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Comparison of Double Stage Heat Transformer with Double Absorption Heat Transformer Operating with Carrol – Water for Industrial Waste Heat Recovery

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This work shows the first comparison of two industrial energy saving devices. An absorption heat transformer (AHT) is an industrial device based on thermodynamic cycle with the purpose to recover heat at higher temperatures. The thermodynamics cycles have crystallization fluids limits. The gross temperature lift (GTL) is a parameter for comparison of heat pumps devices. Heat pumps may compare themselves with GTL and Coefficient of Performance (COP) to define the best fluid or operating conditions for same process. Double stage heat transformer (DSHT) is a device designed for cover the upper conditions and avoid crystallization problem of AHT using two AHT, also double absorption heat transformer (DAHT) is an alternative device for operating conditions where AHT is not able to operate. The studied industrial process (sterilization vegetables) has operating temperatures from 120 to 140 °C from waste heat at 60 °C or 70 °C. The results show the operating conditions for DSHT and DAHT with Carrol – water mixture. Conclusion show COP values as function of GTL, waste heat temperature, ambient temperature and revalorized temperature. DSHT COP is higher than DAHT COP for same operating purposes. These devices are a technological alternative for waste energy recovery.

1. Introduction

A heat pump (HP) is a thermal machine that transfers heat from something at a lower temperature to something at a higher temperature. There are different kinds of "heat-pumps". There are two heat pumps: Type I and II. "Type I" is a device with evaporation process at lower temperature than condensation process. Type II is another device with condensation process at lower temperature than evaporation process. The main disadvantage of the process of absorption heat pumps is due to cyclical feature that requires a transitional period in which thermodynamic equilibrium is established throughout the system.

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2. Industrial waste recovery state of the art

Several processes are able for heat recovery by heat integration analysis (Feng, 2011). However, heat integration only exchange heat at similar levels. An absorption heat transformer (AHT) or Single Stage Heat Transformer (SSHT) is a thermal device made for heat revalorization. The main objective of a SSHT is to increase the temperature value of industrial waste heat or solar energy (Sözen, 2007).

2.1 Advanced cycles of heat transformers

A single-stage heat transformer (SSHT) can be used for industrial waste heat recovery at intermediate temperatures when it is necessary to increase the temperature similar to or lower than 50 ° C. However, when it is necessary to increase the temperature higher than 50 °C from original source, it could be used advanced thermal transformer such as double stage heat transformer (DSHT) and double absorption heat transformer (DAHT).

2.1.1 Double absorption heat transformers

Double absorption heat transformers (DAHT) consist of a generator, a condenser, an evaporator, an absorber, a second absorber/evaporator and an economizer as shown in Figure 2. A heat source is supplied to separate the working fluid in the generator at an intermediate temperature. Then the vapourized working fluid is condensed in the condenser at a lower temperature. Then the condensed working fluid is split into two parts, one of them is pumped into the evaporator where it is vapourized at an intermediate temperature and pressure (doted lines), and the other part is pumped at a higher pressure and vapourized in the second absorber/evaporator by means of an amount of available heat. The vapourized working fluid is absorbed in the absorber, at the highest temperature by the rich solution coming from the generator. The solution at an intermediate salt concentration is split into two streams, one goes to the generator preheating the rich solution through the heat exchanger and the other is fed to the absorber/evaporator absorbing the vaporized working fluid coming from the evaporator and delivering an amount of heat. Finally, the poor salt solution at a low concentration leaving the absorber/evaporator goes to the generator starting the cycle again.

2.1.2 Double Stage heat transformer

A double stage heat transformer (DSHT) consists of two SSHT, which can be coupled in three different ways. There are some studies for the interconnection for DSHT. The useful heat from first absorber may be divided for the second evaporator and second generator.

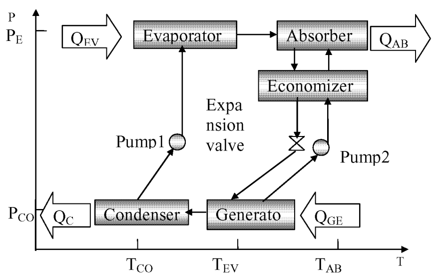

Figure 1: Schematic diagram for SSHT

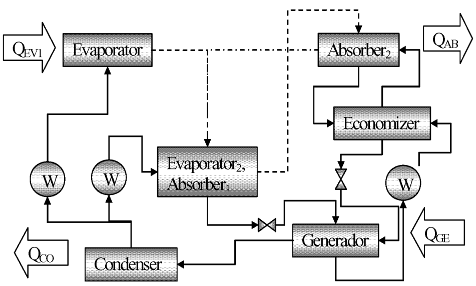

Figure 2: DAHT schematic diagram

The amount of entering energy in second stage is almost 50 % from the total amount entering at first stage. Other way to connect the stages is from first absorber to second generator; however this connection is limited by crystallization risk. The best option for the connection of DSHT is to add the useful heat from first absorber to the second evaporator, and add waste heat in second generator to avoid crystallization problems. In the figure 3 the dotted lines represent vapour from evaporators to absorbers and vapour from generators to condensers. In this figures there is not draw the heat loads to avoid confusion, because there are many lines for the interconnection of components. The waste heat is added in the DSHT in the generator 1 (Q_{GE1}), evaporator 1 (Q_{EV1}), and generator 2 (Q_{GE2}) and the useful heat from absorber 1 (Q_{AB1}) is conducted to evaporator 2 (Q_{EV2}), so the useful heat at higher temperature is obtained in absorber 2 (Q_{AB2}).

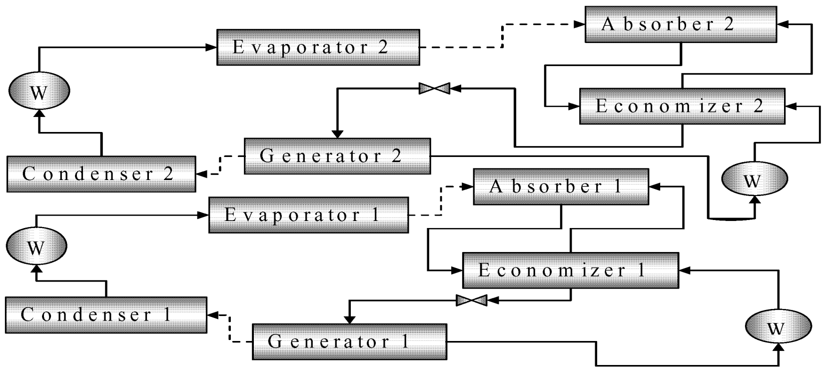

Figure 3: DSHT schematic diagram.

3. Operation conditions

Following the mathematical models developed by previous papers (Romero, 2010; Jun 1999) and their assumptions, comparisons were carried out. The waste heat is added at 60 °C or 70 °C into the evaporators and generator. The surroundings leads to the condenser to operate at 20 °C or 25 °C, and the purpose temperature is above 120 °C and still 140 °C for sterilization vegetables process, because for higher temperatures there is undesirable effect in the vitamins concentrations (De Roeck, 2008). The useful heat obtained from DAHT and DSHT must be constant for the sterilization process because the exposed time is a critical variable (Oerlemans, 2006). Carrol – water (Reimann, 1984) is used into the advanced system for higher COP compared with commercial mixture (aqueous lithium bromide) (McNelly, 1979). Waste heat lead to the DAHT and DSHT to keep constant generator (T_{GE}) and evaporator (T_{EV}) temperatures. While absorber temperature (T_{AB}) affect the useful heat and according equations 1 to 3, diminished also the respective COP. Economizers are pre-heater for concentrated solution from generator and it is assumed with constant effectiveness equal to 0.7 in all calculations for the comparison of both DAHT and DSHT. The effect of the effectiveness of economizer was previously reported (Kakac, 2002) and 0.7 is a value for commercial plate heat exchanger. Finally, waste heat was considered as constant value between 10 and 15 kW for this study, this waste heat is added as Q_{EV} and Q_{GE} for DAHT and Q_{GE1}, Q_{EV1} and Q_{EV2} for DSHT. Temperature of waste heat is considering the same for the entering into de DAHT and DSHT, of course for industrial process this mean that are large areas for heat transfer and the losses are negligible.

4. Comparison main parameters

The most important design parameters for an absorption heat transformer are: the coefficient of performance and the gross temperature lift. It is defined as the ratio of useful heat delivered and wasted heat added to the system.

$$COP_{SSHT} = \frac{Q_{AB}}{Q_{GE} + Q_{EV} + W_1} \tag{1}$$

$$COP_{DAHT} = \frac{Q_{AB,2}}{Q_{GE} + Q_{EV,1} + W_1 + W_2} \tag{2}$$

$$COP_{DSHT} = \frac{Q_{AB,2}}{Q_{GE,1} + Q_{EV,1} + Q_{GE,2} + W_1 + W_2 + W_3 + W_4} \tag{3}$$

In a previous paper it was concluded that work done by centrifugal pumps were negligible because those were only 2 % of waste heat. These works are not considered for COP calculation. Although the COP is less than unity always for these systems, they have the unique ability to raise the temperature of any waste heat to transform it at a useful heat. (Holland, 1999; Rivera, 2001). The gross temperature lift (GTL) is defined as the difference between the useful temperature and the added waste heat temperature:

$$GTL_{SSHT} = T_{AB} - T_{EV} \tag{4}$$

$$GTL_{DAHT} = T_{AB,2} - T_{EV,1} \tag{5}$$

$$GTL_{DSHT} = T_{AB,2} - T_{GE,1} \tag{6}$$

5. Results

In Figure 4, DAHT COP as function of GTL is shown, for condensation temperature at 20 °C and 25 °C, upper and lower lines. Both lines are for waste heat added at 70 °C. In this Figure it can be observe useful temperature from 111 °C (according Equation 5) still 140 °C (GTL = 70 °C). The highest COP is almost the same (0.27) and diminishes for higher temperature. Useful heat at 120 °C may operate with a COP of 0.249 and 0.235. For 130 °C the COP are 0.198 and 0.147 for each line, and both conditions are able for the sterilization purpose.

Figure 5, compared with the previous one, are both similar. The highest COP for these conditions happens at 135 °C (GTL = 65 °C) for two first absorber temperatures: 100 and 95 °C, upper and lower lines. The COP goes from 0.297 to 0.244 in the upper line and from 0.292 to 0.091 in the lower line. For useful recovery heat at 140 °C (GTL equal to 70 according equation 6) the COP are 0.289 and 0.277 for first stage absorber temperature at 100 and 95 °C.

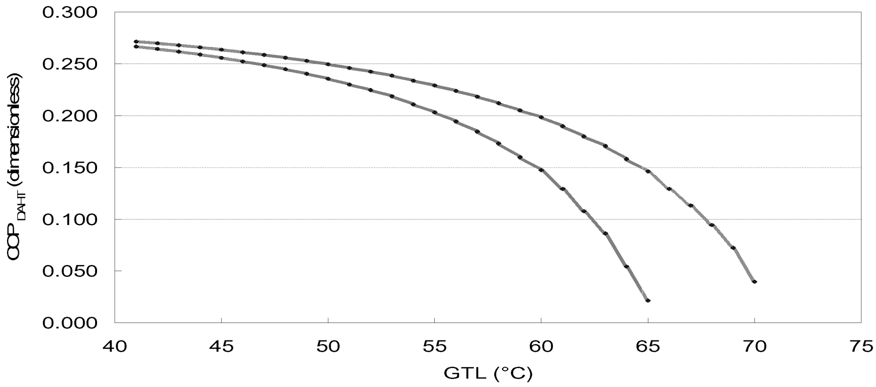

Figure 4: COP for DAHT for industrial energy recovery as GTL function.

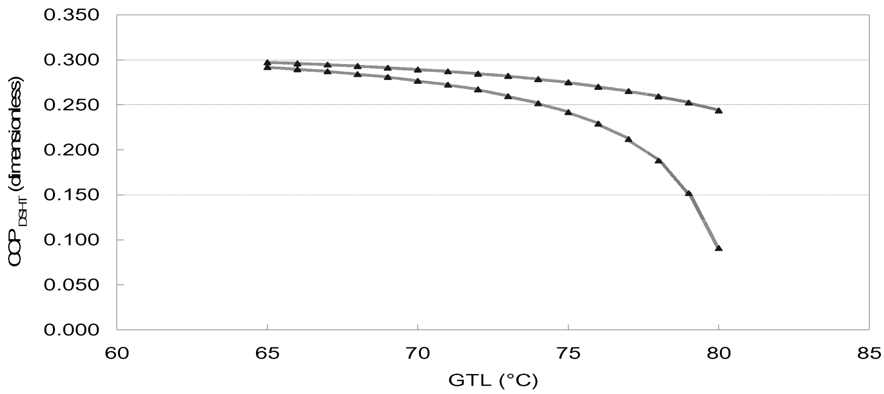

Figure 5: COP as function of GTL for DSHT whit T_{CO} = 25 °C, waste heat temperature at 70 °C and first absorber temperature at 95 and 100 °C.

6. Conclusions

The single stage heat transformer (SSHT) has crystallization limit, therefore advanced heat transformer are proposed for recovery energy at higher levels than SSHT. For industrial process the double absorption heat transformer (DAHT) and double stage heat transformer (DSHT) are proposed for temperatures from 120 °C to 140 °C, for sterilization vegetables process. The results shows that it is possible to recover energy from 70 °C for this purpose, with a Coefficient of performance (COP), in DAHT from 0.147 to 0.198, than means between 14 to 19 % of recovery from waste heat at 70 °C.

The other analyzed advanced system is DSHT, with a first stage useful temperature at 95 or 100 °C, in this case, the COP is higher than for DAHT at 120 °C, and 140 °C. The COP for 140 °C goes from 0.277 to 0.289, which is 27 % to 28 % from energy at 70 °C and revalued to 140 °C. Finally, the comparison of both systems indicates that surroundings temperature affect the performance of system. The higher condensation temperature into de DAHT and DSHT diminish the COP values, both systems recovers higher amount of energy (higher COP) at 20 °C instead 25 °C.

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