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REVIEW OF THERMODYNAMIC AND TRANSPORT PROPERTIES OF 1-BUTANOL AS RENEWABLE COMPONENT OF NEW BIOFUELS.

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ABSTRACT

Alternative and renewable energy technologies are being sought throughout the world to reduce pollutant emissions and increase the efficiency of energy use. Oxygenates produced from renewable resources, including higher alcohols (those containing more than two carbon atoms) and several other oxygenated compounds, have been proposed as blend components in gasoline for reduction in petroleum consumption and greenhouse gas emissions. Amongst these oxygenates, butanol has been proposed as an alternative to conventional gasoline and diesel fuels.

Interest in butanol as a second-generation biofuel has increased because it has many advantages over other potential alternative fuel candidates such as ethanol. Oxygenated fuels such as butanol have been shown to improve reforming activity and reduce carbon monoxide emissions, and are less susceptible to separation in the presence of water than ethanol/gasoline blends, therefore allowing use of the industry's existing distribution infrastructure without requiring modifications to blending facilities, storage tanks or retail station pumps.

This paper concerns thermodynamic and transport properties of 1-butanol. The evaluation of experimental properties has become of high importance in the scientific community. Accurate empirical equations, models and simulation programs need to be fed with such experimental data to be useful. Moreover, for the optimized design of several industrial processes (storage, transport, separation and mixing processes), reliable experimental data are needed. Experimental property studies of pure 1-butanol and its mixtures with hydrocarbons and other oxygenates can provide valuable information about the fluid behavior under various temperature and pressure conditions The paper presents a review of thermodynamic (density, vapor-liquid equilibrium, specific heat, excess enthalpy) and transport (viscosity) properties of 1-butanol and its mixtures with hydrocarbons and oxygenates representatives of gasoline. This review could be of interest for the fuel and biofuel industry, within the production, transport and end-users (automotive) sectors.

INTRODUCTION

Increasing global concern due greenhouse gas emissions has generated much interest in the environmental friendly alternative bio-fuels. Bio-fuels for internal combustion engines as oxygenated compounds are also becoming important because of diminishing petroleum reserves and increasing air pollution [1, 2].

The oxygenated compounds used worldwide like simple alcohols and ethers, are used as gasoline additives to reduce pollutants from vehicle exhaust gases. Proponents of these oxygenates claim several advantages: they are octane enhancers, they have significant anti-knock properties important for unleaded fuels, they can be produced from renewable agricultural and raw materials instead of fossil sources, and they reduce carbon monoxide pollution from vehicle exhaust [3, 4]. Alcohols have higher octane number than gasoline, which can endure higher compression ratios before engine starts knocking, thus giving the engine the ability to deliver more power efficiently. Alcohols also burn cleaner than regular gasoline and produce lesser carbon monoxide, volatile hydrocarbons and oxides of nitrogen. Alcohols have higher heat of vaporization; therefore, they reduce the peak temperature inside the combustion chamber leading to lower oxides of nitrogen emissions and increased engine power.

Alternative and renewable energy technologies are being sought to reduce pollutant emissions and increase the efficiency of energy use. Recently n-butanol has been proposed as an alternative to conventional gasoline and diesel fuels [5, 6]. It is a higher member of the series of straight chain alcohols with each molecule of butanol ($C_4H_{10}O$) containing four carbon atoms rather than two as in ethanol. Interest in butanols as a second-generation biofuel has increased because they have many advantages over other potential alternative fuel candidates such as ethanol. At 85% by volume with gasoline, butanols can be demonstrated to work in the internal combustion engine designed for use with gasoline without modification (unlike 85% ethanol, E85). They have a higher energy content for a given volume than ethanol, and almost as much as gasoline. And butanol is an oxygenated hydrocarbon like methanol, ethanol etc. with a similar contribution to the antinocking effect. Oxygenated fuels have been shown to improve reforming activity and reduce carbon monoxide emissions, and are less susceptible to separation in the presence of water than ethanol/gasoline blends, therefore allowing use of the industry's existing distribution infrastructure without requiring modifications to blending facilities, storage tanks or retail station pumps. Butanol, which can be synthesized chemically or biologically, is an alternative transportation fuel since it has properties that would allow its use in existing engines with minor hardware modifications [6]. In October 2013, ASTM D7862 [7] was announced for blends of butanol with gasoline at 1 - 12.5 % vol in automotive spark ignition engines. The specification covers three butanol isomers: 1-butanol, 2-butanol, and 2-methyl-1-propanol. The specification specifically excludes 2-methyl-2-propanol (that is, tert-butyl alcohol)

Besides its use as fuel component, the literature classifies n-butanol as both an oxo-chemical derivative and a plasticizer alcohol for market purposes. The uses of butanol vary by geographic area, but in general it is used to make other chemicals, or used as a solvent or an ingredient in formulated products such as cosmetics. Applications, chemicals and products that use butanol include solvents, plasticizers, coatings, chemical intermediate or raw material, textiles, cleaners, cosmetics, drugs and antibiotics, hormones, and vitamins.

Since the 1950s, most butanol is produced commercially from fossil fuels. The most common process starts with propene (propylene), which is run through a hydroformylation reaction to form butyraldehyde, which is then reduced with hydrogen to 1-butanol and/or 2-butanol. Tert-butanol is derived from isobutane as a co-product of propylene oxide production. Butanol can also be produced by fermentation of biomass by bacteria. Prior to the 1950s, *Clostridium acetobutylicum* was used in industrial fermentation processes producing butanol. Research in the past few decades showed results of other microorganisms that can produce butanol through fermentation.

Butanol from biomass is called biobutanol [8], and it can be used in unmodified gasoline engines. Biobutanol can be produced by fermentation of biomass by the A.B.E. process. The process uses the bacterium *Clostridium acetobutylicum*, the bacterium for the production of acetone from starch (with the main use of acetone). The butanol was a by-product of this fermentation (twice as much butanol was produced). The process also creates a recoverable amount of H_2 and a number of other by-products: acetic, lactic and propionic acids, isopropanol and ethanol. Biobutanol can also be made using *Ralstonia eutropha*. This process requires the use of an electro-bioreactor and the input of carbon dioxide and electricity.

The difference from ethanol production is primarily in the fermentation of the feedstock and minor changes in distillation. The feedstocks are the same as for ethanol: energy crops such as sugar beets, sugar cane, corn grain, wheat and cassava, prospective non-food energy crops such as switchgrass and even guayule, as well as agricultural byproducts such as straw and corn stalks. According to DuPont [9], existing bioethanol plants can cost-effectively be retrofitted to biobutanol production.

This paper concerns thermodynamic and transport properties of 1-butanol, whose thermo-physical properties are shown in Table 1. The evaluation of experimental properties has become of high importance in the scientific community. Accurate empirical equations, models and simulation programs need to be fed with such experimental data to be useful. Moreover, for the optimized design of several industrial processes (storage, transport, separation and mixing processes), reliable experimental data are needed. Experimental property studies of pure 1-butanol and its mixtures with hydrocarbons and other oxygenates can provide valuable information about the fluid behavior under various temperature and pressure conditions

Table 1. Thermo-physical properties of 1-butanol [6].

Molar mass ($g \cdot mol^{-1}$)	74.12	Boiling point (ºC)	117.7
Density ($g \cdot cm^{-3}$)	0.81	Solubility in water ($g \cdot L^{-1}$ at 25ºC)	73

The paper presents a review of thermodynamic (density, vapor-liquid equilibrium, specific heat, heat of mixing) and transport (viscosity) properties of 1-butanol and its mixtures with hydrocarbons and oxygenates representatives of gasoline. Due to editorial limitations of the conference, the review includes only the interval of temperature and pressure of every property reported. Discussion of further data (uncertainties, experimental apparatus, etc.) would require more space than available. Interested readers should access literature references to check these issues.

NOMENCLATURE

C_P	[J/kg·K]	Specific Heat at Constant Pressure
H^E	[J/kg]	Excess Enthalpy
P	[kPa]	Pressure
T	[K]	Temperature
V	[m^3]	Volume
VLE	[-]	Vapour-liquid equilibria

Special characters

η	[mPa·s]	Viscosity
ρ	[kg/m^3]	Density

Subscripts

max	Maximum
min	Minimum

LITERATURE REVIEW

Thermodynamic and transport properties of liquid 1-butanol and its liquid mixtures with some ethers, alcohols and hydrocarbon have been obtained from a literature search using the on-line version of the NIST scientific database ThermoLit©.

Due to the scope and editorial limitations of this conference, a limited number of compounds have been chosen. Special attention is given to 1-butanol + oxygenates mixtures, while 1-butanol + hydrocarbon limits to one mixture. Apart from 1-butanol, the 8 ethers and 5 alcohols selected are some of those oxygenates that are in present or proposed use in unleaded gasolines [1, 2]. As representative of hydrocarbons, 2,2,4 trimethylpentane (iso-octane) has been selected. Table 2 presents the list of selected compounds. The review includes only the interval of temperature and pressure of every property reported.

Table 2. Selected ethers, alcohols and hydrocarbon.

Compound	CAS Number	Chemical Formula	Molar mass ($g \cdot mol^{-1}$)
	Ethers		
Dimethyl ether (DME)	115-10-6	C_2H_6O	46.07
Diethyl ether (DEE)	60-29-7	$C_4H_{10}O$	74.12
Methyl *tert*-butyl ether (MTBE)	1634-04-4	$C_5H_{12}O$	88.15
Tert-amyl methyl ether (TAME)	994-05-8	$C_6H_{14}O$	102.17
Ethyl *tert*-butyl ether (ETBE)	637-92-3	$C_6H_{14}O$	102.17
Dipropyl ether (DPE)	111-43-3	$C_6H_{14}O$	102.17
Diisopropyl ether (DIPE)	108-20-3	$C_6H_{14}O$	102.17
Dibutyl ether (DBE)	142-96-1	$C_8H_{18}O$	130.23
	Alcohols		
Methanol	67-56-1	CH_4O	32.04
Ethanol	64-17-5	C_2H_6O	46.07
1-Propanol	71-23-8	C_3H_8O	60.10
1-Butanol	71-36-3	$C_4H_{10}O$	74.12
1-Pentanol	71-41-0	$C_5H_{12}O$	88.15
1-Hexanol	111-27-3	$C_6H_{14}O$	102.17
	Hydrocarbon		
2,2,4 trimethylpentane (TMP)	540-84-1	C_8H_{18}	114.23

Concerning properties, there is a huge amount of available density data at atmospheric pressure, while high pressure data, which are scarce, add more critical information to determine the *PVT* behavior. Then, only high pressure density data are shown in Table 3 for 1-butanol and in Table 4 for binary mixtures. Heat capacity data for 1-butanol are provided only for atmospheric pressure, while no viscosity data is presented due to the editorial limitation of this paper. Tables 5 to 7 present the rest of the selected binary mixture properties, it is to say, excess enthalpy, vapor-liquid equilibria (VLE) and viscosity. No heat capacity data were found for the selected 1-butanol binary mixtures.

Table 3. Reported thermodynamic and transport properties for 1-butanol as pure compound.

Reference	Year	T_{min}/K	T_{max}/K	P_{min}/kPa	P_{max}/kPa
		Density, $\rho/g \cdot cm^{-3}$			
[10]	1931	273.15	368.15	49000	1176800
[11]	1942	298.15	348.15	980600	1863200
[12]	1963	292.69	553.83	290	50010
[13]	1975	298.14	333.13	1000	150000
[14]	1976	293.15	298.14	1000	7000
[15]	1979	297.30	558.42	1086	49410
[16]	1979	194.62	236.37	1086	49410
[17]	1980	200.01	559.96	1000	50000
[18]	1985	298.13	399.78	200	20500
[19]	1986	298.13	399.78	200	20500
[20]	1987	283.15	348.13	15500	206100
[21]	1990	298.20	348.20	689	6891
[22]	1993	298.15	298.15	2000	33900
[23]	1996	448.15	548.15	500	58600
[24]	1997	278.15	323.15	20000	60000
[25]	2002	273.20	473.12	285	39994
[26]	2003	316.85	458.15	4930	4930
[27]	2007	313.10	362.68	1013	25100
[28]	2007	313.08	362.67	999	24621
[29]	2011	313.15	313.15	1000	10000
[30]	2011	293.15	403.15	100	140000
[31]	2012	273.15	333.15	1000	140000
		Heat Capacity $C_p/ J \cdot kg^{-1}K^{-1}$			
[32]	1924	302.98	347.97	101	101
[33]	1949	298.14	298.14	101	101
[34]	1965	184.55	322.31	101	101
[35]	1986	321.04	522.11	101	101
[36]	1986	298.14	298.14	101	101
[19]	1986	298.14	368.13	101	101
[37]	1987	298.09	298.09	101	101
[38]	1993	298.15	298.15	101	101
[39]	1999	298.15	298.15	101	101
[40]	2002	278.15	348.15	101	101
[41]	2003	303.15	343.15	101	101
[42]	2004	298.15	298.15	101	101
[43]	2005	285.15	353.15	101	101
[44]	2007	293.15	353.15	101	101
[45]	2007	288.15	323.15	101	101
[31]	2012	273.15	333.15	101	101

DISCUSSION

Properties of pure 1-butanol

Table 3 reports 22 literature references related to high pressure density data of pure 1-butanol. With the exception of the two older references [10, 11], which did not report sample purities of the very high pressure data, most references correspond to measurements under 60 MPa. Only references [13], [20], [30] and [31] are above 100 MPa, but [30] is the only one above 400 K simultaneously. Data concerning heat capacity involves 16 references, all of them at atmospheric pressure. Most of them [33, 36-39, 42] are also at temperature close to 298.15 K. Reference [34] is the only one below 273.15 K, and the maximum temperature reported is 522 K [35].

Density of mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon

Table 4 presents density data for the selected 1-butanol mixtures. 40 references are shown. No data were found for liquid mixtures 1-butanol + DME, + DEE or + 1-hexanol. Only atmospheric pressure density data have been found for the rest of the binary mixtures, except references [24], [25] and [75] that are above 35 MPa. The highest pressure, 140 MPa, is reported by [75]. Temperatures above 350 K are only measured

by [25[, [75] and [122]. Only 1-butanol mixtures with DIPE and DBE have been measured at high pressure and temperature.

Table 4. Reported density ($g \cdot cm^{-3}$) for binary mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon.

Reference	Year	T_{min}/K	T_{max}/K	P_{min}/kPa	P_{max} /kPa
			DME		
-	-	-	-	-	-
			DEE		
-	-	-	-	-	-
			MTBE		
[49]	1995	298.15	298.15	101	101
[50]	1999	298.15	298.15	101	101
[51]	2002	288.15	308.15	101	101
[52]	2002	298.15	298.15	101	101
[53]	2011	293.15	308.15	101	101
			TAME		
[56]	2000	298.15	298.15	101	101
[57]	2001	298.15	298.15	101	101
			ETBE		
[59]	1998	298.15	298.15	101	101
[60]	2000	298.15	298.15	101	101
			DPE		
[62]	1988	298.14	308.14	101	101
			DIPE		
[24]	1997	278.15	323.15	100	60000
[66]	1999	298.15	298.15	101	101
[25]	2002	273.21	473.13	0.3	35008
[67]	2004	298.15	298.15	101	101
			DBE		
[71]	1998	298.15	298.15	101	101
[72]	2001	298.15	298.15	101	101
[73]	2006	298.15	298.15	101	101
[74]	2008	293.15	303.15	101	101
[75]	2011	293.15	393.15	100	140000
			Methanol		
[93]	1981	303.14	303.14	101	101
[37]	1987	298.14	298.14	101	101
[94]	1996	298.15	298.15	101	101
[95]	1997	293.15	293.15	101	101
[96]	1998	298.15	298.15	101	101
[97]	1999	298.15	298.15	101	101
[98]	2000	298.15	298.15	101	101
[57]	2001	298.15	298.15	101	101
			Ethanol		
[92]	1968	298.14	298.14	101	101
[109]	1979	298.14	298.14	101	101
[50]	1999	298.15	298.15	101	101
			1-Propanol		
[115]	1933	298.14	298.14	101	101
[92]	1968	298.14	298.14	101	101
[116]	1998	308.15	313.15	101	101
[117]	1999	293.15	298.15	101	101
			1-Pentanol		
[116]	1998	308.15	313.15	101	101
[117]	1999	293.15	298.15	101	101
			1-Hexanol		
[92]	1968	298.14	298.14	101	101
			TMP		
[122]	1936	298.74	363.12	101	101
[123]	1997	288.15	298.15	101	101
[124]	1997	293.15	293.15	101	101

Excess enthalpy of mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon

31 references in Table 5 present excess enthalpy data of mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon. Mixtures with DEE, MTBE and TAME were not found. Only reference [126] was measured at moderate pressure, 600 kPa for the mixture 1-butanol + TMP. No high pressure data was found for mixtures 1-butanol + ether, or + alcohol. All temperatures reported are also moderate, under 323 K. 21 references were measured at only ambient temperature and pressure.

Table 5. Reported excess enthalpy ($J \cdot kg^{-1} \cdot K^{-1}$) for binary mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon.

Reference	Year	T_{min}/K	T_{max}/K	P_{min}/kPa	P_{max} /kPa
			DME		
[46]	2007	323.15	323.15	101	101
			DEE		
-	-	-	-	-	-
			MTBE		
-	-	-	-	-	-
			TAME		
-	-	-	-	-	-
			ETBE		
[61]	1986	298.14	298.14	101	101
[60]	2000	298.15	298.15	101	101
			DPE		
[63]	1979	298.14	298.14	101	101
[64]	1982	298.14	298.14	101	101
[62]	1988	298.14	308.14	101	101
			DIPE		
[66]	1999	298.15	298.15	101	101
[68]	2001	298.15	298.15	101	101
[69]	2010	303.15	303.15	101	101
			DBE		
[76]	1966	298.14	298.14	101	101
[77]	1978	298.14	298.14	101	101
[78]	1985	298.00	298.00	101	101
[79]	1985	298.15	298.15	101	101
[71]	1998	298.15	298.15	101	101
[80]	2009	298.15	298.15	101	101
[81]	2009	298.15	313.15	101	101
[82]	2010	298.15	313.15	101	101
[83]	2010	298.15	298.15	101	101
[84]	2010	298.15	298.15	101	101
			Methanol		
[99]	1963	298.14	298.14	101	101
[100]	1967	298.14	298.14	101	101
[101]	1985	293.15	323.14	101	101
[79]	1985	298.15	298.15	101	101
			Ethanol		
[100]	1967	298.14	298.14	101	101
			1-Propanol		
[100]	1967	298.14	298.14	101	101
[118]	1972	303.14	303.14	101	101
			1-Pentanol		
-	-	-	-	-	-
			1-Hexanol		
[100]	1967	298.14	298.14	101	101
			TMP		
[125]	1979	298.14	298.14	101	101
[126]	1992	298.06	343.15	600	600
[83]	2010	298.15	298.15	101	101
[127]	2012	313.15	313.15	101	101

Vapour-liquid equilibria of mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon

35 VLE references of binary mixtures are shown in Table 6.

Table 6. Reported vapour-liquid equilibria for binary mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon.

Reference	Year	T_{min}/K	T_{max}/K	P_{min}/kPa	P_{max}/kPa
			DME		
[47]	2006	249.96	330.01	101	101
[46]	2007	323.15	323.15	4.61	1143.2
			DEE		
[48]	1955	408.93	558.58	1379	4136.9
			MTBE		
[54]	1999	328.11	390.88	101	101
[55]	2001	298.15	298.15	-	-
[52]	2002	313.15	313.15	3.19	59.56
			TAME		
[58]	2000	360.13	387.99	101	101
			ETBE		
[59]	1998	333.15	333.15	10.30	66.45
			DPE		
[65]	1997	278.15	323.15	0.2	25.14
			DIPE		
[70]	2006	313.15	313.15	2.49	37.10
			DBE		
[85]	1954	338.12	338.12	7.05	12.41
[86]	1954	338.12	338.12	7.05	12.41
[87]	1963	390.57	397.03	101	101
[88]	1979	390.47	408.62	101	101
[89]	1977	326.22	415.07	6.67	6.67
[90]	2006	388.15	404.15	101	101
[91]	2006	349.32	413.67	20	101
			Methanol		
[102]	1952	344.51	375.62	101	101
[48]	1955	408.93	558.58	1379	4136.9
[103]	1970	298.14	298.14	2.45	15.84
[104]	1971	337.98	377.47	101	101
[105]	1977	336.98	389.97	101	101
[106]	1986	313.14	313.14	2.52	35.45
[107]	2000	338.26	386.44	101	101
			Ethanol		
[110]	1927	351.42	390.73	101	101
[111]	1943	352.22	387.43	101	101
[112]	1953	351.47	390.18	101	101
[113]	1969	323.14	403.12	6.53	561.55
[106]	1986	313.14	313.14	2.52	35.45
[54]	1999	328.11	390.88	101	101
[114]	2006	351.42	390.73	101	101
			1-Propanol		
[110]	1927	351.42	390.73	101	101
[106]	1986	313.14	313.14	2.52	35.45
[119]	2001	337.15	373.74	21.9	114.05
[120]	2010	354.25	388.05	53.3	91.3
			1-Pentanol		
[106]	1986	313.14	313.14	2.52	35.45
[121]	1974	314.64	371.12	2.67	24
			1-Hexanol		
-	-	-	-	-	-
			TMP		
[128]	2006	308.15	318.15	-	-
[129]	2011	318.15	318.15	7.2	16.4
[130]	2012	313.15	313.15	2.55	13.71

VLE has been measured for all selected mixtures, with the only exception of the system 1-butanol + 1-hexanol. Some of the references present constant pressure measurements, while some other are at constant temperature, corresponding to the most frequent dynamic and static experimental apparatus used. 21 references [47-48, 54, 58, 65, 88-91, 102, 104-105, 107, 110-114, 119-121] vary temperature and pressure simultaneously. Maximum pressures are moderate, under 4.2 MPa, and many of them are well under atmospheric pressure. Temperatures above 400 K are only reported by [48], [88-91] and [113].

Viscosity of mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon

Viscosity data of chosen binary mixtures are very scarce, as shown in Table 7. Viscosity of 1-butanol + MTBE is the only found mixture with ethers, while mixtures with alcohols (methanol, ethanol, 1-propanol and 1-pentanol) are more frequent. All data were taken at atmospheric pressure, while temperatures are ambient temperature or close values (up to 313 K). No data of viscosity for 1-butanol + TMP was found.

Table 7. Reported viscosity (mPa·s) for binary mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon

Reference	Year	T_{min}/K	T_{max}/K	P_{min}/kPa	P_{max}/kPa
			DME		
-	-	-	-	-	-
			DEE		
-	-	-	-	-	
			MTBE		
[49]	1995	298.15	298.15	101	101
[53]	2011	293.15	308.15	101	101
			TAME		
-	-	-	-	-	-
			ETBE		
-	-	-	-	-	-
			DPE		
-	-	-	-	-	-
			DIPE		
-	-	-	-	-	
			DBE		
-	-	-	-	-	-
			Methanol		
[93]	1981	303.15	303.15	101	101
[108]	1998	298.15	298.15	101	101
			Ethanol		
-	-	-	-	-	-
			1-Propanol		
[115]	1933	298.15	298.15	101	101
[116]	1998	308.15	313.15	101	101
[117]	1999	293.15	298.15	101	101
			1-Pentanol		
[116]	1998	308.15	313.15	101	101
[117]	1999	293.15	298.15	101	101
			1-Hexanol		
-	-	-	-	-	-
			TMP		
-	-	-	-	-	-

CONCLUSION

Thermodynamic and transport properties of liquid 1-butanol and its liquid mixtures with some ethers, alcohols and hydrocarbon have been reported. 8 ethers, 5 alcohols and 1 hydrocarbon have been selected as representative of present and future unleaded gasolines.

Reliable high pressure density data of pure 1-butanol are available up to 400 K and 140 MPa, while most heat capacity values have been measured at atmospheric pressure and low temperatures.

Concerning the binary mixtures 1-butanol + ether, or + alcohol, or + hydrocarbon, high pressure density data have been found only for 1-butanol + DIPE, or + DBE. Though atmospheric pressure data are valuable, more high temperature and pressure *PVT* data should be performed for oxygenate and hydrocarbon binary systems.

With relation to the excess enthalpy, no high pressure data was found for mixtures 1-butanol + ether, or + alcohol. All temperatures reported are also moderate, under 323 K.

VLE data at low temperature and pressure are the most frequent for the selected mixtures. Data at high temperature, above 400 K, are very scarce. Availability of high pressure data should be strongly recommended.

Viscosity data are almost unavailable for most binary 1-butanol + ether systems, while 1-butanol + alcohol mixtures are more frequent data. Nevertheless, only low pressure and temperature data are reported.

Though heat capacity could be derived from other thermodynamic properties, it is surprising that no experimental data on this property were found for the concerned binary systems.

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