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Measurement of Kinematic Viscosity of Refrigeration Oil and Refrigerant Mixture

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ABSTRACT

Refrigerant dissolves in refrigeration oil which is used to lubricate the compressor. Because the viscosity of the oil in which the refrigerant is dissolved is significantly reduced, the rate of the reduction is important information to select a proper oil. However, viscosities have not been sufficiently measured for mixtures of refrigeration oil and new refrigerants which are HFOs and mixtures of HFO and HFC. In order to utilize HFO refrigerants in alternative refrigeration systems, viscosity data of mixtures of refrigeration oil and HFO are essential. In this study, mixture of a refrigeration oil and refrigerant (R410A and R1234yf) viscosity are measured with temperature from 40 to 80 ℃ (313 – 353 K) and the oil mass concentration from 80 to 100 % using the tandem capillary tubes method. In this method, the test fluid flows inside two different length and same diameter capillary tubes connected in series in order to eliminate the pressure drop at the inlet and outlet therefore the measurements have better accuracy than the single capillary tube method.

1. INTRODUCTION

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) have been used in refrigeration systems such as air conditioners and heat pump because of their suitable characteristics such as nonflammability, chemical stability, and low toxicity to the human body. However, since it was confirmed that CFCs and HCFCs where the ozone-depleting potential (ODP) of them is not zero are depleting the ozone layer, it was decided to phase out the production and use of the CFCs and HCFCs. Although hydrofluorocarbons (HFCs) of which ODPs are zero were nominated and used as alternative refrigerants, the global worming caused by the HFCs became an environmental issue and the reduction of HFCs has been decided. The global warming potential (GWP) of HFCs is hundreds to around fifteen thousand. As a result, recently, hydrofluoroolefins (HFOs) of which ODP is zero and GWP is low are recognized as next generation refrigerants.

Lubricant oil is required to protect the compressor from wear in most of vapor compression refrigeration systems. In the system, refrigerants are used as working fluids. In order to estimate or design compressor in vapor compression refrigeration system, viscosity investigation of refrigerant and lubricant oil mixture is required. When refrigerant dissolves in lubricant oil, thermophysical properties of lubricant is change significantly. Especially inside the compressor, the kinematic viscosity of the oil is very important, so it is necessary to investigate and research its physical properties. Chang et al. (1993) measured the concentration and temperature dependence of the viscosity of mixtures (R123 and 3GSD, R134a and PAG). Richard et al. (1994) measured viscosity and density of mixture (synthetic 32 ISO VG and 100 ISO VG branched acid pentaerythritol polyester and R134a) by an oscillating body viscometer. Hyung et al. (1996) compared the wear data of mixture of lubricant (esters, alkylbenzene and mineral oil) and refrigerant (R134a and R22) from compressor tests to pin/block testers and others. Takigawa et. al (2002) measured solubility and viscosity of HFCs (R125, R134a, R143a and R32) and alkylbenzene lubricant oil mixture and developed correlation of the solubility and viscosity based on the physical modeling of the mixture. Hung et al. (2014) suggested a new physical model for calculating viscosity and solubility of lubricant-refrigerant mixtures. Ana et al. (2020) measured kinematic viscosity of polyol ester lubricant oil and HFO refrigerants (R1234yf and R1234ze(E)) mixture. Sun et al. (2021) are also investigated viscosity of lubricants and HFO refrigerants (R1234yf and R1234ze(E)) mixture. In this paper, we report the measurement results of kinematic viscosity of oil/refrigerants mixtures which are POE/R410A and R1234yf under the conditions of high oil mass fraction at temperature of 40 to 80 °C. The kinematic viscosity was measured by the tandem capillary tube method where a test fluid flows though the long and short capillary tube and the pressure drops are measured.

2. EXPERIMENTAL SETUP

2.1 Basic theory of capillary tube method

Kinematic viscosity of test fluids (lubricant oil and Refrigerant mixture) are measured with a capillary tube method. In the single capillary tube method based on Hagen-Poiseuille theory, viscosity is obtained from measuring pressure drop of laminar flow inside a capillary tube. Relationship between viscosity and pressure drop of laminar flow inside a capillary tube as shown in Figure 1 are expressed as below;

$$\eta = \frac{\pi a^4 \mathit{\Delta} P}{8Lq} \tag{1}$$

here η, a, $\mathit{\Delta} P$, L, and q are viscosity, radius of capillary tube, pressure drop inside a capillary tube, the tube length and volume flow rate. However, as shown in Figure 1, since expansion/contraction and the pressure drop occurs at the tube entrance and exit, measured pressure drop is higher than $\mathit{\Delta} P$ in Eq. (1). In addition, the end face effect of the tube occurs. Therefore, Eq. (2) is applied for correction of end face effect and kinetic energy.

$$\eta = \frac{\pi a^4 \mathit{\Delta} P}{8(L+na)q} - \frac{mq\rho}{8\pi(L+na)} \tag{2}$$

where n and m are respectively end face and kinetic energy correction coefficients obtained empirically depending on experimental apparatus and ρ indicates fluid density. The length of the capillary tube should be decided as long as possible in order to reduce the end face effect.

Schematic of pressure gradient in tandem capillary tubes is shown in Figure 2. Measured each pressure drop of two sections include pressure drop of fully developed laminar flow and inlet and outlet end face (entrance and exit) of tubes. By superposition of two pressure drops, both the inlet and outlet face effect of tube and the kinetic energy effect can be eliminated and the viscosity of laminar flow is obtained as below.

$$\eta = \frac{\pi a^4 (\mathit{\Delta} P_1 - \mathit{\Delta} P_2)}{8(L_1 - L_2)q} \tag{3}$$

In this work, the kinematic viscosity is measured by the following Eq. (4).

$$\nu = \frac{\pi a^4 (\mathit{\Delta} P_1 - \mathit{\Delta} P_2)}{8(L_1 - L_2)\dot{m}} \tag{4}$$

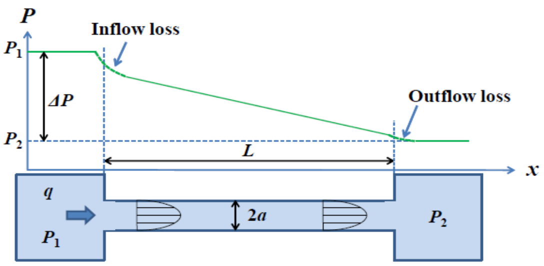


Figure 1: Distribution of pressure gradient in a single capillary tube

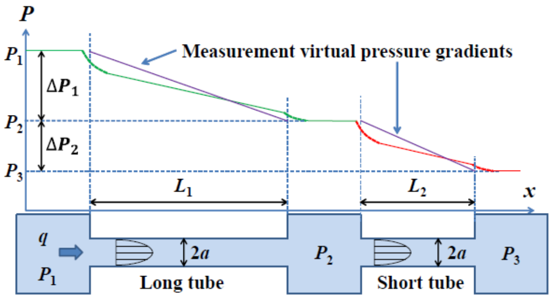
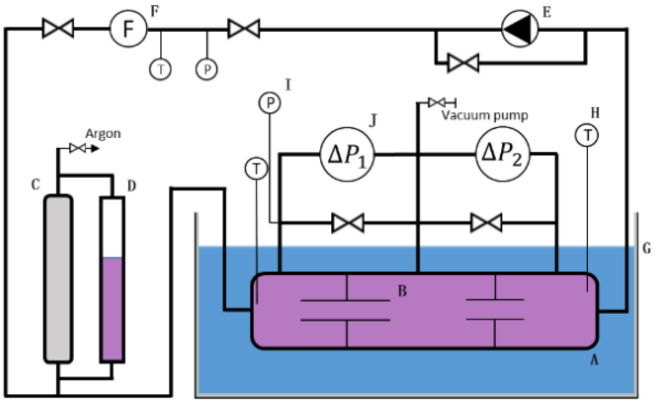


Figure 2: Distribution of pressure gradient in tandem capillary tubes

2.2 Experimental apparatus

Figure 3 shows schematic of experimental apparatus. Test fluid is enclosed in a viscometer vessel (A) in Isothermal bath (G) and a pressure vessel (C) put respectively expose to room temperature as it is. The fluid flow is created by the pump (E). Fluid flows in serial two different length Pyrex capillary tubes (B) of which inner diameter are 0.3 mm, length are respectively 100 and 50 mm. Flowing oil mass fraction of the mixture are estimated by calibrated density value at the Coriolis mass flow meter and the uncertainty is within approximately 3 %

The length and the inner diameter of the present capillary tubes ware measured by reading microscope and gravimetric method using liquid mercury and their uncertainties are calculated for long and short tubes. Their uncertainties are 0.044 and 0.016 % for long tube, 0.024 and 0.037 %, respectively. In addition, the uncertainty of the temperature, pressure, differential pressure and mass flow rate is measured by PRT, pressure transducer, differential pressure transducer and Coriolis mass flow meter. The maximum uncertainties of these four measuring instruments are estimated to be 0.18 °C, 0.11 %, 0.36 % and 0.24%. Eventually, according to the uncertainty analysis of the present measurement apparatus system, uncertainty of the kinematic viscosity obtained by Eq. (4) is estimated to be 0.46 mm^2/s.



A : Viscometer
B : Capillary tube
C : Pressurizing device
D : Sight glass
E : Nonpulsation pump
F : Coriolis flowmeter
G : Isothermal bath
H : Thermometer
I : Pressure transducer
J : Differential pressure transducer

Figure 3: Experimental apparatus

3. RESULTS AND DISSCUSION

3.1 Experimental Condition

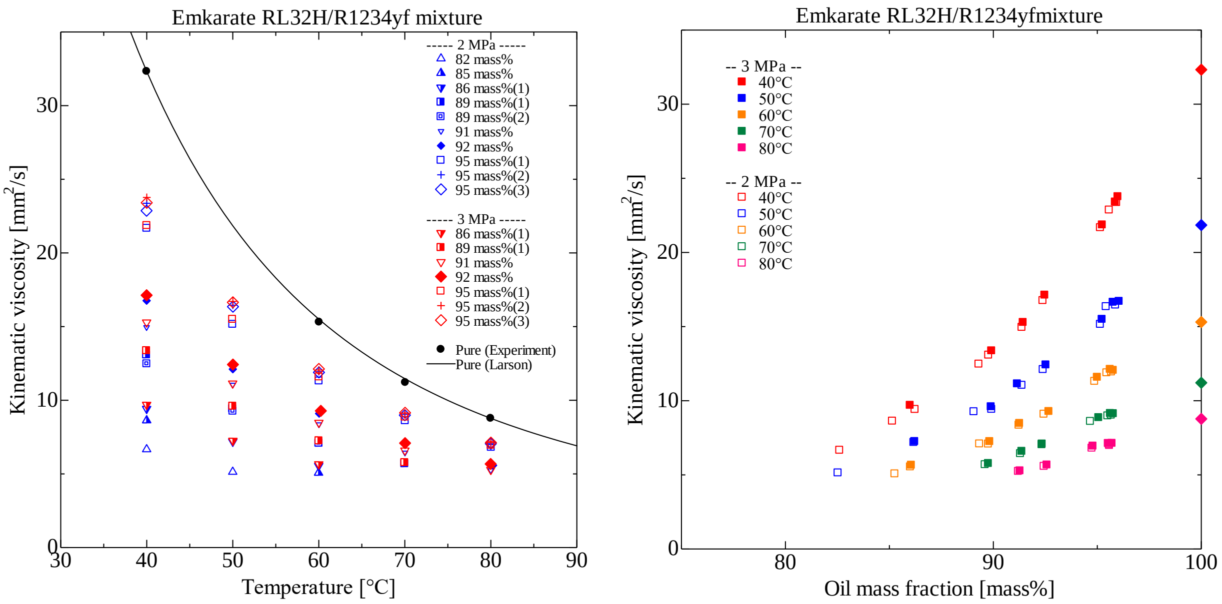
Table 1 shows the experimental conditions. The test fluids are mixture of Refrigeration oil and Refrigerant. The Refrigeration oil used is Emkarate RL32H (2019), which is a type of Polyol ester, and refrigerants are R1234yf and R410A, which are respectively standard refrigerants of HFO and HFC. As shown in the Table 1, kinematic viscosity of mixtures is measured under completely dissolved condition with oil mass fraction of between 85 and 100 % at temperature of 40 to 80 °C.

Table 1: Experimental conditions

Oil mass fraction [mass%]	**Temperature [℃]**
85 to 100	40, 50, 60, 70, 80

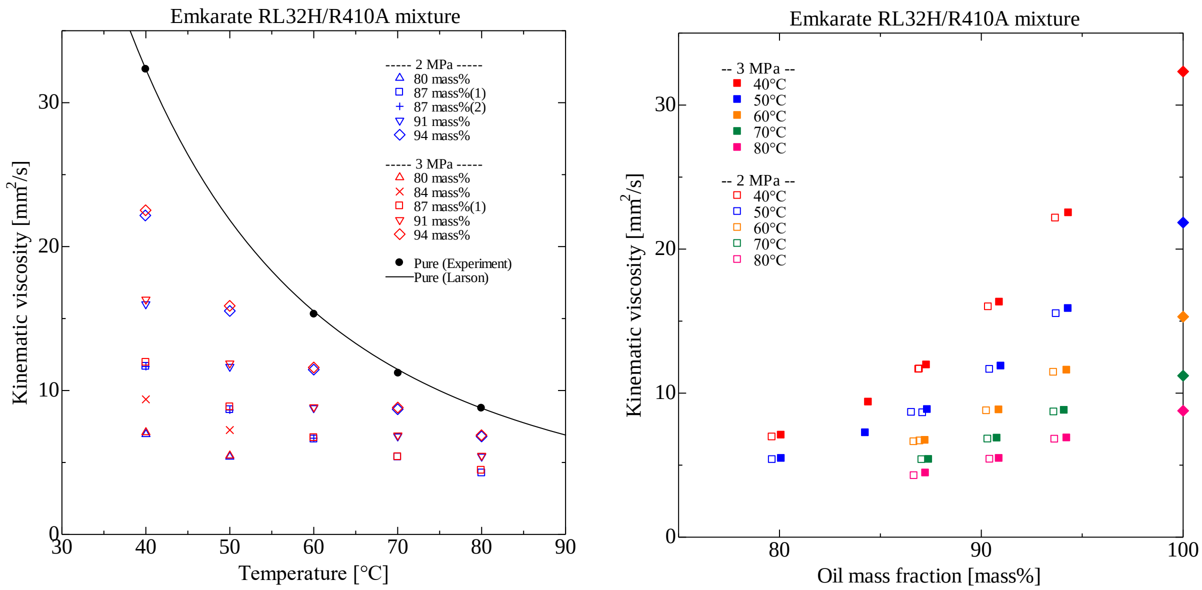
3.2 Result

Figure 4 and 5 shows kinematic viscosity of POE/R1234yf and POE/R410A, (a) and (b) in each figures show effect of temperature and oil mass fraction on kinematic viscosity, respectively. Black line and plot in figure 4 (a) and 5 (a) indicate pure oil measured value and calculation by Larson (1955) correlation. As shown in each figures, kinematic viscosity decreases with increasing temperature same as general characteristics of liquid kinematic viscosity and increases with increasing oil mass fraction. It is also found that the pure oil kinematic viscosity value is reduced by half with only 10 mass % refrigerant mixing.



(a) Effect of temperature (b) Effect of oil fraction

Figure 4: Kinematic viscosity of POE/R1234yf



(a) Effect of temperature (b) Effect of oil fraction

Figure 5: Kinematic viscosity of POE/R410A

Figure 6 shows comparison result of measurements between POE/R1234yf and POE/R410A mixtures. Value of kinematic viscosity of POE/R410A mixture are slightly higher than that of R1234yf at same temperature and oil mass fraction. All the kinematic viscosity value of POE/R1234yf and POE/R410A mixture with pressure, temperature and oil mass fraction conditions obtained by the present study are summarized in table 2 and 3, respectively.

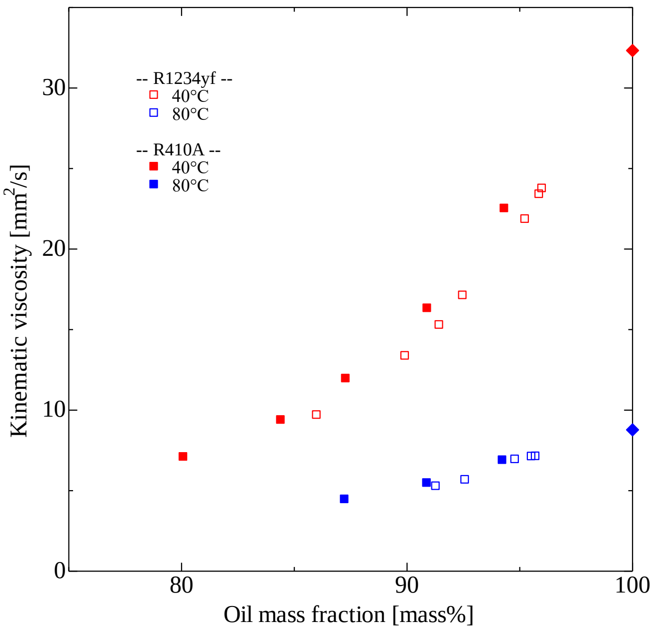


Figure 6: Comparison between POE/R1234yf and POE/R410A

Table 2: Measured kinematic viscosity of Emkarate RL32H/R1234yf mixture

Refrigerant	P (MPa)	T (°C)	w_{oil} (mass%)	ν (mm^2/s)
R1234yf	2.02	39.99	82.6	6.7
R1234yf	2.02	50.00	82.5	5.1
R1234yf	2.02	39.99	85.1	8.6
R1234yf	2.03	59.97	85.3	5.1
R1234yf	2.04	39.99	86.2	9.4
R1234yf	2.03	50.01	86.2	7.2
R1234yf	2.00	60.00	86.0	5.5
R1234yf	2.02	39.98	89.8	13.1
R1234yf	2.01	49.99	89.9	9.4
R1234yf	2.03	60.03	89.8	7.1
R1234yf	2.03	70.00	89.6	5.7
R1234yf	2.02	40.00	89.3	12.5
R1234yf	2.01	50.01	89.1	9.3
R1234yf	2.03	60.00	89.3	7.1
R1234yf	2.03	39.98	91.4	15.0
R1234yf	2.04	50.00	91.4	11.0
R1234yf	2.00	60.02	91.2	8.4
R1234yf	2.08	70.02	91.3	6.4
R1234yf	2.01	79.99	91.2	5.2
R1234yf	2.01	39.98	92.4	16.8
R1234yf	2.01	50.01	92.4	12.1
R1234yf	2.03	60.04	92.4	9.1
R1234yf	2.00	70.02	92.3	7.0
R1234yf	1.99	80.26	92.4	5.6
R1234yf	2.01	40.00	95.1	21.7
R1234yf	2.04	49.99	95.1	15.2
R1234yf	2.01	60.03	94.9	11.3
R1234yf	2.03	70.05	94.7	8.6
R1234yf	2.02	80.04	94.7	6.8
R1234yf	2.02	39.99	95.9	23.4
R1234yf	2.02	50.01	95.9	16.5
R1234yf	2.03	60.01	95.7	11.9
R1234yf	2.04	70.00	95.7	9.0
R1234yf	2.01	80.00	95.6	7.0
R1234yf	2.03	39.98	95.6	22.9
R1234yf	2.04	50.02	95.4	16.4
R1234yf	2.04	60.02	95.5	11.9
R1234yf	2.03	70.00	95.5	9.0
R1234yf	2.03	80.00	95.6	7.1
R1234yf	3.02	39.99	86.0	9.7
R1234yf	3.03	50.02	86.2	7.3
R1234yf	3.02	60.00	86.1	5.7
R1234yf	3.03	39.98	89.9	13.4
R1234yf	3.01	49.99	89.9	9.6
R1234yf	3.01	60.02	89.8	7.3
R1234yf	3.01	70.00	89.8	5.8
R1234yf	2.99	39.99	91.4	15.3
R1234yf	3.03	49.99	91.2	11.1
R1234yf	3.02	60.01	91.3	8.5
R1234yf	3.02	70.01	91.4	6.6
R1234yf	3.02	80.00	91.3	5.3
R1234yf	3.00	39.98	92.5	17.1
R1234yf	2.99	50.02	92.5	12.4
R1234yf	2.97	60.24	92.7	9.3
R1234yf	3.00	70.03	92.3	7.1
R1234yf	2.96	79.98	92.6	5.7
R1234yf	3.03	40.01	95.2	21.9
R1234yf	3.03	49.97	95.2	15.5
R1234yf	3.01	60.02	95.0	11.6
R1234yf	3.01	70.03	95.1	8.9
R1234yf	3.03	80.02	94.8	6.9
R1234yf	2.99	40.00	96.0	23.8
R1234yf	2.98	50.01	96.0	16.7
R1234yf	3.03	60.01	95.8	12.1
R1234yf	3.00	70.01	95.8	9.1
R1234yf	3.03	80.01	95.7	7.1
R1234yf	2.99	39.99	95.9	23.4
R1234yf	3.01	50.01	95.8	16.6
R1234yf	3.01	60.01	95.6	12.1
R1234yf	2.99	70.03	95.6	9.1
R1234yf	3.02	80.01	95.5	7.1

Table 3: Measured kinematic viscosity of Emkarate RL32H/R410A mixture

Refrigerant	P (MPa)	T (℃)	w_{oil} (mass%)	ν (mm^2/s)	Refrigerant	P (MPa)	T (℃)	w_{oil} (mass%)	ν (mm^2/s)
R410A	2.03	40.01	79.6	7.0	R410A	3.03	40.01	80.1	7.1
R410A	2.01	50.00	79.6	5.4	R410A	3.03	50.00	80.1	5.5
R410A	2.00	39.99	86.9	11.7	R410A	3.04	40.00	84.4	9.4
R410A	1.99	50.00	86.5	8.7	R410A	3.00	50.00	84.3	7.3
R410A	1.98	60.02	86.7	6.6	R410A	3.03	40.00	87.3	12.0
R410A	1.99	70.00	87.0	5.4	R410A	3.03	50.00	87.3	8.9
R410A	2.02	80.02	86.7	4.3	R410A	3.03	60.01	87.2	6.7
R410A	2.30	40.01	86.9	11.7	R410A	3.04	70.01	87.4	5.4
R410A	2.31	50.00	87.1	8.6	R410A	3.01	79.96	87.2	4.5
R410A	2.31	60.01	87.0	6.7	R410A	3.00	40.00	90.9	16.3
R410A	2.02	39.99	90.3	16.0	R410A	3.00	50.00	91.0	11.9
R410A	2.00	50.00	90.4	11.7	R410A	3.05	60.01	90.9	8.8
R410A	2.01	60.00	90.3	8.8	R410A	3.04	70.02	90.8	6.9
R410A	2.03	70.01	90.3	6.8	R410A	3.04	80.01	90.9	5.5
R410A	2.03	80.00	90.4	5.4	R410A	3.02	39.97	94.3	22.5
R410A	2.01	39.94	93.7	22.2	R410A	3.01	49.99	94.3	15.9
R410A	2.03	50.00	93.7	15.5	R410A	3.02	60.00	94.2	11.6
R410A	2.04	60.00	93.6	11.5	R410A	3.02	70.01	94.1	8.8
R410A	2.04	70.00	93.6	8.7	R410A	3.02	79.98	94.2	6.9
R410A	2.05	79.99	93.6	6.8					

4. CONCLUSION

The kinematic viscosity of refrigeration oil/Refrigerant mixtures (POE/R1234yf, POE/R410A) are measured by tandem capillary tube method. Followings were obtained by the present study.

- Values of kinematic viscosity of both POE/R1234yf and POE/R410A increase with increasing oil mass fraction and with decrease temperature, same as general characteristics of fluid.
- The pure oil kinematic viscosity value is reduced by half with only 10 mass % refrigerant mixing.
- The value of kinematic viscosity of POE/R410A mixture is slightly higher than that of POE/R1234yf mixture in all mass concentration and temperature conditions.

NOMENCLATURE

a	radius of capillary tube	(mm)
L	length of capillary tube	(mm)
m	correction coefficient of kinetic energy	(–)
$\dot{m}$	mass flow rate	(kg/s)
n	correction coefficient of pipe end	(–)
P	pressure	(MPa)
ΔP	pressure drop	(Pa)
q	volume flow rate	(mm^3/s)
η	viscosity	(μPa・s)

ν	kinematic viscosity	(mm^2/s)
π	pi	
ρ	density	(kg/m^3)

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