption process to be totally absorbed. Therefore pumping instabilities were noticed during the experiments and experiments with higher mass flows than 10 kg/h failed. The geometry of the heat exchanger seems to have considerable influence. When the working fluid flowed from bottom to top instead of top to bottom the stability increased. In this case the overall heat transfer however decreased.

## 3. Conclusions

CRHPs are an attractive option for waste heat recovery and have the potential to have significantly improved performance compared to the traditionally used VCHP. The experimental work reported in this study illustrates how the temperature glide in the resorber of a CRHP can perfectly match the temperature glide needed for upgrading

| $T_{avg}$ = 105 oC | CRHPwet | VCHP | TCHP |
|---|---|---|---|
| 60 oC → Hot | 150 oC | 105 oC | 150 oC |
| 60 oC → Cold | 6 oC | 45 oC | 26 oC |
| COP | 3.20 | 2.81 | 2.61 |
| Max. savings (k€/yr) | 274 | 177 | 127 |

*Table 2 – Comparison of alternative heat pump systems (Van de Bor et al., 2015).*

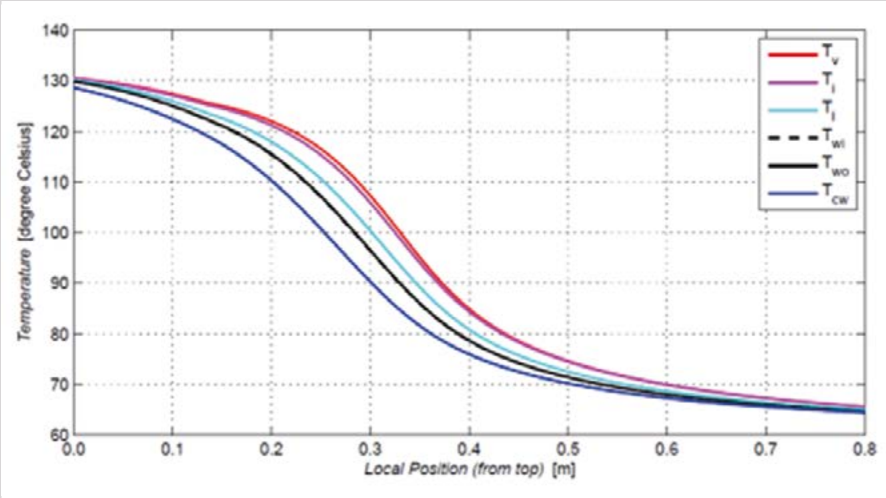


*Fig. 3 – Model prediction of the internal temperatures along the length of the resorber. Tv is the vapor temperature, Ti is the vapor-liquid interface temperature and Tl is the liquid (film) temperature, all in the ammonia-water side of the heat exchanger. Tcw is the water temperature. Twi and Two are the internal and external wall temperatures.*

waste streams, like spent cooling tower water, to more useful temperature levels. The experiments additionally indicate that the potential of CRHP can be even greater with NH3-CO2-H2O as a working fluid.


## Acknowledgements

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| Parameter | Unit | without CO2/with CO2 | without CO2/with CO2 | without CO2/with CO2 |
|---|---|---|---|---|
| $M_s$ | kg/h | 5.0/5.0 | 7.5/7.5 | 10.0/10.0 |
| $T_{t,in}$ | oC | 132.0/132.5 | 131.0/131.4 | 135.4/134.3 |
| $T_{s,out}$ | oC | 127.1/131.3 | 125.9/130.1 | 127.2/133.4 |
| $T_{t,out}$ | oC | 50.7/58.5 | 49.9/58.4 | 50.2/54.8 |
| $T_{s,in}$ | oC | 50.6/50.8 | 49.7/50.1 | 50.1/50.2 |
| LMTD1 | K | 1.1/3.5 | 1.5/3.8 | 1.9/2.2 |

*1LMTD is short for logarithmic mean temperature difference*

*Table 3 – Comparison of the resorber performance without and with CO2 added to the ammonia-water solution. is the mass flow of the binary / ternary mixture. Tt stands for the temperatures in the resorber side. Ts stands for the water side temperatures.*