Int. J. of Thermal & Environmental Engineering
Volume 15, No. 2 (2017) 151-156

Performance Study of Two Circuits Lorenz – Mutzner Vapour Compression Cycle

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Abstract

The operational parameters for a modified Lorenz – Mutzner refrigeration cycle working with mixed refrigerant were studied experimentally. A Lorenz – Mutzner refrigeration system was designed, built and tested under two types of refrigerants. The first one was pure R-134a refrigerant while the second was a hydrocarbon zeotropic mixture of R-290/600a refrigerant in a mass ratio of 60:40. Also, a new control strategy was applied to both refrigerant types. The effects of various parameters on cycle performance were investigated such as refrigeration effect, compressor power consumption, inside freezing and cooling temperatures. It was found that, replacing R-134a by hydrocarbon mixture reducing compressor power consumption by 21%, increasing COP by 16%, and reducing operating time by 25 min. using controlled circuit with the hydrocarbon mixture cycle reduced compressor power consumption by about 20% and the time required reaching the freezing set point by 4 min. While the time required reaching the cooling set point was reduced by about 12 min. The cycle COP was augmented by about 9%.

Keywords: *Lorenz – Mutzner cycle, Dual evaporators, Refrigerant mixture, Refrigeration cycle*

1. Introduction

The domestic refrigerator- freezer usually contains two cabinets, one for cooling and the other for freezing. This is achieved traditionally by pumping the refrigerant after the expansion valve to the freezer first and then to the refrigerator. The flow of refrigerant continues even if one of the two cabinets reaches its temperature limits. Two difficulties may be encountered in such systems; the first is how to maintain different temperature levels by single vapor compression cycle, and the second is how to control the temperature in each cabinet. One such solution to these difficulties is to use a zeotropic mixture. Using zeotropic mixtures can produce two temperature levels in the respective cabinets; since it has a temperature difference glide resulted from the different boiling temperatures of the constituent refrigerants. Such cycles are called Lorenz-Mutzner (LM) cycle. Lorenz and Meutzner [1] proposed a dual evaporator refrigeration cycle with two intercoolers using a zeotropic refrigerant mixtures, they reported a 20% energy saving for a Lorenz-Mutzner cycle with a mixture of R22/R11 (50/50 wt.%) compared to a conventional refrigerator. Liu et al. [2] proposed the hydrocarbon refrigerant mixture R-290/R-600 as a retrofit in a domestic refrigerator/freezer unit. The capillary tube was increased to control the flow of refrigerant, while, all components of the refrigerator/freezer were kept the same. The maximum power savings of 6.5 % were achieved with a blend of R-290/R-600 (70/30 % wt) with a charge of 70g. Liu et al [3], studied the improvement that can be achieved on the Lorenz-Meutzner cycle. Three hydrocarbon mixtures were used, namely, R-290/n-C5, R-290/R-600 and R-290/R-600/n-C5. In such a cycle the possible advantages of the temperature glide of the zeotropic blends were utilized. A modified Lorenz-Mutzner refrigeration cycle with economizer heat exchanger was studied theoretically by Khalifa et al [4] . The system was charged with zeotropic mixed refrigerant (R290:R600a) in ratios (60:40). A mathematical model for each component of the cycle was build, using the Engineering Equation Solver (EES) program. An energy and exergy analysis was performed on each individual component of the cycle. Bayoglu and Delafield [5], presented a Lorenz-Mutzner refrigerator/freezer with two evaporators and two intercoolers. It was tested experimentally in an environmental chamber according to the association of home appliance using several hydrofluoric propane-based-zeotropic mixtures. Binneberg et al, [6] have investigated three different control methods for household refrigerator compressors such as

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DOI: 10.5383/ijtee.15.02.003

on/off control, continuous operation with variable speed control, and continuous operation with two fixed speed controls. Yoon et al [7], studied a domestic refrigerator-freezer with two-circuit cycle and parallel evaporators to show the energy saving potential compared with a conventional cycle with a single loop or serial evaporators. Yoon et al [8], studied the performance of Lorenz-Mutzner cycle for a domestic refrigerator-freezer. The objective of the study was to compare the performance of the LM cycle using hydrocarbon (HC) mixtures with that of a bypass two-circuit cycle for a domestic R-F. Also, theoretical analysis for an optimum HC mixture was performed. Yoon et al. [9] were studied a dual-loop cycle for a domestic refrigerator-freezer (RF) using individual R-600a and hydrocarbon (HC) mixtures. Baskaran and Mathews [10], have studied experimentally the performance of vapour compression cycle with azeotropic mixture of R-152a and Di-methyl-ether (DME) of 60% DME + 40% R-152a.In this work a new modification to the Lorenz – Mutzner refrigeration cycle was suggested, designed and built. The proposed cycle is to be tested with two types of refrigerants. The first one was a pure R-134a refrigerant and the second one was a zeotropic mixed refrigerant of R-290/600a in the mass ratio of 60:40. A new control strategy was applied to both refrigerant types. Different cycle performance parameters were studied such as: coefficient of performance, refrigeration effect, and power consumed by the compressor, and freezing / cooling temperature.

2. Experimental

A cold store was built from a sandwich panel; consist of two sheet metals each 0.5 mm in thickness, separated by 3 cm foam insulation. The cold store consists of two compartments. The inner freezing compartment dimensions are 0.63 m × 1.9 m, while the outer cold compartment dimensions are 1.26 m× 1.9 m. The freezing compartment setting temperature was 0ºC, and it was 5ºC for the cold compartment. Figure 1 shows the cold store dimensions. The refrigeration unit that services the cold store comprises two evaporators, single compressor, single condenser, single expansion valve, accumulator, and four control valves. Two types of refrigerant were used in studying the performance of this refrigeration cycle; the first was R-134a while the second was a hydrocarbon mixture of R-20/R600a in a mass ratio of 60:40.

3. Cycle Operating Modes

The refrigeration control circuit was designed to stop the refrigerant flow to any compartment reaches its setting temperature, as well as turning off the whole refrigeration cycle when both compartments reach their setting temperatures. The control circuit consists of four solenoid valves, four contactors, and two thermostats. Refer to Fig. 2; the control circuit generates four modes of cycle operation. Mode 1 when both evaporators are in operation: the two thermostats are in ON positions, the contactors K2 and K3 open, leading to close both solenoids S1 and E2. Then the refrigerant flows from condenser to expansion valve, freezer evaporator and to food evaporator, and finally to the compressor through the accumulator. Mode 2 when only food evaporator is on duty and freezer is out of duty; when the freezing compartment reaches its OFF temperature, the freezer thermostat opens leading to open the contactors K3 and K1. The freezer evaporator is separated from the refrigeration cycle by closing solenoids E1, S1, and opening solenoids E2, thus all the refrigerant flows through food evaporator to reduce the time required to reach food compartment its OFF temperature. Mode 3 when freezer in duty and food evaporator is out of duty: If the food compartment reaches its setting temperature earlier than freezer compartment, then contactors K3 and K4 are open, while contactor K1 is partially opened, leading to close both solenoids E2 and S2. On the other hand, solenoid S1 opened, the output separates food freezer from the refrigerator cycle. Thus, the freezer evaporator capacity increases because it receives the whole cycle refrigerant. Finally in Mode 4, OFF mode cycle: both compartments reach setting temperature, all contactor cycles open, leading to close all solenoid valves. Thus, the suction pressure decrease rapidly and the compressor stopped by the low-pressure switch. Table 1 summarized the operating modes mentioned above. Measuring uncertainty refers to how the measurements are close to the true physical properties. In this study the accuracy was determined by using the methodology [11] and taking into consideration in determining deviation. The summarized analysis of the experimental accuracy of the measuring properties of some selected measuring devices is shown in Table 2.

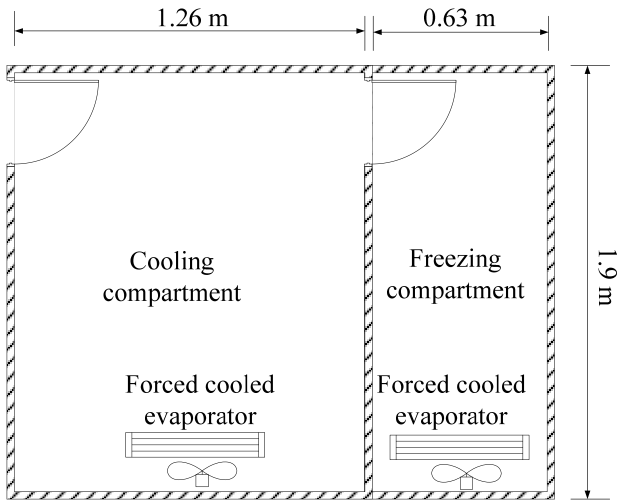

Fig. 1. Cooling and freezing compartments

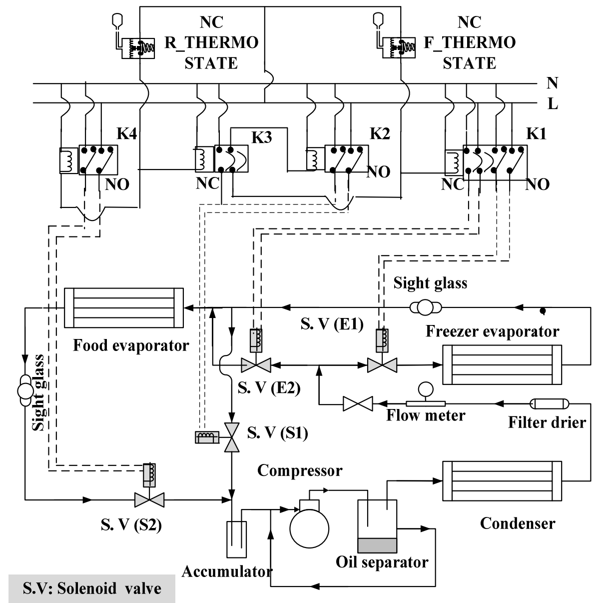

Fig. 2. Wiring diagram and control circuit of refrigerator cycle

Table 1. Summary of refrigeration cycle operation modes

Mod	Description	Solenoid valves S_1	E_1	S_2	E_2	Comp.
1	Food and freezer evaporators on duty	Closed	Open	Open	Closed	running
2	Food evaporator on duty	Closed	Closed	Open	Open	running
3	Freezer evaporator on duty	Open	Open	Closed	Closed	running
4	Food and freezer evaporators are set	Closed	Closed	Closed	Closed	stopped

Table 2. Experimental accuracy

Independent variables	Uncertainty interval
Thermometer	± 1 ºC
Temperature readers	± 1 ºC
Voltage	± 2 % volt
Current	± 2 % Amp.
Pressure gauge	± 1.5 % psi
Weight electronic scalar	± 1 % gr
Power meter (ammeter and voltmeter)	± 1 % kW
Flow meter	± 0.2 % m^3/h

4. Results and Discussion

Figure 3 shows a comparison between the power consumption for controlled and uncontrolled cycles using R-134a refrigerant. The figure showed that when using the control system, the time required to reach the setting point of compartment cooling was about 44 min. Afterwards, the control system removed out the cooling evaporator from the cycle and consequently reducing the required useful work by 21.2 %. After that time, there is an additional 10 min period required to reach the setting point of the freezing compartment and therefore, shut down the compressor. At the contrary, the uncontrolled system required 73 minutes to reach the setting conditions for both compartments. The comparison between the area under the curves of each system shows that the uncontrolled system required 5223.15 kJ while the control system required 3576.3 kJ with 46 % energy saving. Thus, the control system merits are two folds, reducing the necessary operational time and the input energy.

Figure 4 shows the power consumed by the compressor for both controlled and uncontrolled systems, using hydrocarbon mixture of R-290/R-600a in a mass ratio of (60:40). After an initial period of 36 min, one of the evaporators has reached its setting point and thus, activated the control system which resulted in the removal of that evaporator from the cycle. A slight reduction in the compressor power is observed at this point. After this initial period, an about 15 minutes period is required for the second evaporator set point and hence setting the compressor off. The area under curves estimated the reduction in individual energy consumption. The comparison between the area under the curves of each system shows that the uncontrolled system required 3853 kJ while the controlled system required 3301.5 kJ with 16.7 to 14.3% energy saving.

Figure 5 shows the variation of refrigeration effect with time for both R134a and hydrocarbon mixture for the uncontrolled system. The cooling potential of zeotropic mixtures is much higher than that of R134a, and it is almost constant throughout the operation period; this explains the steeper behavior of hydrocarbon mixture in the previous figures.
As expected, this potential has its impact on the COP as shown in Fig. 6 which depicts a comparison for COP variation with time of both R134a and hydrocarbon mixture in the uncontrolled system. Both refrigerants have almost uniform COP throughout the whole period of operation. The COP for the mixture is 4 while it's about 3.5 for R134a system.

Figure 7 shows a comparison between the time required to reach the setting point for the cooling compartment for both controlled and uncontrolled systems with hydrocarbon mixture. The required operational time for the uncontrolled mode of operation is bigger than that for the controlled mode, because of the delayed setting time of the cooling compartment in this case even though the freezing compartment reaches its set point. This drives the freezing compartment below its set point as well as wasting an additional amount of energy as mentioned before. The use of control system overcomes this deficiency. As the cooling compartment removed out by the controlled system, all the refrigerant devoted to the freezer compartment, hence reducing the time required to reach the setting temperature for freezing compartment, as shown in Fig. 8.

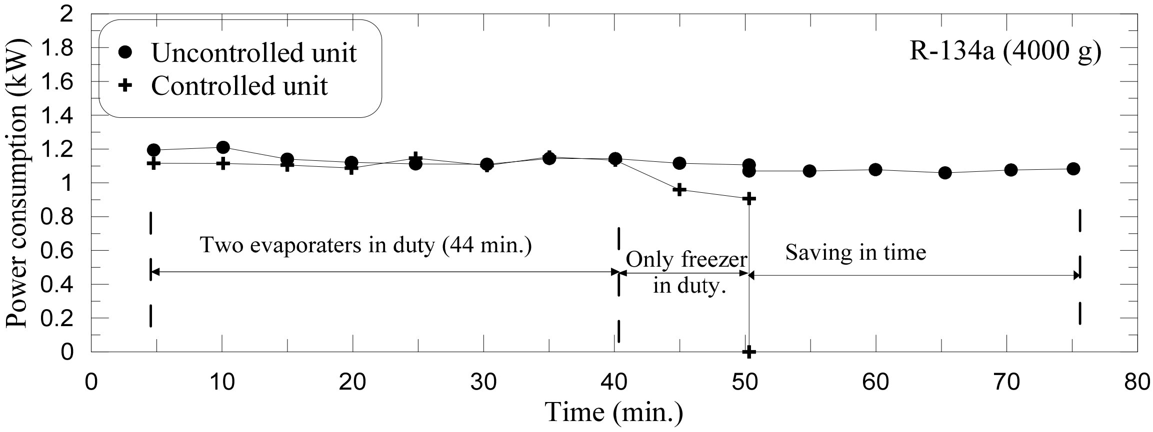

Fig. 3. Compressor power consumption for controlled and uncontrolled operation with time, (R134a)

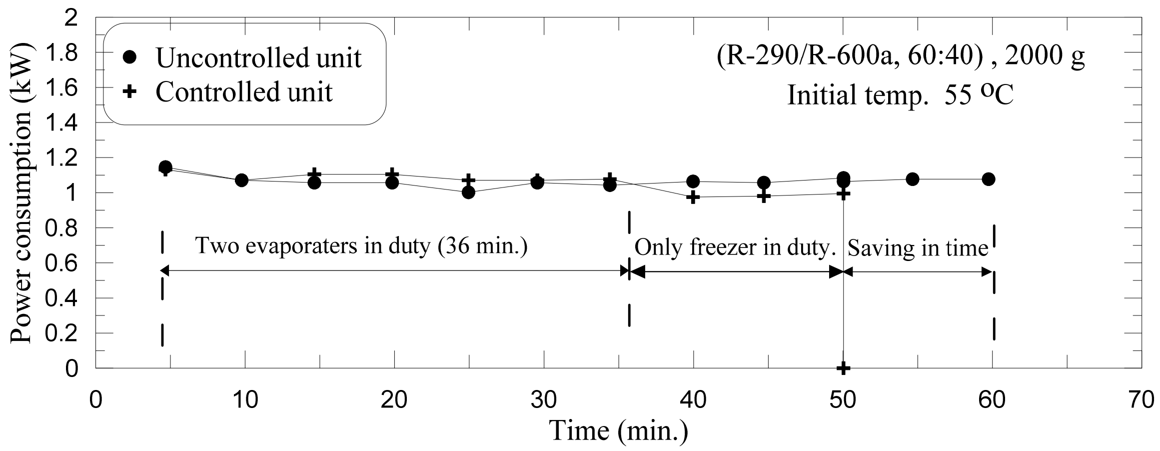

Fig. 4. Variation of compressor power consumption with time for the controlled and uncontrolled cycle, (Hydrocarbon mixture)

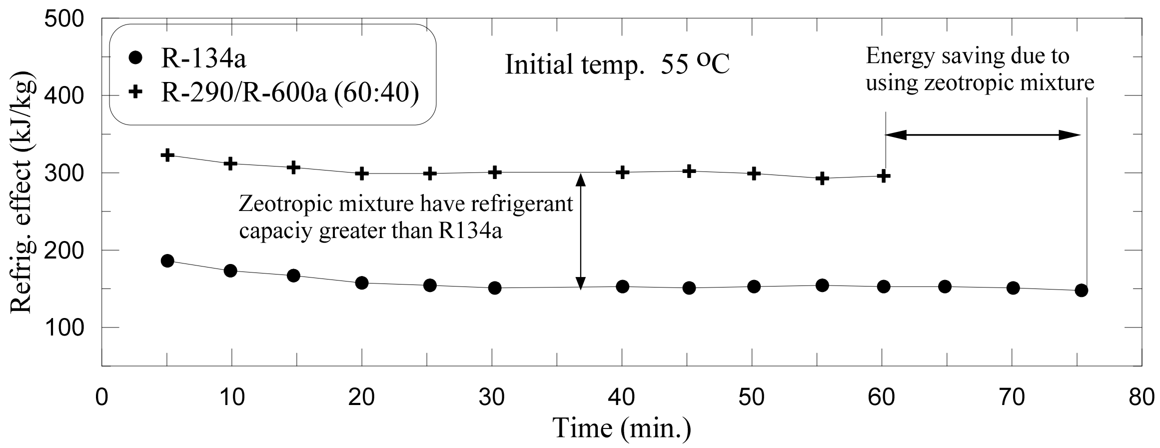

Fig. 5. Variation of refrigeration effect with time for both R134a and hydrocarbon mixture, (uncontrolled system)

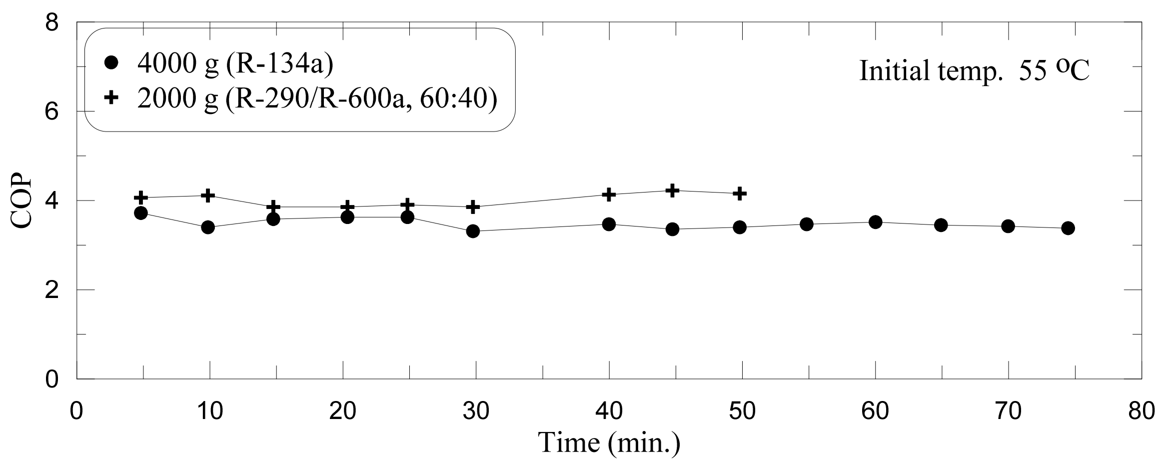

Fig. 6. Variation of COP with time for both R134a and hydrocarbon mixture, (uncontrolled system)

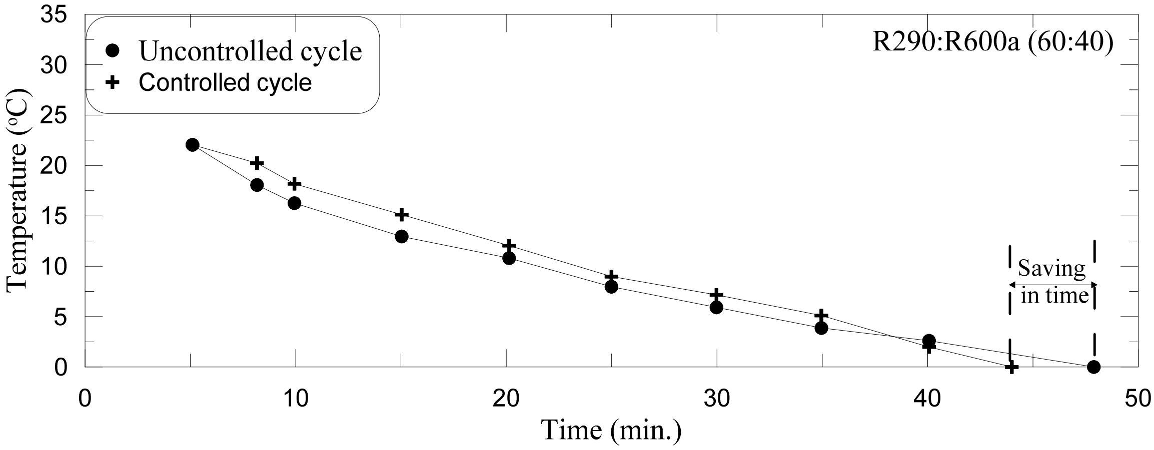

Fig. 7. Effect of using control circuits on the time required to reach cold room set point, (hydrocarbon mixture)

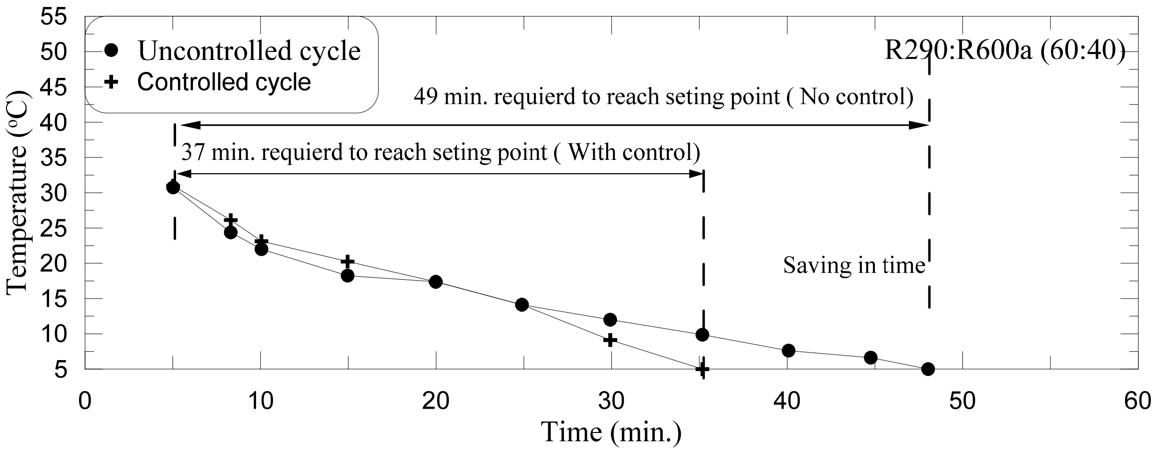

Fig .8. Effect of using control circuit on the time required to reach freezing room set point, (hydrocarbon mixture)

5. Conclusion

Replacing R-134a by a hydrocarbon mixture has the following effects on the cycle: reducing compressor power consumption by 21%, increasing COP by 16%, and reducing operating time by 25 min.

Using circuit controlled cycle working with hydrocarbon mixture have the following effects on the cycle: reducing compressor power consumption by about 20%, reducing the time required to reach the freezing set point by 4 min, about 12 min reduction in reaching the cooling set point, and increasing cycle COP by about 9%.

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