A REVIEW STUDY ON LPG AS AN ALTERNATIVE REFRIGERANT

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ABSTRACT

This study reviews the literature, which has numerous works on the use of LPG, a hydrocarbon fuel utilized in many types of equipment, as an alternative refrigerant without any change in refrigerators, air conditioners, and similar cooling devices at various sizes. Referring to the results obtained from these studies LPG provides improvement of COP, reduction of the refrigerant amount used and energy saving compared to the other refrigerants in cooling devices draw attention of scientists. Outlining the results of the works given in this study, COP improvement, refrigerant reduction by mass, and energy saving reach to the values of 25.1%, 50%, and 90%, respectively, in case of using LPG instead of convensional refrigerants in different types of cooling machines.

Keywords: LPG, refrigerant, cooling machines, energy saving.

INTRODUCTİON

In our days, improvement of cooling systems is a significant issue due to the concerns about energy efficiency and environmental reasons. Having good refrigerating behaviors for cooling devices, environmentally friendly hydrocarbon refrigerants -mainly propane, butane, and isobutane, which constitute LPG- have been researched by scientists in several appliances in recent years. The authors recommend in their studies that those hydrocarbon gases can be used in cooling devices as refrigerants instead of ozone layer damaging conventional refrigerant gases (Mohanraj et al., 2009). In addition to the better cooling features, hydrocarbons have other advantages such as being economical and available in large quantities (Mohanraj et al., 2009; Meyer, 1998; Peixoto, et al., 2000). Furthermore, they have an environment productive nature with zero ozone depletion and greenhouse effect potential (Mohanraj et al., 2009). The only noteworthy disadvantage of hydrocarbons is that they must be used carefully in cooling devices, since they are flammable (Meyer, 1998).

In this study, LPG has been compared with conventional refrigerants in terms of their relevant properties and obtained results from works encountered in literature when they are used in cooling devices. Multiple comparisons of the outstanding results of the studies will lead new researchers to work on the issue. Thus, properties of LPG constituting propane, butane, isobutane and some common refrigerants are given, and prominent results for different situations the authors found are reviewed with this investigation. LPG is a good substitute for common refrigerant gases is presented in conjunction with reasons.

LPG as a refrigerant

Refrigerants are used in heat engines such as heat pumps, air conditioners, and refrigerators as process gases circulating in a closed loop through the device.While corrosive, toxic, explosive, and flammable properties are undesirable characteristics for ideal refrigerants, low boiling point, high latent heat of vaporization, and high critical temperature are the appropriate thermodynamic properties. A comparison of some refrigerants to propane, butane, isobutene is given in Table 1.

Upon considering the table, it is clearly seen that LPG is a good substitute for common refrigerant gases with its thermodynamic and environmental features. For instance, LPG constituting gases, which are coded with the letter R referring that they are refrigerants and a number i.e. R290 for propane, R600 for butane, and R600a isobutane, have a higher latent heat of vaporization and lower boiling temperature compared to the other refrigerants (Fig.1 and Fig.2).

Higher latent heat of vaporization and lower boiling temperature of LPG allows it to have a higher cooling effect, and this provides more cooling with less mass flow rate. The meaning of a cooling machine that needs less refrigerant flow is the compressor of the machine operates less consuming lower energy. And this will also lower the environmental hazards arising from energy consumption. Furthermore, the compressor could be manufactured smaller and lighter decreasing the valume, weight and price of the system.

On the other hand, there are two features of refrigerants crucial for the environment. They are ODP (ozone depletion potential) and GWP (global warming potential). When we check the table, we see that those values of LPG are little or nothing compared to other refrigerants. ODP value of LPG is zero and its GWP value is

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3, which the other refrigerants have a GWP of over 1300. Zero ODP value of LPG shows it is not harmful to the ozone layer, and compared to other commonly used refrigerants, nearly a thousand times lower GWP value of LPG indicates that it does not contribute to the global warming.

The only disadvantage of LPG is its explosion feature, as it is seen from the table. For this reason, LPG should be handled with carefully in cooling devices, as that is also carried out in other usage of all hydrocarbons.

Studies on the use of LPG as an alternative refrigerant

In literature, there are numerous studies that LPG constitutes conventional refrigerants as an alternative without any change in refrigerators, air conditioners and similar cooling devices at various sizes. In this respect, prominent ones of those studies between the years of 1991-2015 are given in Table 2 as examples. When we refer to these studies, following results could be obtained in general draw attention: improvement of COP, reduction of the refrigerant amount used, and energy saving in the cooling machines. Increase in COP, decrease in refrigerant charge, and decrease in energy consumption have been found between the values of 1-25.1%, 14.6-50%, and 3-90%, respectively. There have been nearly no negative results in the authors' experiments and calculations, and the worst result of LPG has been similar performance and similar capacity. Thus, it has been understood from the studies that LPG can be used as a refrigerant; even it has a higher cooling effect than the other refrigerants. The reason that LPG has better cooling properties comparing to the other refrigerants is mostly because of its higher latent heat of vaporization.

Table1: Comparison of some refrigerants (Mohanraj et al., 2009; World Meteorological Organization, 1991; IPCC, 1994; Maclaine-cross and Leonardi, 1995; Wongwises, et al., 2006; Calm and Hourahan, 2001; Rasti et al., 2012; Jwo et al., 2009; Hesselgreaves, 2001; Ed. Kreith, 2000; Leonardi and Maclaine-cross, 1995; Kara, 2008; Beser, 1997; Özkol, 1999; Dossat, 1997; NIST, 2002; Hwang et al., 2004; Beşer, 1998; Şengür, 2005)

Refrigerant	R11	R12	R22	R134a	R290	R600	R600a
Common name	Trichloro fluoro methane	Dichloro difluoro methane	Chloro difluoro methane	1,1,1,2-Tetrafluo roethane	Propane	Butane	Isobutane
Chemical formula	CCl_3F	CCl_2F_2	$CHClF_2$	F_3CCH_2F	C_3H_8	C_4H_{10}	C_4H_{10}
Refrigerant class	CFC	CFC	HCFC	HFC	HC	HC	HC
Molecular mass (g/mol)	137.37	120.91	86.47	102.03	44.1	58.13	58.13
Density (kg/L)	1.47 (21.1°C)	1.34 (30°C)	1.21 (21.1°C)	<1.22	0.500 (20°C)	0.579 (20°C)	0.564
Vapor density (air=1)	4.8	4.2	3	3.5	1.6	2	2
Boiling point (°C)	-23.8	-29.8	-40.8	-26.1	-42.1	-0.4	-11.7
Critical point (°C)	198	111.8	96.2	101.08	96.67	152	135
Critical pressure (bar)	44.1	41.1	49.9	40.6	42.5	38	36.5
ODP	1	1	0.07	0	0	0	0
GWP (100 years)	3400	8500	1700	1300	3	3	3
Latent heat of vaporization at 1 atm (kJ/kg)	227.3	165.24	-	216.87	427.8	385.2	364.25
Life in the atmosphere (years)	-	130	15	16	<1	<1	<1
Explosion limits (in air% by volume)	Not explosive	Not explosive	-	Not explosive	2.3 - 7.3	1.6 - 6.5	1.8 - 8.4

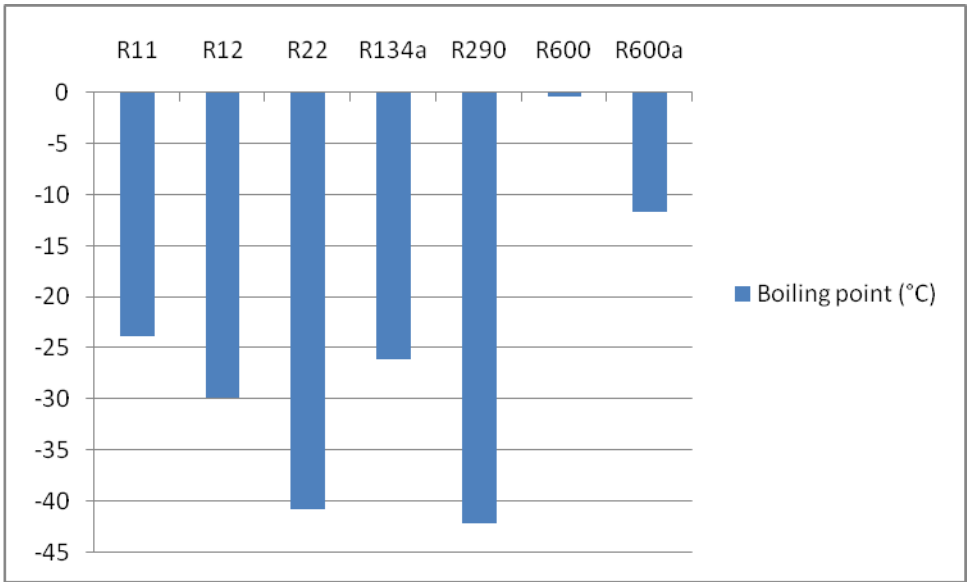

Figure 1: Boiling points of common refrigerants

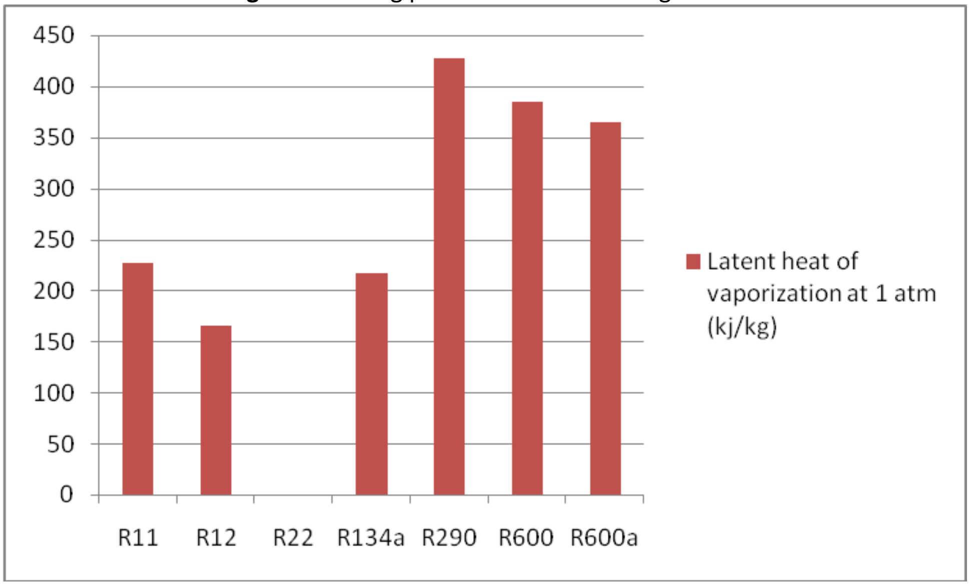

Figure 2: Latent heat of vaporization of common refrigerants

Table 2: Studies on the use of LPG as an alternative refrigerant by year

Date	Author(s)	Appliance	Refrigerant	Alternative	Results
1991	Dieckmann et al.	Automobile air conditioner	-	HC	* 4% decrease in fuel consumption.
1994	Rivis and Bidone	Theoretical	R12	50% propane + 50% isobutane	* Similar performance. * 3.2 COP value in Te=-15°C.
1994	Abboud	Automobile air conditioner	R12	HC	* 13% decrease in energy consumption.
1995	Richardson and Butterworth	Refrigerator	R12	50% propane + 50% isobutane	* Increase in COP. * Lower refrigerant amount. * Lower compressor body temperature.
1995	Leonardi and Maclaine-cross	Automobile air conditioner	R12	LPG	* 10% higher refrigerating effect.
1995	Liu et al.	Refrigerator	R12	70% propane + 30%	* Lower energy consumption.

				butane	
1995	Parmar	Automobile air conditioner	R12	HC	* 13% decrease in energy consumption.
1996	Jung et al.	Refrigerator	R12	20-60% propane + 80-40% isobutane	* 2.3% increase in COP. * 3% energy saving from the total energy consumption.
1996	Choi et al.	Heat pump	R22	Propane / isobutane	* Better COP value. * Decrease in capacity.
1998	Meyer	Theoretical	R22	LPG	* Almost the same cooling capacity.
1998	Alsaad and Hammad	Refrigerator	R12	24% propane + 58% butane + 18% isobutane	* 3.4 COP value at Te=-15°C and Tc=27°C.
1998	Purkayastha and Bansal	Heat pump	R22	Propane	* 18% increase in COP.
1999	Hammad and Alsaad	Refrigerator	R12	50% propane + 38.3% butane + 11.7% isobutane	* Higher COP.
1999	Ghodbane	Automobile air conditioner	R134a	Propane	* Increase in performance.
1999	Jung et al.	Automobile air conditioner	R12	60% propane + 40% isobutane	* Similar performance.
2000	Jung et al.	Refrigerator	R12	20-60% propane + 80-40% isobutane	* 2.3% increase in COP. * About 3-4%increase in energy efficiency.
2000	Peixoto et al.	Water cooler	R134a	Isobutane	* Improvement in COP. * 13% decrease in energy consumption. * 50% decrease in refrigerant amount.
2000	Chang et al.	Heat pump	R22	Propane	* Improvement in COP.
2003	Akash and Said	Refrigerator	R12	30% propane + 55% butane + 15% isobutane	* 3-4 times higher cooling capacity.
2003	Elefsen et al.	Ice cream machine	R404a	Propane	* 90% decrease in energy consumption.
2003	Chaichana et al.	Heat pump	R22	Propane	* Similar performance.
2003	Joudi et al.	Automobile air conditioner	R12	Propane / isobutane	* Similar results.
2004	Urchueguia et al.	Compressor	R22	Propane	* 13-20% decrease in cooling capacity. * 1-3% increase in COP value.
2005	Wongwises and Chimres	Refrigerator	R134a	60% propane + 40% butane	* Lower energy consumption due to higher latent heat of LPG.
2006	Fatouh and El Kafafy	Refrigerator	R134a	60% propane + 20% butane + 20% isobutane	* 7.6% higher COP. * 4.3% decrease in power.
2006	Park and Jung	Household air conditioners	R22	Propane	* Similar cooling capacity. * Higher COP.
2006	Wongwises et al.	Automobile air conditioner	R134a	50% propane + 40% butane + 10% isobutane	* Increase in COP. * Similar cooling capacity.
2008	Mani and Selladurai	Vapor compression refrigeration system	R12 and R134a	Propane / isobutane	* Higher cooling capasities between 19.9-50.1% from R12, and 28.6-87.2% from R134. * 3.9-25.1% higher COP from R12.

2009	Jwo et al.	Refrigerator	R134a	50% propane +50% isobutane	* Better cooling effect. * 4.4% saving from the total consumed energy. * 40% decrease in refrigerant amount used by mass.
2009	Mohanraj et al.	Refrigerator	R134a	45.2% propane + 54.8% isobutane	* 11.1% decrease in energy consumption of the compressor.
2009	Ravikumar et al.	Automobile air conditioner	R12	R134a / propane / isobutane	* Similar performans.
2010	Dalkilic and Wongwises	Vapor compression refrigeration system	R12 and R22	40% propane + 60% isobutane	* The most suitable alternative refrigerant mixture.
2012	Rasti et al.	Refrigerator	R134a	56% propane + 44% isobutane	* 13% decrease in operating time of the compressor. * 5.3% decrease in daily energy consumption.
2013	Rasti et al.	Refrigerator	R134a	46% isobutane + 54% propane / isobutane	* 7-14% decrease in energy consumption. * 14.6-18.7% decrease in refrigerant charge.
2014	Teng and Yu	Refrigerator	R134a	65% propane + 35% isobutene / 50% propane + 50% isobutene / isobutane	*40% decrease in refrigerant charge. * Lower electricity consumption. * Lower on-time ratio.
2015	El-Morsi	Theoretical	R134a	Propane / butane	* Increase in COP.

CONCLUSİON

LPG is a kind of hydrocarbon gas, consisting of propane, butane, and isobutene at different rates, and is used mostly as fuel in heating appliances, cooking equipment, and vehicles.The little-known feature of LPG is its good refrigerating property and with that it can be used in cooling appliances as a refrigerant. There are numerous works on the usage of LPG as a refrigerant in cooling devices.

This study reviews the comparison of LPG to some common refrigerants in respect of cooling properties and featured results of works that LPG is used as a refrigerant in cooling devices substituting other refrigerants. As understood from the properties of LPG and the aforementioned works, LPG can be used as a refrigerant in refrigerators, air conditioners, and other cooling devices without any change providing higher COP, lower refrigerant amount, and energy consumption. COP improvement, refrigerant reduction by mass, and energy saving reach to the values of 25.1%, 50%, and 90%, respectively, in case of using LPG instead of convensional refrigerants in different types of cooling machines.

Benefitting from the refrigerating feature of LPG, cooling devices can be charged directly with LPG, those appliances can be improved for a higher efficiency, new equipments can be designed, and even some novel systems like integrated fuel and air conditioning systems for LPG powered vehicles can be produced. As authors of this study, we suggest that all equipments that utilize LPG as a fuel or so on should be checked and modified with small changes if possible to take advantage of this refrigerating effect of LPG.

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