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EVALUATION OF ALTERNATIVE REFRIGERANT FOR A 255000 KCAL/HR, 130KW VAPOUR COMPRESSION REFRIGERATION SYSTEM FOR PROPYLENE PURIFICATION PROCESS

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ABSTRACT

Common refrigerants such as CFCs and HCFCs have unfavorable environmental impacts and this has brought about concerns and regulations prohibiting their production and use as refrigerants by the year 2030. The 255000 kCal/h, 130 kW capacity refrigerating system uses R-22 refrigerant which is of the HCFCs' family, hence, the need for alternative refrigerant because of the negative environmental impacts of this family of refrigerants. Natural refrigerants such as hydrocarbons and their mix in various ratios are currently being investigated to replace CFC and HCFC based solvents. In this study, propane (R-290), propylene (R-1270), ammonia (R-717) and ethane (R-170) were evaluated as alternative refrigerants for the **255000 kCal/h** Freon (R-22) refrigerating system through modelling and simulation using Aspen Hysys V8.0. Combining energy efficiency, economics, environmental and safety criteria, propane was favoured amongst the studied refrigerants as the choice alternative refrigerant to replace R-22 even though there is need to also replace the existing compressor with a propane compressor because of the extra power of 79.6 kW required to compress propane.

Keywords: Refrigerants, Process modelling and simulation, Aspen HYSYS, Refrigeration cycle, Propane.

I. INTRODUCTION

Society faces many environmental challenges, the most significant being global climate change, stratospheric ozone depletion and acid precipitation; of which release of chemical refrigerants such as chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) are partly causative factors **[1]**. International treaties such as the Montreal Protocol banned the production and importation of these refrigerants by 2030 as such, the need to replace these refrigerants in processes where they are being utilized **[2]**. A Refinery and Petrochemical plant in West Africa (name withheld) utilizes one of the HCFCs in the refrigerating system of their propylene plant. The need to replace the HCFC with an environmentally friendly refrigerant arises to avoid plant shutdown because of environmental regulations. Therefore, the objective of this study is to evaluate alternative refrigerants and identify a cost effective refrigerant that would replace the existing HCFC.

Previous work

Concerns over the effects of the release of some chemicals on the environment even though they possess excellent thermodynamics and thermo-physical properties as refrigerants; has led to the ban of Chlorofluorocarbons (CFCs) and Hydro-chlorofluorocarbons (HCFCs) by international treaties- Montreal **[3]** and Kyoto Protocols **[4, 5]**. In search for alternative refrigerants to replace chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) of which R-22 is a family member, many researchers had made remarkable contributions among which include: Bolaji et al **[6]** carried out a comparative analysis of the performance of hydrocarbon refrigerants with R-22 in a sub-cooling heat exchanger refrigeration system. In their study, the performance of some hydrocarbon refrigerants (R-290, R-600a and R-1270) as alternatives to R-22 in vapour compression refrigeration system was investigated theoretically employing a sub-cooling heat exchanger. The results obtained showed that the saturated vapour pressure and specific volume of R-290 and R-1270 are very close to those of R-22; therefore, they could be used as substitutes for R22. Ameya et al **[7]** researched on evaluation of refrigerant R-290 as a replacement to R-22. Their paper discusses the theoretical aspects of R290 (propane) as a potential substitute for R-22. Their theoretical analysis shows that the thermo-physical properties and environmental properties of R-290 is much better than R-22 hence, making it feasible for replacement alternative. Mitesh et al **[8]** likewise carried out a research on the performance comparison of R-22 refrigerant with alternative hydrocarbon refrigerants. They stated that hydrocarbon refrigerants such as R-290, R-600a, R-1270 as well as their blend mixtures in various ratios are considered as a drop in candidate for R-22. Their analysis involve keeping constant the condensing temperature at 50^0C and varying evaporator temperature from -10 to 100C. Their theoretical results shows that the alternative refrigerants investigated have a slightly lower COP as compared to R-22 but much higher refrigerating effect. Blend mixtures shows higher tendency for replacement of R-22

Table 1-Summary of previous works done, objectives and remarks

Author/year	**Objective**	**Remarks**
Bolaji et al/2012	Comparative analysis of the performance of hydrocarbon refrigerants with R-22 in a sub-cooling heat exchanger refrigeration system	The thermo-physical properties of R-290 and R-1270 matched that of R-22 and the two refrigerants exhibited better performance (based on relative capacity index) than R-22 in sub-cooling heat exchanger refrigeration system
Ameya et al/2016	Evaluation of refrigerant R290 as a replacement to R22	The thermo-physical and environmental properties of R-290 is much better than that of R-22, hence making it feasible as replacement alternative for R-22
Mitesh et al/2015	Performance comparison of R22 refrigerant with alternative hydrocarbon refrigerants	Alternative refrigerants have slightly lower COP compared to R-22 but, much higher refrigerating effect

II. MATERIALS AND METHODS

The refrigerants to be analysed in this research as alternative for R-22 are: propane (R-290), propylene (R-1270), ammonia (R-717) and ethane (R-170). A description of the vapour compression refrigeration system is made as well as the propylene purification section of which the vapour compression refrigeration system is part of. The work involves modelling and simulating the vapour compression refrigerating system in ASPEN Hysys V8.0 using R-22 and the alternative refrigerants as the working fluids in different cases of the simulation. The refrigerant nomenclature is presented in Table 2. The choice of R-290, R-1270, R-170 is because of the fact that they are available from the refining plant of which the propylene purification section is a part. The choice of ammonia is from the fact that it is one of the oldest refrigerants used in the comfort industries with excellent thermodynamics and relatively good environmental properties.

Table 2-Refrigerants nomenclature **[2, 5 and 8]**

Refrigerant	**Chemical name**	**Trade name**	**Molecular formula**
R-22	**Chlorodifluoromethane**	**Freon-22**	$CHClF_2$
R-290	**Propane**	**Propane**	C_3H_8

R-1270	**Propene**	**Propylene**	**C_3H_6**
R-717	**Ammonia**	**Ammonia**	**NH_3**
R-170	**Ethane**	**Ethane**	**C_2H_6**

i. Description of polypropylene plant

The polypropylene plant is a unit in 125000 BPSD petroleum refining plant with a capacity of 35000 MT/year, and four sub-sections namely raw propylene purification, polymerization, extrusion and pelletizing and a storage section. The raw propylene purification section which forms the core of this work consists of sub-units which include propane and propylene (raw and polymer grade) storage, carbonyl sulphide removal, raw propylene condensation; purged propylene compression and condensation, light separation, propane-propylene splitting, propylene drying and refrigeration units. The propylene purification unit receives raw propylene feed from a 175m^3/hr. capacity fluid catalytic cracking unit (FCCU) into storage vessels with minimum requirement of 75% by volume propylene. The feed (raw propylene) from storage is pumped to the carbonyl sulphide removal unit where sulphur in form of hydrogen sulphide is removed after a hydrolysis reaction. The raw propylene condensation, purged propylene compression and condensation unit further condenses the propylene to remove incondensable such as oxides of nitrogen and sulphur. The unit also serves the purpose of re-purification of unreacted monomers from the polymerization section of the plant. In the light ends separation unit, lighter components such as methane and ethane are separated by distillation from the propylene. The product of the light end separation unit is pumped to the propane-propylene splitter unit where propane and propylene are separated by distillation. The propylene drying unit removes water and moisture from the propylene. The essence of the refrigeration unit is to refrigerate glycol water-ethylene alcohol ($C_2H_60_2$), and use same as a cooling medium in some condensers.

ii. Process description of refrigeration unit

The refrigeration unit has a capacity of 255000 kCal/h, 130 kW compression power requirement and uses Freon 22 (R-22) as a refrigerant. It operates on the principle of vapour compression refrigeration system with an evaporator, compressor, condenser and a throttling device (expansion valve) as its major components. The compressor is a screw type reciprocating compressor and has a designed power rating of 160 kW at 2950 rpm. The evaporator is a shell and tube heat exchanger with the refrigerant passing through the shell side and ethylene glycol passing through the tube side. The condenser is also a shell and tube type heat exchanger with the refrigerant going through the tube side and cooling water passing through the tube side. The expansion valve is a pressure-temperature letting device. The equipment reduces the pressure and temperature of the refrigerant thereby turning to liquid before entering the evaporator. The main function of the refrigeration unit in propylene purification process is to refrigerate glycol water from 4.6^{0}C to -5^{0}C. The refrigerated glycol water is used as a cooling medium in heat exchangers so as to recover propylene from being flared alongside incondensibles. As the refrigerant enters the refrigeration circuit, it is allowed to flow through the expansion valve for pressure-temperature let down. The refrigerant flows into the evaporator and gains latent heat of vaporization from the glycol water and vaporizes, the compressor takes suction of the vaporized refrigerant at 320 kPa, -12^{0}C and compresses it, increasing both the pressure and the temperature of the refrigerant. The compressed refrigerant enters into the condenser where its temperature is reduced. At the outlet of the condenser is a high pressure liquid vapor mixture. The pressure and temperature is further reduced as the refrigerant undergoes expansion in the throttling device and the cycle is repeated again.

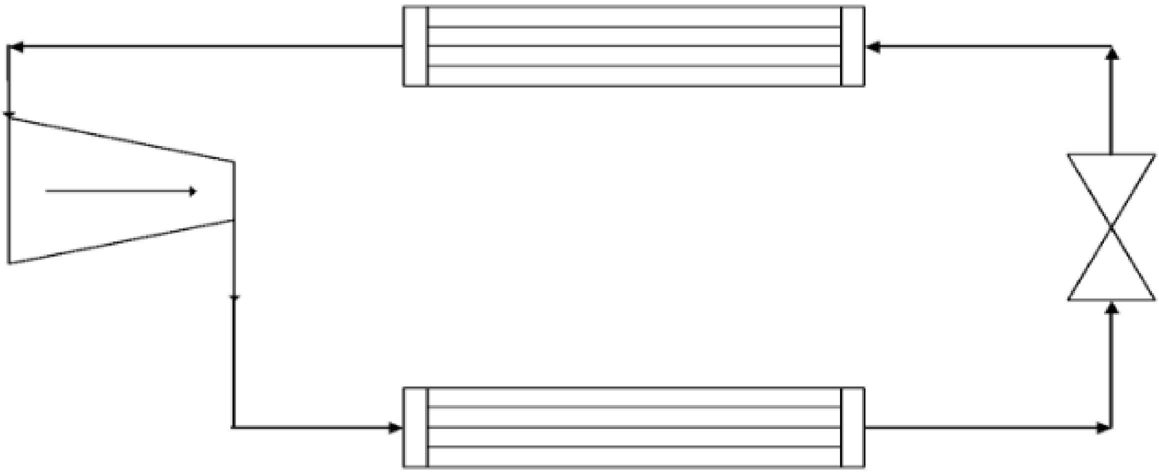

Fig 1: Schematic diagram of a vapour compression refrigeration system (VCRS)

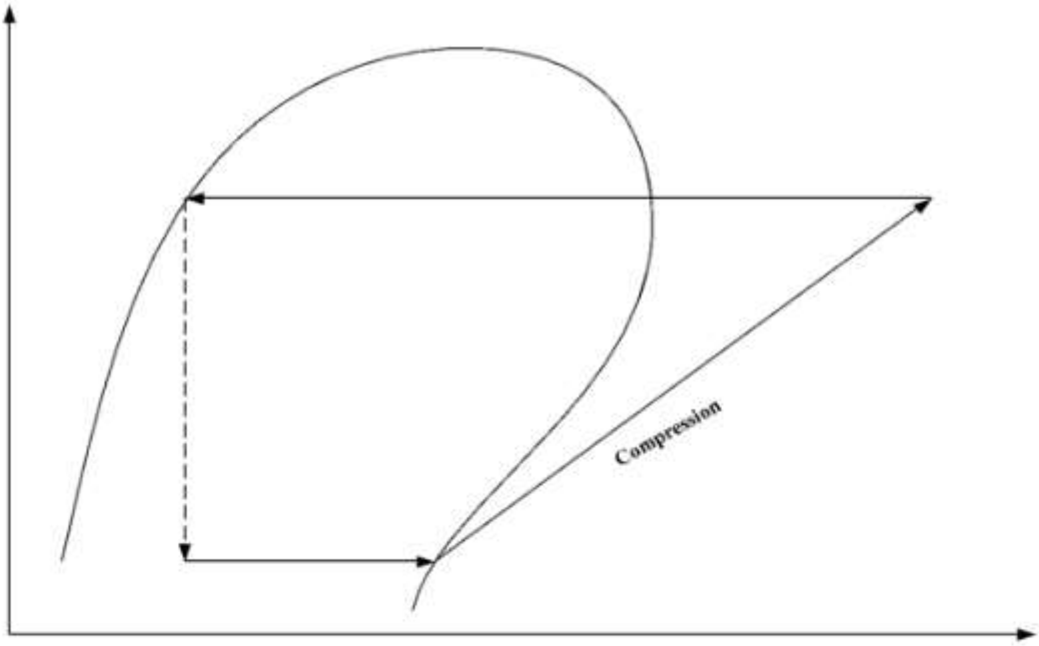

Fig 2: Pressure-enthalpy diagram of a VCRS

Theoretically, many fluids may serve as refrigerants but, practically speaking, they do not. The criteria for selection of ideal refrigerant include;

Thermo-physical Factors*:* These factors include refrigerants suction pressure, discharge pressure, pressure ratio, latent heat of vaporization, isentropic index of compression, liquid specific heat, vapour specific heat, liquid and vapour thermal conductivity, liquid and vapour viscosity. These thermodynamic and thermo-physical properties are interrelated and mainly depend on the normal boiling point, critical temperature and molecular structure of the refrigerant **[9]**.

The normal boiling point indicates the useful temperature levels as it is directly related to the operating pressures. A high critical temperature yields higher Coefficient of performance (COP) due to smaller compressor superheat and smaller flash gas losses. Properties such as the latent heat of vaporization and specific heat depend on the molecular weight and structure of the molecule. By Trouton’s rule, we see that the latent heat of vaporization will be high for refrigerants having lower molecular weight.

Table 3 -Thermo-physical properties of the investigated refrigerants [6, 7 and 8]

Refrigerant	Molecular Weight (kg/kmol)	Saturation Temperature (^{0}C)	Critical Temperature T_c (^{0}C)	Critical Pressure P_c (Bar)
R-22	**86.468**	**-40.81**	**96.14**	**49.90**
R-290	**44.096**	**-42.09**	**96.68**	**42.47**
R-1270	**42.08**	**-47.70**	**92.40**	**46.65**
R-717	**17.03**	**-77.7**	**132.50**	**113.30**
R-170	**30.07**	**-88.60**	**32.20**	**48.72**

***Environmental and Safety Factors**:* To determine impact of a refrigerant on ozone layer and global warming and by extension effects on the environment, key parameters to be considered are:

***Ozone Depletion Potential (ODP)**:* This is an index that characterizes the participation of the molecule to the depletion of the ozone layer. We calculate the value of this index compared to a reference molecule, namely either R-11 or R-12 that have ODP = 1. **[10]**

***Global warming Potential (GWP)**:* This is an index that characterizes the participation of the molecule to the greenhouse effect. We calculate the value of this index compared to a reference molecule, namely CO2, and for well-defined periods (20, 100, 500 years). CO_2 has a GWP = 1. **[2, 10]**

***Total Equivalent Warming Index (TEWI)**:* This factor analyses the equivalent CO_2 emission to the atmosphere from system leakage (direct emission) and energy consumption (indirect emission). The largest portion of the global warming effect of a system is normally attributed to the (indirect) CO2 emission due to the required energy generation which is of typical value of between 90 to 98% of the global warming effect. Naturally, refrigerants with low value of TEWI are preferable from global warming point of view. **[2 and 11]**

***Toxicity and flammability**:* should be non-toxic that is not causing or capable of causing harm to humans, animals and the environment. The refrigerant should also be non-flammable and non-explosive. In ANSI/ASHRAE Standard 34-1997, the toxicity of refrigerants is classified as class A or B. Class A refrigerants are of lower toxicity, Class B refrigerants are of high toxicity. ANSI/ASHRAE Standard 34-1997 classifies the flammability of refrigerants into classes 1, 2, and 3. A refrigerant's safety classification is its combination of toxicity and flammability. According to ANSI/ASHRAE Standard 34-1997, safety groups are classified as follows: **[12]**

A1 lower toxicity and no flame propagation, A2 lower toxicity and lower flammability,
A3 lower toxicity and higher flammability, B1 higher toxicity and no flame propagation
B2 higher toxicity and lower flammability, and B3 higher toxicity and higher flammability

Table 4 – Environmental and safety properties of investigated refrigerants [6, 8 and 11]

Refrigerant	ODP (R-11=1)	$GWP_{C02=1}$ (100 years)	Safety Class
R-22	**0.055**	**1500**	**A_1**
R-290	**0**	**3**	**A_3**
R-1270	**0**	**3**	**A_3**
R-717	**0**	**0**	**B_2**
R-170	**0**	**3**	**A_3**

Economic Factors:

Refrigerant cost*:* it should be as cheap as possible and easy to come by to reduce initial and operating cost in times of refill **[12]**

Commercial availability*:* the refrigerant should be readily available any time there is need for refilling the refrigerating system **[12]**

III. MODELLING AND SIMULATION OF VCRS

In this study, the vapour compression refrigeration was modelled and simulated in AspenONE Engineering V8.0 software. The data used for modelling the refrigeration unit are operational data obtained from the propylene purification and refrigeration units. The software is a process design and optimization tool developed in 2012 and managed by Aspen Technology, Inc. It has many database with more than 1800 components and 16000 binary interaction coefficients. It also has an integrated steady state and dynamic modelling capabilities that allows the same model to be evaluated from each font with full sharing of process information **[13, 14]**

i. Thermo-physical model

The thermos-physical properties of R-290, R1270, R-717 and R-170 refrigerants are simulated using Peng-Robinson and glycol package equations of state. The Peng-Robinson package contains enhanced binary interaction parameters for all library hydrocarbon-hydrocarbon pairs (a combination of fitted and generated interaction parameters), as well as for most hydrocarbon-nonhydrocarbon binaries **[13]**. The Peng-Robinson equation of state generates all the required equilibrium and thermodynamics properties directly. The glycol package contains all the thermodynamics properties of glycol in its library.

ii. Simulation data source and model assumptions

The data used for the simulation of the refrigeration process are real time operational data gotten from gauges and operational manual of the polypropylene plant .The assumptions for modelling and simulating the refrigeration system is that: no pressure drop across the shell and tube of both the evaporator and condenser, the expansion process is assumed isenthalpic, no pressure losses in the pipings and the compressor efficiency is 80%

Table 5- Simulation input data

Simulation input data	**Refrigerant**					**Cooling water**	**Ethylene glycol solution**
	R-22	**R-290**	**R-1270**	**R-717**	**R-170**		
Pressure (kPa)	**320**	**320**	**320**	**320**	**320**	**411.9**	**354.6**
Temperature (K)	**261**	**261**	**261**	**266**	**261**	**304**	**277.6**
Flow rate (kg/h)	**7524**	**7524**	**7524**	**7524**	**7524**	**46910**	**45000**
Composition liquid volume fraction (%)	**100**	**100**	**100**	**100**	**100**	**100**	**45 for ethylene glycol and 55 for water**

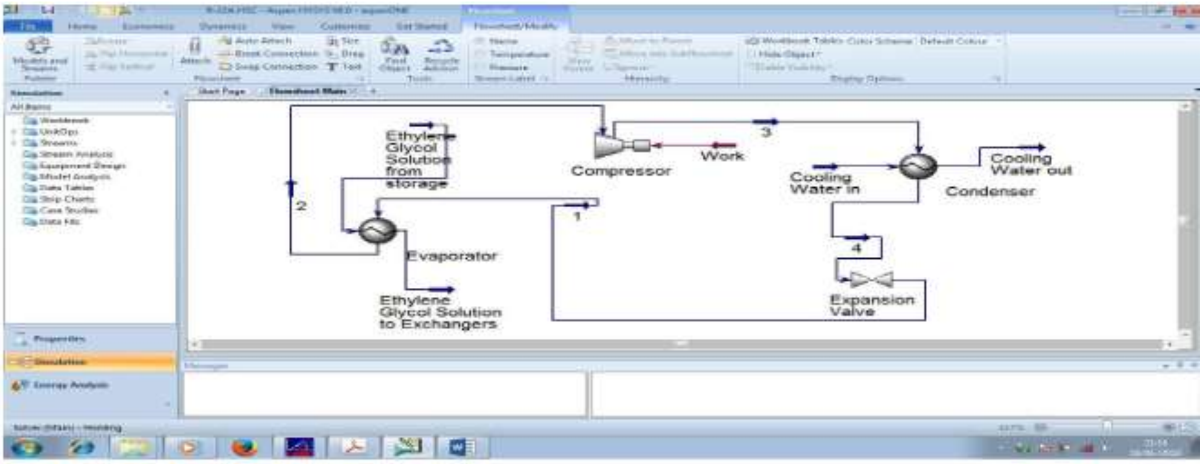

Fig 3: Screen Shot of VCRS Model with R-22 as Refrigerant

iii. Coefficient of performance (COP), model validation, and sensitivity analysis

The refrigerant absorbs heat in the evaporator (Q_{ref}) also known as refrigerating effect and is expressed as:

$$Q_{ref} = h_2 - h_1 \qquad (1)$$

The isentropic work input to the compressor is expressed as:

$$W_{in} = h_3 - h_2 \qquad (2)$$

Where h_1, h_2, h_3 and h_4 are enthalpies at point 1, 2, 3 and 4 respectively (from Fig 2)

The coefficient of performance is the refrigeration effect or evaporator duty (Q_{ref}) per unit compressor work or compressor duty (W) in the same thermal units.

Q_{ref} = refrigerating effect or evaporator duty, W = Compressor work or compressor duty

Coefficient of performance (C.O.P) is given by: **[15]**

$$\text{C.O.P} = Q_{ref}/W_{in} \qquad (3)$$

The C.O.P of a refrigeration system is a reflection of the system's energy performance and is one of the key indicators for selecting a refrigerant as a possible replacement of R-22.

Model validation was done by comparing the plant's operational data with data gotten from the simulation of the VCRS using R-22 (Freon-22) refrigerant and the results are presented in Table 6 below.

Table 6: Model validation, COP and model sensitivity analysis results

	Evaporator			Compressor			Condenser			Expansion Valve		
	Plant	**Simulation**	**% Change**	**Plant**	**Simulation**	**% Change**	**Plant**	**Simulation**	**% Change**	**Plant**	**Simulation**	**% Change**
Inlet Temp. (K)	**259.000**	**260.210**	**0.467%**	**259.000**	**261.000**	**0.772%**	**353.000**	**362.490**	**2.688 %**	**313.600**	**318.990**	**1.719 %**
Outlet Temp. (K)	**262.000**	**261.000**	**0.382%**	**353.000**	**362.490**	**2.688%**	**313.600**	**318.990**	**1.719 %**	**259.000**	**260.210**	**0.467 %**
Inlet Press. (kPa)	**312.500**	**320.000**	**2.400%**	**315.000**	**320.000**	**1.587%**	**1741.950**	**1770.000**	**1.610 %**	**1708.530**	**1770.000**	**3.598 %**
Outlet Press. (kPa)	**315.000**	**320.000**	**1.587%**	**1770.000**	**1770.000**	**0.000%**	**1708.530**	**1770.000**	**3.598 %**	**312.500**	**320.000**	**2.400 %**
Duty (kJ/h)	**1067630**	**1502000**	**40.685 %**	**468000**	**413300**	**11.688 %**						
COP	**2.281**	**3.634**	**59.305 %**									

Note: The unpopulated cells are not applicable

From Table 6 above, the pressure differences between the plant and the simulation stems from the fact that the simulation assumes no pressure drop in the evaporator and condenser (for ease of simulation) whereas in reality, even though these equipment are not pressure let-down equipment, there is usually some pressure drop across them. The differences in temperature, pressure and even coefficient of performance for the plant and simulated condition may also be due to advances in software package used for the simulation. The simulation also assumes no pressure drop in the pipings connecting these equipment but, there is usually pressure drop in any given length of pipe having a flowing fluid.

IV. ECONOMIC ANALYSIS

Operating cost to be incurred because of the choice of any of the refrigerants under study is shown in table 7 below:

Table 7 - Operating cost to be incurred for the choice of any one

Refrigerant	Price (£) per kg less shipping	Refrigerant flow rate (kg/h)	Cost of refrigerant per hour (£/h)
R-290	7.02	7524	52818.48
R-1270	9.00	7524	67716.00
R-717	6.14	7524	46197.36
R-170	4.90	7524	36867.60

For charging the refrigerant per hour into the refrigeration circuit considering the refrigerants under study, R-290, R-1270, R-717 and R-170 would cost 52,800, 67,716, 46,200 and 36,894 Pound respectively. This shows that R-170 should be preferred since all the refrigerants are commercially available.

V. RESULTS AND DISCUSSIONS

The results extracted from AspenHysys simulation for all the refrigerants under study is displayed in Table 8 below.

Table 8- COP of all investigated refrigerants

Refrigerant	Refrigerating effect (kJ/h)	Ratio of refrigeration effect compared to R-22 (simulation)	Compressor work (kJ/h)	Ratio of Compressor work Compared to R-22 (simulation)	COP
R-22 (simulation)	1502000.00	1.000	413300.000	1.000	3.634
R-290	1502000.00	1.000	754200.000	1.825	1.992
R-1270	1502000.00	1.000	826100.000	1.999	1.818
R-717	1502000.00	1.000	2453000.000	5.935	0.612
R-170	1565000.00	1.042	1261000.000	3.051	1.241

From Table 8, all the investigated refrigerants under simulation produce refrigeration effect 150200 kJ/h except for R1270 which produces refrigerating effect of 1565000 kJ/h which is 1.042 times the refrigerating effect produced by other refrigerants. COP of R-22, R-290, R-1270, R-717 and R-170 are 3.634, 1.992, 1.818, 0.612 and 1.241 respectively. R-290 has better COP value of 1.992 and because this value is higher than that of other refrigerants under investigation, operating the refrigeration system with R-290 as refrigerant would be more efficient than operating with other refrigerants under investigation.

ODP, GWP, TEWI and safety properties are indicators of the environmental factors. R-290, R-1270, R-717, and R-170 all have ODP values zero (0) from Table 4 above, which makes them options to be possibly used as alternative refrigerants in place of R-22. Also from Table 4 above under GWP column, R-290, R-1270 and R-170 all have values of 3 over a hundred years' (100 years) consideration, while R-717 has zero (0) GWP under the same period. The total equivalent warming index (TEWI) is a parameter of the environmental factor that takes into account both direct and indirect contribution of a refrigerant to global warming. As earlier stated, the indirect contribution to global warming of a refrigerant is between 90-98% of TEWI and from Table 8 above, we seen that R-717 has the highest compressor power requirement of 2453000 kJ/h representing 5.935 times power required by R-22 compressor, followed by R-170 with 1261000 kJ/h, R-1270 with 826100 kJ/h and R-

290 with the least compressor power requirement of 754200 kJ/h (1.825 times power required by R-22 compressor). This implies that R-290 will contribute least to indirect contribution to global warming because of less fossil fuel needed to be burnt to generate power to run the compressor. Therefore combining GWP and TEWI, R-290 is favoured as alternative replacement of R-22 as refrigerant. From the view point of safety (Table 4 above), R-290, R-1270, R-170 are all in A_3 safety group and this means that they all are non-toxic refrigerants with high tendencies for flame propagation. R-717 on the other hand, is in B_2 safety group and by implication it has higher toxicity and lower flame propagation. On safety font, it favours R-290, R1270 and R-170 as alternative refrigerants to replace R-22 in the refrigeration unit.

Refrigerants' price and commercial availability are key indicators for economic factors. It is seen that from price's view point, it favours R-170 as alternative refrigerant to replace R-22. But R-170 would need to be sourced and treated to refrigerant grade ethane from the petroleum refining plant of which the propylene purification section is a part of. R-717 on the other hand is not found in the process, neither can be sourced from the refining plant where the propylene purification process is located; as such, is not an alternative in terms of economics to replace R-22 as alternative refrigerant. R-290 and R-1270 are from the propane-propylene splitting unit of the propylene purification process refrigerant grade fluids with 99.8 and 99.9% purity level respectively; thus, this has eliminated the price required to purchase and ship these refrigerants. From economy view point, R-290 and R-1270 are the favoured alternative refrigerants to replace R-22.

Table 9- Scoring chart for final selection of alternative refrigerant

Refrigerant	**Highest refrigerating effect**	**Least Compressor work requirement**	**Highest C.O.P**	**Least ODP**	**least TEWI**	**Most Safe to use**	**Most economical**
R-290	🟦	🟩	🟩	🟩	🟩	🟩	🟩
R-1270	🟩	🟦	🟦	🟩	🟦	🟩	🟩
R-717	🟦	🟥	🟥	🟩	🟥	🟥	🟥
R-170	🟦	🟨	🟨	🟩	🟨	🟩	🟨

Legend
Green-Most preferred to replace R-22
Blue – Second most preferred to replace R-22
Yellow – Third most preferred to replace R-22
Red – Least Preferred to replace R-22

Note: Anytime a particular colour appears more than once under a column, it signifies that the refrigerants have the preference under such a criteria to replace R-22.

From table 9 above, we see that:
R-290 is most preferred six-times and second most preferred once,
R-1270 is most preferred four-times and second most preferred three-times,
R-170 is most preferred twice, second most preferred once and third most preferred four-times while
R-717 is most preferred once, second most preferred once and least most preferred five-times
Therefore, the most preferred refrigerant to replace R-22 is R-290, followed by R-1270, R-170 and R-717.

VI. CONCLUSION

It can be seen that in terms of COP, R-290 is favoured compared to the other refrigerants as alternative replacement for R-22, considering environmental factors, R-290 is also favoured to replace R-22. Also looking at the advantage that R-290 can be sourced from the propylene purification process in the propane-propylene splitter sub-unit, it is favoured as the choice alternative to R-22. Therefore, R-290 should be the choice refrigerant to replace R-22 as alternative in running the refrigeration unit of the propylene purification process.A high efficiency propane compressor should be purchased and install in the 358,747 kCal/h refrigerating effect, and 209.5 kW compressor power refrigeration system. The challenge of propane's flammability can be arrested by developing flame-proof protection measures and proper training for operators of the refrigeration unit using industry's best practice guidelines for handling flammable refrigerants.

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