Journal of Kerbala University , Vol. 6 No.2 Scientific. 2008

Domestic Refrigerator Energy Testing with Alternative Refrigerants

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Abstract:

As a result of the Montreal protocol (**UNEP, 1987**) that limits the production of ozone-depleting refrigerants, manufacturers are searching for alternatives to replace the R12 that is presently used in domestic refrigerator-freezers. Before an alternative can be selected, several issues must be resolved. Among these are energy impacts system, compatibility, cost, and availability. In an effort to determine the energy impact of some of the alternatives, energy consumption tests were preformed in accordance with section 8 of the Association of Home Appliance Manufacturers (**AHAM**) standard for household refrigerators and household freezers (**AHAM, 1985**). The results are presented for a 9 ft^3 (0.2548 m^3) top-mount refrigerator-freezer with static condenser using the following refrigerants: R12, R290/R600a, R134a/R22, and R134a. All refrigeration components remained the same throughout the tests, except that the length of the capillary tube, compressor size, and the amount of the charge were changed for each refrigerant. The experimental results from **AHAM** test obtained with the same compressor used with R12 indicated that the hydrocarbon mixture of R290/R600a at 61% mass fraction of R290 showed a (3-4)% increase in energy efficiency and a faster cooling rate as compared with R12. On another side the R134a/R22 mixture with 0.48 mass fraction of R22 result was more promising (12% lower energy consumption) relative to R12 with changes to refrigeration system, such as a different capillary tube and compressor. Meanwhile the R134a was less promising (7.5% higher energy consumption) using different capillary tube and compressor size as compared with R12. It is noted that the test results are only an initial step in determining a replacement for R12. Further analysis should be performed to determine long-term effects on compressor life and operation over a wide range of ambient temperature.

الخلاصــــــــــة :

بموجب اتفاقيات بروتوكول مونتريال عام1987 والتي حددت أنتاج موائع التثليج المؤثرة على البيئة مما دفع المصنعين للبحث عن بدائل مناسبة الى مائع التثليج R12 والذي يستخدم في الثلاجات المنزلية. وقبل أختيار مائع التثليج البديل المناسب فأن هناك الكثير من العوامل التي يجب الاهتمام بها ومنها: متطلبات الطاقة الكهربائية والملائمية والكلفة و التوفير. ومن اجل الحصول على متطلبات الطاقة الكهربائية للنظام المستخدم لهذه البدائل ، يجب أختبار أستهلاك الطاقة الكهربائية حسب توصيات القسم الثامـــــــن لجمعية المصنعين التطبيقيين المنزلية (AHAM) للثلاجات والفريزرات القياسية. ان النتائج المعدة في هذا البحث تم استخراجها بأستخدام ثلاجـــة حجم ($9\ ft^3$) ذات مبخر freezer في الجزء العلوي للثلاجة مع مكثف ثابت خلفها وبأستخدام موائـــــــــع التثليج الآتية : , R290/R600a , R134a/R22 , R12 R134a . تم تغيير طول الانبوب الشعري وحجم الضاغط وكمية مائع التثليج مع الحفاظ على بقية مكونات نظام التثليج على حالها عند استبدال مائع التثليج بأخـــر. بينت النتائج العملية المستحصلة بموجب أختبار AHAM وباستخدام نفس الضاغط المستخدم مع R12 بأن الخليط الهيدروكاربوني R290/R600a عند النسبة الكتلية % 61 من R290 يمتلك زيادة من (3 - 4) % في كفاءة الطاقة ويكون اكبر معدل تبريد مقارنة مع R12. من جهة اخـــرى ، فأن الخليط R134a/R22 عند النسبة الكتلية 48% من R22 يكون أقل أستهلاك في الطاقة الكهربائية بنسبة % 12 مقارنة مع R12 مع تغيير لبعض مكونات نظام التثليج مثل طول الانبوب الشعري والضاغط . بينما بينت النتائج ايضا" ان النظام المجهز بـــ R134a يكون أكثر استهلاك للطاقة الكهربائيـــــــة بنسبة % 7.5 وبأستخدام أنبوب شعري وضاغط مختلف عما هو عليه بالنسبة الى R12 . ان الاختبارات والنتائج المستحصلة في هذا البحث تتطلب التعمق بأيجاد مختلف العوامل المؤثرة على عمر الضاغط والظروف التشغيلية المختلفة عند العمل بمديات اخرى لدرجات حرارة المحيط المختلفة.

Key words: Domestic refrigerator, Alternative refrigerants, Experimental analysis of refrigeration systems, Energy-optimized refrigeration systems, Capillary tube - Compressor performance analysis.

Introduction:

The Montreal Protocol has created a major problem for refrigerator-freezer manufactures. They are faced with trying to reduce energy consumption in the same time period in which they must begin using replacement refrigerants that may increase energy consumption. Adding to this dilemma, most changes in refrigeration system design require long lead times to implement in production, and requirements for replacement refrigerants will cause many candidates to be eliminated in the early going. Some of the requirements are that the refrigerant must be nontoxic, stable, nonflammable, compatible with lubrication oils, similar in thermodynamic performance, and available at low cost. Compromises will probably be made in some of these criteria in order to ensure that the energy efficiency targets are met. An outside influence on the choice for replacements involves the refrigerant selected for automotive air-conditioning system. Automobile air-conditioning requires approximately (12-20) times more R12 than refrigerator-freezers, thus giving the automobile manufactures a larger voice in the replacement refrigerants produced (**Satt, 1988**). However, automobile manufactures are not concerned with energy efficiency of air-conditioning system since it has little effect on the gas mileage. For this reason, a replacement for R12 that does not meet the energy-efficiency needs of refrigerator-freezer manufactures may be produced.

Boot (1990), Radermacher *et al.* (1993), Jurgensen (1995), Tiedemann and **Kruse (1995), Junge *et al.* (1996), *Dossat*** and ***Horan*** **(2002)** and ***Sattar et al.*** **(2007)** have done work in the issue of alternative refrigerants (R134a, R152a, R409A, R409B, R290, R744, R600a) but none of these works, his to our knowledge, led to a general methodology for the optimum choice for selecting between these refrigerants.

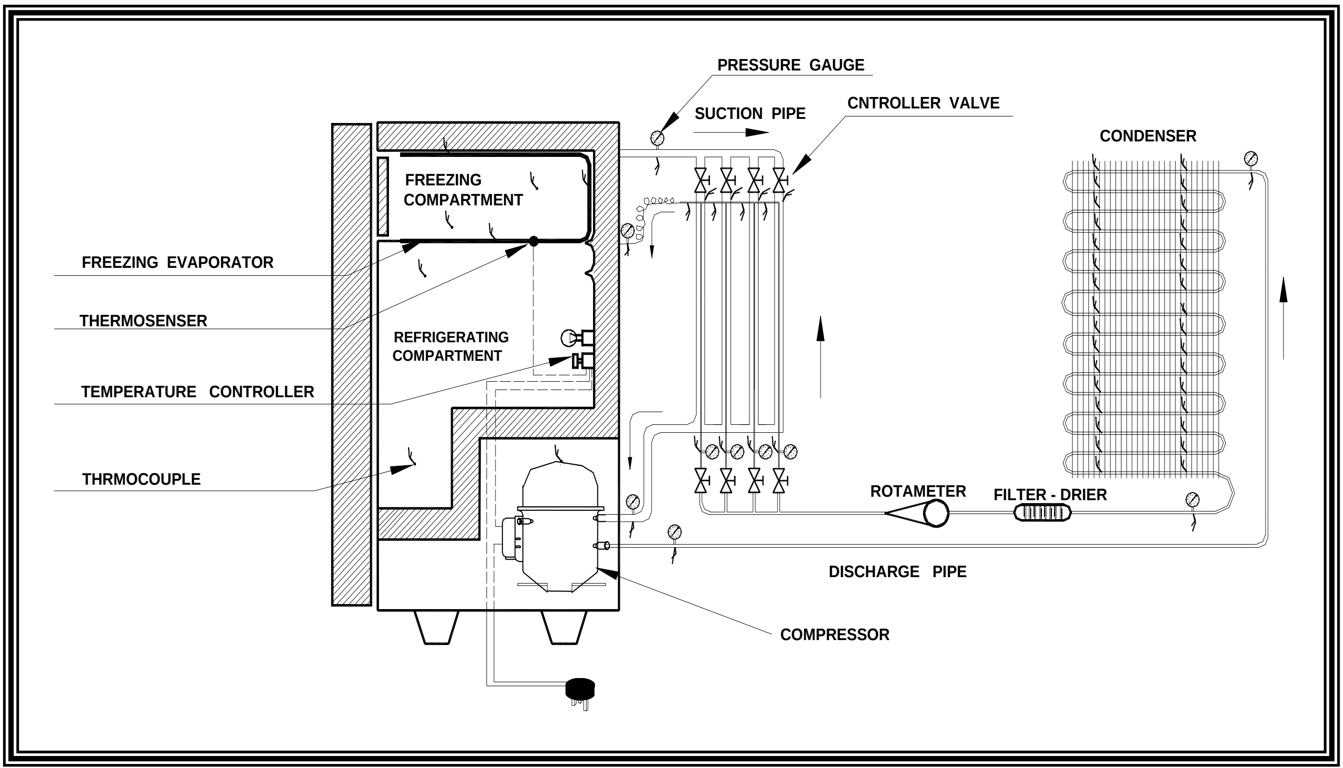
Test procedure:

Testing of several alternative refrigerants to determine the estimated annual energy consumption was performed in a 9 ft^3 (0.2548 m^3) refrigerator-freezers in accordance with section 8 of the **AHAM** standard for household refrigerators and household freezers (**AHAM, 1985**). The refrigerator was fully instrumented with more than 64 thermocouples, 10 pressure gauges, and digital watt and watt-hour meters and a high precision rotameter with a range of (0-10 cc/sec. water) for measuring the flow rate of the refrigerant and the locations of this instruments shown in figure (1). In order to optimize the capillary tube size for the mixture refrigerants, the refrigerator was equipped with four of the same inside capillary tubes diameter (0.71 mm) and different length (2.5, 3.0, 3.6, 4.0 m respectively). The presented test results are then used to calculate the energy consumption based on a -10°F(-23.3°C) freezer reference temperature and test room conditions are that the ambient temperature must be 32°C ±2.5°C.

The procedure for loading the charge was to first evacuate the system to a minimum vacuum of 10 microns of mercury (1.33E-06 Pa). The refrigerant was then weighed into the refrigerator-freezer as a vapour on the low side using a laboratory balance. If a refrigerant mixture was used, the high boiler refrigerant was charged first. If a premixed mixture was being tested (such as 61% R290/ 39% R600a), the refrigerant was charged as a liquid rather than vapour. For most of the high boiling refrigerants, it was necessary to heat the charging cylinders to raise the pressure to a point where the refrigerant would flow into the refrigerator-freezer.

Results:

A total of four refrigerants, including R12, were tested. The three alternative refrigerants were R290/R600a, R134a and R134a/R22. Refrigerants were selected on the basis



R134a Tests:

R134a is one of the alternative refrigerants mentioned most often as a replacement for R12. From thermodynamic data (**Wilson and Basu, 1988**), it can be estimated that R134a has a lower cooling capacity and operates at lower suction and higher discharge pressures than R12 for the same evaporation and condensing temperatures. Based on this information, a larger compressor would be necessary to achieve cooling capacities equivalent to those obtained with R12. Test results obtained from the present work are listed in table (1) for R134a and polyolester oil with a viscosity semi similar to that of the mineral oil used with R12. The results show an increased energy consumption of 7.5% relative to R12. Compressor run time was higher than those for R12, indicating that the capacity of R134a is lower, as previously estimated from the thermodynamic data.

R134a/R22 Tests:

R134a/R22 has been mentioned as a possible replacement for R12 on the basis of its low ozone depletion potential (less than 0.05). The experimental results obtained with the same compressor used with R134a indicated that R134a/R22 mixture in the composition range 0.12 to 0.48 mass fraction of R22 showed a 6% to 12% increase energy efficiency and a faster cooling rate as compared to R12. The R134a/R22 mixture at 0.48 mass fraction of R22 showed an optimum composition of this mixture, which gives maximum increase in energy efficiency and a shorter compressor on-time and lower compressor dome temperature than R12. Tests with this mixture were originally performed using polyolester oil identical to that used with R134a.

R290/R600a Tests:

R290/R600a, a mixture of 61 wt% R290 and 39wt% R600a, is a long-term, zero-ozone-depletion-potential replacement for the refrigerant R12. The experimental results obtained with the same compressor and mineral oil used with R12 indicated that the R290/R600a mixture at 0.61 mass fraction of R290 showed a 3% to 4% increase in energy efficiency and faster cooling rate as compared to R12. The R290/R600a mixture showed a shorter compressor on-time and lower compressor dome temperature than R12.

Table (1) Refrigerant Test Results of The Present Work for Alternative Refrigerant Versus R12 at Ambient Temperature 32°C.

Refrigerant	*Oil*	*Charge*		*Capillary Tube Length (m)*	*Compressor Swept Volume (cm^3)*	*Energy Consumption (kW. h/day)*	*Energy Consumption % Increase*
		(oz)	(g)				
R12	**Mineral-150**	**8.46**	**240**	**3.6**	**5.70**	**1.132**	**-**
R134a	**Polyolester**	**8.18**	**232**	**3.0**	**5.99**	**1.217**	**+7.5**
R290/R600a (61/39)	**Mineral-150**	**3.24**	**92**	**4.0**	**5.70**	**1.085**	**-4.0**
R134a/R22 (52/48)	**Polyolester**	**6.70**	**190**	**2.5**	**5.99**	**0.995**	**-12.0**

In comparison with the computational results of Hussain and Murtadha 2003, the experimental results yield results accurate to within (4.54%) for the compressor input power and (5.74%) for the coefficient of performance (COP) using R12 and (4.3%) for the compressor input power and (5.32%) for COP using R134a. The verification is done for within domestic refrigerator operation within range of ambient room conditions from (20^o C to 35^o C) as shown in figures (2) to (5) respectively.

Conclusion and Recommendations:

The following conclusion and recommendations apply only to domestic refrigerator-freezers and more specifically to the particular unit tested. Other refrigeration systems, such as heat pumps, operate at different conditions that could affect the refrigerant performance and thus alter the result. In addition, the conclusions are based on only one test series for determine energy consumption and are not sufficient to adequately predict the overall performance of the system under other conditions such as pull-down and elevated ambient temperatures. Therefore, further tests, such as system reliability and accelerated life, are required before a final decision can be made as to the adequacy of the alternative refrigerants.

- The use of R134a as an alternative refrigerant along with polyolester oil resulted in a 7.5% increase in energy consumption compared to R12.
- R134a/R22 is possible short-term alternative on the basis of reduced energy consumption. The reason it is only short-term alternative is that still contain R22, which is in the process of being phased out of production. However, the tests results reveal that a reduction of approximately 90% to 95% in the ozone depletion potential could be realized from it use.
- The hydrocarbon mixture of 61 wt.% R290/39 wt.% R600a has 4% lower energy consumption than R12 when run in a system with a mineral oil.

The preceding results were for a modified refrigeration system by using a different compressor and optimizing the capillary tube size for each alternative refrigerant. The possibility exists that some of the results could be altered by changing the system design either by using a different condenser and evaporator size. Additionally, results could be affected by testing in another manufacturer’s product.

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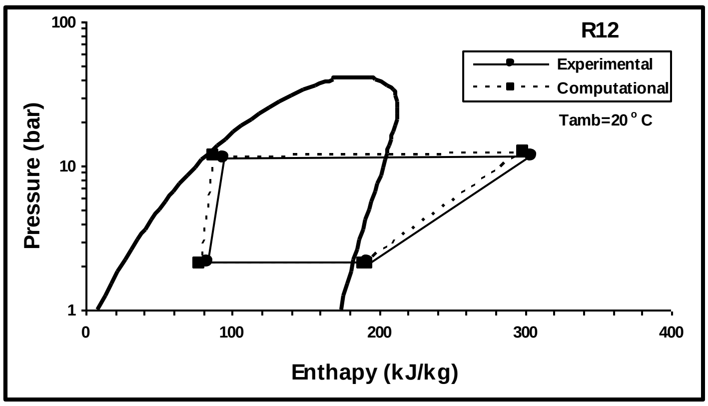

Figure (2) Comparison Between The Present Experimental Results and Computational Results of Hussain and Murtadha 2003 Using R12 at Ambient Temperature (20°C)

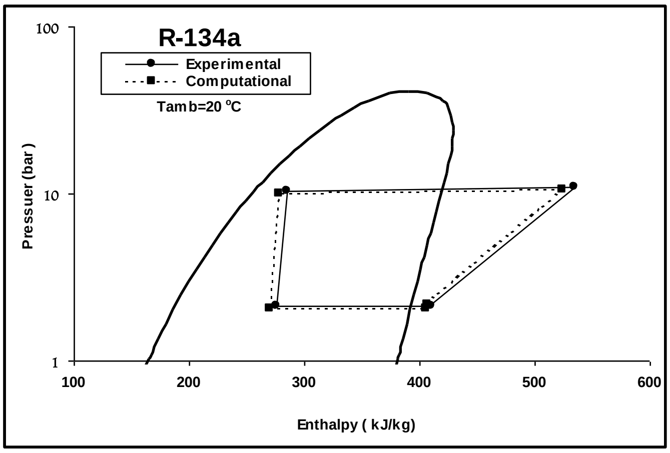

Figure (3) Comparison Between The Present Experimental Results and Computational Results of Hussain and Murtadha 2003 Using R134a at Ambient Temperature (20°C)

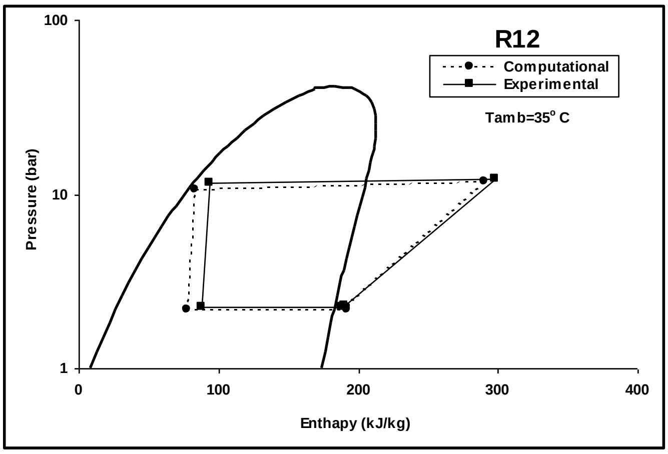

Figure (4) Comparison Between The Present Experimental Results and Computational Results of Hussain and Murtadha 2003 Using R12 at Ambient Temperature (35°C)

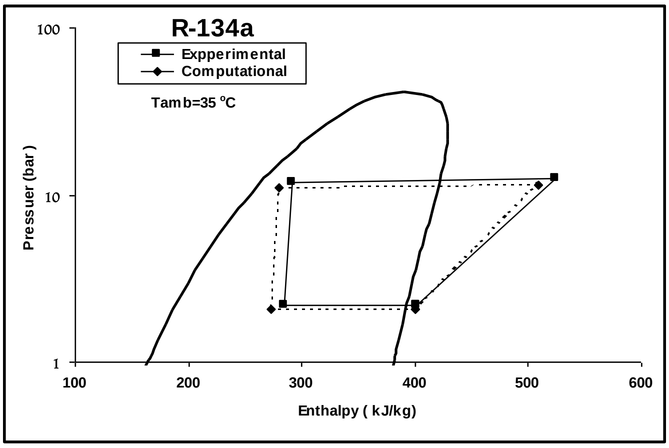

Figure (5) Comparison Between The Present Experimental Results and Computational Results of Hussain and Murtadha 2003 Using R134a at Ambient Temperature (35°C)