A STUDY ON THE EXPLOSION SAFETY ASSESSMENT OF HYDROCARBON REFRIGERANT REFRIGERATOR

Kyu-hyung Oh, Min-kyu Kim
Division of Safety Engineering, Hoseo University, Korea

Euy-sung Chu, Byung-han Lim, Man-hoe Kim, Yoon-ser Park
Living System R&D Center, Samsung Electronic Co., LTD, Korea

ABSTRACT

This paper discribes an experimental explosion risk assessment study on refrigerators containing flammable hydrocarbon refrigerant. A refrigerator used in this study is a larder fridge type, 215 liter in volume. The hydrocarbon refrigerant used in the refrigerator is iso-butane(C_4H_{10}). For the explosion safety assessment of the refrigerator, temperature of compressor, cooling air circulation fan motor, defrost heater and inner lamp were measured during the operation. And to confirm the ignitablity of flammable gas by the electric spark of the switches of the refrigerator, ON-OFF test of all switches were conducted with compulsorily near the stoichiometric concentration atmosphere of iso-butane-air mixture.

As the result of experiment above mentioned and another experiment for the explosion safety assessment, we can conclude that explosion hazard in connection with the use of hydrocarbon refrigerant was few.

1. Introduction

After the Montreal protocol, CFC alternative refrigerants are developing with remarkably, and many kinds of alternatives were developed. However, the choice of alternative refrigerant is still being debated. HFC-134a is the most favoured alternativ to CFC-12 in the United States, Japan and other countries but it is not free from ozon layer depletion and global warming, on the other hand hydrocarbon is clear from both the environmental issues. Although the use of hydrocarbon refrigerants was in practice before the CFC era but it was difficult to assure the safety. A German company re-introduce hydrocarbon into the modern refrigerator industry for the environmental issues. And nowdays almost all the european countries are manufactured the hydrocarbon refrigerator instead of CFC alternatives. Initially a German company Foron chosen the propane/iso-butane

mixture(50/50) to convert thier existing line as the vapour pressure characteristics of this mixture are identical to those of CFC-12, but recently many countries are used the isobutane and propane respectively. There are many national and international standards for the safety aspects of refrigerators and it deals with various aspects of safety particulary with respect to compressor, motor, electrical connections, insulation, mechanical stability etc for the use of CFC-12. But there is no specific international standards prescribed to test the safety issues arising out of the use of hydrocarbon as refrigerants. Even if there is no national standard for hydrocarbon refrigerators, it is advisible to design, manufacture and test as per evolving international standards.

The first step for the safety of hydrocarbon refrigerators is to minimise the possiblity of any leak. Even if there is any leak, the subsquent logic is to make sure that a combustible mixture is not formed. In addition to this, the system should be controlled in such a way that the sources of ignition are eliminated or avoided. In this paper we studied the ignitablity of flammable gas mixtures by the electrical ignition sources of refrigerators.

2. DESCRIPTION OF THE REFRIGERATOR

Refrigerator used in this study was developed by the Samsung Electronic Co. LTD. Inner volume of the refrigerator is 215 *l*, and freezing part and larder part is separated with horizontal evaporator part, and the electric power was 220 volt. Figure 1 is a photograph of the refrigerator.

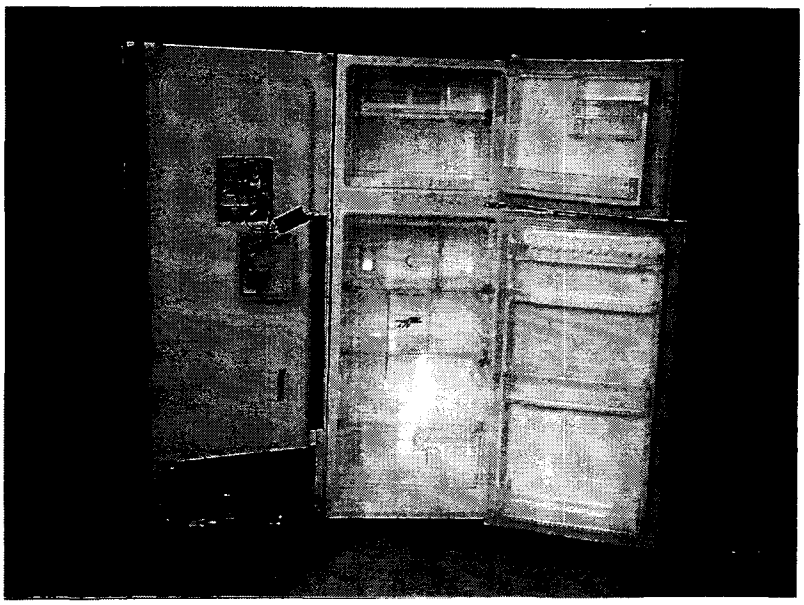


Figure 1. Front and rear aspects of refrigerator

3. EXPERIMENTS AND RESULTS

1. Potential risk assessment of ignition sources

1). Temperature measuring of electrical components

To estimate the ignitablity of flammable gas by the temperature rising of electrical components during operation, surface temperture of compressor, defrost heater, cooling air circulation fan motor and inner lamp were measured using the K type thermocouple untill the saturated temperatur(no more temperatue rising). Surface temperature of compressor was measured for 6 hours at 4 points and the maximum temperatre was 66°C.

A temperature of defrost heater which made by silicate glass and nichrom wire coil also measured for 3 hours in closed vessel with 3 samples. Figure 2 showes the maximum surface temperature of 440°C which was get after 20 minute of beginning of the test. And to confirm the ignitablity by the defrost heater, it was put in a closed vessel of 3.5% isobutane-air mixture atmosphere for 3 hours as shown in figure 3, but there was no ignition.

A temperature of inner lamp and the cooling air circulation fan motor were measured. The maximum temperature of lamp surface was 88°C and the cooling air circulation fan motor part was 50°C.

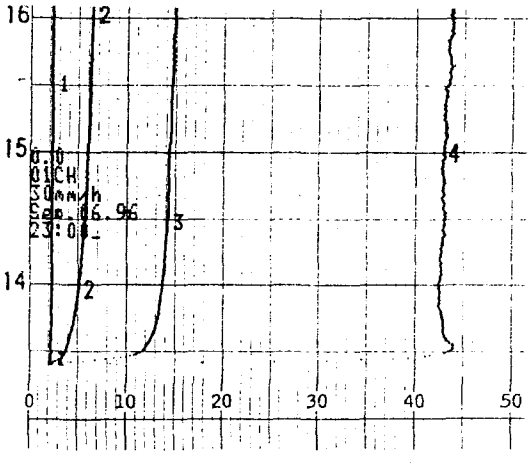


Figure 2. A results of temperature measuring of defrost heater
. horizontal div. : 10=100°C
. vertical 1div.=25min.

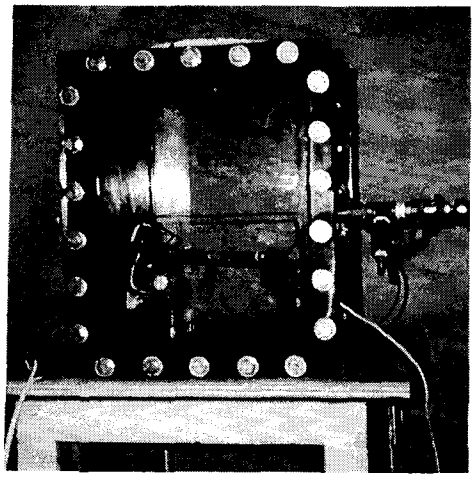
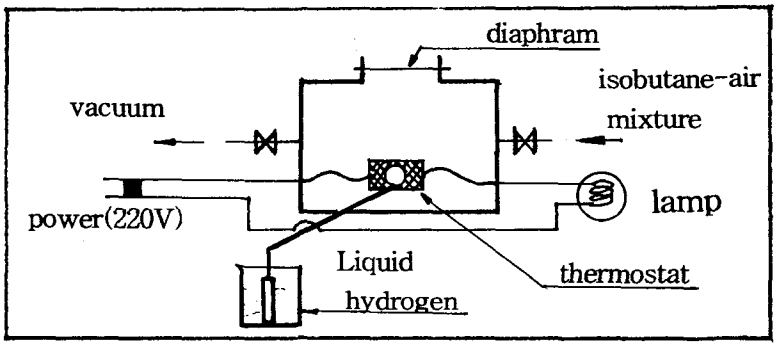


Figure 3. Photograph of Ignitability of defrost heater in 3.5% isobutane-air mixture

2). Ignitability of flammable atmosphere by electric spark of switches

There are three switches in the refrigerator, one is a thermostat to regulated the temperature of the refrigerator and the others are inner lamp switch and cooling air circulation fan motor switch. Figure 4 is schematic diagram of ignitability test of flammable gas by the thermostat. Switch part was put in the closed vessel of 3.5% isobutane-air mixture, and the metal tube contain a working fluid was dipping and take out 30 times in liquid nitrogen outside the closed vessel for ON-OFF test the switch, but the flammable mixture was not ignited during the test. The test were carried out in 3 and 4 % of isobutane-air mixture again but there were no ignition also. And than we disassembled the switch and than only the contact point of the switch was fixed in the closed vessel of 3.5% isobutane-air mixture. The switching point was compulsorily operated using a steel bar instead of pressure of working fluid as shown in figure 5, but there was no ignition also.



Figur 4. Schematic diagram of ignitability test by the thermostat

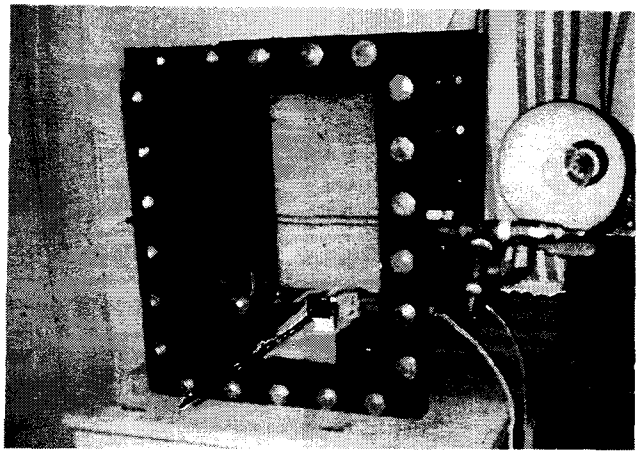


Figure 5. Compulsorily ignitability test of flammable atmosphere by thermostat

Another switches of lamp and fan motor which is combine togather and if we open the door, fan motor switch was OFF and lamp switch is ON. To test the ignitability by the two switch operation and refrigerator operation, the refrigerator was put in a closed small kitchen model of 1600x1600x1750 mm(4.48m^3) which was made of transparent acryl plate of 15mm in thickness. To test the ON-OFF operation test of the switches, the refrigerator was put in the model as the door open state, and the test was conducted compulsorily about 300 cycles for 2 hours using a long steel bar, like the thermostat switch test method. Figure 6 is the photographs of experimental set up. The concentration in the model was made to 3.5% isobutane-air mixture. To make the concentration in the model, 157 *l* isobutane was injected, and normal operation test of refrigertor was carried out 24 hours. Above mentioned two test, there were no ignition.

2. Explosion pressure endurance test of compressor shell

Experiment was conducted with 3.5% isobutane-air mixture and compressor shell. Figure 7 is a schmatic diagram of experimental set up. Initial pressure of gas mixture before explosion were varied from 1 to 9 kg/cm^2 abs., and the result of explosion pressure was shown from 4 to 40.6 kg/cm^2 gage as shown in table 1.

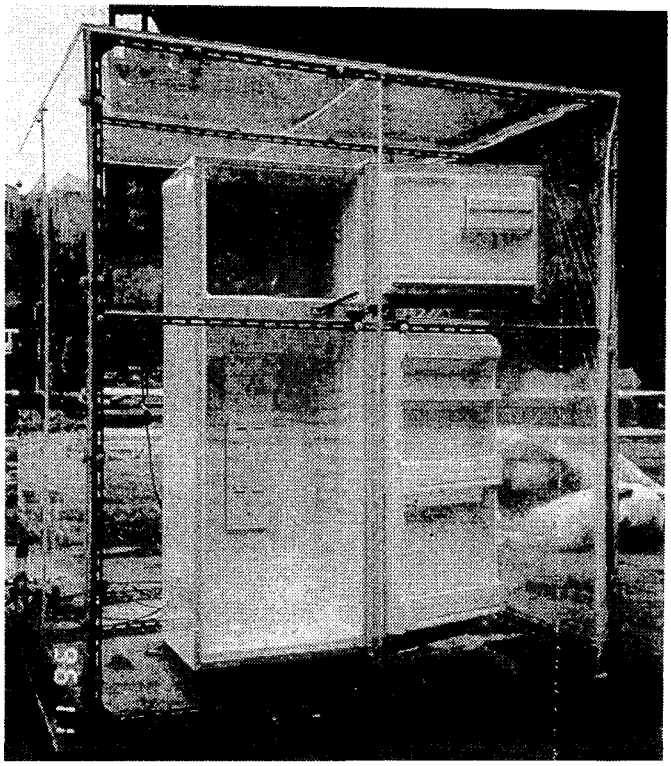


Figure 6. Photograph of experimental set up to test the ignitability by switches

The explosion pressure of compressor shell was smaller than as usual because of complicate inner structure. The explosion tests were conducted 3 times every initial pressure. After the explosion test of compressor shell, we investigated the shell whether it was deformed or not but there was no deformation

3. Explosion risk test in case of refrigerant leak in kitchen

The experiment were conducted in the small kitchen model of 4.48m^3 above mentioned. Isobutane refrigerant has charged in the refrigerator was 60g and if it converse to the volume of STP state, it is about 24 *l*. If the isobutane disperse in the model homogeneously, the concentration will become 0.54% and the concentraion is far below the lower explosion limit, and one can easily estimate that an explosion will not happen. But in case of leak, the gas will not diffuse homogeneously in a short time and than an explosion hazard will exist. We

Table 1. The result of compressor shell explosion pressure test

Initial pressure (kg/cm, abs)	1	2	3	4	5	6	7	8	9 9
Expl. pressure (Kg/cm, gage)	4	7.5	12.4	16.5	19.1	26.2	32.6	34.4	40.6
Avr. pres. rise rate(kg/cm sec	107	145.3	215.9	290.6	347.6	455.5	608	671.5	752.3

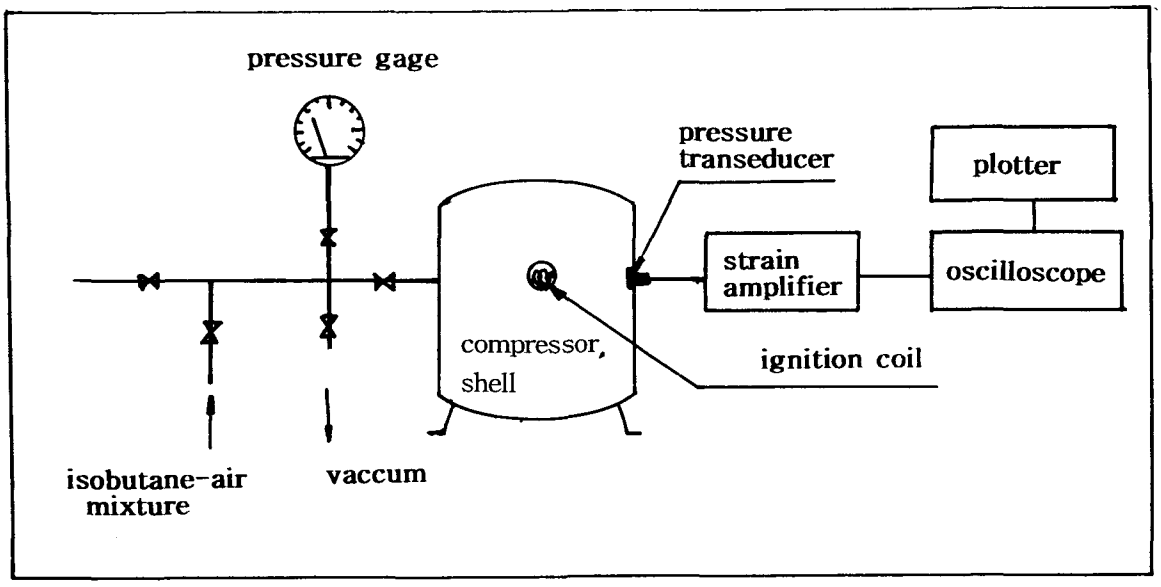


Figure 7. Schematic diagram of explosion pressure test of compressor shell

assume that the gas is leak in 4*l*/min therefore the gas was injected in the model 4*l*/min from the isobutane cylinder using the flowmeter. An ignition sourc was a 10kv electric spark of neotrans and we switching the ignition spark plug as soon as the gas injection ended. Distances between the ignition plug and gas injection positions were varied to 20, 30, 40, 50cm., and the gas injection position were varied from 10 to 90cm above the bottom. In this experiment an ignition was not occur.

4. Explosion risk test in case of refrigerant leak in the refrigerator

Above mentioned experiments of ignitability of flammable gas by switches, it was found that there was no ignition sources in a actual operation of the refrigerator, therefor if the refrigerant which charged in the refrigerator leaking or leaked in the refrigerator, there will be no explosion risk in actual operation.

Therefore we experiment a explosion risk of refrigerants against the ignition sources out of the refrigerators when the gas leaked in the refrigerator. 24*l* isobutane gas was injected and refrigerator door was opened 3 minute after, as the ignition source was operating. Ignition source position were 10cm and 20cm apart from the refrigerator door, and 10cm 30cm and 60cm above from the ground as shown the table 2. In this experiment, only a case which 10cm apart from the refrigerator door and 10cm above from from the ground was ignited. From this result, though an ignition source is located around the refrigerator, if it is apart more than 20cm and above 30cm from the regrigerator door, there will be no ignition because gas would be disperse below the lower explosion limit befor reach the ignition source.

Table 2. Test result of explosion risk in case of refrigerant leak in and an ignition sources is out of refrigerator.

Vol. of gas injected in the refrigerator	Igntion time after injected	Concentration in the refrigerator	Ignition source position	Results
24 liter	3 minute	11.2 %	10cm apart 10cm above	Ignition
24 liter	3 minute	11.2 %	20cm apart 30cm above	No ignition
24 liter	3 minute	11.2 %	20cm apart 60cm above	No ignition
24 liter	3 minute	11.2 %	60cm apart 10cm above	No ignition

5. CONCLUSION

In this study we test the electrical component as a potential ignition sources, and an explosion risk assessment has been done in case of refrigerant leaked in a kitchen or in the refrigerators.

From the experiment we could get the following results

1. There was no ignitability of flammable gas by electrical components
2. The compressor shell has enough mechanical strength against explosion pressure of refrigerants.
3. Though the refrigerants leak in the refrigerator or kitchen, there will be no ignition and explosion, if the ignition sources is apart more than 20 cm from the leakage point in this refrigerator.

From this study of explopsion safety of hydrocarbon rerigerant refrigerator, we can conclude that explosion risk in connection with the use of hydrocarbon refrigerant was few.

REFERENCES

Flammability evaluation of HFC-32 and HFC-32/134a under practical operating conditions,proc. of Inter. Refrigeration Conf., Perdue, 33-44, July 1996

Use of Hydrocarbon Blends In Indian Household Refrigerators, Proc. of Inter. conf. on Ozone Protection Technology, 1996

Experimental Results of the Safety Tests on Domestic Refrigerators for Refrigerant R600a, Proc. of Application for Natural Refrigerants, Arhus Denmark, Sept. 1996

Contribution to Safety Aspects Discussion on Isobutane Compressors for Domestic Refrigeration. Proc. New application of Natural Working Fluids in Refrigeration and Air Conditioning. Hannover, 433-442, May 1994

Alternative Refrigerants Evaluation Program Technical Committee, Minutes of Meeting Reports, San antonio, Texas, June 1996

Particular Requirements for refrigeratos, Food Freezers and Ice-makers, IEC Standards 335-2-24, 1992-01

Kyu-hyung Oh, Eyu-sung Chu etal, A Study on the safety Assessmsent of Refrigerator of Isobutane Refrigerant, Hoseo Univ., Technical Report, 1996

No-Frost Combis in Asia and America with R600a Refrigerant or with hydrocarbon Blends. Proc. Int. Conf. on Ozon Protection Technology, Washington. Oct. 1996