THERMOPHYSICAL PROPERTIES OF ALTERNATIVE FUEL IN A WIDE RANGE OF PARAMETERS

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ABSTRACT

In the presented article, butanol-1 and diesel B0 fuel are degassed in special flasks and their purity is checked using a Karl Fischer 756 KF titratron. Then binary mixtures are prepared in appropriate mole fractions xb-1=(0.0, 0.1773, 0.3493, 0.5514, 1.0) or Vb-1=(0.0, 7.0, 15.79, 30.04 and 100.0)%)in volume percentages by using special connected flasks. Two different static devices with high accuracy were used to measure the saturated vapor pressure of butanol-1, diesel B0 fuel and their binary mixtures [8]. Glass gauge sockets (3, 4, 27) are used to measure saturated vapor pressure at subatmospheric pressure and temperature T=(274.15÷323.15) K (Fig. 1). The metal gauge socket is used to measure the saturated vapor pressure at temperatures T= (323.15÷473.15)K (Fig. 2). The experimentally obtained results of saturated vapor pressure of butanol-1 and diesel B0 fuel mixtures were fitted to analytically by means of Clausius-Clapeyron type equations.Experiments to measure the isobaric heat capacity cp/(C·kg-1·K-1) of butanol-1, diesel B0 fuel and their mixtures at atmospheric and saturated vapor pressures were measured in a Pyris 1 type differential scanning calorimeter (Fig. 4) [10] . The measuring chamber is resistant to a temperature of T=573.15 K and a pressure of 24 bar. Measurements were carried out at temperatures (263.15÷468.15) K, atmospheric p=0.101 MPa and saturated steam pressures Ps/MPa. The experimentally obtained results of heat capacity of butanol-1 and diesel B0 fuel mixtures were analytically written by means of an empirical polynomial equation.

Keywords: Butanol-1, diesel B0, vapor pressure, isobaric heat capacity, wıde range of parameters.

INTRODUCTION

Currently, as the amount of traditional fuels in the world is running out, the instability of their prices, damage to the environment during production and use, including the "greenhouse effect", etc. such factors create the need for the development of alternative energy sources. By adding various alternatives to traditional fuels, such as the use of alternative energy sources, both the amount of total fuel is increased and the amount of harmful exhaust gases released into the environment after combustion is reduced. In the presented article, butanol-1 is taken as an alternative additive to diesel fuel. Butanol-1 belongs to the group of biomass-based renewable fuels and is obtained by fermentation of alcohols from biomass feedstock during ethanol production [7].

Regarding the use of Butanol-1 in direct internal combustion engines, it should be noted that fuel is injected under a pressure of up to 220 MPa in cars with diesel engines. In the future, it is planned to raise this pressure to 400 MPa and higher in the direction of the development of internal combustion engine technology. This leads to an increase in the speed of the engine and, the car, and to obtain the optimal speed in a short time. In recent years, the addition of butanol-1 as an alternative to diesel fuel, its direct use in an engine, and the analysis of engine properties have been reflected in many scientific works [1]. Some alternative additives do not affect the general construction and technical indicators of the engine and are used successfully [2, 3, 4, 5, 6].

Butanol-1 is a classic chemical substance and has a wide range of uses, so its thermal-physical properties have been studied detailed. However, since diesel fuel is not a stable chemical liquid, diesel fuel obtained from petroleum from different sources is also different. Suffice it to say that the density of diesel fuel varies in the range of 820-850 kg·m^{-3}. Therefore, for the first time, we will measure the saturated vapor pressure and heat capacity of diesel B0 fuel and its corresponding fractions with butanol-1 and in the wide range of case parameters we have chosen.

Experimental materials: Ultra pure butanol-1 (w=99.995%, absolute for analysis EMPLURA®, CAS No. 71-36-3, Art. Nr. 8.22262.2500) Merck Schuchardt OHG (Germany) and world standard diesel B0 fuel (Shell) Global Solution DK5037).

First, our selected samples are degassed under vacuum in a special flask and checked for purity in a Karl Fischer 756 KF titratron. Then, by means of special flasks, details are prepared in the external fractions in general table 1. ED224S (Germany) is measured with an accuracy of 0.0001 g.

Table 1.

Concentrations of butanol-1 and diesel B0 fuel mixtures.

Stage	**gram**	**cm^3**
Vacuum flask	147.1955	
Vacuum flask + Diesel B0	312.2430	
Diesel B0	165.0475	201.18421
Vacuum flask + Diesel B0 + Butanol-1	324.5030	
Butanol-1	12.2600	15.14253
Mixed	177.3075	216.3267
Concentration of Butanol-1, %	**w_{b-1}=6.9145%**	**V_{b-1}=6.9998**
	mass %	volume, %
x- mole fraction of Butanol-1	**x=0.1773**	
Stage	**gram**	**cm^3**
Vacuum flask	135.1763	
Vacuum flask + Diesel B0	260.9620	
Diesel B0	125.7857	153.32614
Vacuum flask + Diesel B0 + Butanol-1	284.2370	
Butanol-1	23.2750	28.74734
Mixed	149.0607	182.0735
Concentration of Butanol-1, %	**w_{b-1}=15.6144**	**V_{b-1}=15.7889**
	mass %	volume, %
x- mole fraction of Butanol-1	**x=0.3493**	
Stage	**gram**	**cm^3**
Vacuum flask	110.9190	
Vacuum flask + Diesel B0	229.6580	
Diesel B0	118.7390	144.73659
Vacuum flask + Diesel B0 + Butanol-1	279.9740	
Butanol-1	50.3160	62.14614
Mixed	169.0550	206.8827
Concentration of Butanol-1, %	**w_{b-1}=29.7631**	**V_{b-1}=30.0393**
	mass %	volume, %
x- mole fraction of Butanol-1	**x=0.5514**	

All concentrations of all mixtures were prepared in this manner. The volume, mass and mole fractions of the mixtures are given below in table 2:

Table 2.

Concentrations of butanol-1 and diesel B0 fuel mixtures.

$V_{b\text{-}1}$, volume %	0.0000	6.9998	15.7889	30.0393	100.0000
$w_{b\text{-}1}$, mass %	0.0000	6.9145	15.6144	29.7631	100.0000
$x_{b\text{-}1}$ /mole fr.	0.0000	0.1773	0.3493	0.5514	1.0000
M/kg·mol^{-1}	0.2150	0.2053	0.1930	0.1731	0.0741

Experimental process of saturated vapor pressure: The saturated vapor pressure of butanol-1, diesel B0 fuel and their binary mixtures was measured using two different static devices with high accuracy [8]. Glass measuring sockets (3, 4, 27) are used to measure the saturated vapor pressure at a pressure below then atmospheric pressure and at a temperature T=(274.15÷323.15) K (Fig. 1). The metal gauge socket is used for measuring the saturated vapor pressure at temperatures T=(323.15÷ 473.15) K (Fig. 2). Figure 1 shows pressure sensors-blue, electric heaters-red, temperature measurement scheme-green. The internal volume of each measuring cell was approximately 80 cm^3 for both glass and steel parts [8].

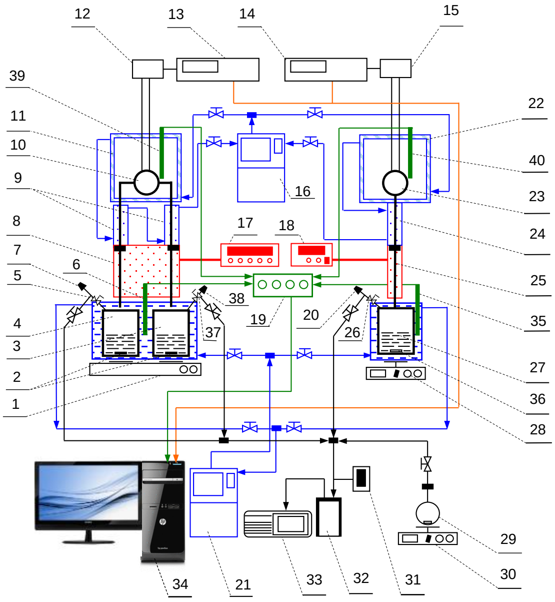

Fig. 1.

Experimental device for measuring saturated vapor pressure at temperatures T=(274.15 - 323.15) K: (1), (28), (30) magnetic stirrer; (2), (36) magnetic, (3), (4) measuring slots of the differential method; (5), (37) valves for closing the measuring slots of the differential method and (26) of the static method; (6), (35), (39), (40) platinum resistance thermometers, (19) Omega PT-104A temperature signal transducer; (7), (20), (38) nozzle for pouring the measured sample into the measuring slot; (8), (25) electric heater; (9), (24) water heat exchanger; (10) pressure sensor head of differential method and (23) static method; (11) differential method and (22) static method pressure sensor thermostating reservoir; (12) pressure signal combination of differential method and (15) static method; (13) differential method and (14) static method pressure signal sensors; (16) HAAKE F5 thermostat; (17), (18) electric heater control system; (21) Lauda Gold RE-630 G thermo-stat; (27) external flask for thermostatizing the measuring chamber of the static method; (29)

degassing flask; (31) vacuum indicator; (32) Duar container with nitrogen inside; (33) vacuum pump; (34) PC.

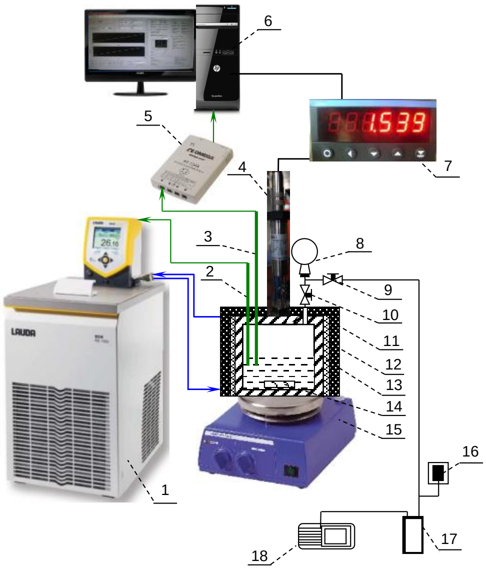

Fig. 2.

Experimental setup for measuring saturated vapor pressure at temperatures T=(333.15 - 468.15) K: (1) Lauda Gold RE-415 G thermostat; (2) PT-100 platinum resistance thermometer for monitoring the temperature of the measurement chamber by means of a thermostat; (3) platinum resistance thermometer PT-100 for monitoring the temperature of the measuring socket; (4) 35 X HTC Omega GmbH and Co. pressure transmitter; (5) Omega PT-104A Channel RTD Input Data Acquisition module for temperature measurement; (6) PC; (7) manual pressure signal display; (8) a flask containing the sample to be measured; (9), (10) valves; (11) gauge socket insulation; (12) heat transfer reservoir; (13) gauge housing; (14) magnetic; (15) magnetic stirrer; (16) vacuum indicator; (17) Duar container with nitrogen inside; (18) vacuum pump.

Before the experiment, the measuring cell was washed with water and acetone. With the help of a vacuum pump (33), all liquids are blown out of the system using vacuum systems (31, 32) TRIVAC® (Germany). This process lasts for about 3-5 hours until the pressure is less than about 5-10 Pa. All gauge sockets are dried and prepared for the experiment.

Then the flask with the mixture is attached to the nozzle to pour the sample to be measured into the measuring well, and the valves (7, 26) are closed. Part of the liquid to be measured evaporates at that moment and this process continues until the fully saturated vapor pressure is obtained. Due to the magnetic stirrer (1,28) and the rotation of the Teflon-coated magnet (2, 36) located inside the housing, an equilibrium between the liquid and vapor phase is created [8].

The equilibration process in the nest occurs very quickly, and a stable pressure in the stationary mode is achieved within 15 minutes. Balance pressure indicators in every 10-20 min. recorded in the interval. The computer receives the vapor pressure signal every minute and records the stabilization of the pressure in the cavity. After that, the temperature is automatically changed by LabVIEW software. Measurements are taken in the intended temperature range from low temperatures (T=274.15 K) to high temperatures (T=323.15 K). After reaching the maximum temperature, the thermostat stops automatically. Then measurements from high temperature (T=323.15 K) to low temperature (T=274.15 K) are made in the same way. The device is designed in such a way that when the automatic system fails, the entire experiment is performed mechanically.

Saturated vapor pressures of water, methanol, acetone, and other reference substances are used to verify both experimental setups.

Experiments conducted to determine the vapor pressure of butanol-1, diesel B0 fuel and their mixtures at temperatures T=(323.15÷468.67) K were carried out using the static method in a metal nest (Fig. 2). In Figure 2, the connections of the heat carrier between the thermostat (1) and the measuring socket (13) are shown in blue. Temperature measuring connections are shown in green and pressure connections in black. The device consists of a measuring housing (13) made of stainless steel DIN 1.4571 (V4A) and KORASILON M50 oil (Kurt Obermeier GmbH & Co. KG, Germany) circulating in the reservoir.

Experimental values of saturated vapor pressure of butanol-1 and diesel B0 mixture P_{ex}/Pa values were also measured by the same rule at low temperature. The obtained results are presented in table 3 and figure 3. The temperature step was ΔT=(5-10) K. All measurements at T=(333.15÷468.67) K take about 10 hours.

Table 3.

Experimental values of saturated vapor pressure of butanol-1 diesel B0 mixture P_{ex}/Pa.

T/K	$x_{\text{butanol-1}}$, mole fr.				
	0.0000	0.1773	0.3493	0.5514	1.0000
	$V_{\text{butanol-1}}$, % - volume				
	0.0	7.0	15.79	30.04	100.0
	P_{ex}/Pa				
274.15	40	64	86	106	133
278.15	52	89	121	151	188
283.15	71	132	182	229	285
293.15	129	275	392	500	624
303.15	222	539	788	1017	1281
313.15	367	1000	1495	1946	2483
323.15	587	1770	2692	3530	4571
333.15	907	2999	4630	6109	8030
343.15	1363	4890	7646	10142	13517
353.15	1995	7701	12179	16227	21890
363.15	2851	11754	18777	25123	34224
373.15	3986	17441	28118	37764	51825
383.15	5465	25224	41010	55277	76225
393.15	7358	35638	58403	78989	109178
403.15	9745	49293	81387	110443	152632
413.15	12711	66868	111200	151393	208708
423.15	16348	89111	149216	203809	279656
433.15	20758	116829	196948	269872	367818
443.15	26043	150887	256033	351967	475581
453.15	32314	192194	328229	452673	605332
463.15	39684	241701	415397	574750	759418
468.67	44267	272898	470637	652350	855726

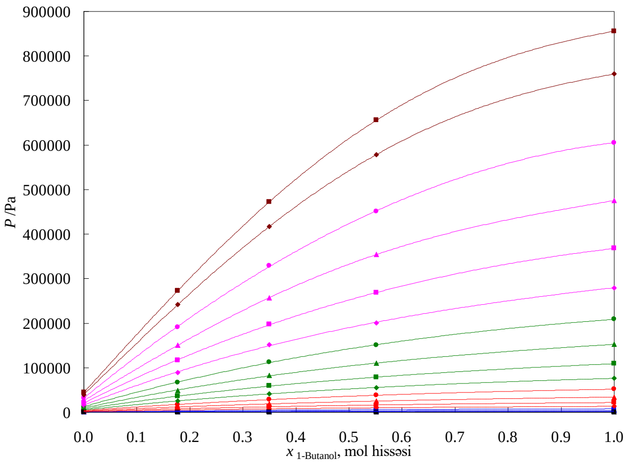

Fig. 3.

The dependence of the vapor pressure of the butanol-1 diesel B0 mixture on the T/K concentration at different temperatures: ◆, 274.15 K; ■, 278.15 K; ▲, 283.15 K; ●, 293.15 K; ◆, 303.15 K; ■, 313.15 K; ▲, 323.15 K; ●, 333.15 K; ◆, 343.15 K; ■, 353.15 K; ▲, 363.15 K; ●, 373.15 K; ◆, 383.15 K; ■, 393.15 K; ▲, 403.15 K; ●, 413.15 K; ◆, 423.15 K; ■, 433.15 K; ▲, 443.15 K; ●, 453.15 K; ◆, 463.15 K; ■, 468.65 K.

As the temperature increases, the saturated vapor pressure of the mixture begins to increase rapidly, which is due to the saturated vapor pressure of butanol-1. The extremely high saturated steam pressure requires the calculation of the engine and its feeding systems to higher pressures and the deeper design of the cylinders.

Experimental process of heat capacity: Experiments to measure the isobaric heat capacity $c_p/(C\cdot kg^{-1}\cdot K^{-1})$ of butanol-1, diesel B0 fuel and their mixtures at atmospheric and saturated vapor pressures were fitted in a Pyris 1 type differential scanning calorimeter (Fig. 4).

Fig. 4.
Pyris 1 type differential scanning calorimeter [10] .

A differential scanning calorimeter allows to measure the temperature-dependent heat imparted to materials with very high accuracy. Inside the main element of the device are stainless steel housings, heaters and platinum thermoresistors coated with platinum-iridium alloy, which is the substance to be measured. The measuring chamber is resistant to a temperature of T=573.15 K and a pressure of 24 bar. Approximately 30-70 mg of sample is placed in the measuring well and is performed using two parallel measuring wells. The substance to be measured is placed in the first measuring slot, and the standard substance (sapphire) is placed in the second. Since the experiments are carried out by the method of changing the temperature at a constant rate, the temperature of both measurement slots is kept equal to each other. The heating rate was 3 K/min in the experiments[10]. Since the samples in the measurement cells are different (the sample to be measured and the reference sample with well-known literature values in advance), the amount of heat supplied to both cells is different to keep them at a constant temperature. According to these heat differences, the heat capacity is calculated:

$$c_p(T) = \frac{dq}{dt}, \tag{1}$$

The measuring cup is weighed first empty, then filled with liquid, and the amount of liquid inside it is found. By the same rule, the second measuring slot is also weighed on the scale [10]. Once both measuring cells are placed in a special part of the device, the device starts up fully automatically, first the measuring cells are cooled and heated twice from 150 °C to -70 °C. At this time, the heat transfer rate is 10 K/min. is kept within the limit. In the second process, the samples are cooled and heated from 150 °C to -70 °C in 50 K intervals. Again, the heat transfer rate is 10 K/min. is kept stable. Then, on the basis of the given amount of heat [heat flow – time curve, Φ (t)], the isobaric heat capacity can be calculated with the help of the following formulas [9]:

$$c_p(T) = c_{p\,sapfir}(T)\frac{m_{sapfir}\cdot\beta}{m_{nümune}\cdot\beta}\cdot\frac{\Phi_{nümune}(T)-\Phi_{bos}(T)}{\Phi_{sapfir}(T)-\Phi_{bos}(T)} = K(T)\cdot\frac{\Phi_{nümune}(T)-\Phi_{bos}(T)}{m_{nümune}\cdot\beta}, \tag{2}$$

Here, $K(T)$ the temperature dependent calibration coefficient is found as follows [9]:

$$K(T) = c_{p\,sapfir}(T)\cdot\frac{m_{sapfir}\cdot\beta}{\Phi_{sapfir}(T)-\Phi_{bos}(T)}. \tag{3}$$

In the presented article, the isobaric heat capacity $c_p/(C\cdot kg^{-1}\cdot K^{-1})$ of butanol-1, diesel B0 fuel and their mixtures in the temperature range T=(263.15÷468.15) K and atmospheric and saturated vapor pressures was experimentally measured. The experiments were repeated many times. The obtained results are given in table 4 every 10 K. Figure 5 shows the experimentally analyzed isobaric heat capacity $c_p/(C\cdot kg^{-1}\cdot K^{-1})$ of butanol-1, diesel B0 fuel and their mixtures at atmospheric and saturated vapor pressures as a function of T/K concentration at different temperatures.

Table 4.

Experimental values of heat capacity $c_p/(C\cdot kg_{-}^{1}\cdot K^{-1})$ of butanol-1 - diesel B0 mixture at atmospheric pressure.

T/K	$x_{\text{butanol-1}}$, mole fr.				
	0.0000	0.1773	0.3493	0.5514	1.0000
	$V_{\text{butanol-1}}$, % - volume				
	0.0	7.0	15.79	30.04	100.0
	$c_p/(C\cdot kg^{-1}\cdot K^{-1})$				
263.15	1799.53	1851.83	1905.20	1977.02	2113.63
273.15	1844.22	1892.45	1945.28	2019.03	2182.20
283.15	1887.84	1937.61	1994.28	2078.02	2260.21
293.15	1930.49	1985.57	2049.02	2133.02	2347.41
303.15	1972.26	2034.98	2106.93	2206.94	2443.01
313.15	2013.23	2084.74	2165.99	2276.93	2545.74
323.15	2053.50	2134.05	2224.66	2346.00	2653.95
333.15	2093.16	2182.36	2281.84	2423.83	2765.75

343.15	2132.29	2229.30	2336.79	2488.77	2879.03
353.15	2170.99	2274.69	2389.12	2547.92	2991.62
363.15	2209.35	2318.48	2438.66	2609.00	3101.36
373.15	2247.45	2360.74	2485.48	2662.00	3206.17
383.15	2285.38	2401.60	2529.78	2714.00	3304.20
393.15	2323.25	2441.24	2571.86	2760.06	3393.85
403.15	2361.12	2479.86	2612.06	2806.00	3473.95
413.15	2399.11	2517.62	2650.67	2845.91	3543.77
423.15	2437.29	2554.63	2687.93	2884.00	3603.17
433.15	2475.75	2590.91	2723.93	2917.03	3652.70
443.15	2514.59	2626.37	2758.58	2958.00	3693.62
453.15	2553.90	2660.75	2791.53	2983.86	3728.10
463.15	2593.76	2691.00	2822.12	3013.12	3759.23
468.65	2615.95	2710.80	2837.59	3030.09	3776.37

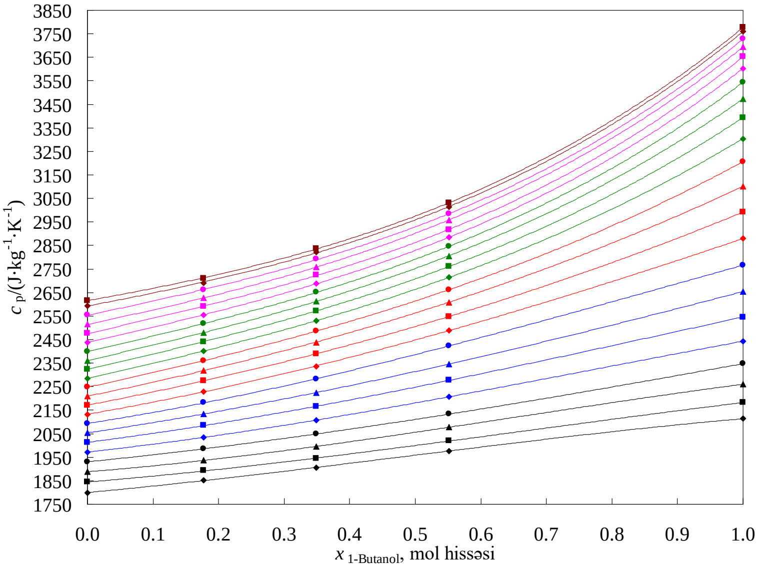

Fig. 5.

Dependence of isobaric heat capacity c_p/(C·kg^{-1}·K^{-1}) of butanol-1 – diesel B0 mixture on T/K concentration at different temperatures: ◆, 263.15 K; ■, 273.15 K; ▲, 283.15 K; ●, 293.15 K; ◆, 303.15 K; ■, 313.15 K; ▲, 323.15 K; ●, 333.15 K; ◆, 343.15 K; ■, 353.15 K; ▲, 363.15 K; ●, 373.15 K; ◆, 383.15 K; ■, 393.15 K; ▲, 403.15 K; ●, 413.15 K; ◆, 423.15 K; ■, 433.15 K; ▲, 443.15 K; ●, 453.15 K; ◆, 463.15 K; ■, 468.65 K.

Summary of the experimental result of saturated vapor pressure: An accurate study of the liquid and saturated vapor boundary is the main and first goal. The experimentally obtained results of saturated vapor pressure of butanol-1 and diesel B0 fuel mixtures studied in this article are fitted to analytically by means of Clausius-Clapeyron equations. First, let's use the Clausius-Clapeyron equation to write the saturated vapor pressure of the pure substances (butanol-1 and diesel B0 fuel) that make up the mixture:

$$\ln P(T) = D + \frac{E}{T} + F \ln T + GT, \tag{4}$$

Where: P/Pa, saturated vapor pressure; The constants D, E, F and G are the coefficients of equation (4) and are listed in Table 5 along with the standard relative error:

Table 5.

Clausius-Clapeyron equation coefficients D, E, F, G and standard error (ΔP/P) of the saturated vapor pressure of the pure substances that make up the mixture (butanol-1 and diesel B0 fuel).

D	E	F	G	$(\Delta P/P)/\%$
butanol-1				
125.277	-10321.5	-15.043	0.00622461	±0.114
dizel B0 yanacağı				
100.318	−7560.68	−12.9263	0.0128199	±0.105

The values of the saturated vapor pressure of butanol-1 calculated by equation (4) are given in Table 6 along with the experimental results:

Table 6.

Results of experimentally measured $P_{ex.}$/Pa and P_{cal}/Pa vapor pressures of butanol-1 calculated by the Clausius-Clapeyron equation.

T/K	P_{ex}/Pa	P_{cal}/Pa	(P_{ex} - $_{cal}$)/Pa	T/K	P_{ex}/Pa	P_{cal}/Pa	(P_{ex} - P_{cal})/Pa
274.15	133	133	0	373.15	51825	51787	38
278.15	188	188	0	383.15	76225	76210	15
283.15	285	286	-1	393.15	109178	109219	-41
293.15	624	625	-1	403.15	152632	152774	-142
303.15	1281	1284	-3	413.15	208708	208994	-286
313.15	2483	2487	-4	423.15	279656	280108	-452
323.15	4571	4573	-2	433.15	367818	368407	-589
333.15	8030	8027	3	443.15	475581	476185	-604
343.15	13517	13504	13	453.15	605332	605682	-350
353.15	21890	21864	26	463.15	759418	759025	393
363.15	34224	34187	37	468.67	855726	854610	1116

The saturated vapor pressure of butanol-1 has been extensively analyzed in the literature. However, since the saturated vapor pressures of diesel B0 and its mixtures with butanol-1 were obtained for the first time by us, there is no such information in the literature.

It was after this stage that a generalized equation based on the form of the Clausius–Clapeyron equation was developed for the first time, including the two mixtures presented:

$$\ln P(T,x) = D(x) + \frac{E(x)\cdot T}{100} + F(x)\cdot \ln\frac{100}{T} + G(x)\cdot\frac{100}{T} + H(x)\cdot\left(\frac{100}{T}\right)^2, \tag{5}$$

where: D, E, F, G and H are the coefficients of equation (5), they depend on the mole fraction of butanol-1 in the following form:

$$D = \sum_{i=0}^{3} d_i x^i,\ E = \sum_{i=0}^{3} e_i x^i,\ F = \sum_{i=0}^{3} f_i x^i,\ G = \sum_{i=0}^{3} g_i x^i,\ H = \sum_{i=0}^{3} h_i x^i, \tag{6}$$

where: d_i, e_i, f_i, g_i və h_i - (6) are the coefficients of the equations and are given in table 7.

Table 7. coefficients of the equations (6).

$d_0 = -159.816$	$e_0 = -7.16203$	$f_0 = -86.0816$	$g_0 = 345.969$	$h_0 = -242.395$
$d_1 = -219.883$	$e_1 = -9.84237$	$f_1 = -117.224$	$g_1 = 470.324$	$h_1 = -316.54$
$d_2 = 388.525$	$e_2 = 17.3569$	$f_2 = 206.694$	$g_2 = -834.269$	$h_2 = 569.737$
$d_3 = -160.05$	$e_3 = -7.10404$	$f_3 = -84.786$	$g_3 = 347.882$	$h_3 = -244.562$

Summary of the experimental result of heat capacity: The heat capacity $c_p(p_{0 \text{ or } s},T,x)$ of the studied butanol-1 and diesel B0 fuel at atmospheric and saturated vapor pressures is written using an empirical polynomial equation:

$$c_p /(\mathrm{J} \cdot \mathrm{kg}^{-1} \cdot \mathrm{K}^{-1}) = \sum_{\mathrm{i=0}}^{\mathrm{n}} a_i T^i , \quad (7)$$

where: a_i are the coefficients of the polynomial and are given in table 8.

Table 8.

The values of coefficients ai in equation (7).

a) butanol-1

a_0	**a_1**	**a_2**
-23502.8045706606	423.127542637313	-2.77467824697277
a_3	**a_4**	**a_5**
$0.883160039558228 \cdot 10^{-2}$	$-0.13436353941981 \cdot 10^{-4}$	$0.785140077009 \cdot 10^{-8}$

b) diesel B0

a_0	**a_1**	**a_2**
63.4177019498666	10.6715485019306	-0.0175932706258731
a_3		
$0.14982929595897 \cdot 10^{-4}$		

Writing the obtained experimental results using an empirical equation $\Delta c_p/c_p = 100 \cdot (c_{p\ \mathrm{exp}} - c_{p\ \mathrm{cal}})/c_{p\ \mathrm{exp}} = \pm\ 0.01\%$ for butanol-1, $\Delta c_p/c_p = 100 \cdot (c_{p\ \mathrm{exp}} - c_{p\ \mathrm{cal}})/c_{p\ \mathrm{exp}} = \pm\ 0.02\%$ for diesel B0 fuel average relative gave an error.

After writing the experimental results of the isobaric heat capacity of the mixture of butanol-1 and diesel B0 fuel with an equation, an empirical equation was prepared in the following form for the concentration and temperature dependence of the heat capacity at atmospheric and saturated vapor pressures for the mixtures:

$$c_{\mathrm{p}}(p_{0\,\mathrm{or}\,s}, T, x) = \sum_{i=0}^{3} (x/\mathrm{mol\,fr.})^i \sum_{j=0}^{3} q_{ij}(T/K)^j , \quad (8)$$

where: q_{ij} – are the coefficients of equation (8) and are given in table 9.

Table 9.

The values of the q_{ij} coefficients in equation (8).

$q_{00} = 455.9261019$	$q_{12} = 135.1477835$	$q_{30} = 0.1497809549 \cdot 10^{-5}$
$q_{01} = 4977.747691$	$q_{13} = -157.328961$	$q_{31} = -0.1461735009 \cdot 10^{-3}$
$q_{02} = -16154.10817$	$q_{20} = -0.3783420129 \cdot 10^{-2}$	$q_{32} = 0.3010091204 \cdot 10^{-3}$
$q_{03} = 18288.20477$	$q_{21} = 0.150583102$	$q_{33} = -0.3742342538 \cdot 10^{-3}$
$q_{10} = 6.008842245$	$q_{22} = -0.3571181928$	
$q_{11} = -47.63529006$	$q_{23} = 0.4312149091$	

When writing the heat capacity of butanol-1 and diesel B0 fuel mixtures using the equation (8), a relative average error of $u_r(\Delta c_p/c_p) = \pm\ 0.18\ \%$ was obtained. These equations show the different thermal-physical properties of butanol-1, diesel B0 fuel and their mixtures (isothermal compression κ_T/MPa^{-1}, isobaric thermal expansion α_p/K^{-1}, specific isobaric and isochoric heat capacity differences (c_p-c_v)/C·kg^{-1}·K^{-1}, thermal pressure coefficient γ/MPa·K^{-1}, internal pressure p_{int}/MPa, isobaric heat capacity c_p/C·kg^{-1}·K^{-1}, isochoric heat capacity c_v/C·kg^{-1}·K^{-1}, speed of sound u/m·s^{-1} and isentropic expansion coefficient κ_s) is an important equation for calculation.

Results: Alternative fuel (butanol-1 and diesel B0 fuel) x_{b-1}=(0.0, 0.1773, 0.3493, 0.5514, 1.0) mole fractions or V_{b-1}=(0.0, 7.0, 15.79, 30.04 and 100.0)% volume percentages of binary mixtures saturated vapor pressure p_s/MPa at temperatures T=(274.15÷468.15)K was measured experimentally and generalized using Clausius-Clapeyron type equation.

Heat capacity of binary mixtures of butanol-1, diesel B0 fuel in mole fractions x_{b-1}=(0.0, 0.1773, 0.3493, 0.5514, 1.0) or V_{b-1}=(0.0, 7.0, 15.79, 30.04 and 100.0)% volume percentages was experimentally measured at temperature T=(263.15÷468.15) K, atmosphere p=0.101 MPa and pressure of saturated steam p_s/MPa. Based on the obtained experimental results, the empirical equations for the analytical descriptions of the dependence of the heat capacity (c_p, T, x) on the mole fraction of butanol-1 were obtained.

When binary mixtures of butanol-1 and diesel B0 fuel are used as alternative fuels in internal combustion engines, important experimental results were obtained in order to be able to study the design of the engine's injection system and other thermal-physical properties and tabulated. The experimental results obtained in the article are defined as prospective data for use as an alternative fuel (butanol-1) in modern internal combustion engines.

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