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Possibility analyses of using hydrocarbon R-290 and mixing with R-32 refrigerant to retrofit R-32 domestic split air conditioning

M.E. Arsana[a1], I.D.M.C. Santosa[a], I.B.G. Widiantara[a], and I.W. Temaja[a]

[a]*Mechanical Engineering Department, Politeknik Negeri Bali, Badung, Bali 80364, Indonesia*

Abstract

Indonesia government's policy to eliminate the use of R-22 refrigerant in air conditioning cooling system will be enforced by 2020. Air cooling equipment manufacturers, especially domestic air conditioners, dominate Indonesia and Asia markets using R-410a and R-32 refrigerants as a replacement to R-22. This study will present the results of experimental studies of retrofit testing on the system of split type domestic AC using R-32 with hydrocarbon refrigerant and Mixing with R-32. The use of hydrocarbons as a refrigerant retrofit is very potential to retrofit R-32 in split type domestic AC without replacement of any part of the system provided that its possibility study has been performed through theoretical and experimental study. An analysis is also done to provide the solution for split AC utilization using R-32 refrigerant retrofitted with hydrocarbon refrigerant. Testing has been done by simply replacing the refrigerant without replacing any component. This experiment uses commonly used ½ Pk split type domestic AC equipment whose equipment consists of a semi-hermetic inverter compressor, condenser and capillary pipe expansion valve in the outdoor unit and an evaporator as a heat exchanger in the indoor unit. Results obtained in preliminary data processing showed that R-32 retrofit with HR-290 hydrocarbon refrigerant and mixing with R-32 deals with improved COP performance from 4.65 to 5.0, 5.47 respectively with reduced energy use.

Keywords: COP; refrigeration system; retrofit; refrigerant; and energy use

1. Introduction

Here one of point declared in the Montreal and Kyoto protocol (1897 & 1997) was banded the using of refrigerant R-22 (HCFC-22) and changed it by the refrigerant which friendly with environment. The alternative is hydrocarbon refrigerant but because it is flammable, the use is limited. [1]. Recent research on topics leads to HFCs and natural refrigerants such as water (R718), ammonia (R717) and CO_2 (R744) with very low ODP and GWP used to replace HCFCs in refrigeration and AC systems [2]. Manufacturers and importers of air conditioning refrigerants prefer refrigerants such as R-32 and R-410a refrigerants to be applied to air-conditioning systems. Both of these refrigerants have zero ODP and low enough GWP of 675 for R-32 and 2088 for R-410a as well as non-flammability due to its low flame nature [3].

The R-22 cooling machine can still be used by retrofit or drop in refrigerant method from R-22 to R-290 because the compressor oil used on R-22 can be used for R-290[4]. An experimental study with split AC replaced by R 290 showed that its cooling capacity decreased by 1.6% and COPR was higher by 10%. Along with the concern for the Environment the regulation for split AC with R-22 is getting tighter.

The energy efficiency labels (EEL) published in 2007 that a split-market COP with a capacity below 4.5 kW should be no less than 3.2 [5]. The researchers conducted an experimental study with R-22 retrofit small wall room air conditioner with R-290 which found that COP R-32 and cooling capacity were higher than the original but with a heat exchanger with 7 mm diameter tube which by increasing the diameter means to increase production cost also increase the amount of refrigerant inserted so that the maximum refrigerant fill in is below the security standards set for the refrigerant and also flammable. Some researchers are discussing R-32 refrigerants such as; [6] presented that the two-stage suction ejector cycle using R-32 theoretically resulted in the development of this cycle resulted in higher COP cooling and heating capacities but continued with experiments. [4].

Presenting theoretically that R-32 can be used to replace R-410 by utilizing refrigerant flow system (VRF) that R-32 COP is 5% higher and its cooling capacity is 6% results obtain based on system thermodynamic analysis it is known that R-32 COP is 5% higher and its cooling capacity is 6% higher than R-410.

[1]Corresponding author. Tel.: +6281338636816; Fax: +62361702811
E-mail address: eryarsana@pnb.ac.id

Nomenclature

E_{annual}	Energy consumption, in kW/y	n	System operating time, in year
h_{in}	Enthalpy air entering air handling unit (AHU), kJ/kg	ß	CO_2 emission, in Kg/kWh
h_{out}	Enthalpy air out AHU, kJ/kg		
$\dot{m}$	Mass flow rate air, kg/hr		

For that reason, some countries in the world provide alternatives refrigerant such us: Japan with R32, USA with R 410A, Europe with HFC, PFC, SFC, Australia with SGHG (synthetic greenhouse gases), Indonesia with R32, Basic Regulation used is International regulation [7]. Due to differences in technical specifications, especially the working pressure of refrigerant then the cooling machine using R-22 is not possible to retrofit with R 32. In Indonesia the new air conditioner has been imported from China and Japan and used R-32 The consequence is of course in terms of price more expensive because of technical specifications increased such as compressor with a larger capacity and equipped with inverter, condenser pipe with a larger diameter of 6 mm thicker and the price of refrigerant twice more expensive.

Various efforts have been made to find an alternative refrigerant to comply with environmental friendly. The concern of the Indonesia Government on ozone layer protection is stated in Presidential Decree No. 23/1992 and the decisions of ministry commerce and industry No. 110 / MPP / Kep / 1/1998 which contains restrictions on the use and production of ozone depleting substances. To be able to produce products that meet the standards, the government has formulated the Indonesian National Standard (SNI) in the field of hydrocarbons as a strategic step.

Some of the natural refrigerants already used in refrigeration machines such us ammonia (NH_3), hydrocarbons (HC), carbon dioxide (CO_2), water, and air [8]. The use of carbon dioxide, water, and air in commercial refrigerators still requires an extensive research, while the use of ammonia and hydrocarbons still considerable and has a lot of research opportunities. Ammonia is toxic and flammable, while hydrocarbons are included in highly flammable substances; therefore, the refrigerant is generally difficult to use on a direct expansion system. Indirect refrigeration system can be used to overcome the weakness of both refrigerants. Some researchers try to suppress the hydrocarbon refrigerant's level of combustion by mixing it with other non-flammable refrigerants [9]. The study aims to optimize energy use through performance improvements (COP) in air conditioning systems of water-cooled chillers.

These performance improvements are made using appropriate primary refrigerants, as well as the addition of additives to secondary water refrigerants that can provide energy saving effects maintenance approach temperature at condensers. From the result of the research, the best performance improvement was achieved in combination of R-290 primary refrigerant with 0,7 Water +0,3 Tri-methylolethane (mass base) as secondary refrigerant. In this condition the increase the cooling machine performance coefficient is about 42%, saving power consumption 30% (in compressor) and increase cooling capacity about 10%.

In Germany, the latest refrigerators using R-600a and heat pumps and air conditioners now use the R-290 with measurable energy consumption 10 to 20% lower than R-12, R-134a or R-22 [10]. By applying the drop in method using R-290 refrigerant to replace R-22. The test was performed using the Indian standard IS 1391 (1992), states that by refueling refrigerant half of R-22, the cooling capacity is lower 6% compared to R-22. The energy consumption decreased 15.4% and discharge temperature decreased 20°C. So the energy efficiency ratio (EER) is 14% higher than R-22 [11] has also conducted an experiment to replace R-22 and R-410A for mini AC split.

It also performs on 6 other refrigerants, including R290 under different environmental temperature conditions, where the outdoor temperature varies from 27.8 °C up to 55 °C. This is followed by soft optimization, which sets the capillary tube diameter, from 2.0 mm to 1.65 mm and changes the length from 508 mm to 254 mm, using the same Ac split where the result indicates that propane is the most suitable refrigerant for alternative R-22 [12] with the aim of comparing the thermal performance of refrigerants R-22, R-290, R-1270, R-438A, R-404A, R-410A and R-32 with evaporator temperatures varying from -15 °C to -5 °C, using electronic expansion valve and variable speed compressor.

Systems with R-22 refrigerant are used as the basis of comparison only by replacing refrigerant in case for oil HFCs on the system are also replaced. [13] Its environmental impact is measured by the TEWI (Total Equivalent Warming Impact) parameter. The results show that the use of R1270 and R290 gives a maximum COP value. As well as other advantages of lowering the consumption of electrical energy, reduce the use of refrigerant, low HCs and low GWP. Based on that problem, it will need technical studies and experimental testing for R-32 refrigerant retrofit with hydrocarbon refrigerant with loading in the test chamber to obtain COP and assessment for environmental impact.

2. Methods

This research method will be done by drop in method [14] when these methods allow replacing R-32 refrigerant with R-290 and R-290 mixing R-32. Without replacing its components. The test will be use split air-conditioning domestic 1 Pk which is common in Indonesia market. Major parameters such as temperature and pressure on the system are used to verify and calculate performance. The comparison between the three refrigerants will use the same AC with the help of the ESS program [13]. The TEWI parameter is used to determine how much the impact on the environment due to the use of both refrigerants is attributed to BS EN 378, 2008 standard.

1.1 Type, Design and Place of Study

The experimental research method was implemented by direct observation, and by performing several treatments, the R-32 and R-290 refrigerants were tried alternately according to the procedure to determine the changes that occurred in the observed parameters. The data obtained by measurement will be recorded on the installed acquisition data and then intended for the calculation of the COP and EER values of the system, energy use and environmental impact assessment**.** In this study designed included some activities i.e. preparation (literature study, field observation), tool design, retrofit, evacuation, vacuuming and leakage test of oil lubricant replacement (hydrocarbon) and running test. This test will be conduct at Laboratory of Refrigeration and air Conditioning Study Program Department of Mechanical Engineering, Bali State Polytechnic.

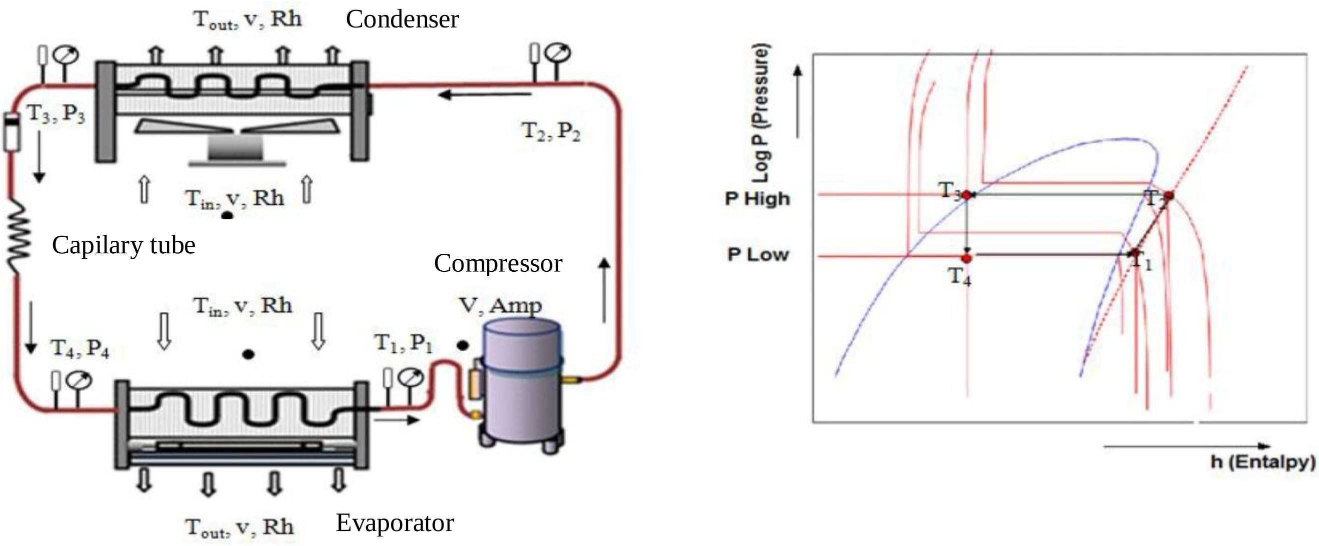

Figure 1. The vapor compression cycle

1.2 Procedure

The test research procedure is carried out in a room with good insulation, following the AHRI 210/240 Standard with load variations from 0.5, 1, 1.5, 2, to 2.5 kW using an electric heater. See Figure 1. Data obtained from this research is primary data. All instruments, including gauges and thermometers, will be calibrated during the measurement test range. The data will be taken on the evaporator and compressor with the following parameters:

Evaporator:

a. Dry air temperature and mass flow rate entering evaporator
b. Temperature out at coil evaporator
c. Relative air humidity in and out evaporator

Compressor:

a. Energy consumption comp
The data is taken every 10 minutes, a single test take 3 hours. The test will be conducted 3 times the analysis, the data will be averaged first.

1.1 Preparing the measurement

The following standard procedure used in determining AC performance [17] will be used on psychometric charts to determine enthalpy (heat content in inlets and outlets)

$$Heat\ Load\ (TR) = \frac{\dot{m}\ (hin - hout)}{4.18\ x\ 3024} \quad (1)$$

The heat load can be calculated theoretically by estimating the sensible heat load and latent heat in the air-conditioned room. The difference between the two shows losses due to leaks, unwanted loads, etc.

1.3 Method of Measurements

a. The rate of air mass flow is calculated by finding the flow velocity of the inlet air as well as determining the extent of the inlet side air in the split air
b. The amount of enthalpy is obtained from the psychometric chart by measuring the temperature and Rh at the air inlet and outside of the evaporator coil (indoor unit)
c. The energy consumption by compressor can be measured with a portable power analysis tool that will provide direct reading in kW. If not present, the ampere shall be measured with an available on-line ohm meter or by using a tang tester. The power can then be calculated assuming a power factor of 0.9 by the formula.
Power (kW) $= \sqrt{3}$ xVx I x cos $\emptyset$(2)

Performance calculations can be used values as shown in Table 1.

Table 1. Conversion factor for refrigeration performance

COP = 0.293 EER	EER = 3.413 COP
kW/Ton = 12 /EER	EER = 12/(kw/Ton)
kW/Ton = 3.516 /COP	COP = 3.516/kW/Ton

Source: *American refrigeration institute*

d. The TEWI parameter is used to determine how much the impact on the environment due to the use of all refrigerants is attributed to BS EN 378, 2008 standard. TEWI assessment (total equivalent warming impact) by assuming losses of leakage and recovery ~ 0 can be calculated using the TEWI formula approach only is the impact of energy consumption:

$$TEWI = n \times E_{annual} \times ß \quad (3)$$

Figure 2. Instrumentation of the test system

3. Results and Discussion

From the data that has been obtained in the measurement as shown in the picture below will be followed by using MS-Excel program. The results obtained by EES program will then be plotted on the P-h diagram to get its COP value.

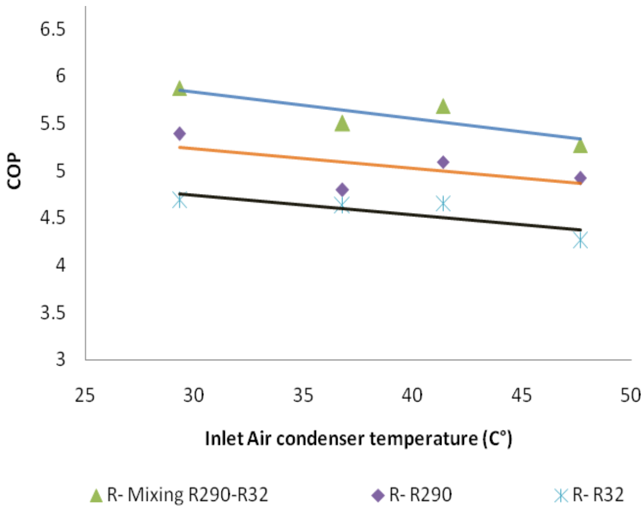

Figure 3. COP system

Another result is the comparison between the Inlet Air condenser temperature with the power compressor used by the compressor and the ratio of condenser and evaporator temperature.

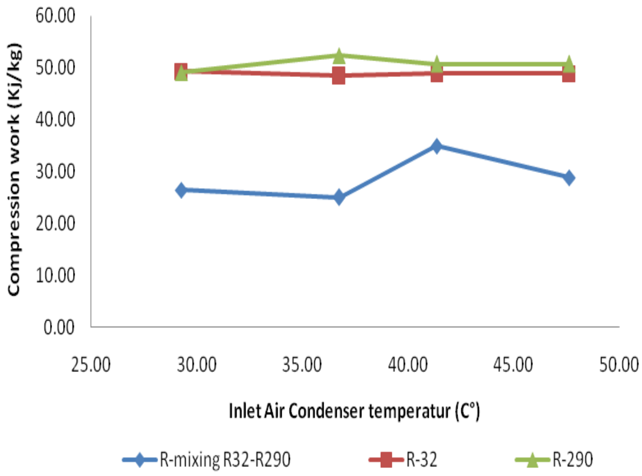

Figure 4. Compression work

From pictures above, Figure 3 we can see some different COP the highest COP value of 5.47 was Refrigerant mixing R-290/R-32 and then R-290 with average COP 5.0 and the R-32 COP refrigerant is 4.65. For mixing R290-R32 refrigerant are obtained by using the R410a refrigerant properties. Comparison of the compression works in kJ / kg sees Figure 4. The red line is for R-32 refrigerant while the green color is R-290 refrigerant and blue is the mixed refrigerant. From the comparison of the compression work, it is known that mixed refrigerants have the smallest compression work so that the use of electricity is reduced by an average compression work for the use of mixed refrigerants of 25.78 kJ / kg. When compared with compression work for R-32, the average value is 48.89 kJ / kg then there is a decrease in power usage by 0.47.

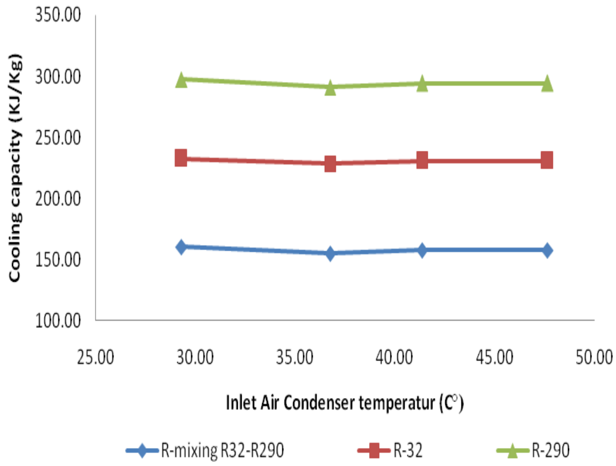

Figure 5. Cooling capacity

Figure 5 shows the comparison of its cooling capacity. The highest cooling capacity is R-290. The mixed refrigerants it has the smallest cooling capacity as a result of a decrease in its compression work. It can also be said to be the result of mixing R-32/R-290 refrigerants so that they have their own performance characteristics. The evaporator temperature of the mixed refrigerant is an average value of 19.46 °C so that it is higher than the refrigerant R.32 whose value is 12.88 °C.

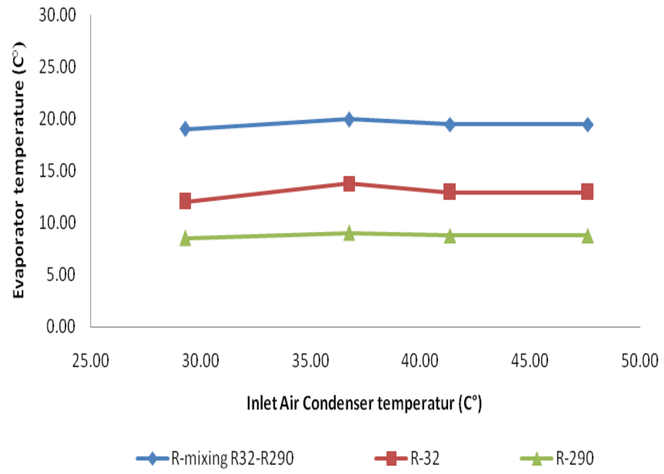

Figure 6. Evaporator temperature

Achievements for the R-290 have the lowest average value of 8.75 °C among them. this indicates that the temperature performance is best achieved by retrofit it with R-290.

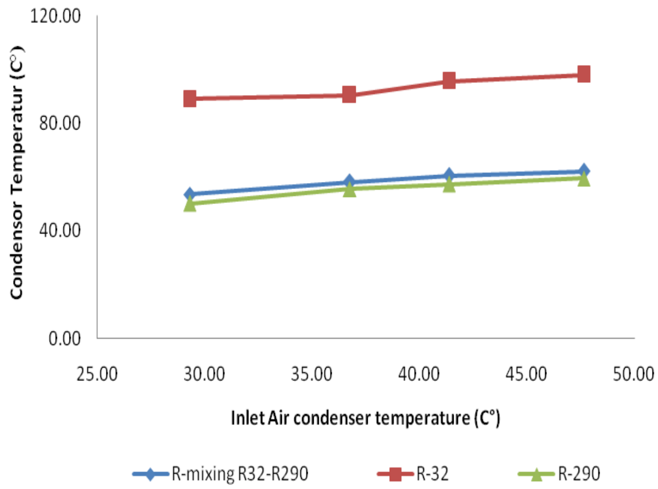

Figure 7. Condenser temperature

Figure 7 shows temperature of the condenser measured on the discharge side is based on the measurement results that the discharge temperature of refrigerant R-32 for the condenser inlet air temperature is 29.5 °C is 89 °C. while the use of a mixture of R-290/R-32 refrigerants approached the discharge temperature of R-290, respectively 58.60 ° C and 50.76 °C. In Figure 8. shows the power used by the compressor. The highest value is indicated by the use of the refrigerant R-32 which is 5.08 kWh, then the R-290 is 3.83 kWh and the lowest is the R mix R32-R290 with an average value of 3.02 kWh so there is a potential energy savings of 39% for refrigerant mixture R-32/R-290 and 25% for the use of refrigerant R-290. While the impact on TEWI system, which is a way to assess global warming by combining direct contributions from refrigerant emissions the air conditioning, split system is 0.5 Pk. See Figure 9. TEWI value for Refrigerant R-32 is 1339.74 Kg eq.CO_2 per year and for R-290 is 964,241 Kg eq.CO_2 per year while the lowest is for Mixing R-32/R-290 refrigerant.

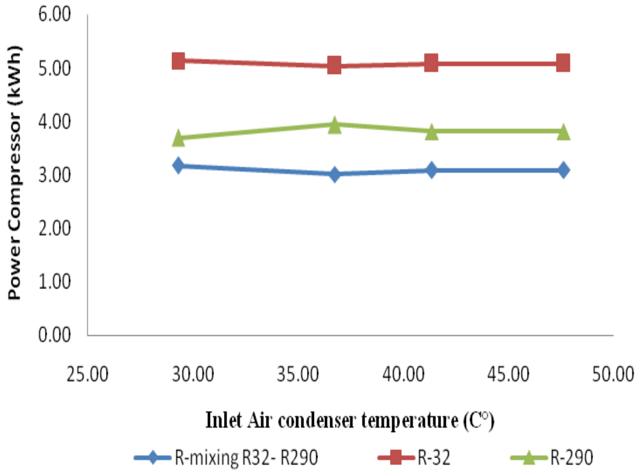

Figure 8. Power of compressor (kWh)

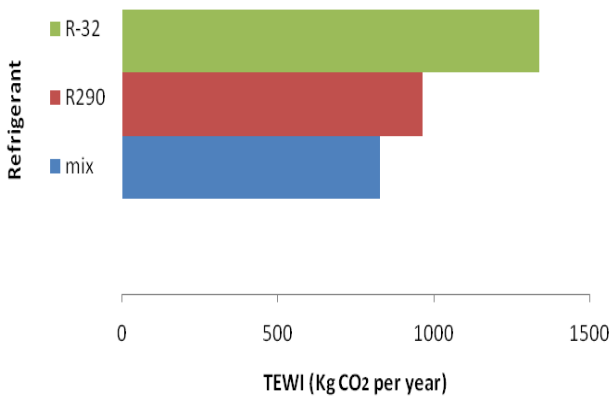

Figure 9. TEWI total equivalent warming impact

This is 828.52 Kg eq.CO2 per year. Thus, there is an opportunity to reduce its environmental impact for refrigerant R-290 and mixing the R-32/R-290 by 28%, 38% respectively

4. Conclusion

The possibility to use R-290 and mixing R-32 / R-290 to retrofit R-32 without replacement equipment is possible. From the research, we can see some primary parameters, which are indicated by R-290 having similar characteristics with R-32 but with some advantages as well as if they were mixed based on the composition of 40:60 for R-290 and R-32. COP improvement 15% for R-290 and 25% for R mix R32 / R290. Potentials energy saving at the compressor is 39% for refrigerant mixture R-32/R-290 and 25% if replaced with Refrigerants R290. TEWI has a reduction potential of 28% to 38%.

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