Experimental Investigation of the Enthalpy of Isobutane−Compressor Oil Solutions

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This paper reports new experimental data for the specific enthalpy of the solution of isobutane (refrigerant R600a, $CH(CH_3)_2-CH_3$, CAS Registry No. 75-28-5) with mineral naphthenic compressor oil WF 15A. The experimental data were obtained in the temperature range from (273 to 355) K by a mixing method realized in an ice calorimeter. The behavior of the temperature and weight fraction dependencies of the enthalpy for the refrigerant−oil solution (ROS) of R600a and mineral compressor oil WF 15A have been examined.

Introduction

Refrigerant R600a (isobutane, $CH(CH_3)_2-CH_3$, CAS Registry No. 75-28-5) is a replacement for ozone depleting substances, which have a high impact on the environment. Isobutane has zero ozone depletion potential and a negligible value for the global warming potential. The refrigerant R600a has been in use in the past and has now again found a wide use in the domestic refrigerators and freezers in Europe. The mineral compressor oil WF series is used to lubricate small hermetically sealed compressors, in refrigerators, especially those operating with the refrigerant R600a. That is why correct information on thermal and caloric properties of the refrigerant−oil solution (ROS) which circulates in the refrigerant system has considerable scientific and industrial interest.[1−8]

Despite numerous investigations (see reviews of Youbi-Idrissi and Bonjour,[6] Marsh and Kandil,[7] and Mermond et al.[8]), a proper choice of the compressor oils for certain refrigerants is complicated and an important industrial problem. To the best of our knowledge, experimental data on caloric properties of the compressor oils and ROS's are still absent in existing literature. We found only one paper, of Maogang et al.,[9] where the specific heat capacity at constant pressure and the specific heat capacity at constant volume of the 1,1,1,2-tetrafluoroethane (R134a) refrigerant−oil mixtures in the saturated liquid phase were measured when the lubricant concentrations were equal to (20, 50, 80, and 100) ppm. In addition, methods for the calculation of the compressor oil enthalpy described in Mermond et al.[8] and Youbi-Idrissi et al.[10] do not respond to demands which are necessary for correct modeling of the thermodynamic properties of the ROS. That is why obtaining information on thermal properties of the ROS has a considerable scientific and practical interest, especially for cases when the investigated system is widely used in refrigeration industry. A solution of isobutane (refrigerant R600a) with mineral compressor oil WF 15A is precisely such a system. The real working fluid R600a-WF 15 is widely used in a new generation of domestic refrigerators. Therefore, our paper is dedicated to the experimental investigation of the enthalpy for the real working fluid R600a-WF 15A.

Experimental Section

For the experimental investigation of the enthalpy for the ROS, an experimental setup has been designed and constructed. The apparatus gauges the heat released during the melting of a compound by measuring the increase in volume of the surrounding ice−water solution caused by the melting of the ice. In the literature this type of calorimeter is well-known as a Bunsen calorimeter.[11] This method for investigation of the enthalpy gives high accuracy for the experimental data obtained, being reliable and relatively simple. The sketch of the experimental setup is shown in Figure 1.

The experimental setup is based on a container with investigated fluid, 4; a massive copper thermostat, 12; a calorimetric vessel, 2, filled with distilled water at a 0 °C temperature; a Dewar vessel with melting ice, 1; and a calibrated glass tube, 24, for measuring the mass of the melted ice preliminarily frozen on the copper cartridge 6. The experimental setup is provided by a vacuum system, which consists of the forevacuum, 30; diffusion, 29, pumps; cryogenic trap, 28; and ionization, 26 and 31, and thermocouple, 27, manometric transmitters. The container, 4, was made from copper. In the upper part of the container, 4, the capillary is disposed. The components of the investigated solution are pumped through this capillary. The volume of the container was precisely defined based on the calibration experiment and is equal to 23.715 cm^3.

On the external surface of the massive thermostat the coil is placed. Through the coil the heat-transfer liquid with constant temperature is pumped from the subsidiary thermostat (water cooler), 15. The temperature of the massive copper thermostat, 12, and, respectively, the temperature of the container, 4, are measured with a platinum resistance thermometer (type PRT 100) 14. The uncertainty in determining the temperature in the thermostat can be estimated as ± 0.02 K. Consistency of the temperature for the container, 4, and the thermostat, 12, is controlled by the differential thermocouple, which indication is measured using the millivoltmeter, 17 (type F-136). One of the joints of the differential thermocouple was fastened on the surface of the container. Another joint of the thermocouple was fastened in the thermometric pocket of the Dewar vessel, 8,

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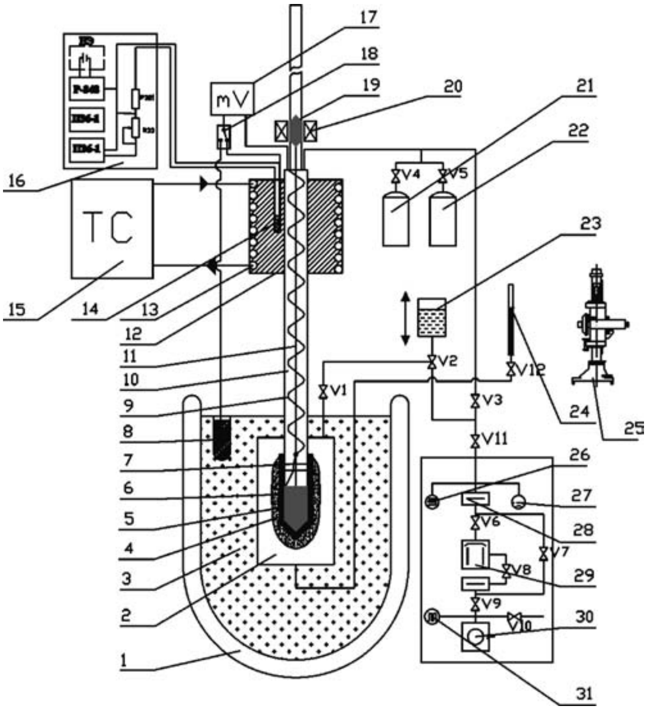

Figure 1. Scheme of the experimental setup: 1, Dewar vessel; 2, calorimetric vessel with a distilled water; 3, water/ice mixture; 4, container; 5, ice; 6, copper cartridge; 7, screens; 8, thermometric pocket; 9, spring; 10, tube; 11, thread of the suspension; 12, copper block; 13, coil; 14, the platinum resistance thermometer; 15, thermostat; 16, temperature-measuring system; 17, millivoltmeter; 18, position switch of the differential thermocouple; 19, ferromagnetic core; 20, constant magnet; 21, balloon with the refrigerant R134a; 22, balloon with the helium; 23, measured vessel with the distilled water; 24, calibrated glass tube; 25, cathetometer; 26 and 31, thermocouple reformer; 27, ionization reformer; 28, vacuum trap; 29, diffusion pump; 30, forvacuum pump.

and the copper thermostat. The presence of the differential thermocouple provides control for the heating process of the container in the thermostat, 12, and its cooling in the calorimetric vessel, 2. To exclude possible bends and ruptures of the differential thermocouple at the lifting and lowering of the container in the tube, 10, the thermoelectrodes is laid along the spring, 9.

The massive thermostat, 12, is connected with the calorimetric vessel, 2, by the thin-walled nonrusting pipe, 10. At the lower part of the tube the massive copper cartridge, 6, is installed. Through massive copper cartridge, 6, an intensive and steady heat abstraction from the container with investigated solution to the melting ice, 5, is supplied. Frosting of the ice, 5, on the external surface of the copper cartridge, 6, is realized by boiling-off the necessary quantity of the refrigerant R134a from the balloon, 21. The boiling-off of the R134a was provided by return condensation, and the R134a is cooled by the liquid nitrogen balloon, 21. The calorimetric vessel is filled by the distilled water and cleaned from the dissolved air as well as the measured vessel, 23.

The quantity of the melting ice is defined by changing the water level in the calibrated glass tube, 24 (diameter $D = 2.644 \pm 0.0025$ mm). Measuring the water meniscus levels in the calibrated tube during the experiment is realized by the cathetometer, 25 (KM-6), with an uncertainty of 0.015 mm. Removable balloons with refrigerant R134a (21) and helium (22) are connected to the vacuum line of the experimental setup. Gaseous helium is necessary for intensification of the heat exchange process between the thermostat, 12, and the container, 4, in the heating process.

Movement of the container, 4 (from the copper thermostat, 12, to the calorimetric vessel, 2, and backward), is realized with the help of the magnetic hanger, which consists from a ferromagnetic core, 19, and a constant magnet, 20. The ferromagnetic core is connected with the container by the thin silk thread, 11. To decrease heat losses to the environment from the container, 4, due to possible convection in the tube, 10, it is foreseen to evacuate air from the tube, 10, during the experiment.

Influences of the radiant heat exchange between the container and the massive thermostat, 12, is limited by two screens, 7, which are placed on the thread, 11, above the container, 4. Adiabatic conditions of the calorimetric experiment are supplied by maintenance of the zero temperature difference between the calorimetric vessel, 2, and melting ice, 5, in the Dewar vessel, 1.

To clean the investigated sample from water admixtures and permanent gases, the compressor oil was heated to $T = 388$ K, and then all admixtures and permanent gases were evacuated for 60 s. The cleaning procedure was repeated several times. The purity of mineral compressor oil WF 15A was checked by a universal laboratory refractometer IRF-23.

A defined mass of the cleaned compressor oil was added to the container, 4, and the container was weighed. In this way, the mass of oil in the container was determined since the mass of the empty container was known beforehand. After the container was closed, it was cooled by liquid nitrogen to the crystallization point of the compressor oil WF 15A, and then container was evacuated. The necessary concentration of the ROS was achieved by the addition of the isobutane from the filling balloon. The mass of isobutane was determined by the subsequent weighing of the container using an analytical balance ADV-200 M with an uncertainty of $5 \cdot 10^{-7}$ kg. The concentration of the liquid phase of the ROS can be determined by formulas:

$$w_{\mathrm{R}}/(\mathrm{kg} \cdot \mathrm{kg}^{-1}) = \frac{m_R - m_{\mathrm{R}}^{\mathrm{vap}}}{m_{\mathrm{R}} + m_{\mathrm{OIL}} - m_{\mathrm{R}}^{\mathrm{vap}}} \tag{1}$$

where m_{OIL} is the mass of oil added to the container, m_{R} is the mass of refrigerant added to the container, and $m_{\mathrm{R}}^{\mathrm{vap}}$ is the mass of the vapor phase of refrigerant in the container. The mass of the $m_{\mathrm{R}}^{\mathrm{vap}}$ was calculated from data obtained for the volume of vapor phase and from information on the density of superheated vapor for the isobutane at parameters of the experiment.[12] The volume for the vapor phase was defined as a difference between the entire volume of the container and the volume of the liquid phase for the ROS. The computation of the volume for the vapor phase was carried out within iteration calculation. For determination of the pressure in the container and volume of the liquid phase of the investigated sample, the data for the vapor pressure and density for the ROS R600a−WF 15A were used.[16] Achievement of thermodynamic equilibrium for the investigated ROS in the container, 4, may be observed from the temperature dependence obtained from the indication of the differential thermocouples. In other words, the indication of the differential thermocouples should be invariable in time.

Thermostatting the container with the ROS sample was performed in the massive thermostat, 12. For decreasing the transition time for specific temperatures at the container, the tube, 10, was filled by the gaseous helium from the balloon, 22, with the opened valve V5. Control over temperature change in the thermostat, 12, and container, 4, is performed using the resistance thermometer, 14, and the differential thermocouple.

Experiments by definition of the caloric properties for the compressor oil and ROS were taken at the different temperatures and practically constant mass concentration for the investigated sample in the measuring cell. A performed calculation shows that changing the concentration of the liquid phase for the ROS did not exceed 3 % (at low concentration of the refrigerant). Thermodynamic equilibrium criteria in the experiment were the following: constant temperature values at the thermostat, 12; constant temperature difference between the container, 4, and copper bloc of the thermostat, 12; and constant changing by time of the water level in the calibrated glass tube, 24, which is caused by unrequited heat losses in the experiment. After achievement of the thermodynamic equilibrium, the container, 4, moved down to the calorimetric vessel, 2. After that, the heat supply from the container to the copper cartridge was initiated. It led to the melting of the preliminarily frozen ice and, correspondingly, changing the level of liquid in the calibrated tube, 24. Then, level differences were measured.

The quantity of the heat received by melting ice at the experiment in the calorimetric vessel can be calculated by the equation:

$$Q/(\mathrm{kJ}) = \lambda\,\Delta m \tag{2}$$

where λ is the melting heat of the ice[11] and Δm is the mass of the melting ice, which is calculated by the equation:

$$\Delta m/(\mathrm{kg}) = \frac{\Delta V}{v_{\mathrm{ice}} - v_{\mathrm{W}}} \tag{3}$$

where v_{W} is a specific volume of the water at 0 °C and v_{ice} is a specific volume of the ice at 0 °C. The volume of the melted ice, ΔL, is defined by the difference in the water meniscus level in the calibrated glass tube during the experiment.

The quantity of the heat given from the ROS investigated sample to the melting ice at the experiment process, $Q_{\mathrm{ROS}}(T)$, is defined by the equation:

$$Q_{\mathrm{ROS}}(T)/(\mathrm{kJ}) = Q(\tau) - Q_{\mathrm{HI}} - Q_{\mathrm{A}} - Q_{C_p}^{\mathrm{vap}} - Q_{\mathrm{r}}^{\mathrm{vap}} \tag{4}$$

where $Q(\tau)$ is the heat quantity received by the calorimetric system during the experiment, Q_{HI} is the heat quantity brought in the calorimetric system as a result of the heat inflow, Q_{A} is the heat quantity received by melting ice from cooling the empty calorimeter and defined at the calibration experiment, $Q_{C_p}^{\mathrm{vap}}$ is the heat quantity received from cooling the vapor phase of the ROS, and $Q_{\mathrm{r}}^{\mathrm{vap}}$ is a heat quantity received at the condensing process of the refrigerant from the ROS vapor phase. Performed calculations show that total value of the $Q_{C_p}^{\mathrm{vap}}$ and $Q_{\mathrm{r}}^{\mathrm{vap}}$ does not exceed 4 % from the value of $Q_{\mathrm{ROS}}(T)$. In addition, absolute uncertainty in the determination of $Q_{\mathrm{ROS}}(T)$ does not exceed (3 to 5) J.

Value of the specific enthalpy for investigated sample of the ROS, $H'_{\mathrm{ROS}}(T)$, is defined by equation:

$$H'_{\mathrm{ROS}}(T)/(\mathrm{kJ}) = Q_{\mathrm{ROS}}(T)/m + H_{0\mathrm{C}} \tag{5}$$

where m is the average mass value (in the course of the experiment) of the ROS liquid phase and $H_{0\mathrm{C}}$ is the enthalpy value at a reference point. As reference point of the enthalpy, $H_{0\mathrm{C}}$ was taken as the state of the boiling liquid at 273.15 K. The enthalpy value at this point, according to McLinden et al.,[12] is equal to 200 kJ·kg^{-1}. The absolute uncertainty in the determination of the enthalpy of the ROS R600A-WF 15A can be estimated in the range from (0.6 to 0.7) kJ·kg^{-1}.

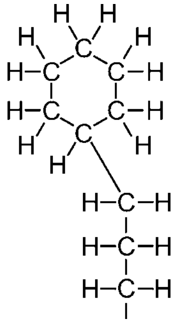

Figure 2. General formulas of refrigeration mineral compressor oils.[7]

The purity of the isobutane was 99.99 % (molar basis). The thermodynamic properties of the isobutane were taken from McLinden et al.[12] Mineral naphthen compressor oil WF 15A was produced by Fuchs Lubritech GMBH, Germany. General formulas of mineral napthenic compressor oils are reported in Marsh and Kandil[7] (Figure 2). The molecular weight of compressor oil WF 15A was experimentally defined by the ebullioscopic method and equal to 319 kg·kmol^{-1} (see Semenyuk et al).[13] The main chemical and thermodynamic properties such as the refractive index n, capillary constant a^2, density ρ, surface tension σ, and kinematic viscosity ν of the mineral compressor oil WF 15A are listed in Tables 1 and 2.[13]

Results and Discussion

The enthalpy of the ROS R600a−WF 15A was measured in the temperature range from (273.15 to 353.15) K. Experimental data obtained on the specific enthalpy for compressor oil WF 15A and R600a−WF15A are listed in the Table 3.

The experimental data obtained on the enthalpy for the ROS R600a−WF 15A was described by method reported in Ancherbak.[14] The proposed correlation for the temperature dependence of the ROS enthalpy is the following:

$$\ln(H'_{\mathrm{ROS}}) = \ln(H_{\mathrm{c,ROS}}) + H'_0\tau^{\beta\,F'_H(\tau)} \tag{6}$$

where H'_0 and β are coefficients, defined from the experimental data, H_{C} is the enthalpy value at critical point, $\tau = \ln(T_{\mathrm{C}}/T)$ is a reduced temperature, $F'_H(\tau)$ is a universal crossover function for the non-associated substances.

It should be pointed out that range of the reduced temperatures where the enthalpy of the compressor oil was investigated goes beyond the applicability of eq 6. Therefore, application of the universal crossover function in eq 6 is impossible. To save high extrapolation abilities for eq 6, we proposed to define the crossover function for the ROS by the equation:

$$F'_H(\tau) = F'_H(\tau)_{\mathrm{R}}w_{\mathrm{R}} + F'_H(\tau)_{\mathrm{OIL}}(1 - w_{\mathrm{R}}) \tag{7}$$

where $F'_H(\tau)_{\mathrm{OIL}}$ and $F'_H(\tau)_{\mathrm{R}}$ are individual crossover functions of the oil and the refrigerant, correspondingly, and w_{R} is the mass fraction of the refrigerant in the solution. The crossover functions were obtained by fitting the enthalpy data for the solution components.

Information for the enthalpy of the R600a was taken from the McLinden et al.[12] The thermodynamical properties of the compressor oil WF 15 are listed in the Table 2.[13]

Obtained equations for individual crossover functions for the components of the ROS R600a−WF 15A are the following:

$$F'(\tau)_{\mathrm{R}} = 1 + 9.62001\frac{\tau}{\ln(\tau)} - 15.5033\frac{\tau^{1.5}}{\ln(\tau)} + 10.1392\frac{\tau^2}{\ln(\tau)} - 0.909226\frac{\tau^3}{\ln(\tau)} \tag{8}$$

$$F'(\tau)_{\mathrm{OIL}} = 1 + 10.0044\frac{\tau}{\ln(\tau)} - 16.5664\frac{\tau^{1.5}}{\ln(\tau)} + 9.16386\frac{\tau^{2}}{\ln(\tau)} - 0.910842\frac{\tau^{3}}{\ln(\tau)} \quad (9)$$

The pseudocritical temperature for the ROS was obtained by method proposed in Zhelezny et al.[15] For calculation of the pseudocritical temperature for the ROS R600a−WF 15A, we proposed to use the following correlation:

$$\bar{T}_{\mathrm{C},L}/(\mathrm{K}) = (773 - 717.492x_{\mathrm{R}})(1 - 0.396439x_{\mathrm{R}} - 0.4674478{x_{\mathrm{R}}}^{2})^{-1} \quad (10)$$

where x_R is a molar fraction of the refrigerant.

In its turn, the concentration dependencies of the coefficients in eq 6 are fitted by correlations:

$$H_{\mathrm{C}}/(\mathrm{kJ\cdot kg^{-1}}) = (2480.3 + 10658w_{\mathrm{R}} - 7132.6{w_{\mathrm{R}}}^{2})(1 + 15.04w_{\mathrm{R}} - 13.29{w_{\mathrm{R}}}^{2} + 6.7676{w_{\mathrm{R}}}^{3})^{-1} \quad (11)$$

$$H'_0 = (0.9065 + 1.776w_{\mathrm{R}} + 1.263{w_{\mathrm{R}}}^{2})(1 - 1.1516w_{\mathrm{R}} + 4.837{w_{\mathrm{R}}}^{2})^{-1} \quad (12)$$

$$\beta = 0.5784 + 2.2825w_{\mathrm{R}} + 5.561{w_{\mathrm{R}}}^{2} - 26.986{w_{\mathrm{R}}}^{3} + 31.26{w_{\mathrm{R}}}^{4} - 12.163{w_{\mathrm{R}}}^{5} \quad (13)$$

Concentration dependence of the enthalpy for the ROS R600a−WF 15A is shown in Figure 3.

On the basis of obtained experimental information for the enthalpy of the ROS R600a−WF 15A, using information on the thermodynamic properties for the ROS R600a−WF 15A (vapor pressure) reported in Nichenko[16] and the methodology reported in Zhelezny et al.,[1] we developed pressure−enthalpy ($P-H$) and concentration−enthalpy diagrams ($w-H$) for the real working fluid. The examples of $P-H$ and $w-H$ diagrams are shown in Figures 4 and 5.

Conclusions

In this paper for the first time the experimental information on the specific enthalpy for the system refrigerant−compressor oil is

Table 1. Physical-Chemical Properties of the Mineral Compressor Oil WF15A

substance	oil type	color	acid number mg KOH·g^{-1}	flash point K	floc point K	pour point K	molecular weight g·mol^{-1}
WF 15A	mineral	0.5[a]	0.02[a]	437[a]	214[a] (9 % in R-600a)		319[b]

[a] Manufacturer's data. [b] The molecular weight for mineral compressor oil WF 15A was measured by the ebullioscopic method.[13]

Table 2. Thermophysical Properties of the Mineral Compressor Oil WF 15A

T / K	n	T / K	a^2 / mm^2	T / K	ρ / kg·m^{-3}	T / K	σ / mN·m^{-1}	T / K	$\nu\cdot10^{-7}$ / m^2·s^{-1}
293.35	1.4824	292.35	7.4000	292.35	886.41	292.35	32.163	292.75	38.53
297.95	1.4810	297.05	7.3577	299.35	881.77	297.05	31.867	298.45	28.69
302.55	1.4792	299.35	7.3100	302.95	879.38	299.35	31.606	302.95	23.28
312.35	1.4756	302.95	7.2687	307.15	876.47	302.95	31.342	307.75	18.79
318.15	1.4730	307.15	7.2147	313.75	872.19	307.15	31.011	313.75	14.89
323.95	1.4708	313.75	7.1157	318.95	868.75	313.75	30.433	318.55	12.40
327.15	1.4696	318.95	7.0407	323.55	865.62	318.95	29.994	323.15	10.64
332.55	1.4676	323.55	6.9627	329.35	861.69	323.55	29.558	328.55	8.88
337.15	1.4658	329.35	6.9057	332.95	859.47	329.35	29.186	333.15	7.77
342.55	1.4638	332.95	6.8370	338.35	855.87	332.95	28.816	338.15	6.77
347.35	1.4620	338.35	6.7827	343.35	852.67	338.35	28.468	342.15	6.11
352.95	1.4598	343.35	6.7047	348.35	849.50	343.35	28.032	348.35	5.27
		348.35	6.6207	353.55	846.08	348.35	27.573	353.15	4.72
		353.55	6.5470			353.55	27.155		

Table 3. Experimental Results on the Specific Enthalpy for the ROS R600a−WF 15A

T / K	$w_{\mathrm{R,min}}$[a] / kg·kg^{-1}	$w_{\mathrm{R,max}}$[b] / kg·kg^{-1}	$w_{\mathrm{R,aver}}$[c] / kg·kg^{-1}	$H'_{\mathrm{ROS,exp}}$ / J·g^{-1}	T / K	$w_{\mathrm{R,min}}$[a] / kg·kg^{-1}	$w_{\mathrm{R,max}}$[b] / kg·kg^{-1}	$w_{\mathrm{R,aver}}$[c] / kg·kg^{-1}	$H'_{\mathrm{ROS,exp}}$ / J·g^{-1}
273.15	0.0000	0.0000	0.0000	200	348.19	0.1582	0.2049	0.1815	351.12
296.15	0.0000	0.0000	0.0000	241.75	347.27	0.1594	0.2049	0.1821	355.24
310.06	0.0000	0.0000	0.0000	272.43	357.15	0.1449	0.2049	0.1749	375.77
327.83	0.0000	0.0000	0.0000	311.08	356.28	0.1463	0.2049	0.1756	375.93
340.93	0.0000	0.0000	0.0000	336.01	273.15	0.4619	0.4619	0.4619	200
355.48	0.0000	0.0000	0.0000	369.26	297.23	0.4600	0.4619	0.4610	248.43
273.15	0.0707	0.0707	0.0707	200	305.99	0.4590	0.4619	0.4605	267.16
291.38	0.0691	0.0707	0.0699	231.61	316.30	0.4575	0.4619	0.4597	291.15
307.82	0.0670	0.0707	0.0688	265.47	327.00	0.4556	0.4619	0.4588	313.63
321.69	0.0646	0.0707	0.0676	293.43	335.88	0.4536	0.4619	0.4578	333.59
313.92	0.0660	0.0707	0.0684	275.76	346.64	0.4507	0.4619	0.4563	361.76
329.30	0.0629	0.0707	0.0668	309.81	356.74	0.4471	0.4619	0.4545	387.23
341.09	0.0597	0.0707	0.0652	335.47	273.15	0.7630	0.7630	0.7630	200
273.15	0.2049	0.2049	0.2049	200	295.19	0.7619	0.7630	0.7624	247.06
298.26	0.1970	0.2049	0.2009	245.32	309.17	0.7608	0.7630	0.7619	280.68
308.98	0.1919	0.2049	0.1984	267.87	319.36	0.7599	0.7630	0.7614	304.55
319.86	0.1853	0.2049	0.1951	289.96	332.63	0.7582	0.7630	0.7606	337.58
328.98	0.1784	0.2049	0.1916	309.53	344.18	0.7563	0.7630	0.7596	362.27
337.45	0.1706	0.2049	0.1877	331.17					

[a] Concentration of the refrigerant in the experiment at the temperature of the cooper block. [b] Concentration of the refrigerant at the temperature of the end of experiment, −0 °C. [c] Average refrigerant concentration in the experiment.

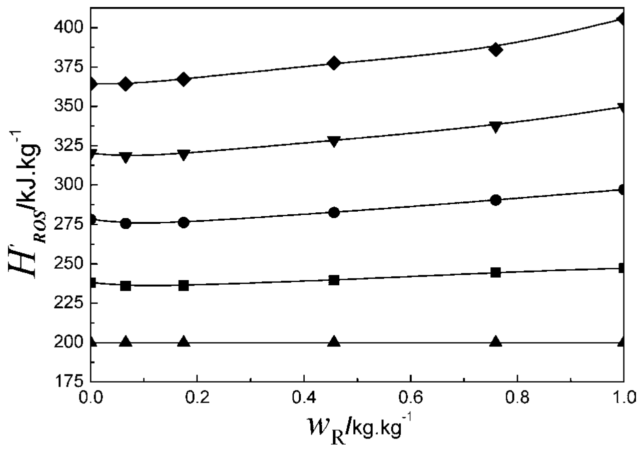

Figure 3. Concentration dependencies on the enthalpy for the ROS R600a−WF 15A at different temperatures. ▲, $T = 273.15$ K; ■, $T = 293.15$ K; ●, $T = 313.15$ K; ▼, $T = 333.15$ K; ◆, $T = 353.15$ K.

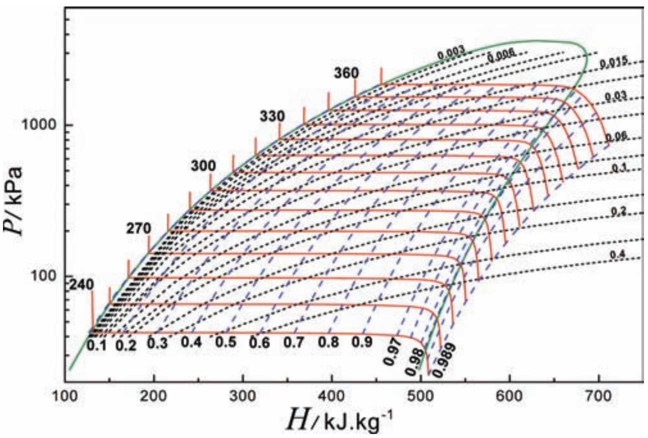

Figure 4. Pressure−enthalpy diagram for the real working fluid R600a−WF 15 at $c_g = 1$ % (∗). ∗, c_g is a weight concentration of the compressor oil before throttle, kg·kg^{-1}; red solid line indicates the isotherm curve (R600a/oil mixture)/K; blue dashed line indicates the vapor quality curve (R600a/oil mixture); green solid line indicates the boundary curve (pure R600a); black dotted line indicates the constant volume curve (pure R600a)/m^3·kg^{-1}.

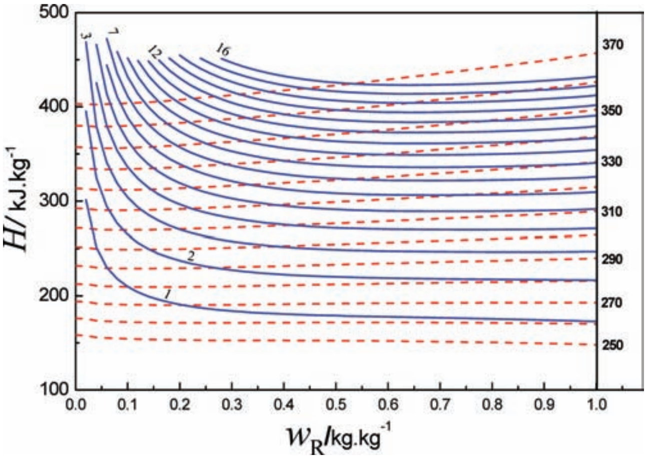

Figure 5. Enthalpy−fraction diagram for the refrigerant oil solution R600a−WF 15 at $c_g = 1$ % (∗). ∗, c_g is a weight concentration of the compressor oil before throttle, kg·kg^{-1}; red dotted line indicates the isotherm curve (R600a/oil mixture)/K; blue solid line indicates the constant pressure curve (R600a/oil mixture)/bar.

presented. For experimental investigation of the enthalpy for the ROS the experimental setup has been designed and constructed. On the basis of the result obtained the $P-H$ and $w-H$ diagrams for the real working fluid R600a−WF 15A are developed. Proposed $P-H$ and $w-H$ diagrams are suitable for practical application for the real working fluid R600a−WF 15A. We should mention that diagrams cannot solve all problems which appear during designing or operation of the refrigeration plant. However, analysis of the $P-H$ and $w-H$ diagrams for the ROS can be extremely useful for control of oil circulation in circuit of the refrigerator, for determination of the necessary level of the apparent superheat for the working fluid in the evaporator, or for estimation of the influence of the compressor−oil admixtures onto the efficiency the compressor system, and so forth.

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