Absorption cooling cycle serving two temperature levels

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ABSTRACT

In the project “RE-WITCH (Renewable and Waste heat valorisation in Industries via Technologies for Cooling production and energy Harvesting)” sponsored by the European Union, several waste-heat driven cooling systems will be demonstrated in industrial application. Here we will report on development of a special absorption chiller which uses the working pair water – lithium bromide. The chiller will be applied for providing about 200 kW cooling at a temperature level of about 10°C and, simultaneously, up to 200 kW cooling at a temperature level of about 20°C. As there are several ways of how to supply these cooling loads, the question arises which scheme performs best, shows best economics, or is most easy to operate. In this paper those questions will not be answered yet, but some possible process options will be presented and discussed. Cycle complexity, efficiency, and the required temperature of the driving heat can be traded against each other.

Keywords: absorption, industrial application, heat recovery, process optimisation

INTRODUCTION

The basic process scheme is shown qualitatively in the vapor pressure-temperature diagram in fig. 1: A regenerator receives the driving heat input Q_2 at a temperature T_2. A condenser rejects heat Q_{13} at a temperature T_{12} (or T_{11}, or a third level T_{13}, not shown) to one or more heat sinks. A first evaporator provides cold Q_{01} at a temperature T_{01}. The corresponding absorber rejects heat Q_{11} at a temperature T_{11}. A second evaporator provides cold Q_{02} at an elevated temperature T_{02} and the corresponding absorber rejects heat Q_{12} at a temperature T_{12}, correspondingly. As compared to a standard chiller operating with the lower pressure evaporator-absorber pair (01-11) only, using two evaporator-absorber pairs at different pressure and temperature levels as shown increases thermodynamic efficiency and allows for a larger (partial) temperature lift. This, of course, goes with a higher degree of complexity.

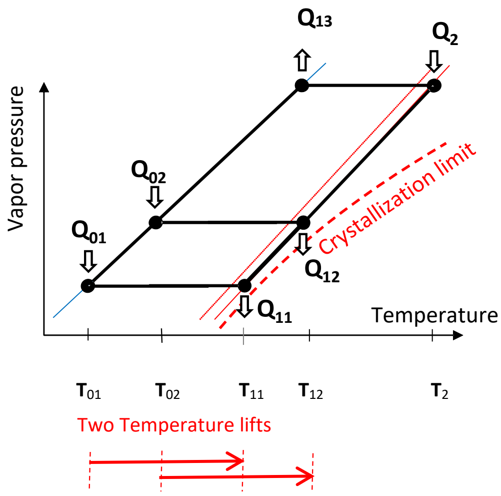

Figure 1: Fundamental process scheme

The goal of the project is to find a design for the process which shows the expected benefits and at the same time is easy to control, is safe and flexible in operation, and does not add significantly to first cost in comparison to a standard chiller. In this presentation, we discuss simple relationships only, in order to see the big picture. Real optimisation will be performed within the project later and reported in due time. The exact temperatures, pressures, and heat flows will be adapted to the application, later also.

PROCESS CONFIGURATIONS

The most simple way to fulfil the cooling duty will be to install two independent devices. This is not at all a bad decision, because it allows for a large flexibility in operation, so we start with this concept. The operational parameters dew temperature (pressure), boiling temperature, and solution composition of the two envisaged processes are shown in a Dühring diagram for aqueous solution of LiBr (Patek and Klomfar, 2006) according to fig. 2. A mass fraction difference of 4 % between strong and weak solution was assumed. The thin vertical blue lines locate the process temperatures providing the cold (evaporation), the green line locates the processes reject heat temperature (absorber, condenser), and the thick red line stands for the maximum process temperature and fixes the minimum temperature of the supply of driving heat.

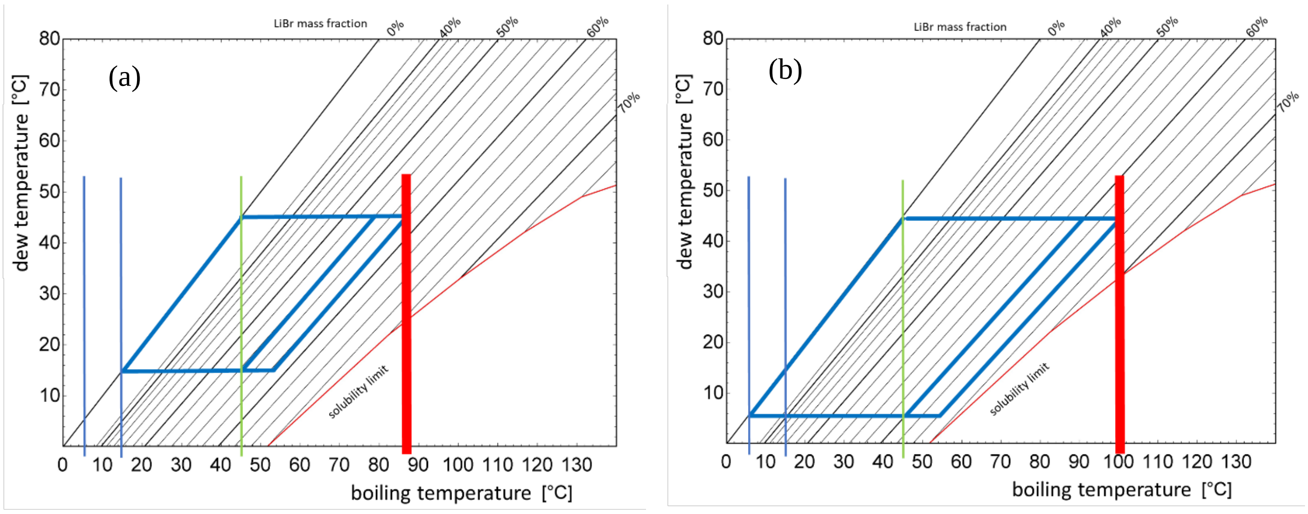

Figure 2: Single effect processes. Evaporator in a): high temperature (HT), in b): low temperature (LT)

The process which serves the high temperature evaporator (abbreviated HT in the following, fig. 2a) operates in a comfortable range with a maximum solution temperature of 87°C and far from the solubility limit. The process which serves the low temperature evaporator (LT, fig. 2b), however, operates with a maximum solution temperature of 100°C and near to the solubility limit. Due to the larger temperature lift and the increase of irreversibility with temperature lift the COP will be a bit smaller, temperature of the driving heat must be higher, and operation will be more delicate.

The other extreme option - which reduces the investment and installation cost – is to design the LT process (fig. 2b) in such a way that it serves the HT cooling need also. Of course, this one-serves-all device covers both cooling loads HT+LT at the LT level, i.e. for the HT load at an excessively low temperature. Roughly speaking, the heat transfer area from the two processes above must be combined into one device and the splitting of the temperatures HT-LT would be realised externally. It is easy to design, but requires the input heat at the 100°C-level, and it is less performant, because there is only one large temperature lift now. A cost reduction could be realised by separating the evaporator tube bundles into HT and LT: then the HT part could operate with a very small transfer area.

A simple and small step from the one-serves-all process with separate evaporator bundles in one shell into the direction of the separate processes, is introducing a separate second evaporator at the HT level (fig. 3a), with a throttling process to the absorber (dashed line). The throttling of the condensate will produce a little bit less entropy due to the staging, and the entropy production in heat exchange will be smaller, on the expense of larger heat transfer area, of course. However, these benefits in entropy production will be compensated by the additional vapor throttling which creates much more entropy than the liquid throttling. So it will be better to include a complete third pressure level as shown next.

We include an additional absorber at the pressure level of the HT evaporator and two complete solution loops (fig. 3b). In a simple version there would be two generators and a common condenser. A little bit more complex due to the handling of the solution would be one generator with two separate tube bundles and a common condenser. Performance, driving heat temperature, and required heat exchange area will be similar to the two separate single-effect processes (fig. 2), with a small improvement in efficiency due to the integrated staged throttling. The two steps of generation at different temperatures, in any case, can be beneficial for a large glide in the hot external heat source.

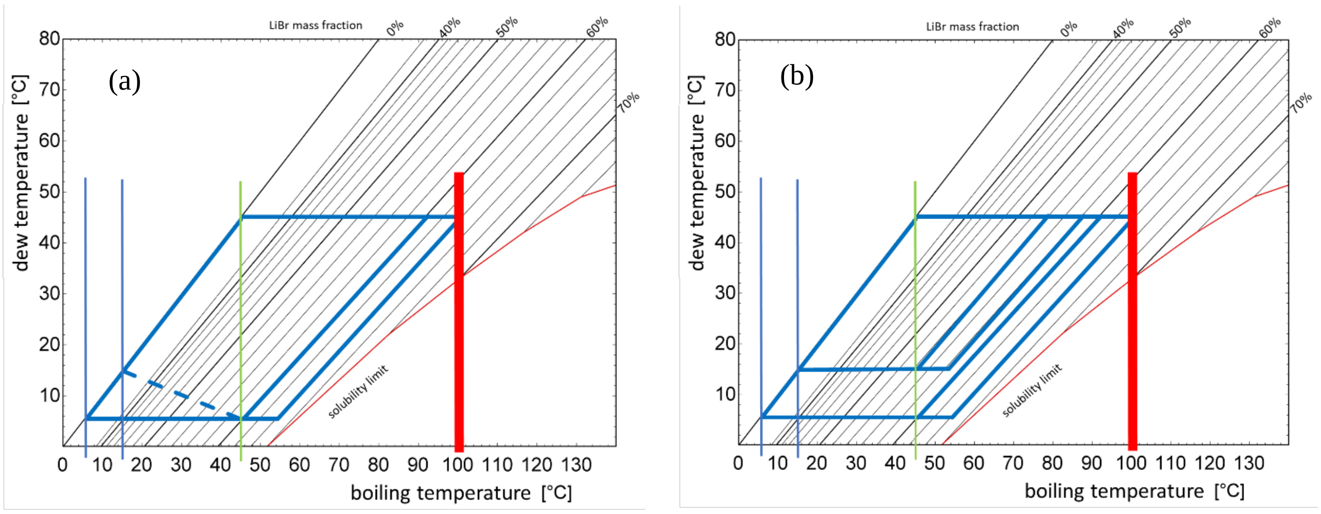

Figure 3: a) Separate evaporators for HT and LT; b) Dual loop process

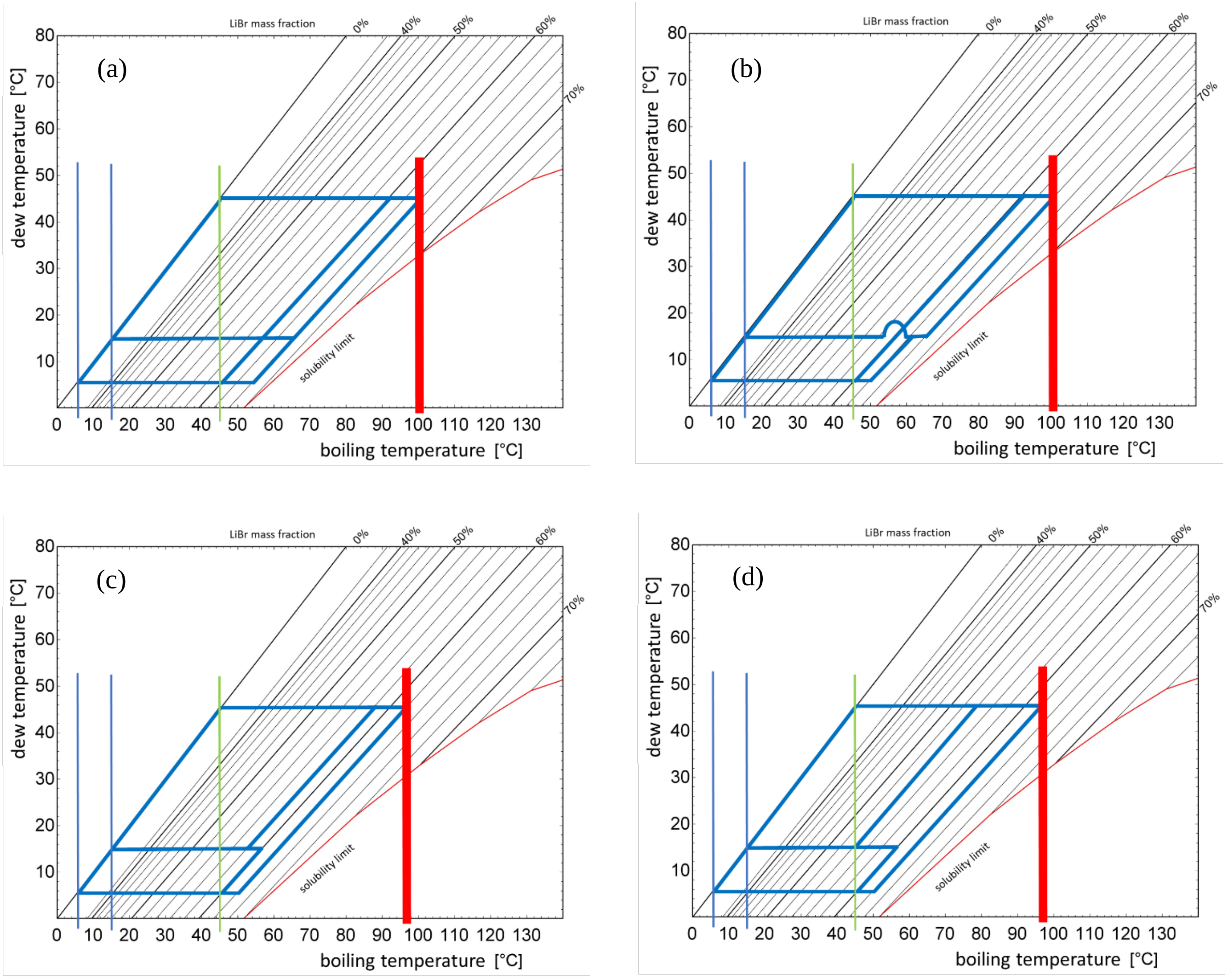

Figure 4: a) Parallel solution flow; b), c) and d) Serial solution flow (see text)

The process can be simplified largely by using only one solution circuit which serves both absorbers. In fig. 4a parallel flow design is shown. The strong solution leaving the generator is branched into the two absorbers; the weak solutions are collected again after the absorption. Here still two solution pumps are required. Another drawback is that again the generator requires the high temperature of 100°C. This is traded in for a large reduction in required heat exchange area for the HT absorber, which works with a very large driving temperature difference now. Due to the staged solution loop an additional efficiency increase can be incurred.

Serial flow designs are shown in figs. 4b-d. In the scheme of fig. 4b the solution flows from the generator to the absorber of the HT-evaporator (first part of absorption) and from there to the absorber of the LT-evaporator (second part of absorption). The diluted solution then is pumped back to the generator: only one pump is needed. The area requirement of the first absorber is reduced further and the distance of the process state points to the solubility limit is increased.

In the scheme of fig. 4c the flow goes from the generator to the absorber at the lower pressure first. Then there is a pump required to increase the pressure of the partly diluted solution to the higher HT evaporator pressure level, where the second part of absorption now takes place. The drawback is the need for the second pump. A benefit, however, is the decrease of the generator temperature. Additionally, the distance to the solubility limit is increased further. The required heat exchange area for the high temperature absorber will be larger than in 4b, but still decent.

Alternatively, instead of making use of the large driving temperature difference in the high temperature absorber to reduce cost, the absorber area could be increased with the intention to cool down the solution further and by this to increase the composition change (fig.4d), which would reduce the circulation rate and in turn increase efficiency.

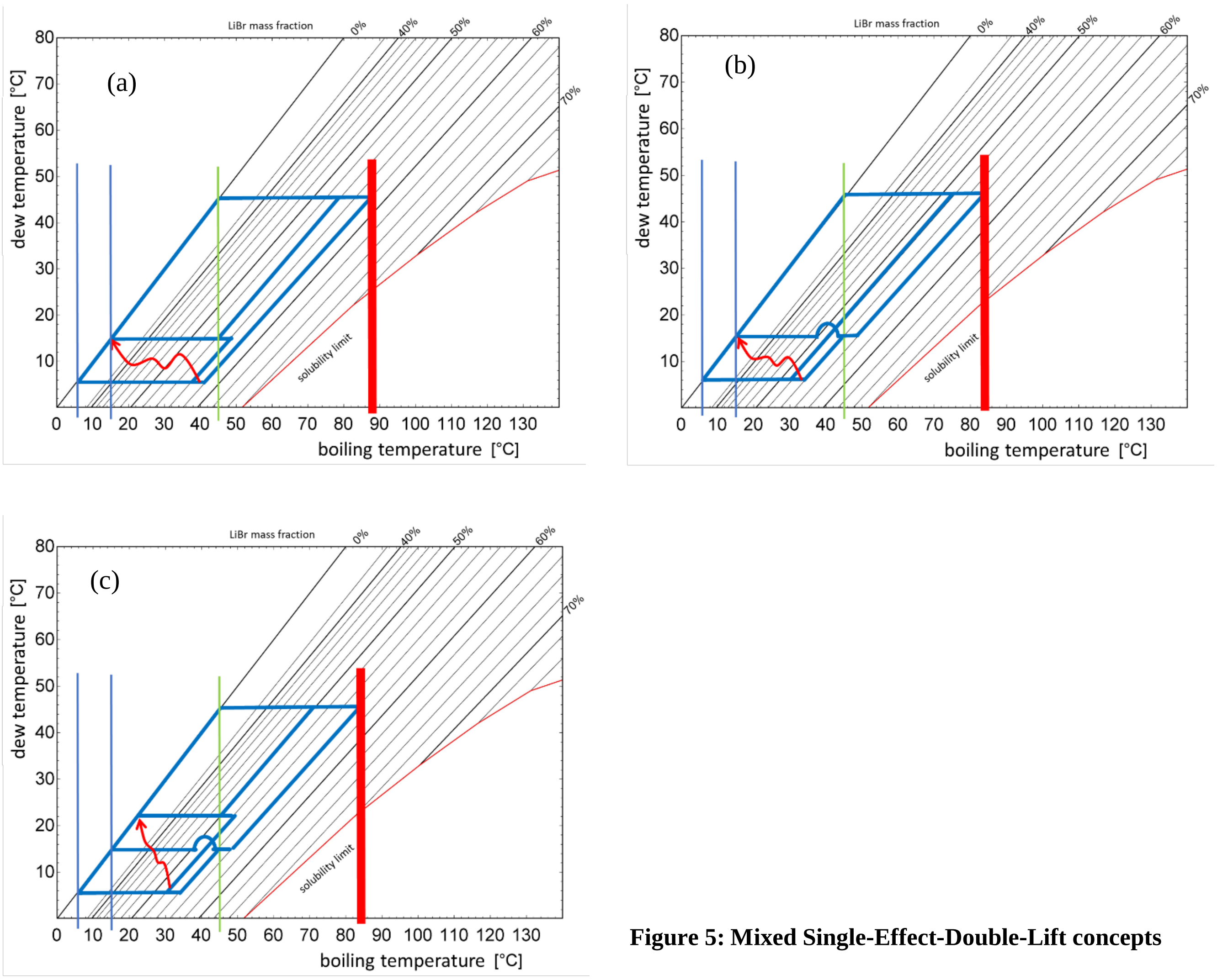

Figure 5: Mixed Single-Effect-Double-Lift concepts

In applications where the temperature of the driving heat is limited, a mixed single-effect-double-lift concept (Schweigler, 1998) can be realised (fig. 5). In fig. 5a the serial flow according to fig. 4c and 4d is used. However, the heat of absorption at the pressure level of the LT evaporator is not rejected to the heat rejection circuit (cooling water) but is taken by the HT evaporator. The generator temperature then is at the level of the stand-alone HT cycle (fig. 2a). If the solution flow scheme of fig. 4b is used, only one pump is necessary and the temperature at the generator is decreased even further (fig. 5b). In the more complex scheme of fig. 5c with same source and sink temperatures, the change in composition is increased, what is expected to improve performance. On the other hand, with keeping the total composition change as in 5b, also the input temperature could be reduced further.

Of course, including the double-lift concept brings a significant trade-off in COP of the device. While the COP for the former processes is expected to be in the order of 0.7 to 0.8, for the processes of fig. 5 it will be in the order of 0.46 to 0.53, assuming a 50% contribution of both evaporators to the total load. Still, it may be beneficial to switch from a process scheme according to fig. 4 to this kind of internal coupling of absorber and evaporator especially of fig. 5b, at least for some time, as a possibility to keep the system operating even in extreme summer conditions, perhaps only for some few days in the year.

Depending on the conditions of the driving heat temperature, many other options can be envisaged. With a fourth pressure and higher input temperatures also double-effect-schemes are possible.

FURTHER DISCUSSION

The schematics presented above leave room for many more variations and optimisation paths. The following issues must and will be addressed in future work:

- *Adaptation of the cycle to the glide of the external heat carrier fluids.* For instance, the schemes of figs. 3b, 4d, and also 5c are very well adapted to a driving heat source at two temperature levels (3b) or with a large glide. On the other hand, in almost all cases the process can be adapted well to a large glide in the heat sink.

- *Arrangement of pumps and heat exchangers in the solution circuit.* The issue of the pumps was addressed in the paper; however, more arrangements and combinations with ejectors can be envisaged. In almost all cases a splitted solution heat exchanger will improve efficiency; however, it may be traded in for less complexity.

- *Control, part-load operation, and auxiliary power.* Especially options to shift load between the temperature levels should be regarded. Also the auxiliary power demand is to be investigated and can have an impact on design conditions.

CONCLUSION

In industrial cooling applications sometimes the cooling load appears at two or more temperature levels. When these cooling loads are being covered separately, but in one integrated process, efficiency of the process can be increased as compared to a simple process which serves both needs together. Several options have been presented and will be evaluated in future work.

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