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Design and Fabrication of a LPG Cooling System

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Abstract: *Supply of continuous electricity is still not available in several areas of the country especially in remote part of India. So the refrigeration of food, medicines, etc. becomes difficult and costly.To overcome this difficulty, use of LPG for refrigeration is best contender as it is easily available and cheaper than other fuel. This work investigate design and analysis of an experimental study carried out to determine the performance of LPG cooling system. LPG is mixture of propane-butane mixed in percentage of 56.4% butane, 24.4% propane, and 17.2% isobutene.Also the LPG is environmental friendly and do not produce greenhouse gases and has no global warming potential (GWP). This project is based on vapor compression cycle which will use LPG as a refrigerant but not in close cycle as it is an open cycle where the outlet is connected to the burner.*

Keywords: *Refrigeration system, LPG, cooling system*

I. Introduction

The refrigeration system is known to the man, since the middle nineteenth century. The scientist, of the time, developed a few stray machines to achieve some pleasure. But it paved the way by inviting the attention of scientist for proper studies and research. They were able to build a reasonably reliable machine by the end of nineteenth century for the refrigeration jobs. But with the advent of efficient rotary compressors and gas turbines, the science of refrigeration reached its present height.

Hebrews, Greeks, and Romans placed large amounts of snow into storage pits dug into the ground and insulated with wood and straw. The ancient Egyptians filled earthen jars with boiled water and put them their roofs, thus exposing the jars to the night's cool air. In India, evaporating cooling was employed. When a liquid vaporizes rapidly, it expands quickly. The rising molecules of vapour abruptly increase their kinetic energy and this increase is drawn from the immediate surroundings of the vapour. These surroundings are therefore cooled.The intermediate stage in the history of cooling foods was to add chemicals likes' sodium nitrate or potassium nitrate to water causing the temperature to fall. Cooling wine via above method was recorded in 1550, as were the words "to refrigerate".

Cooling drinks came into vogue by 1600 in France. Instead of cooling water at night, people rotate long-necked bottles in water in which saltpeter had been dissolved. This solution could be used to produce very low temperature and to make ice. By the end of the 17th century, iced liquors and frozen juices were popular in French society.The first known artificial refrigeration was demonstrated by William Cullen atthe University of Glasgow in 1748.

Beginning in the 1840, refrigerated cars were used to transport milk and butter. By 1860, refrigerated transport was limited to mostly seafood and dairy products. The refrigerated railroad car was patented by J.B.Sutherland of Detroit; Michigan in 1867.He designed an insulated car with ice bunkers in each end. Air came in on the top, passed through the bunkers, and circulated through the car by gravity, controlled by the use of hanging flaps that created differences in air temperature.

Brewing was the first activity in the northern states to use mechanical refrigeration extensively, beginning with an absorption machine used by S. Liebmann's Sons Brewing Company in Brooklyn, New York in 1870.commercial refrigeration was primarily directed at breweries in the 1870 and 1891, nearly every brewery was equipped with refrigerating machines.

Natural ice supply became an industry into itself. By 1879, there were 35commercial ice plants in America, more than 200 a decade later, and 2,000 by 1909. No pond was safe from scraping for ice production, not even Thoreau's Walden Pond, where 1,000 tons of ice was extracted each day in 1847.

However, as time went on, ice, as a refrigeration agent, became health problem. Says Bern Nagengast, co-author of Heat and Cold: Mastering the Great Indoors (published by the American Society of Heating, Refrigeration and Air-conditioning Engineers), "Good sources were harder and harder to find. By the 1890's, natural ice became a problem because of pollution and sewage dumping." Signs of a problem were first evident in the brewing industry. Soon the meatpacking and dairy industries followed with their complaints.

Refrigeration technology provided the solution: ice, mechanically manufactured, and giving birth to mechanical refrigeration.

Carl (Paul Gottfried) von Linde in 1895 set up a large scale plant for the production of liquid air. Six years later he developed a method for separating pure liquid oxygen from liquid air that resulted in widespread industrial conversion to processes utilizing oxygen (e.g. in steel manufacture).

II. Literature Review

Bilal A. Akash etc. Al., has conducted performance tests on the performance of liquefied petroleum gas (LPG) as a possible substitute for R12 in domestic refrigerators. The refrigerator which is initially designed to work with R12 is used to conduct the experiment for (LPG 30%, propane 55%, n-butane and isobutene 15%). Various mass charges of 50, 80,100g of LPG were used during experimentation. LPG compares very well to R12. The COP was higher for all mass charges at evaporator temperature lower than -15$°C$. Overall, it was found that at 80g charge, LPG had the best results when use in this refrigerator. The condenser was kept at a constant temperature of 47$°C$. Cooling capacities were obtained and they were in the order of about three to fourfold higher for LPG than those of R12[1].

I. H. Shah and K. Gupta has designed the components of LPG refrigerator (evaporator, capillary tube, cabinet). They studied behaviour of LPG refrigerator for a period of 60mins and lowest temperature of -9.3$°C$ for evaporator was achieved. COP (5.08) was also higher than what was achieved by domestic refrigerator (2.53)[2].

B.O.Bolaji, have experimental study of R152a/R32 to replace R134a in a domestic refrigerator and find out that COP obtained by R152a is 4.7% higher than that of R134a. COP of R32 is 8.5% lower than that of R134a and propane is an attractive and environmentally friendly alternative to CFCs used currently[3].Z. Shahrum and Z. Zakaria have studied the properties of LPG by substituting as refrigerant. Parameters of LPG were checked at different components of refrigerator. They were very close to actual behaviour of the refrigerant used[4].

M. Fatouh ET. al., investigated a drop in substitute for R134a in a single evaporator domestic refrigerator with a total volume of 0.283 m3 with Liquefied petroleum gas (LPG) of 60% propane and 40% commercial butane. To optimize the performance of the refrigerator, tests were conducted with different capillary lengths and different charges of R134a and LPG. Experimental results of the refrigerator using LPG of 60g and capillary tube length of 5 m were compared with those using R134a of 100g and capillary tube length of 4 m. Pull-down time, pressure ratio and power consumption of LPG refrigerator were lower than those of R134a by about 7.6%, 5.5% and 4.3%, respectively. COP of LPG refrigerator was 7.6% higher than that of R134a. Lower on-time ratio and energy consumption of LPG refrigerator was lower than 14.3% and 10.8%, respectively, compared to those of R134a refrigerator were obtained. In conclusion, the proposed LPG is dropping in replacement for R134a, to have the better performance, optimization of capillary length and refrigerant charge was needed[5].

A.Baskaran&Koshy Mathews A Performance Comparison of Vapour Compression Refrigeration System Using Eco Friendly.Refrigerants of Low Global Warming Potential VCR system with the new R290/R600a refrigerant mixture as a substitute refrigerant for CFC12 and HFC 134a. The refrigerant R290/R600a had a refrigerating capacity 28.6% to 87.2% higher than that of R134a[6].

Sanjeev Singh Punia&Jagdev Singh, have Experimental investigation on the performance of coiled adiabatic capillary tube with LPG as refrigerant and conclude that There was an increase in mass flow rate by 106%, when the capillary inner diameter was increased from 1.12mm to 1. 52mm.When the coil diameter of capillary tube was decreased from 190mm to 70mm, the mass flow rate was decreased by 13%, 7% and 9% for 1.12mm, 1.4mm and 1.52mm inner diameter of capillary tube respectively. 1.40 mm diameter capillary affected the system more as compared to 1.12 mm diameter capillary tube. Mass flow rate increases with increase in capillary inner diameter and coil diameter whereas mass flow rate decreases with increase in length. It was observed that the COP of system increases with similar change in geometry of capillary tube[7].

M.A. Hammad ET. al. has experimentally investigated the performance parameters of a domestic refrigerator with four proportions of R290, R600 and R600a are used as possible alternative replacements to the R12.An unmodified R12domestic refrigerator was charged and tested with each of the four hydrocarbon mixtures that consist of 100% R290, 75% R290/19.1% R600/5.9% R600a, 50%R290/38.3% R600/11.7% R600a and 25%R290/ 57.5%R600/17.5%R600a. The results show that the hydrocarbon mixture with 50%R290/38.3%R600/11.7%R600a is the most suitable alternative refrigerant which has COP which is 2.7% higher than the R12[8].

III. Experimental Setup

Fig. 1. Basic experimental setup of LPG refrigeration system

The basic setup of experiment is shown in figure 1.
LPG is Liquefied Petroleum Gas. This is general description of Propane (C_3H_8) and Butane (C_4H_{10}), either stored separately or together as a mix. This is because these gases can be liquefied at a normal temperature by application of a moderate pressure increases, or at normal pressure by application of LPG using refrigeration. LPG is used as a fuel for domestic, industrial, horticultural, agricultural, cooking, heating and drying processes. LPG can be used as an automotive fuel or as propellant for aerosol, in addition to other specialist applications. LPG can also be used to provide lighting through the use of pressure lanterns.
We have used 2 cylinders one domestic (16 kg) and one commercial cylinder (19.5 kg) for test purpose to check the performance difference and rate of cooling

Fig. 2 LPG Gas Cylinder

Fig. 3 Capillary Tube 1Size: d= 0.031-inch, L= 11 feet

The capillary tube is the commonly used throttlingdevice in the domestic refrigeration. The capillary tube is a copper tube of very small internal diameter. It is of very long length and it is coiled to several turns so that it would occupy less space.

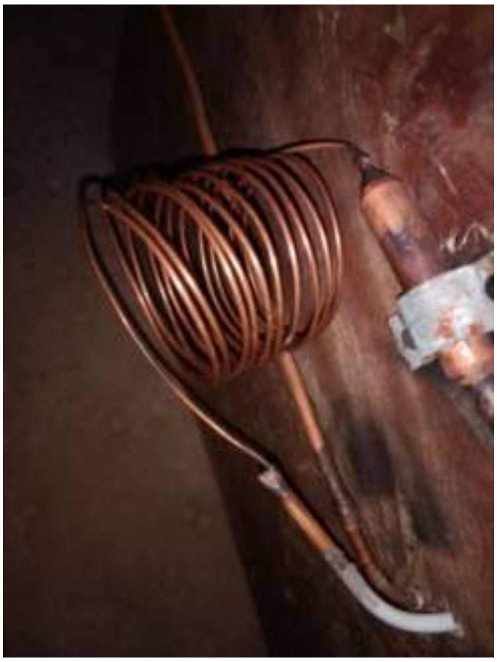

Fig. 4.capillary tube 2Size: d= 0.04-inch, L: 8 feet

The internal diameter of the capillary tube used for the refrigeration applications varies from 0.5 to 2.28 mm (0.020 to 0.09 inch). The capillary tube is shown in picture. When the refrigerant enters in the capillary tube, its pressure drops down suddenly due to very small diameter. The decrease in pressure of the refrigerant through the capillary depends on the diameter of capillary and the length of capillary. Smaller is the diameter and more is the length of capillary more is the drop-in pressure of the refrigerant as it passes through it.We have used 2 capillary tube of different dimension and performed test on it to check the performance of cooling system with changing diameter and length of capillary tube.

The evaporators are another important parts of the refrigeration systems. It through the evaporators that the cooling effect is produced in the refrigeration system. It is in the evaporators when the actual cooling effect takes place in the refrigeration systems. For many people the evaporator is the main part of the refrigeration system, consider other part as less useful. The evaporators are heat exchanger surface that transfer the heat from the substance to be cooled to the refrigerant, thus removing the heat from the substance. The evaporators are used for wide variety of diverse application in refrigeration and hence the available in wide variety of shape, sizes and designs. They are also classified in different manner depending on the method of feeding the refrigerant, construction of the evaporator, direction of air circulation around the evaporator, application and also the refrigerant control. In the domestic refrigerators the evaporators are commonly known as freezers since the ice is made in these compartments. In the evaporators the refrigerant enters at very low pressure and temperature after passing through the capillary tube. This refrigerant absorbs the heat from the substance that is to be cooled so the refrigerant gets heated while the substance gets cooled. Even after cooling the substance the temperature of the refrigerant leaving the evaporator is less than the substance. In the large refrigeration plants the evaporator is used for chilling water. In such cases shell and tube type of heat exchanger are used as the evaporators.

Fig. 5 Evaporator

In Fig.6 Many techniques have been developed for the measurement of pressure and vacuums. Instruments used to measure pressure are called pressure gauges or vacuum gauges.A manometer could also refer to a pressure measuring instrument, usually limited to measuring pressures near to atmospheric. The term manometer is often used to refer specifically to liquid column hydrostatic instruments.The range of high-pressure pipes covers most application where there is a requirement to transfer gas at high pressure. They consist of a steel pipe with a steel ball fitted to both ends. Two swiveling connection nipples press these balls against the seating of the connecting hole and thus sealing against gas leakage.

Fig. 6 Pressure Gauges

Gas coming out of evaporator is very chilled which causes incomplete combustion, sooty flame to avoid incomplete combustion and to decrease the temperature of gas flowing though the pressure pipe to the burner we use water cooler another advantage of using water cooler is we can get chilled water for drinking purpose basically this increase the efficiency of the system shown in fig.7.

Fig.7 watercooler

In Fig.8 Since we took application based on candle industry so our main aim was to test temperature drop of wax mould inside the cabinet. We are using wax mould inside the cabinet to check number of mould it can cool in a given particular of time.

Fig 8. Wax mould

IV. Design And Fabrication

Heat Interaction Between Atmosphere and Cabinet Due to Conduction, Convection and Radiation: The following are the dimensions of the cabinet:

Length = 0.438 m
Breadth = 0.473 m
Height = 0.44 m
Area 1 = 0.438×0.44 = 0.19272 m^2 =Area 4
Area 2 = 0.473× 0.44 = 0.20812 m^2 =Area 5
Area 3 = 0.438×0.473 = 0.207174m^2 = Area 6
Cabinet Surface area= $2\times(A_1+A_2+A_3) = 1.216028\ m^2$

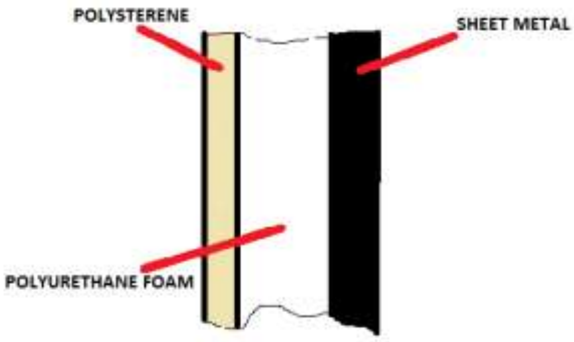

Fig.9 Cross-section of Cabinet

Sheet metal thickness (L_1) = 0.003 m
Polystyrene thickness(L_3) = 0.002 m
Polyurethane foam thickness(L_2) = 0.02332 m
Temperature of atmosphere ($T_{atm.}$) =29.5°C = 302.5 K
Temperature of cabinet ($T_{cab.)}$ = 15.8°C = 288.8 K
Temperature at outer surface of cabinet wall ($T_{surface}$) = 26 °C = 299 KThermal conductivity of sheet metal, K_1 = 80 W/m-k
Thermal conductivity of polyurethane foam, K_2= 0.03 W/m-kThermal conductivity of polystyrene, K_3 = 0.033 W/m-k. The cabinet is made from sheet metal of 3 mm thickness.Insulation is polyurethane foam of 23.32 mm thickness. Inner case is of polystyrene of 2 mm thickness.

HEAT FLOW DUE TO CONDUCTION

Heat flow from area1 due to conduction is,

$$Q_1 = \frac{T_{atmosphere} - T_{cab.}}{R_{th_1} + R_{th_2} + R_{th_3}}$$

$$Q_1 = \frac{T_{atmosphere} - T_{cab.}}{\left(\frac{L_1}{k_1 \cdot A_1}\right) + \left(\frac{L_2}{k_2 \cdot A_1}\right) + \left(\frac{L_3}{k_3 \cdot A_1}\right)}$$

where,R_{th1}, Rth_2 and R_{th3} are thermal resistances offered by layers of sheet metal, Polyurethane foamand Polystyrene respectively.

$$R_{th} = \frac{L}{k \cdot A}$$

Heat flow due to convection

Rate of heat transfer (Q),

$$(Q_{total})_{convection} = U \times A_{surface} \times (T_{atmosphere} - T_{cab.})$$

The overall heat transfer coefficient (U)

$$\frac{1}{U} = \left(\frac{1}{U_o}\right) + \left(\frac{L_1}{k_1}\right) + \left(\frac{L_2}{k_2}\right) + \left(\frac{L_3}{k_3}\right) + \left(\frac{1}{U_i}\right)$$

Heat transfer due to radiation,

$$(Q_{total})_{radiation} = \varepsilon \cdot \sigma \cdot (T_{atmosphere}{}^4 - T_{outer-surface}{}^4) \cdot A_{surface}$$

V. Results

Test 1: [Capillary: d=0.031", L=11 ft.]

The experiment of this project was done on 6th June 2017 at 1:03 p.m. and readings were taken at 1 min difference for 10 min without any load (i.e. empty cabinet) with new domestic cylinder (16 kg). The inlet pressure at the inlet of capillary tube was 40 psi or 2.5 Kgf/cm^2 and the outlet pressure at the outlet of evaporator is 8 psi or 0.5 Kgf/cm^2.

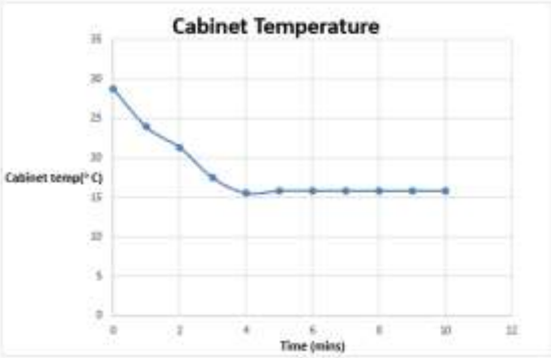

Fig. 10 Cabinet Temperature(^{0}C) v/s Time (mins)

Test 2: [Capillary=0.031", L=11 ft.]
Again, test was done on same day (06/06/17) at 04:02 p.m. with a container containing water. Domestic cylinder of 16 kg was used. test was performed to check temperature drop of water in 1 hour

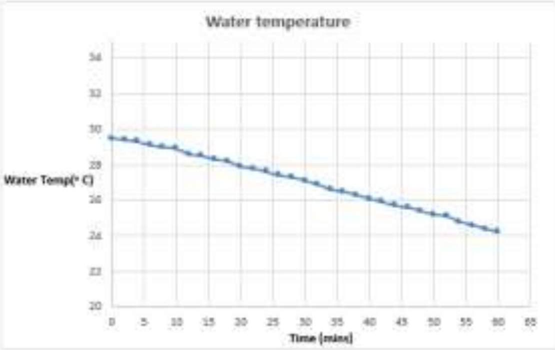

Fig. 11 Water Temperature(^{o}C) v/s Time (min)

Test 3: [Capillary=0.031", L=11 ft.] Third test was done on 07/06/17 at 10:05 p.m. keeping hot water inside the cabinet. Domestic cylinder of 16 kg was used Temperature drop in 1 hours was noted with time interval of 2 minutes

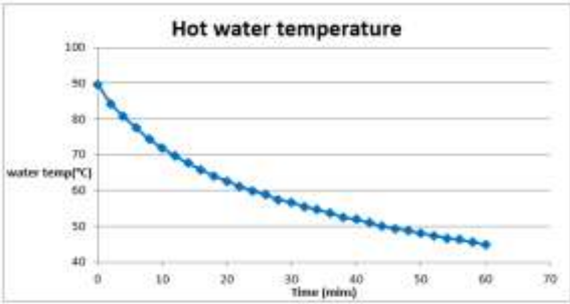

Fig. 12 Temperature drop of hot water

Test 4: [capillary=0.04", L=8 ft.]
A test was performed on 19/06/17 at 12.07 p.m. with commercial cylinder,19.2 kg with capillary diameter 0.04" and length of 8 ft. to see if the change in capillary and use of commercial cylinder can yield to a good result.

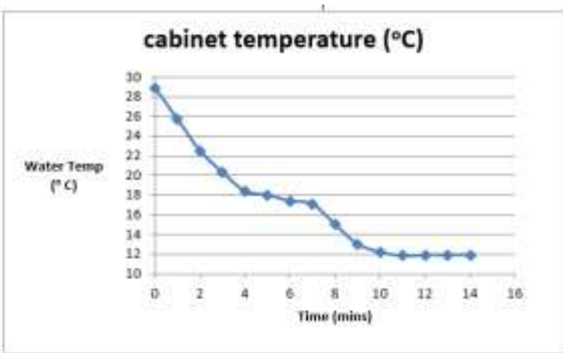

Fig. 13 Cabinet Temperature(0C) v/s Time (mins)

Test 5: [Capillary=0.04”, L=8 ft.]
A test was performed on 23/06/17 at 1:12 p.m. with commercial cylinder,19.2 kg with capillary diameter 0.04" and length of 8 ft. to see if the change in capillary and use of commercial cylinder can yield to a good result.

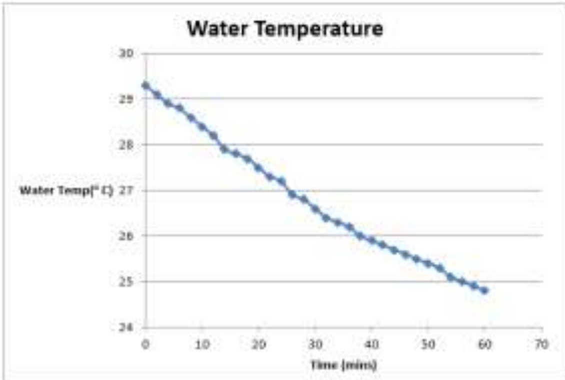

Fig. 14 Water Temperature (^{o}C) v/s Time (min)

Test 6: [Capillary: d=0.04", L=8 ft.]
A test was performed on 09/06/17 at 1:08 p.m. with commercial cylinder (19.2 kg) using hot mould to check whether the commercial cylinder can give better performance as compared to domestic cylinder (16 kg).

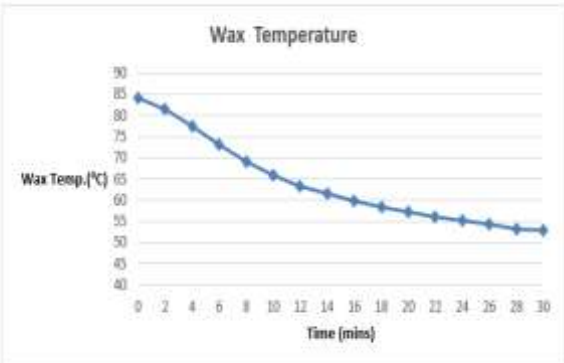

Fig. 15 Wax Temperature (^{o}C) v/s Time (mins)

Test 7: [Capillary: d=0.04", L=8 ft.]
Again experiment with 2 mould was done with size of capillary tube to diameter 0.04 inches and length 8 feet, Commercial cylinder (19.2 kg) was used. Readings were taken at 2 min difference for 50 mins.

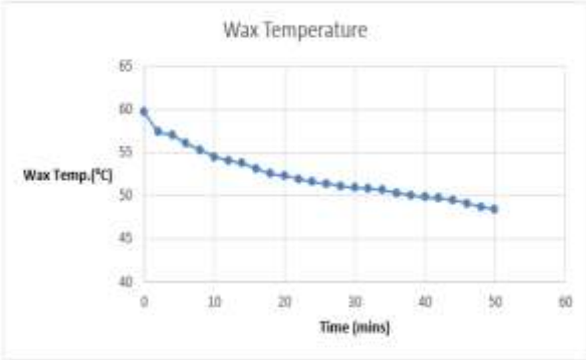

Fig. 16 Wax Temperature (°C) v/s Time (mins)

VI. Conclusions

In this paper Design and Fabrication of LPG Cooling Systemis based on the principle of adiabatic expansion of a refrigerant (In this case LPG) from 80 psi to 10 psi so that thermodynamically it absorbs heat from surrounding and cooling may have done. Expected cooling is predicted up to range of 26°C to 0.33 °C.Using the sophisticated data and instruments the relevant refrigeration system will be developing practically. In this project the capillary tube/thermoset valve is more suitable throttling device in LPG refrigeration system. This system is cheaper in initial as well as running cost. It does not require an external energy sources to run the system and no moving part in the system so maintenance is also very low. In this system this refrigeration is amplified remarkably and a cheaper and eco-friendly method is developed. LPG refrigerants have superior properties often giving 10 to 20% energy savings.This system most suitable for hotel, industries, refinery, chemical industries where consumption of LPG is very high.

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