NUMERICAL AND EXPERIMENTAL ANALYSIS OF THE MV3T REFRIGERANT

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Abstract. This paper shows a modelling study for mixture MV3T used in an air-water heat pump refrigeration system. The paper has focused on theoretical and experimental data for validation purposes, using ClimaCheck software. Mathematical simulations were done with the EES software. After experimental and mathematical analysis, very good results were obtained for this mixture and thus we validated the cooling capacity and COP. Regarding F-Gas Regulation the optimum alternative for this application is MV3T.

Keywords: refrigerant mixture, heat pump, ecological, COP, GWP.

1. Introduction

At an international level, according to the new legislative Regulations \cite{1}, ecological alternatives for refrigerants must be found in order to decrease the global warming potential (GWP).

The refrigerant mixture MV3T is proposed in this validation of mathematical and experimental modelling.

The paper also shows a possible retrofit solution for R134a currently used in heat-pump refrigeration systems \cite{5,7} with low GWP in accordance with EU Regulations.

In table 1 some properties of the new refrigerant mixture are presented \cite{6}.

\textbf{Table 1}

\begin{tabular}{|c|c|}
\hline
Refrigerant & MV3T \\
\hline
Critical temperature [°C] & 98.06 \\
Critical density [kg/m\textsuperscript{3}] & 493.06 \\
Molar mass [kg/kmol] & 108 \\
\hline
\end{tabular}

It is necessary to replace HFC \cite{1} with zero ODP and low GWP refrigerant and such an example is MV3T.
1.1. The operating mode of the air-water equipment.

The equipment uses the ambient air to heat water. Air is drawn in at the top with the help of a fan, led to the evaporator unit and blown out again sideways. It is called an evaporator because the refrigerant in the heat pump circulation evaporates in it.

During evaporation, heat is extracted from the drawn in ambient air, as this is warmer than the medium in the evaporator [8,9]. Even at relatively low temperatures (down to 6°C or -10°C) heat can still take out of the air.

The working fluid is compressed by the compressor and brought up to a higher temperature level. This heat is transferred to the drinking water by the helical tube condenser built into the double casing of the reservoir.

The cooled medium, that is now liquid again, is expanded via the expansion valve, returns to the evaporator and thus is again ready to take up heat.

2. Mathematical model

This chapter focuses on the mathematical modelling of the thermodynamic processes for the air-water heat pump which works with MV3T. The pages describe the parameters of the model [3].

Introduced parameters in the model: evaporating pressure, condensing pressure, external air temperature (T_amb), water temperature inlet and outlet of the condenser, air temperature inlet and outlet evaporator, refrigerant temperature inlet and outlet evaporator, refrigerant temperature inlet and outlet compressor, electrical input, wet bubble air temperature (T_aer_wb) and mass flow for water and condenser (V_dot_water_cd), mass flow air evaporator (V_dot_air_ev) and water specific heat content (c_p_w).

After the mathematical models calculation [10] the resulted parameters are: evaporator and compressor refrigerant mass flow (M_dot_r_ev, M_dot_r_cp), volumetric ratio (ε_cp_v), isentropic ratio (ε_cp), adiabatic ratio (ε_cp_adiab), compression ratio (r_p), the global coefficient of heat transfer (condenser-AU_cd and evaporator AU_ev), performance coefficient for cooling (COP_cool) and heating (COP_heat), condenser (ε_cd) and evaporator ratio (ε_ev), evaporator and condenser number of thermal units (NTU_ev), (NTU_cd), cooling power (Q_dot_ev), condenser thermal power (Q_dot_cd), compressor volumetric ratio (r_v), condenser water thermal power (Q_w_cd), air cooling thermal power (Q_dot_air_ev).

Mathematical model equations for refrigeration system are:
"Condenser"
"Refrigerant"
\[
\text{DELTAT}_r_{\text{ex cd}} = \text{T}_{r_{\text{sat ex cd}}} - \text{T}_{r_{\text{ex cd}}} \quad (1)
\]

"Evaporator"

"Refrigerant"

\[
\text{DELTAT}_r_{\text{ex ev}} = \text{T}_{r_{\text{ex ev}}} - \text{T}_{r_{\text{sat ex ev}}} \quad (2)
\]

"Air"

\[
\text{T}_{\text{dewpoint air}} = 13 + 273.15 \quad (3)
\]

\[
\text{T}_{\text{amb}} = \text{T}_{\text{air su ev}} \quad (4)
\]

\[
c_{p_{\text{air}}} = \text{cp(AirH2O, } T = \text{T}_{\text{air su ev}}, D = \text{T}_{\text{dewpoint air}}, P = 101.325) \quad (5)
\]

\[
\text{Q}_{\text{dot air ev}} = \frac{\text{V}_{\text{dot air ev}}}{\text{V}_{\text{air su ev}} \cdot c_{p_{\text{air}}} \cdot (\text{T}_{\text{air ex ev}} - \text{T}_{\text{air su ev}})} \quad (6)
\]

\[
\text{V}_{\text{air su ev}} = \text{Volume(AirH2O, } T = \text{T}_{\text{air su ev}}, D = \text{T}_{\text{dewpoint air}}, P = 101.325) \quad (7)
\]

"Compressor"

\[
\text{M}_{\text{dot r cp}} = \text{M}_{\text{dot r cd}} \quad (8)
\]

\[
\text{M}_{\text{dot r cp}} = \text{M}_{\text{dot r ev}} \quad (9)
\]

\[
\text{T}_{r_{\text{sat su cp}}} = \text{T}_{r_{\text{sat ex ev}}} \quad (10)
\]

\[
\text{M}_{\text{dot r cp}} \cdot \text{h}_{r_{\text{su cp}}} + \text{W}_{\text{dot cp}} - \text{Q}_{\text{dot amb cp}} = \text{M}_{\text{dot r cp}} \cdot \text{h}_{r_{\text{ex cp}}} \quad (11)
\]

\[
\text{V}_{\text{dot s cp}} = 0.00001528 \quad (12)
\]

\[
\text{M}_{\text{dot r cp}} = \frac{\text{V}_{\text{dot s cp}}}{\text{v}_{r_{\text{su cp}}} \cdot 2900/60} \quad (13)
\]

"AU condenser calculation"

\[
c_{p_{w}} = 4.185 \quad (14)
\]

\[
\text{Q}_{\text{dot cd}} = \text{AU}_{cd} \cdot (\text{T}_{\text{cd mean}} - \text{T}_{w_{\text{su cd}}}) \quad (15)
\]

\[
\text{epsilon}_{cd} = 1 - \exp(-\text{NTU}_{cd}) \quad (16)
\]

\[
\text{NTU}_{cd} = \frac{\text{AU}_{cd}}{c_{dotw_{cd}}} \quad (17)
\]

" AU evaporator calculation"

\[
\text{Q}_{\text{dot ev}} = \text{AU}_{ev} \cdot (\text{T}_{\text{ev mean}} - \text{T}_{\text{air ex ev}}) \quad (18)
\]

\[
\text{C}_{\text{dot air ev}} = \frac{\text{V}_{\text{dot air ev}}}{\text{v}_{\text{air su ev}}} \cdot c_{p_{\text{air}}} \quad (19)
\]

\[
\text{epsilon}_{ev} = 1 - \exp(-\text{NTU}_{ev}) \quad (20)
\]
\[ \text{NTU}_{ev} = \frac{AU_{ev}}{C_{dot\text{air}ev}} \]  \hspace{1cm} (21)

\[ h_{w\_su\_cd} = \text{Enthalpy (Water, } P = 250, T = T_{w\_su\_cd}) \]  \hspace{1cm} (22)

\[ h_{w\_ex\_cd} = \text{Enthalpy (Water, } P = 250, T = T_{w\_ex\_cd}) \]  \hspace{1cm} (23)

"Coefficient of Performance"

\[ \text{COP}_{\text{heat}} = \frac{Q_{dot\_cd}}{W_{dotcp}} \]  \hspace{1cm} (24)

\[ \text{COP}_{\text{cool}} = \frac{Q_{dot\_ev}}{W_{dotcp}} \]  \hspace{1cm} (25)

"Equilibrium equation"

\[ //Q_{dot\_cd} = W_{dotcp} + Q_{dot\_ev} \]  \hspace{1cm} (26)

\[ Q_{w\_cd} + Q_{dot\_amb\_cp} + Q_{dot\_air\_ev} = Q_{dot\_cd} + Q_{dot\_ev} - W_{dotcp} + Q_{dot\_cp} \]  \hspace{1cm} (27)

Figure 1 presents the Climacheck interface of the mathematical model [4] [11].
3. Experimental data

Figures 3 and 4 show the preliminary performance coefficients (COP) for heating and cooling, experimental data before the heat pump gets into the stability regime.

The acquisition of experimental data, when the system enters into operation (Figure 2) was done with the Climacheck software [4].
Figure 4 shows the cooling COP versus cooling capacity [3]. One can observe the increase of COP with the increase of cooling capacity.

![Fig. 4 - Cooling COP versus cooling capacity](image)

Figure 5 presents the normal evolution of COP for cooling and heating in comparison with the compression ratio [3].

![Fig. 5 - Cooling and Heating COP versus compression ratio](image)
Figures 6 and 7 showcase the validation between experimental (measured) and mathematical models (4% accepted technical error).
4. Conclusions and validation

In accordance with the international legislations, the optimum alternative for this application, regarding GWP is refrigerant mixture MV3T.

As an example (Figure 6), the heating and cooling COP (cold, hot) is shown here below (experimental measurement versus calculations for MV3T air-water heat pump).

In this study, experimental and mathematical analyses led to very good results for this mixture and the cooling capacity and COP were validated (Figure 6 and Figure 7).

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