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STUDY ON CONDENSATION IN THE PRESENCE OF NONCONDENSABLES ON A SHELL - TUBE HEAT EXCHANGER

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Abstract

Noncondensable gases in a condenser will reduce the heat transfer coefficient and this is the case of the mixture (steam + air) / R114 heat exchanger in our high temperature heat pump. This heat exchanger is a shell - tube type and is for the purpose of simulating industrial cylinder dryer. The refrigerant R114 evaporates in tube side and the steam in the mixture condenses in shell side.

The condensation in the presence of a noncondensable is a delicate phenomenon especially in a geometrically complex heat exchanger. For this reason, a computer program was developed. The program is based on heat and mass transfer relations and can estimate the local heat transfer coefficient, global heat transfer coefficient and thermal power. The results confirm the importance of air for energy recovery. The influence of refrigerant mass flow rate and quality are also given in this paper.

Experimental studies on this heat exchanger were carried out. Air mass concentration is varied from 7.5% to 26%. Comparison between calculated results and experimental results is given in this paper.

ETUDE DE LA CONDENSATION EN PRESENCE DE GAZ NON CONDENSABLES DANS UN ECHANGEUR DE CHALEUR MULTITUBULAIRE.

RESUME : Les gaz non condensables dans un condenseur réduisent le coefficient de transfert de chaleur et c'est le cas de l'échangeur de chaleur à mélange (vapeur + air)/R114 de la pompe à chaleur à haute température. Cet échangeur de chaleur est du type multitubulaire à calandre et est destiné à simuler un déshydrateur industriel à cylindre. Le R114 s'évapore du côté des tubes et la vapeur du mélange se condense du côté de la calandre.

La condensation en présence d'un gaz non condensable est un phénomène délicat, en particulier dans un échangeur de chaleur à géométrie complexe. C'est pourquoi on a mis au point un programme d'ordinateur. Ce programme s'appuie sur les relations du transfert de chaleur et de masse et permet d'estimer le coefficient de transfert de chaleur local, le coefficient global de transfert de chaleur et la puissance thermique. Les résultats confirment l'importance de l'air pour la récupération de l'énergie. L'influence du débit et de la qualité du frigorigène est aussi mentionnée dans le rapport.

Des études expérimentales ont été effectuées sur cet échangeur de chaleur. La concentration de la masse d'air varie de 7,5 à 26 %. Ce rapport compare les résultats des calculs et des expériences.

STUDY ON CONDENSATION IN PRESENCE OF NON-CONDENSABLES ON A SHELL-TUBE HEAT EXCHANGER

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1 - INTRODUCTION

Condensation of vapour in presence of non-condensables takes place in heat exchangers that are used for waste heat recovery. In many cases, it means condensation of steam in presence of air. The presence of air degrades the heat transfer coefficient and consequently reduces the power to be transferred for a given heat exchanger. In this paper, a refrigerant R114 evaporator in a high temperature heat pump system [1], designed for waste heat recovery from wist (steam/air mixture) is studied. Evaporation of R114 in tube side is ensured by heat recovery from condensation of steam in the mist in shell side of the heat exchanger. The operation of this heat exchanger directly determines the performance of the installation. A preliminary study was made before the construction of this heat exchanger. This paper presents the mathematical modelling results for estimating the influence of different parameters in this heat exchanger. Comparison between calculated and measured results is given in this paper.

2 - CONDENSATION IN PRESENCE OF NON-CONDENSABLES

Condensation in presence of non-condensables is shown in Fig. 1. A temperature drop exists between the bulk temperature T_m and the condensate non-condensables interface temperature $T_{i,ic}$ where condensation takes place. The presence of non-condensables results in two unfavorable influences on heat transfer :

- steam is in its partial pressure and consequently $T_m < T_t$,
- steam must be diffused through a non-condensable film in order to reach the condensate film.

Colburn and al. [2] have developed equations for condensation in presence of non-condensables. Heat transferred in this case is the sum of latent heat by diffusion and sensible heat by convection. Sparow and al. [3] have solved laminar condensation equations for a vertical wall in presence of non-condensables by analytical method. Chisholm [4] obtained a relation governing heat transfer in this case. Henderson and al. [5] proved important degradation of the heat transfer coefficient for steam/air and toluene/nitrogen. [6.7.8] studied the influence of flow rate on the heat transfer coefficient when non-condensables are present, the favorable role of flow rate is confirmed. The work of Cunningham [9] showed that the influence of non-condensables is different for smooth tubes and finned tubes used in heat exchangers.

The heat exchanger in question is a shell-tube one. The steam/air mixture flows in shell side releasing its latent and sensible heat to refrigerant R114, which evaporates in tube side. The function of this heat exchanger is to simulate working conditions of an industrial dryer. The pressure in shell side is close to atmospheric pressure. Air plays a dominant role for the heat transfer coefficient and for heat to be recovered. The construction of this heat exchanger is given in Fig. 2. Considering its particularities, two special measures have been applied to this heat exchanger.

- Baffles have variable distance that allows the mixture to have a constant speed and improves the heat transfer coefficient.

- Two events ensure the condensate drain as it forms.

In fact, our case is more complex in comparison to the cases used by the investigators mentioned above : steam speed is not well known ; there is inundation influence ; air distribution is unknown. Theoretical and experimental studies are necessary in order to know exactly the heat transfer phenomenon in this heat exchanger. The modelisation is one part of this study.

3 - MODELISATION

The steam/air mixture flow rate inside the heat exchanger is considerable, this fact allows us to assume that the characteristics of steam/air mixture on each cross section of heat exchanger are identical. In contrast, the construction of two passes of refrigerant R114 side imposes a great difference on heat transfer and the calculation is then made separately.

The calculation begins at the entrance of the steam/air mixture whose characteristics are known, those of R114 at the entrance are also known but an estimated value for output temperature of R114 is needed to start the calculation. The calculation is based on a temperature interval which corresponds to a thermal power and a heat transfer surface. The calculation ends when there is equality of calculated and given surface. If vapour quality is not the same on two passes at the end of calculation, the calculation is repeated by changing the estimated temperature. The general block diagram of calculation is given in Fig. 4.

4 - ANALYSIS OF CALCULATED RESULTS AND DISCUSSIONS

Fig. 5 shows variation of the heat transfer coefficient along the heat exchanger. The heat transfer coefficient in tube side varies from 580 $W/m^2°C$ to 6000 $W/m^2°C$, this is due to important variations of steam percentage in the steam/air mixture. In fact, it is 70 % at the entrance and only 12 % at the exit. As stated above, the air variation takes place only along the heat exchanger, the heat transfer coefficient is symmetrical on two passes. As for R114, it is a function of vapour quality. The curve is relatively flat near the steam/air mixture exit because of low thermal flux.

The Fig. 6 shows variations of global heat transfer coefficient as a function of percentage of steam. The importance of air is confirmed. Furthermore, the influence of vapour quality can be seen. A high vapour quality ensures a better heat transfer coefficient at the entrance. This increases the global heat transfer coefficient because heat transfer coefficients in the two sides have similar values. But this is not the case at the exit of the heat exchanger as the heat transfer coefficient in the shell side diminishes which decreases the global value.

As for the influence of air quantity, this is shown in Fig. 7. If other conditions are identical, a small quantity of air allows for a high drew point on which the partial pressure depends. This pressure determines heat transfer. It should be indicated that R114 characteristics at the outlet are different in these two cases.

The R114 flow rate also plays a role for the heat transfer coefficient. This can be seen from Fig. 8. In the case of a small air percentage, the difference remains minimal. This difference appears progressively with the increase of steam quality.

Fig. 9 shows a comparison between calculated and measured evaporator power. The air percentage of mass varies from 7,5 % to 26 % in the conditions tested. As one can confirm from this figure, the calculated values agree well with the measured ones. The maximum error is only 10 %. The instruments equiped on this heat exchanger do not allow us to compare the calculated and measured local heat transfer coefficient.

5 - CONCLUSION

This model allows simulation of heat transfer phenomena of the R114 evaporator in the high temperature heat pump. The influences of different parameters can be estimated by this model.

Among the parameters studied, air percentage in the wist is the most important for heat transfer.

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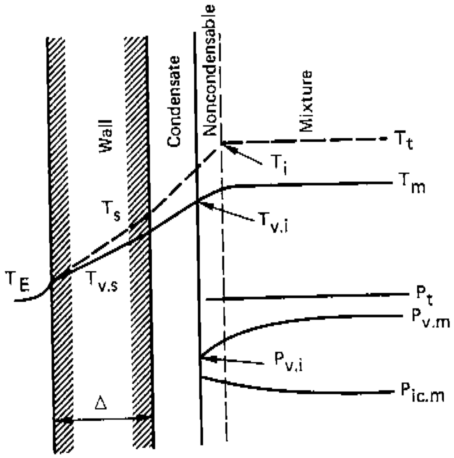


Fig. 1 – Condensation in presence of noncondensable

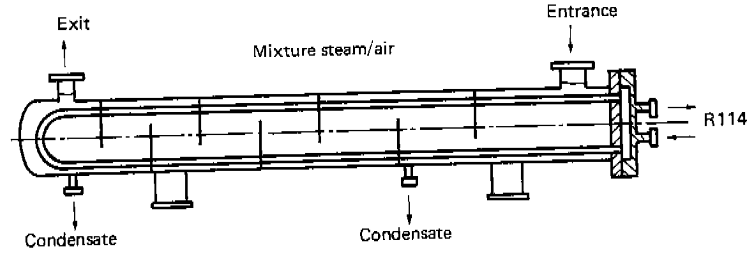


Fig. 2 – Construction of the heat exchanger

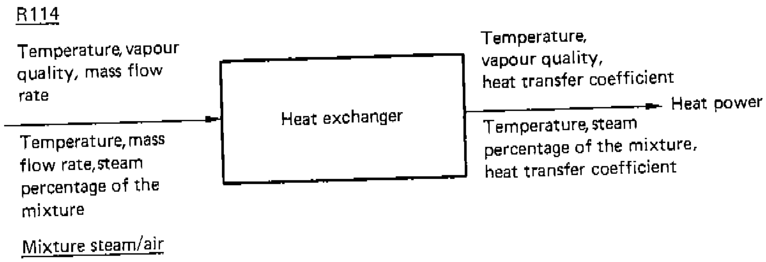


Fig. 3 – Parameters of heat exchanger model

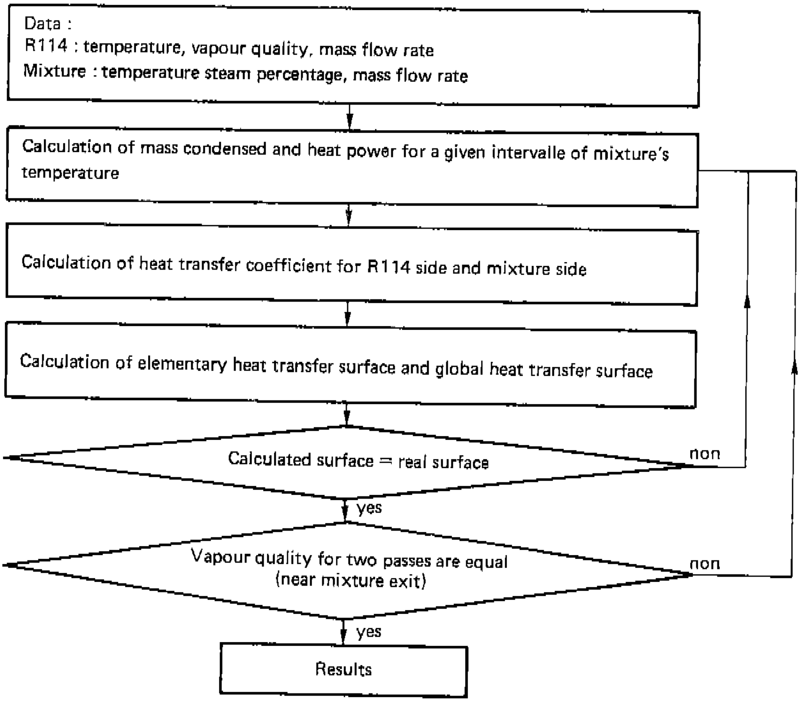


Fig. 4 – Calculation diagram

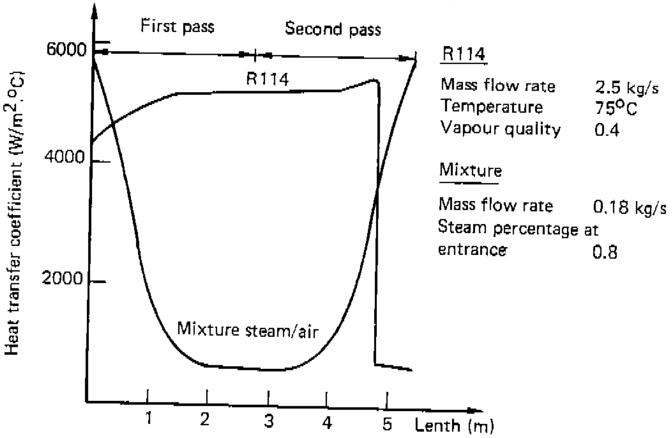
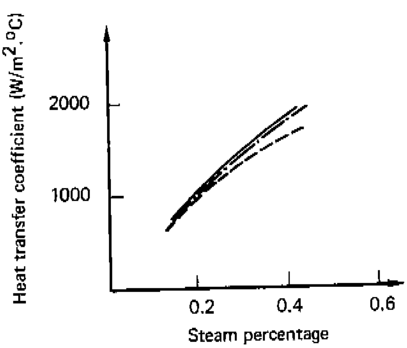


Fig. 5 – Evolution of heat transfer coefficient as a function of heat exchanger lenth

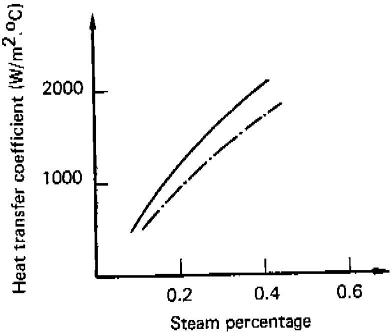


R114 mass flow rate	2 kg/s
Mixture mass flow rate	0.12 kg/s
Steam percentage at entrance	0.3

R114 vapour quality at entrance

—— 0.4
—·— 0.3
---- 0.1

Fig. 6 – Evolution of heat transfer coefficient as a function of steam percentage

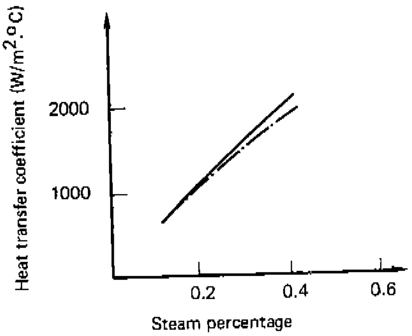


R114 mass flow	2 kg/s
R114 vapour quality at entrance	0.3
Evaporation temperature	75°C
Mixture mass flow	0.12 kg/s

Steam percentage at entrance

—·— 0,7
—— 0,8

Fig. 7 – Evolution of heat transfer coefficient as a function of steam percentage



R114 evaporation temperature	75°C
R114 vapour quality at entrance	0.4
Mixture mass flow rate	0.12 kg/s
Steam percentage at entrance	0.7

R114 mass flow rate

—— 2.5 kg/s
—·— 2.0 kg/s

Fig. 8 – Evolution of heat transfer coefficient as a function of steam percentage.

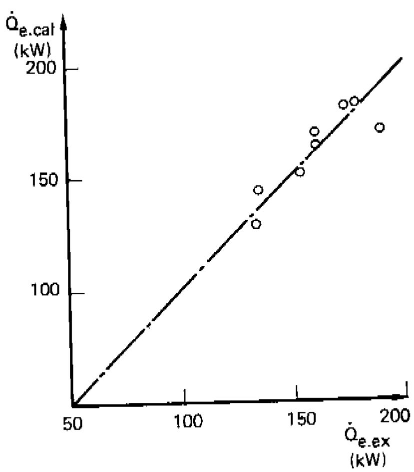


Fig. 9 – Comparison of calculated and mesured R114 evaporation power