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R-1270 Vapor Compression Refrigeration Performance Study

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ABSTRACT

This study aims to obtain performance data on the vapor compression refrigeration system using R-1270. Refrigerant R-1270 classify as a hydrocarbon refrigerant (HC) that is environmentally friendly. This refrigerant has a value of ODP = zero and GWP <3. The Tests were conducted on a vapor compression refrigeration system that consisted of a domestic refrigerator (RD) and a chest freezer (CF). The parameters measured in this research were: refrigeration effect, compression work, the weight of refrigerant circulated, electricity consumption, coefficient of performance, and the time required to reach the lowest evaporator temperature. The first test was to used R-134a as a baseline refrigerant with the mass as the manufacturer recommends. Then, the second step was to test the performance of the vapor compression refrigeration system that used R-1270 with 30 % of the baseline mass. The test was conducted for 300 minutes by recording the observed data at every 30 - minute interval. The results showed that the replacement of baseline refrigerant by R-1270 increase the coefficient of performance of the vapor compression refrigeration system by 13 % - 56 %. It also reduces electricity consumption by 13.5 % - 19 %. This research has implications for the work of compressors that becomes easier and cheaper energy costs.

Keywords: *Energy efficiency, Refrigeration system performance, hydrocarbon refrigerant.*

1. INTRODUCTION

Currently, the vapor compression refrigeration system is widely used for household refrigerators and in commercial chest freezers. In general, both of them use R-134a as their working fluid because R-134a has good thermodynamic properties.

To preserve the environment and the health of living things, alternative refrigerants that can replace the HFC group are needed [1]. Various research results have shown that hydrocarbon refrigerants and their mixtures can replace synthetic refrigerants in the refrigeration system. The latent heat of hydrocarbons is higher than R-134a, so the weight of refrigerant loaded into the system can be reduced. Properties of various types of refrigerants showed in Table 1.

Table 1. Refrigerant Properties [2]

A	B	C	D	E	F	G
R134a	Pure Fluid	R12	102.03	101.1	-26.5	A1
R600a	Pure Fluid	R12, R134a	58.12	134.7	-11.6	A3
R600	Pure Fluid	R12, R22	58.12	152	-0.5	A3
R290	Pure Fluid	R12, R22	44.1	96.7	-42.1	A3
R1270	Pure Fluid	R22	42.08	92.4	-47.7	A3

Notes: A (Refrigerant), B (Composition), C (Replaces), D (Molecular; wt), E (Critical Temperature; ^oC), F (Boiling Point; ^oC), G (ASHRAE Safety Code).

Tests using pure butane (R-600) for refrigerant in a domestic refrigerator design for R134a at an ambient temperature of 25 ^oC and 28 ^oC showed the same energy consumption. It found that the temperature at the evaporator inlet for hydrocarbons was lower than the temperature for

R134a. The required mass of R134a is 140 g, while the hydrocarbon required mass is 70 g. The results showed the refrigerator could using pure butane as a refrigerant without changing the components [3,4]. Further research used hydrocarbon refrigerants consisting of a mixture of propane-isobutane with a composition of 50% mass each, replacing R-134a as the refrigerant. Compared to R134a, the results of the hydrocarbon mixture indicated that caused the energy consumption of the compressor to reduce. It also reduces the mass of the refrigerant that is used, a faster refrigerator temperature change, and less time of compressor running [5–7]. When comparing energy consumption values, mass flow rate, and refrigerant mass between hydrocarbons and R134a, the result was that a decrease occurred for hydrocarbons [8,9]. The hydrocarbons often used as refrigerants are propane (R-290), isobutane (R-600a), n-butane (R-600), and propylene or R1270 [10].

As a hydrocarbon refrigerant, R-1270 has suitable characteristics to replace synthetic refrigerants for refrigerators [12],[13]. Some advantages are that it is not harmful to the ozone layer (ODP-0) and has a low effect on global warming, which is <2, and has a relative capacity index (RCI) of R-1270 that is better than that of R-22, which is 27.5 % [14]. However, not many refrigeration manufacturers using these refrigerants on their products. It is about combustible hydrocarbons issue concern the consumer. This characteristic is harmless if the refrigerant is applied with the correct procedure. Hydrocarbons are flammable in the presence of two other compounds that together form the fire triangle: hydrocarbons, air, and a certain amount of ignition source. If one of the three factors is not available, there will not be a fire [15]. Based on the explanation above, this research aims to investigate the performance of the vapor compression refrigeration system that uses R1270.

2. METHODOLOGY

In this study, the vapor compression refrigeration systems used are a domestic refrigerator (Mitsubishi) with a capacity of 147 L and a chest freezer (GEA) with a capacity of 132 L. The specifications of both refrigerators were shown in Figure 1 and Table 2.

The experimental measurements were made under controlled temperature and humidity conditions. A contactless compressor starter is using to increase the safety experiment. The electrical parts were sealed, and the insulation was reinforced using insulating materials to reduce the risk of combustion and explosion. The measuring instruments consisted of two manifold gauge units (Robinair) and two temperature sensor units (Elitech), each of which was placed in the suction and discharge channels, and a clamp meter (Krisbow) which was used to measure electric current.

(a) (b)

Figure 1. The experimental tools for testing R-1270; a. Domestic Refrigerators and b. Chest Freezer

This experimentally research was conducted with the refrigerant R-134a used as default. Refrigerant retrofitting is done with replacing the refrigerant without replacing the components of the refrigeration machine. The refrigerant control device used in this study is a capillary tube. so there is no need to change settings during the retrofiting process.

Table 2. Specification of Experimental Tools for Testing R-1270

Spesification	Items	
	Refrigerator	Freezer
Brand	Mitsubishi	GEA
Model	MR-147 W/JG/BG/GY-1	
Voltage	220 V	220 V
Frequency	50 Hz	50 Hz
Power	66 W	160 W
Refrigerant Mass	95 gr	90 gr
Net Volume	147 L	132 L

The test was conducted in two-step to measure the performance of the refrigeration machine. In the first step, the refrigerator operated with R-134a as a refrigerant. In the second step, the refrigeration machine operated using refrigerant R-1270. Furthermore, the performances of the refrigeration machines were compared by observing the decrease in evaporating temperature, refrigerating effect, the heat of compression work, and coefficient of performance (COP) every 30 minutes for 300 minutes. Evaporating temperature, refrigerating effect, heat of compression work, *COP* of refrigerator can be calculated using equations (1), (2), and (3).

$$RE = h_1 - h_3 \quad (1)$$

$$Wk = h_2 - h_1 \quad (2)$$

$$COP = RE / Wk \quad (3)$$

Where:

RE = value of *Refrigeration Effect* (kJ/kg)

Wk = compression work (kJ/kg)

COP = coefficient of performance of refrigeration cycle

h_1 = specific enthalpy of refrigerant at evaporator outlet (kJ/kg)

h_2 = specific enthalpy of refrigerant at compressor outlet (kJ/kg)

h_3 = specific enthalpy of refrigerant at evaporator inlet (kJ/kg)

The first stage began with a leak test on the refrigeration machine piping of the refrigerator and the chest freezer. The refrigerators were vacuum for 15 minutes. Then, both machines filled with 95 grams and 90 grams of R-134a, as the manufacturer's recommendations. The data parameters that were observe included compressor suction pressure, compressor discharge pressure, and evaporator temperature. Furthermore, both refrigerators were analyzed to determine the performance of the refrigeration machine that used R-134a.

After completing the first stage, the refrigerators then retrofitted using hydrocarbon refrigerant R-1270. The refrigerant filled into the refrigerators to R-134a (the default refrigerant) with a mass ratio is 30 %. Furthermore, the performance of refrigerators and freezers that have retrofitted R-1270 is measured when the performance of refrigerators using the default refrigerant is measured.

3. RESULTS AND DISCUSSION

The performance of the vapor compression refrigeration system that used R-1270 had tested. Data on changes in evaporating temperature, refrigerating effect (*RE*), the heat of compression work (*Wk*), the weight of refrigerant circulated (*m*), electric energy consumption (*P*), and *COP* at intervals of minute 0 to minute 300 was shown in Figures 2 to 7.

3.1 Evaporating Temperature

Evaporator is the main component of refrigerator refrigeration machine, which is responsible for absorbing heat from the products that are stored in the refrigerator. The lower the temperature of the refrigerant in the evaporator pipe is, the more heat can be absorbed from the food products stored in it, so the temperature will be lower. Figure 2 is graph of the change in evaporator temperature against the running time of the refrigeration system. Testing of the refrigeration system was conducted on domestic refrigerator (RD) and chest freezer (CF) that used the default refrigerant (R-134a) and refrigerant R-1270.

(a)

(b)

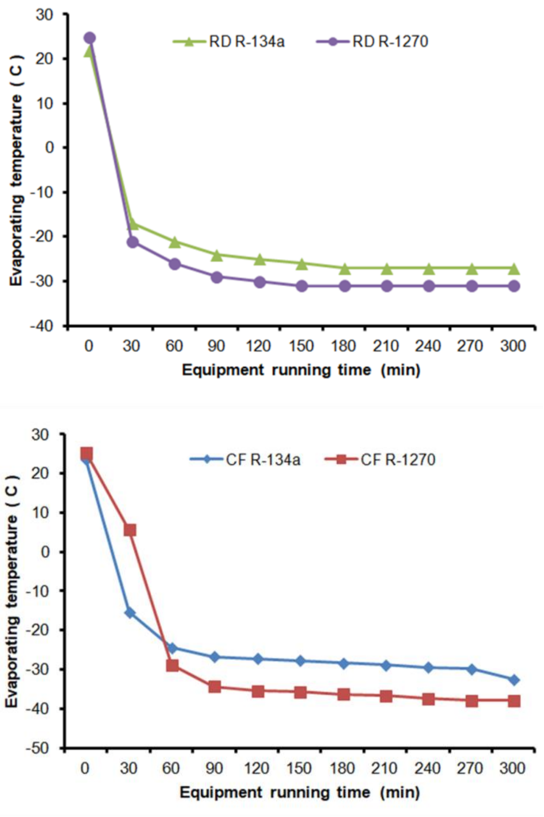

Figure 2. Changes in evaporating temperature versus the running time of the refrigeration system that used R-134a and R-1270; (a) Domestic Refrigerator (RD) and (b) Chest Freezer (CF).

In the first minute of the test, the temperature of the evaporator of domestic refrigerator that used R-134a changed rapidly from 22 °C to -17 °C at minute 30. Furthermore, the temperature gradually decreased to -27 °C until the end of the test. When the domestic refrigerator that used R-1270 was tested, the evaporator temperature at minute 30 was -21 °C. Then, until the final minute of the test, the evaporator temperature was able to reach -31°C.

Next, the test on chest freezer that used R-134a showed a change in evaporator temperature from 24 °C to -15 °C for the initial 30 minutes of the test.

After that, the evaporator temperature dropped to -32 ^{o}C. In the CF that used R-1270, the evaporator temperature decreased until the temperature was below the freezing point of water, occurring at minute 60 from 25 ^{o}C to -29 ^{o}C, until finally it reached the lowest temperature, which was -38 ^{o}C, at the end of testing time.

Based on data on the performance of the refrigeration system that had been tested, the refrigeration system that used the working fluid R-1270 showed better performance [16]. The lowest temperature reached by the domestic refrigerator was -31 ^{o}C and the lowest temperature reached by the chest freezer was -38 ^{o}C in the same interval of machine operating time.

3.2 Refrigeration Effect

The refrigeration effect (*RE*) is the amount of heat absorbed for every unit of refrigerant mass in the evaporator on the chest freezer system. The greater the heat absorbed, the better the evaporation process of the system. The value of RE is obtaining from the difference between saturated vapor value with a saturated liquid value. Each enthalpy value (*h*) is indicating by the suction pressure and the discharge pressure.

Figure 3 displays graph of the change in the refrigeration effect versus the running time of the refrigeration system. In general, the refrigeration effects of domestic refrigerator and chest freezer that used R-1270 were higher than those of domestic refrigerator and chest freezer that used R-134a. At the beginning of the testing, the refrigeration effects of the domestic refrigerator and chest freezer that used R-1270 were 257 kJ/kg and 240 kJ/kg, respectively. Then, the values fluctuated until the testing time ended at minute 300 with final values of 261 kJ/kg and 243 kJ/kg, respectively.

On the other hand, the refrigeration effects of domestic refrigerator and chest freezer that used baseline refrigerant were 128 kJ/ kg and 119 kJ/kg at the beginning of machine operation, which then gradually decreased until they reached 120 kJ/kg and 115 kJ/kg at the end of testing time. Because each hydrocarbon refrigerant has a high value of latent heat, the ability of the refrigerant to absorb room heat is better than R-134a refrigerant. Another factor that causes a high refrigeration effect in the use of hydrocarbon refrigerants is the smaller aspect ratio than that in the use of synthetic refrigerants [17].

(a)

(b)

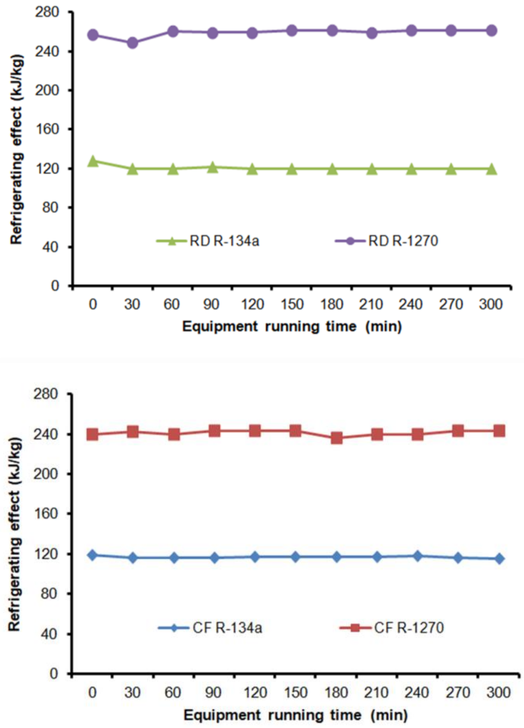

Figure 3. Changes in refrigeration effect versus running time of refrigeration system that used R-134a and R-1270; (a) Domestic Refrigerator (RD) and (b) Chest Freezer (CF).

3.3 Work of Compression

Figure 4 displays the graph of heat of compression work of R-134a and R-1270 versus the running time of the refrigeration system for 300 minutes. The heat of compression work in domestic refrigerator and chest freezer that used R-1270 was higher than the heat of compression work of those that used baseline refrigerant.

At the beginning of the test, the value of heat of compression work of the domestic refrigerator was 58 kJ/kg, while that of the chest freezer was 81 kJ/kg. The heat values of compression work in the two refrigeration machines were relatively constant until system operation finished. Comparing the heat values of compression work between R-1270 and R-134a in the domestic refrigerator and a chest freezer was around 39 % 84 %. The high value of the heat of compression work using hydrocarbon refrigerant that replaced baseline refrigerant was due to the smaller hydrocarbon density. Thus, the enthalpy value of the refrigerant increases at the compressor inlet and outlet [18,19].

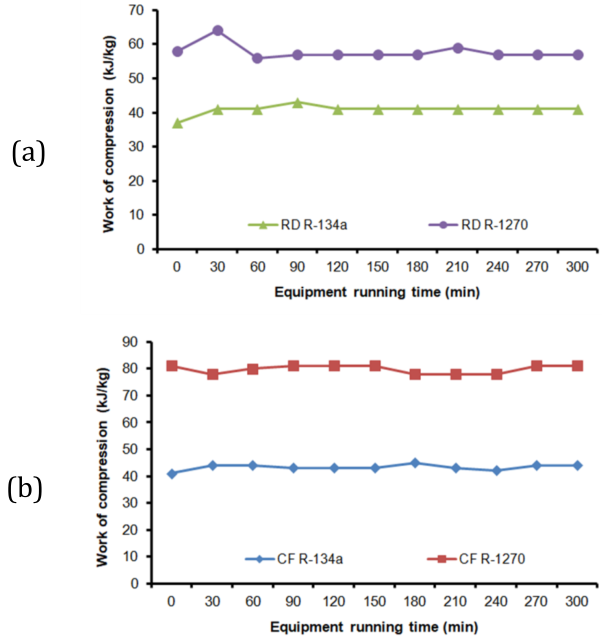

Figure 4. Changes in heat of compression work versus running time of refrigeration system that used R-134a and R-1270; (a) Domestic Refrigerator (RD) and (b) Chest Freezer (CF).

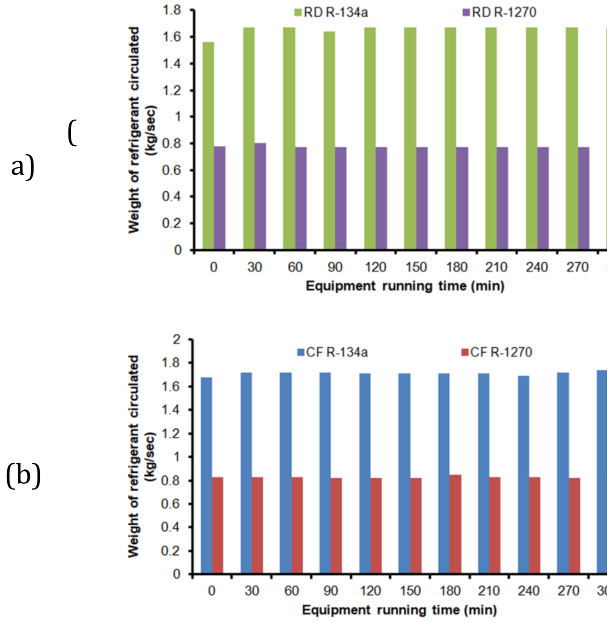

Figure 5. The weight of the refrigerant that circulated during the running time of the refrigeration systems that used R-134a and R-1270; (a) Domestic Refrigerator (RD) and (b) Chest Freezer (CF).

3.4 Weight of Refrigerant Circulated

The total quantity and the quantity of refrigerant that circulates in domestic refrigerator and chest freezer will affect general performance. The total quantity of refrigerant and the quantity of refrigerant that circulates must fit its capacity and power. Therefore, the total quantity and the quantity of refrigerant that circulates must be known with certainty. The total quantity and the quantity of refrigerant circulated are conceptually different. The total quantity of refrigerant is the total quantity of refrigerant in the system. The quantity of refrigerant circulated is the refrigerant that circulates per second in the system. The quantity of refrigerant circulated is very important because it determines the heat absorbed in the evaporator and the heat dissipated in the condenser.

Figure 5 displays the graph of weight of refrigerant that circulated in refrigeration systems that used R-134a and R-1270 for a running time of 300 minutes. In general, it can be seen that the weight of refrigerant R-1270 that circulated in domestic refrigerator and chest freezer was around 53 % lower than the weight of the baseline refrigerant. Since the beginning of the test, the weights of R-1270 that circulated in the domestic refrigerator and chest freezer were 0.78 kg/sec and 0.83 kg/sec, respectively. At the end of the test time, both values were relatively constant.

3.5 Electric Energy Consumption

Electric power is the use of electric energy by the refrigeration system. The electric energy that is consumed is calculated using the formula of electric current when the system is running that is multiplied by the electric voltage of 220 volts. The value of the electric current used is the average data retrieval every thirty minutes for 300 minutes.

Figure 6 presents graph of the consumption of electrical energy in refrigeration systems that used R-134a and R-1270 for an operating time of 300 minutes. In general, it is clear that the consumption of electrical energy in domestic refrigerator and chest freezer that used R-1270 was lower than those that used baseline refrigerants. During the operating time, the electricity consumption of the domestic refrigerator that used the baseline was 117 Watt, while the domestic refrigerator that used R-1270 consumed electricity of 94 Watt. It indicated that there was a decrease in electricity consumption by 19% in domestic refrigerator that used R-1270 as the working fluid.

The same condition occurred in the chest freezer that used R-1270 as the working fluid, which for 300 minutes of operation time had consumed 243 Watts of electricity. Meanwhile, the chest freezer that used R-134a consumed 281 Watts of electricity. It can be seen that there was a reduction in electricity consumption by 13.5 %

when R-1270 was used as the working fluid of chest freezer.

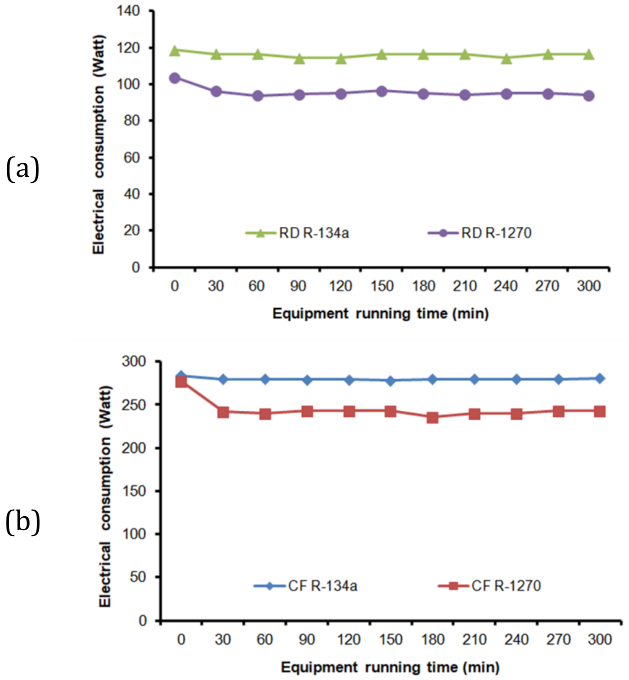

Figure 6. Consumption of electric energy during the operation of the refrigeration systems that used R-134a and R-1270; (a) Domestic Refrigerator (RD) and (b) Chest Freezer (CF).

3.6 *Coefficient of Performance*

The amount of heat absorbed by the refrigerant that circulates in the evaporator (*refrigeration effect*) and the compression work cycle of the compressor will affect the *COP* value. If the refrigeration effect value is larger and the compression value is smaller, the *COP* will be larger. Better *COP* value comes from a combination of larger refrigeration effect value and smaller compression work value [20,21].

Figure 7 shows the graph of *COP* that used R-134a and R-1270 for an operating time of 300 minutes. At the beginning of the test, the Coefficient of Performance of the domestic refrigerator and chest freezer that used R-134a were 3.46 and 2.9, respectively. Meanwhile, domestic refrigerator and chest freezer that used R-1270, at the beginning of the test, obtained Coefficients of Performance of 4.43 and 3.0, respectively.

Furthermore, the *COP* fluctuated until the end of the operation time. At the end of the test, there were increases in *COP* by 56 % and 13 % in the domestic refrigerator unit and chest freezer unit that used R-1270 compared to those that used baseline refrigerants.

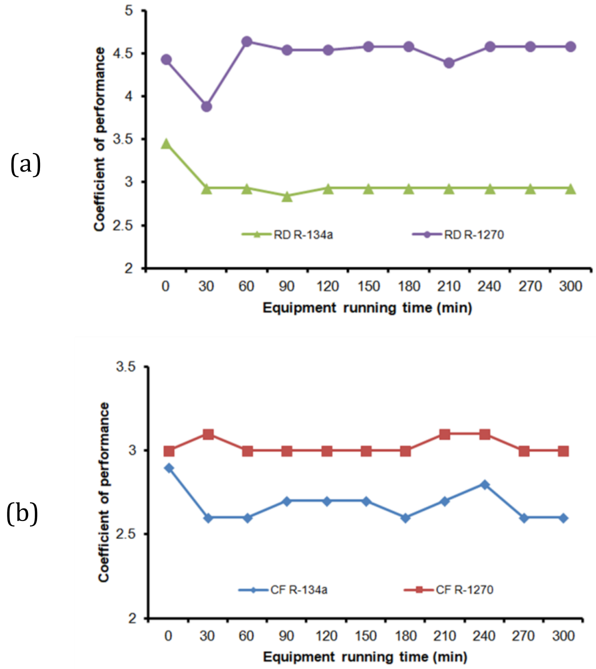

Figure 7. Coefficient of Performance of the refrigeration systems that used R-134a and R-1270 during the operation time; (a) Domestic Refrigerator (RD) and (b) Chest Freezer (CF).

4. CONCLUSION

The use of R-1270 in a vapor compression refrigeration system with a refrigerant quantity of 30 % of the quantity of R134a has been implemented. All parameters that were measured showed better performance, except for the performance of compression work (*Wk*) of R-1270 that was higher than that of R-134a because it was influenced by the working pressure of R-1270. The evaporator temperature that was reached by R-1270 was lower than that reached by R-134a.

Replacement of baseline refrigerant by R-1270 using drop-in substitute could improve performance and minimize electricity consumption of vapor compression refrigeration system.

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