Performance analysis of low GWP refrigerants mixture as a substitute for R410A in residential air conditioner in tropical region

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Abstract. The issue of global warming has triggered more critical issues, and today's refrigerants with high global warming potential (GWP) are facing the challenges of being phased out. According to 2014 Assessment Report of the Refrigeration, Air-Conditioning and Heat Pumps Technical Options Committee (RTOC Assessment Report 2014), the R410A has GWP of 2100 and is widely used in residential air-conditioning and heat pump systems. Currently, in the market, the potential refrigerant that can be used to replace R410A in the air-conditioning system is R32. The purpose of this project is to create a new refrigerant mixture using low GWP refrigerant as a base that can replace for R410A in an air-cooled split air conditioner. Simulation works have been developed using Refprop software to simulate the refrigeration cycle with the operating conditions of the air-cooled split air conditioner, in the tropical region. The chosen cycle was an ideal vapour compression cycle with the evaporating and condensing temperatures of 5 ºC and 47 ºC, respectively. Through this study, two potential refrigerants mixture was found to be suitable to replace the R410A in the air-conditioning system is R32. The purpose of this project is to create a new refrigerant mixture using low GWP refrigerant as a base that can replace for R410A in an air-cooled split air conditioner. Simulation works have been developed using Refprop software to simulate the refrigeration cycle with the operating conditions of the air-cooled split air conditioner, in the tropical region. The chosen cycle was an ideal vapour compression cycle with the evaporating and condensing temperatures of 5 ºC and 47 ºC, respectively. Through this study, two potential refrigerants mixture was found to be suitable to replace the R410A. The two refrigerant mixtures, R32/R1234ze and R32/R600a, both based on R32, were found to have similar thermodynamic properties as the R410A. They were found to be able to produce the coefficient of performance (COP) very close to the R410A when used in an air-cooled split air-conditioner system. Hence, the use of this refrigerants will avoid significant modifications on the present air-conditioning system configurations. Refrigerant R32/R1234ze has the potential to reduce the GWP of R410A by 70 % while refrigerant R32/R600a by 73 %. At the end of the equipment lifespan, refrigerant R32/R1234ze would reduce the direct of Total Equivalent Warming Impact (TEWI) by 23 % while refrigerant R32/R600a by 20 %. in constructing both.
1. Introduction
On October 2016, in Kigali, Rwanda, The Parties to the Montreal Protocol had a 28th meeting and reached an agreement called Kigali Amendment on substances that destroyed ozone layer to phase down HFC. This amendment to be enforced on 1st January 2019 must be fulfilled which is ratified by at least 20 Parties to the Montreal Protocol. The conditions have been reached since November 2017, but the ratification process is still continuing and currently 42 countries have approved this amendment. The main objective of the Amendment is to gradually reduce the production and use of HFCs with periodic guidelines to achieve the 85% reduction target by 2036 for developed countries and by 2047 for developing countries.

According to Chen, X. et al. [1] and Tian, Q., et al [2], HFC-410A (R410A) is one of the most commonly used HFCs for residential split air conditioners and heat pump systems. However, Assessment Report of Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC Assessment Report 2014) reported and published that the R410A has high GWP of 2100. For that reason, it requires to be replaced with low GWP refrigerants to avert global warming that causes the climate change as proposed by Mota-Babiloni, A., et al. [3], Chen, X., et al. [1] and Devecioğlu, A. G. [4].

Many researchers have focused on finding alternative for refrigerant in heat pump systems that discussed by Alabdulkarem, A., et al. [5], Devecioğlu, A. G. [4], Jin, Z., et al. [6], Wu, D., et al. [7] and Domanski, P. A., et al. [8]. Alabdulkarem, A., et al. [5] pay attention to drop-in R410A and examined on split heat pump system. [5] and Wu, D., et al. [7] carry out an exergy analysis of low GWP refrigerants in a heat pump system with hybrid source. At the same time, Jin, Z., et al [6] analysed the Coefficient of Performance (COP) and yearly energy potential of R744 and R410A heat pump system by simulating two different conditions which are ambient air conditions and ground s heat sink condition. In addition, Nawaz, K., et al. [8] simulated residential hot water heat pump system using low GWP refrigerant and then being tested in experiment. In the other hand, Chen, X., et al. [1] investigated and monitored the effect on cooling capacity and space heating of the air-to-water heat pump system with the sub-cooler vapour injection cycle.

Recently, many researchers performed a reconnoitre of low GWP refrigerant, hydrofluoroolefin, as working fluid in refrigeration, air conditioning and heat pump system. Devecioğlu, A. G. [4] and Domanski, P. A., et al. [8] explored low GWP refrigerants as working fluids in heat pump systems. Domanski, P. A., et al. [8] concluded that single component of low GWP refrigerant as replacement for working fluid in refrigeration and air conditioning system applications are very limited in terms of volumetric capacity for R410A and R404A. Devecioğlu, A. G. [4] investigated low GWP refrigerants blend which are R452B, R454B and R446A, their result shown that R452B and R454B with Seasonal Coefficient of Performance (SCOP) value very close to R410A and higher Seasonal Energy Efficiency Ratio (SEER) value than R410A. In the other hand, Chen, X., et al [1] got difference results and indicated capacity of R452B in the system decreased 9 – 15 % as compared with R410A, the discharge temperature of compressor increased by 4 – 8 % and volumetric efficiency is significantly lower than R410A.

In the latest researches, almost all the researchers focus on R32 and its blends to replace R410A as working fluid in heat pump and air conditioning systems. There are three refrigerants like R32, L41a and D2Y60 have been investigated by Al Abdulkarem, A., et al. [5] as an alternative drop-in refrigerant in heat pump systems. Experimental result from this research, refrigerant R32 possess higher capacity in terms of cooling and heating compare with R410A, COP of L41 is greater than R410A and compressor’s discharge temperature of D2Y60 is superior to R410A. Tian, Q., et al. [2] had likewise investigated R32/R290 blend in household air conditioner for cooling and heating mode. The experimental result presented refrigerant charge amount of R32/R290 is reduced by 30.0 to 35.0% and the cooling and heating capacities are increased by 14.0 to 23.7 %. Botticella, F., et al [9] concluded that R32 is the lowest setup cost of all refrigerants considered. The cost of the R32 heat pump is 7% lower than that of the propane heat pump.
From the previous researches on determining the alternative working fluid for RAC system with low GWP refrigerant, many of the studies are focusing on modified the air conditioning and heat pump system to setup the experiment test equipment. No many researches to determine the R410A alternative in household air conditioner split unit without modification or altering the part or components in the RAC and heat pump system. The objective of this study is to determine the R410A alternative by using low or zero GWP working fluid to reduce the direct and indirect CO₂ emission for the existing air conditioning unit.

2. Description and Simulation

2.1. Total Equivalent Warming Impact (TEWI)

The theory of TEWI was established to determine the direct effects of refrigerants emission and the indirect impacts from energy use due to the combustion of fossil fuels or burning of coal in power plant as stated by Makhnatch, P. and R. Khodabandeh [10]. The direct effects of TEWI on environmental impact of greenhouse gases was calculated based on operating, servicing and disposing of the refrigerant at the end of equipment lifespan. The indirect effects of TEWI is also considering the power consumption of the appliances which using refrigerants indirectly will release CO₂ emissions that contribute to global warming and is normally much higher that direct effects of refrigerant. Hence, TEWI is the total amount of the direct and indirect contribution effect of the equipment that use refrigerant as working fluid over their lifespan [10]. Further to calculate the total value of TEWI for air conditioning and refrigeration systems, the following equations shown in BS EN378 – 1: 2016 [11] as below:

\[
\text{TEWI} = \text{TEWI}_{\text{Direct}} + \text{TEWI}_{\text{Indirect}} \\
= \text{GWP}_{100} [M.(1-X)+M.F.N] + W.A.N
\]

GWP of a greenhouse gas expresses the values contributes to global warming which is depending on the amount of gas produced, time elapsed before removal from the atmosphere and the properties of gas that absorbs radiant energy. GWP₁₀₀ is based on a 100 years integrated time horizon and is compared with the single value of CO₂.

Refrigerant charge (M), in kg, is the total quantity of refrigerant charged into the system. It depends on the cooling capacity of the refrigeration plant or air conditioning equipment and also the types of the refrigerant. Frequently, manufacturers of the air conditioning equipment define the accurate refrigerant charge as the amount needed to assure the sufficiently wetted by the working fluid.

The loss during recovery at the end of the lifespan for all stationary equipment, called recovery factor and represented by X. Leakage rate per year, F, means refrigerant direct release to the atmosphere due to hose and seal leakage and during serving of system. The annual leakage rate excluded the percentage of disposal but only considered the accidental leakage percentage due to operating conditions during its lifespan. Normally, the lifespan (N) of an appliances of air conditioning and refrigeration is based on the functioning time. The energy consumption of the systems (W) in the form of electricity and included amount of carbon dioxide released by combustion of fossil fuel or coal to produce energy based on the power generation of CO₂ emission coefficient (A).

It is necessary to analyse a TEWI for air conditioning and refrigeration systems by obtaining all the values of unknown in Eq(2), and carried out a simulation of investigate refrigerant charge and the power consumption of the apparatus for both refrigerants R410A and its alternative which are the common refrigerant used in Malaysia. The remaining unknowns are referred to literature data and actual data
from various resources such as DOE, Ministry of Energy, Science, Technology, Environment and Climate Change in Malaysia.

2.2. A cycle analysis

![Basic Air conditioner’s components](image)

Figure 1 Basic Air conditioner’s components

COP of air conditioning and refrigeration systems is a measure of energy efficiency for a given system charged with a particular refrigerant. There are many factors influencing the performance of air conditioner, for example efficiencies of compressor, types of heat exchanger, and dimensions of capillary. Actually, the selection of refrigerant for air conditioner would have major effects on the performance of air conditioner.

The model used here for simulation consists of four major components such as compressor, condenser, expansion device and evaporator and connected by compressor suction line, compressor discharge line and liquid line. Thermodynamic properties of the cycle are generated by the REFPROP add in for Microsoft Excel. The simulated cycle is defined by 9 corresponding points in the locations as shown in Figure 1 and are the following as showed in Figure 2. There are, 1. inlet of the compressor or evaporator outlet, 2. outlet of the compressor, 3. saturated vapour in the condenser, 4. saturated liquid in the condenser outlet or inlet to the adiabatic expansion device, 5. condenser outlet or inlet to the adiabatic expansion device, 6. expansion device outlet or evaporator inlet, 7. saturated vapour in the evaporator 8. saturated liquid at evaporating line, 9. isentropic point of the compressor.
2.3. Cycle parameters
The working conditions of the cycle with an evaporating temperature and condensing temperature of 4 °C and 45 °C respectively. For refrigerant blends are mixture refrigerant like R410A, the condensing temperature is the dew point temperatures in the condenser. However, the evaporating temperature is the vapour temperature in the evaporator. In this study, the condenser subcooling is 5 K and same as expansion device inlet subcooling. The inlet to the compressor is superheated to 10 K and same as superheated at the exit of the evaporator. The pressure drops for the suction, discharge and liquid lines are negligible. For compressor, calculated compressor volumetric and effective efficiency are 0.8 and 0.6 respectively was kept fixed for the studied refrigerants. The thermal loss rate of the compressor is assumed 0.1

2.4. Properties of refrigerants used for the analysis
Table 1 lists some physical properties of two commonly used refrigerant in Malaysia. This table also includes the chemical name or compositions in terms of percentage by mass, critical properties and molecular mass. Of these properties, boiling point is most important because it is direct indicating the temperature at which a refrigerant can be used. The critical properties describe a material at the point where the distinction between liquid and gas is lost. At higher temperature, no separate liquid phase is possible for pure fluids. In refrigeration cycles involving condensation, a refrigerant must be chosen that allow this change of state to occur at a temperature somewhat below the critical. This table also shows calculated ODPs and GWP100 for refrigerants by using the latest scientific assessment values.

Table 1: Physical properties of selected refrigerants

| NO | Property                        | R410A                  | Refrigerant A         | Refrigerant B       |
|----|--------------------------------|------------------------|-----------------------|---------------------|
| 1  | Chemical formula/ blend composition | 50% R32 & 50% R125     | R32 / R1234ze        | R32 / R600a         |
| 2  | Molar mass (kg/kmol)            | 72.585                 | 52.969                | 54.083              |
| 3  | Critical point temperature Tc(°C) | 71.358                 | 72.95                 | 78.53               |
| 4  | Critical pressure (Pc) (bar)    | 49.026                 | 50.112                | 56.737              |
| 5  | Critical density(kg/m3)         | 459.53                 | 348.05                | 417.06              |
| 6  | GWP                            | 2088                   | 628                   | 561                 |

3. Result and discussion
Figure 3 shown the comparison of GWP of the 3 refrigerants. Refrigerant A has GWP values of 628 and a 70 % reduction from R410A. Meanwhile refrigerant B with GWP values of 561 which further reduced by 73 % as compared with R410A. With this reduction, Refrigerant A and B will help the air conditioning system to comply the regulations and timelines of phasing down HFCs. TEWI_{Direct} of refrigerant A and B is 23 % and 20 % as compared with R410A system respectively. This shown that systems operate with refrigerant A and B can reduce the direct CO₂ emission in the lifespan of the air conditioner in terms of service and maintenance activities. In addition, the system will prolong the life span of the existing HFCs air conditioning system.

Comparison between COP and TEWI_{Indirect} of the air conditioning system with three refrigerants is shown in Figure 4. The system COP of refrigerants A and B is slightly lower than R410A, which is 99.4 % and 98.8 % compared with system operated with R410A, respectively. The TEWI_{Indirect} of refrigerant A and B were higher than R410A as 100.6 % and 101.2 % respectively. Indirectly, the system operate with refrigerant A and B will consume more power than R410A, but still within acceptable levels, increasing only by 0.6 % and 1.2 % compared to R410A. In the other hand, we need more efficient system to operate with refrigerant A and B by modifying the existing system.
4. Conclusion

The comparative study of these refrigerants followed the COP of the system and also the TEWI factors. The TEWI is a method of assessing global warming by combining the direct contribution of refrigerant emissions to the atmosphere with the indirect contribution of CO₂ emissions from the energy required to operate an air conditioning system during its operational lifetime. The lower refrigerant GWP will reduce TEWI's direct contribution to refrigerant emissions into the atmosphere, which means reducing greenhouse gases released into the atmosphere. On the other hand, less refrigerant GWP does not reduce the indirect contribution of TEWI to CO₂ emissions from energy consumption to the operating system. We need more effective systems to reduce the indirect contribution of TEWI. With this study will assist engineer or designer to select suitable refrigerant alternative for their air conditioning application.

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