1986

Some Practical Results Obtained with Non-Azeotropic Mixtures of Refrigerants in High Temperature Heat Pumps

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1. INTRODUCTION

Using non-azeotropic mixtures of refrigerants in heat pumps is the result of a triple need:

- getting a coefficient of performance (C.O.P.) as high as possible,
- to have a condensing pressure as low as possible,
- allowing a capacity control as good as possible.

Many theoretical studies were and can be done on this subject, but very few experimental results are available. Our study deals with some practical aspects of this problem. We tried to answer to two main questions:

- what is the influence of the mixture composition on thermal and mechanical powers of a heat pump,
- what is about the influence of leakages?

After a short recalling of non-azeotropic mixtures properties, we describe our test installation and present our results.

2. PROPERTIES OF NON-AZEOTROPIC MIXTURES

These mixtures have their boiling and condensing curves distincts at the same pressure (Fig. 1).

![Figure 1 - Non-azeotropic mixture curve.](image-url)
So, the composition and the temperature of the mixture are varying during the ebullition (e + f) and in the same way during the condensation (f + e). It is one of the interest of non-azeotropic mixtures.

3. TEST INSTALLATIONS

Experiments were carried out on a high temperature heat pump. It is equipped with a reciprocating compressor powered by an electric motor which can allow variable speed. We briefly describe the various components of our installation.

**Compressor:**

It is an open type piston compressor the swept volume of which is 223 m³/h at 1450 r.p.m.

**Oil separator:**

The installation includes an oil separator placed on the discharge of the compressor.

**Condenser:**

It is a multitubular horizontal heat exchanger. The water circulates inside tubes in two channels, the refrigerant is condensed outside tubes. The area of the condensing surface is equal to 20 m².

**Evaporator:**

It is a multitubular horizontal heat exchanger. The refrigerant is vaporized outside tubes and the water circulates inside tubes in two channels: flooded evaporator. The area of the evaporating surface can vary up to 96 m².

**Expansion valve:**

It is a float type expansion valve operated by changes in liquid level on the low pressure side.

4. INVESTIGATION METHODS

In order to obtain condensing temperatures between 60°C and 120°C, range which is very interesting for industrial applications of heat pumps, we used a R12-R114 mixture.

Tests began with an initial load of the heat pump with pure R114, so that we had a reference in high temperature. With this fluid, two different points were obtained at two different condensing pressures (*).

Then we added up R12 in order to obtain a molar concentration of 30 % of R12 at first, then a molar concentration of 50 % of R12 and finally 75 % of R12. Operating conditions are summarized in the following table (table I).

(*) As the aim of a heat pump is to produce hot water or hot air, we regulate pressures of condensation and evaporation in order to obtain a given outlet temperature of water or air. So, what we named, during this item, condensing or evaporating temperatures correspond in fact at temperatures of the mixture at outlets of the condenser and of the evaporator.

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TABLE 1 – OPERATING CONDITIONS.

<table>
<thead>
<tr>
<th>Molar concentration R12</th>
<th>100%</th>
<th>75%</th>
<th>50%</th>
<th>30%</th>
<th>0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;ev&lt;/sub&gt; / T&lt;sub&gt;cond&lt;/sub&gt;</td>
<td>15°C/65°C</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30°C/80°C</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>60°C/110°C</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

For each different operating points, we recorded a lot of measurements and those which are presented in this item are the most representative ones.

5. EXPERIMENTAL RESULTS

5.1. Influence of the composition on the performances of the heat pump

From table 1, we can see that for conditions 30°C/80°C respectively evaporating and condensing temperatures as defined previously, we can explore all the different compositions of mixtures from pure R12 to pure R114.

Thermodynamic values which can help us to compare experimental results are: condensing, evaporating, mechanical powers, efficiencies of the compressor, C.O.P. The following table (table II) gathers main results obtained.

TABLE II – EXPERIMENTAL RESULTS.

<table>
<thead>
<tr>
<th>Molar concentration R12</th>
<th>100%</th>
<th>75%</th>
<th>50%</th>
<th>30%</th>
<th>0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suction T&lt;sub&gt;oc&lt;/sub&gt; °C</td>
<td>30,5</td>
<td>44,8</td>
<td>45,3</td>
<td>37,3</td>
<td>40,7</td>
</tr>
<tr>
<td>P b.a</td>
<td>6,61</td>
<td>5,18</td>
<td>4,08</td>
<td>3,49</td>
<td>2,54</td>
</tr>
<tr>
<td>Discharge T&lt;sub&gt;oc&lt;/sub&gt; °C</td>
<td>102,8</td>
<td>115,1</td>
<td>111,4</td>
<td>99,5</td>
<td>93,8</td>
</tr>
<tr>
<td>P b.a</td>
<td>23,5</td>
<td>21</td>
<td>17,6</td>
<td>15,2</td>
<td>10,2</td>
</tr>
<tr>
<td>Condensation T&lt;sub&gt;oc&lt;/sub&gt; °C</td>
<td>79</td>
<td>81,7</td>
<td>81,7</td>
<td>83,9</td>
<td>80,1</td>
</tr>
<tr>
<td>P b.a</td>
<td>22,7</td>
<td>20,3</td>
<td>16,9</td>
<td>14,6</td>
<td>9,46</td>
</tr>
<tr>
<td>Evaporation T&lt;sub&gt;oc&lt;/sub&gt; °C</td>
<td>28,5</td>
<td>30,7</td>
<td>32,1</td>
<td>35,5</td>
<td>34</td>
</tr>
<tr>
<td>P b.a</td>
<td>7,15</td>
<td>5,47</td>
<td>4,39</td>
<td>3,85</td>
<td>2,91</td>
</tr>
<tr>
<td>Mass Flow Rate kg/s</td>
<td>1,59</td>
<td>1,056</td>
<td>1,038</td>
<td>1,04</td>
<td>0,87</td>
</tr>
<tr>
<td>Pressure ratio</td>
<td></td>
<td>3,55</td>
<td>4,05</td>
<td>4,31</td>
<td>4,36</td>
</tr>
<tr>
<td>Volumetric efficiency %</td>
<td>70,4</td>
<td>72</td>
<td>70</td>
<td>71</td>
<td>78</td>
</tr>
<tr>
<td>Isentropic efficiency %</td>
<td>69</td>
<td>74</td>
<td>72</td>
<td>70</td>
<td>63</td>
</tr>
<tr>
<td>Condensing Power kW</td>
<td>186</td>
<td>157</td>
<td>127</td>
<td>109</td>
<td>95</td>
</tr>
<tr>
<td>Evaporating Power kW</td>
<td>158</td>
<td>118,5</td>
<td>95</td>
<td>81</td>
<td>73</td>
</tr>
<tr>
<td>Mechanical Power kW</td>
<td>52,8</td>
<td>44,8</td>
<td>35,7</td>
<td>31,7</td>
<td>26,9</td>
</tr>
<tr>
<td>C.O.P.</td>
<td>3,52</td>
<td>3,60</td>
<td>3,56</td>
<td>3,43</td>
<td>3,53</td>
</tr>
</tbody>
</table>
Several informations can be get out from this table. The first one is that it is possible to obtain a large range of variation of thermal and mechanical powers by making vary the composition of the mixture. That means, with the same heat pump, working at the same temperature conditions, the thermal power can vary from 1 to two with the same value of the C.O.P. Applications of this property can be found. For instance, if we are able to make vary continuously the composition of the mixture, during working, we can adapt the power of the heat pump according to needs. We can also, for fixed operating conditions, choose the best mixture which will give the best working point: a fluid made to measure.

The second information obtained is that, with a standard heat pump (not specially built for using non-azeotropic mixtures), the coefficient of performance is not affected by changing the composition of the mixture. For our operating conditions, all values of C.O.P. are close to 3.5. We do not observe an increase of the value of the C.O.P. This fact is due to our heat exchangers which are not pure counterflow but cross-flow heat exchangers. Furthermore the difference between inlet and outlet water temperatures is small (≈ 5°C). These two facts prevent us from observing any theoretical increase of the C.O.P., due to the decrease of non-reversibilities in heat exchangers.

5.2. Influence of leakages

Many authors wrote about the influence of leakages on the composition of non-azeotropic mixtures of refrigerants, but no experimental result has been published until now.

Indeed, when a leakage appears in a heat pump using a non-azeotropic mixture, what the initial composition and performances become?

In order to answer to this important question, we made three experiments on this subject. We created leakages and looked after the evolution of the mixture.

For each experiment, we introduced the same initial load into the heat pump (≈ 1000 kg), then we created a leakage respectively at the condenser (high pressure, gas phase), at the receiver (high pressure, liquid phase) and at the flooded-type evaporator (low pressure, liquid and gas phase). Each leakage lasted several days and each time the total loss of the mixture was important. The following table gathers data and results (table III).

<table>
<thead>
<tr>
<th>TABLE III - INFLUENCE OF LEAKAGES.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leakage at the</td>
</tr>
<tr>
<td>condenser.</td>
</tr>
<tr>
<td>Initial load of mixture kg</td>
</tr>
<tr>
<td>Final load of mixture kg</td>
</tr>
<tr>
<td>Initial composition in R12 %</td>
</tr>
<tr>
<td>Final composition in R12 %</td>
</tr>
</tbody>
</table>

The more interesting result is that leakages have no influence on the composition of a non-azeotropic mixture, even large leakages (more than 30 % of the initial load), and everywhere the leakage occurs: high pressure, low pressure, liquid or and gas phase.
6. CONCLUSION

We can conclude from our tests that using a non-azeotropic mixture in an industrial heat pump, not built for this aim, is possible. The C.O.P. value does not decrease or increase for different compositions of the mixture (for same sink and source temperatures). The thermal power varies as predicted. Then we demonstrated experimentally that leakages have no influence on the composition of a mixture what is very reassuring for future industrial applications.

QUELQUES RESULTATS PRATIQUES OBTENUS SUR DES MÉLANGES NON-AZEOTROPIQUES DANS UNE POMPE À CHALEUR À HAUTE TEMPÉRATURE.

RESUME : Il est maintenant admis que les mélanges non-azeotropiques dans les pompes à chaleur peuvent apporter des performances intéressantes. Malheureusement peu d'expériences dans ce domaine ont été faites. Cet article apporte quelques résultats pratiques dans ce domaine. Tout d'abord nous avons vérifié expérimentalement les performances thermodynamiques de différentes compositions d'un mélange R12-R114. Nous avons noté entre le R12 pur et le R114 pur des rapports de puissance thermique et de puissance mécanique correspondant à ce qui était prévu. Par ailleurs, la valeur du C.O.P. n'a pas été améliorée mais ce fait est dû aux types d'échangeurs que nous avons utilisés. Enfin le résultat le plus important montre que des fuites importantes et en divers endroits du circuit frigorifique ne modifient pas sensiblement la composition du mélange.

SOME PRACTICAL RESULTS OBTAINED ON NON-AZEOTROPIC MIXTURES IN A HIGH-TEMPERATURE HEAT PUMP

SUMMARY

It is now admitted that non-azeotropic mixtures in heat pumps can give interesting results. Unfortunately, few experiences have already been made in this field. This article brings some practical results in this field. First, we tested experimentally thermodynamic performances of different compositions of the mixture R12-R114. We found that between R12 substance and the pure R114, the ratios of thermic power and the pure mechanical power corresponded with what had been expected. Furthermore, the value of the C.O.P. was not improved, but this is due to the types of exchangers used. Eventually, the main result shows that important leaks in many places of the refrigerant system do not change dramatically the composition of the mixture.