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A COMPETITIVE STUDY OF ALL NATURAL REFRIGERANTS IMPLEMENTATION ON 1.5-TON DOMESTIC AIR CONDITIONERS USING COOL PACK SOFTWARE

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Abstract:

Climate change is a present concern all over the world. In India, in the northern regions of the country, temperatures crossed the 50 degrees Celsius mark. Temperatures in the Indian summer over the last decade or so have repeatedly broken heat records, India was expected to become the world's third largest energy consumer by 2030, overtaking the European Union, contributed by rising incomes and improving standards of living. With the increasing demand for home appliances, the Indian air conditioner market with plenty of room to grow and is estimated to reach 9.7 million units in the financial year 2023.

Electricity consumption by room ACs is expected to increase from 8 TWh in 2010 to 239 TWh by 2030. Such growth would have a significant impact on the Indian power sector and would require unprecedented construction of new power plants. We find that 40% of the energy consumed by room ACs could be saved cost-effectively by enhancing their efficiency. This translates to a potential energy saving of 118 TWh at bus-bar or a peak demand saving of 60 GW in 2030. And this energy saving is possible the by implementation of Solar power-based Air conditioners with natural refrigerants. Natural refrigerants used mainly to reduce Global warming potential (GWP) at the same time. This paper indicates the best choice of natural refrigerants R600a & R290 as an organic refrigerant will be preferable for air conditioner among all natural refrigerants analysis by cool pack software for the most wanted domestic 1.5-ton Air Conditioner. Here also, Cool Pack data cross checked with EES Software where both are almost same result reflect here.

Keywords: Natural Refrigerants, Low power rated compressor, 1.5 TON Air-Conditioning Unit, Cool Pack Software,

Nomenclature

Roman	P pressure (MPa)
A: Area, m2	qev: volumetric refrigeration capacity (kJ m-3)
h: Specific enthalpy, (J kg-1)	Qc: heating capacity per unit of mass (kJ kg-1
hlv Latent heat of vaporization, (J kg-1)	Qe: refrigerating capacity per unit of mass (kJ kg-1)
M: Mass, kg	s: entropy (kJ kg-1 k-1)
MW: Molecular weight, (kg kmol-1)	t: refrigerant temperature (0C)
N: Number of moles, (mol)	T_0: the environmental temperature (K)
p: Pressure, Pa	v: specific volume (m3 kg-1)
t: Temperature, K	Wc: specific work of compressor (kJ kg-1)
v: Specific volume, (m3 kg-1)	p pressure (Pa)
V: Volume, m3	V volume (m3)
x: Vapor quality, dimensionless	ηv: volumetric efficiency (–)
h: specific enthalpy (kJ kg-1)	ηs: isentropic efficiency (–)

Abbreviations

AHRI: air conditioning, heating, and refrigeration institute

ASHRAE" American society of heating, refrigerating, and air conditioning engineers

AC	Air-conditioner	IPCC	International panel of climate change
CFC	Cholofluoro carbon	ODP	Ozone depletion potential
COP	Co-efficient of performance	R-717	Ammonia
KW	Kilo-watt	R744	Carbon Dioxide
GHG	Greenhouse Gas	R-290	Propane
GWP	Global warming potential	R-600a	Isobutane
HC	Hydrocarbon	R-1270	**Propylene**
HFC	Hydro-fluoro carbon	R-718	Water

1. Introduction:

The application of Air-Conditioner due to more and more societal modernization increases at home appliances as well as in industries from the last decade. In recent years, the term 'thermal comfort' comes to an issue of person to person based on that they provide the characteristics and properties of the system and working medium required for optimal performance. The Montreal Protocol (1987) stressed to give on bring down of ozone depletion substance that contributes to the radioactive forcing to climate change from the environment [1] while the technological change in the production sector like refrigeration and air-conditioner need to phase down CFC, HCF and carbon dioxide for reducing temperature change; human comfort was taken as vital initiative for scientists and engineers to explore suitable replacements for alternate energy connection as well as use of natural refrigerants. However, no scope for extensive laboratory tests and field data are yet to be collected at the present scenario, still has provided a few statistical data to define a specified percentage of occupants will find thermally comfortable. In the paper, the maximum experimental data are not at present considered under our purview. The proposed research work will focus on how energy consumption pattern changes in domestic areas in three different regions i.e. rural, suburban and urban areas. Moreover, the fact finds that domestic load has been increasing day by day due to the increase of demand of air-conditioning system [2].

2. Literature Review

There had been initiated several studies on substitution of refrigerants uses in years together for distinguishing as alternate refrigerants for improving art-of-sustainable design technology, economic stability and living environment for well-beings. Once upon a time, Abuzahra [3] demonstrated the performance of window type AC unit while replacing R-22 refrigerant with methane (CH_4). During observation, it was concluded that methane gas was not at all satisfactory replacement due to compressor overheating problems. Purkayastha and Bansal [4] investigated that the use of a mixture of propane and LPG as refrigerant that replaced R-22 in heat pumps. The result showed that COP with Propane (R-290) and LPG mixture is better than R-290 use alone but with a small loss of condenser capacity. In a separate experiment, Hammad and Tarawnah [5] used a mixture of Butane and Propane at different ratio at the same Laboratory set-up. In that experiment the mixture of 90 per cent propane gives equal pressure as R-22 with higher COP but 60 per cent propane mixture gives same COP with lower pressure. Thus, the result indicates that the increase percentage of propane will decrease the capacity of compressor work.

Jung [6] studied on thermodynamics performance of two pure HC and seven mixtures of compounds like propane (R-290), propylene (R-1270), HCF (152a) and R-170 etc. in a design of residential unit. The results included that COPs of those refrigerants were slightly higher than that of R-22 except R-1270 which was only 0.7% lower than that of R-22. A series of researcher's has studied solar cooling system using absorption refrigeration cycle such as Bong et al [7], Duffy et al [8] and Zhai et al [9]. Another group, like Kunio et al [10], Habib et al [11] works on cooling systems using solar photovoltaic power-based technology. The main problems faced by them are; initially at high cost, low system performance and availability of solar irradiation only in day time operation. However, some improvements of the main components of the solar cooling systems have been investigated to obtain better performance with reduced initial cost. These experimental works impressed the most to perform solar powered AC units using as eco-friendly refrigerant. Further, in this study, parameters like: refrigeration effect; cooling capacity; COP; refrigerants' mass flow rate and heat rejection were optimized. All these parameters were dealt with function of evaporation temperature and condensation temperature.

Earlier, already mentioned about *Montreal Protocol* and discussed in brief about technology transfer on climate change perspective. Thereafter, *Kyoto Protocol* further phased out the changes of refrigerants used. In the context, we focused on Mukesh K. Agarwal [12] paper wherein it mentioned that refrigerant (heat from lower to higher temperature reservoir) has its own thermo-physical property. Refrigerants used in view of these like R-11 and R-12 are toxic in nature. In case of ammonia (R-717) is flammable. Gaurav Gupta in his paper mentioned [13] that due to high global warming potential HFC as refrigerants phased down from 2015. Thus, the researchers' redundant or made adverse comments for the usage of R-134a, R-152a as refrigerants with various blending proportion. The above-mentioned historical perspectives of this brief review work confirmed that our decision of use of solar powered and solar thermal energy as supply-chain side thus effect, COP of natural refrigerant, R-290 as the present stage and finally, in the long-term basis, using mixture of blending of R-290 and R-600a and their comparative studies will undergo for future work. But One paper already published detailed analysis of comparatives studies of R290 and R600a instead of mixing.[14]

3. List of the natural refrigerants:

Ammonia (R-717), Carbon Dioxide (R-744), Hydrocarbons, Water (R-718), Air (R-729), Methylamine (R-630), Ethylamine (R-631), Hydrogen (R-702), Helium (R-704), Neon (R-720), Nitrogen (R-728), Oxygen (R-732), Argon (R-740), Nitrous Oxide (R-744A), Sulfur Dioxide (R-764), Krypton (R-784).

Natural refrigerants are used in a variety of applications from large scale industrial operations such as a meat packing plant all the way to a dormitory refrigerator. Ammonia for example is used in storing/processing of food/beverages, supermarket refrigerators/freezers, convenience stores, ice rinks, and much more. Here all natural refrigerants we have used using cool pack software for analysis and observation for outcome with respect of 1.5-ton Air conditioner.

3a. Natural Refrigerants Today & Future:

Since the 1930s, natural refrigerants like ammonia, carbon dioxide, and hydrocarbons have been the dominant refrigerants. However, fluorocarbons have become a concern due to their environmental impact, leading to a shift towards natural refrigerants. Countries and companies are choosing between the new fluorinated class of hydrofluoric olefins (HFC) and natural refrigerants and hydrocarbons. Companies like Ajinomoto Frozen Foods in Japan are implementing measures to be completely HFFC and HFC-free by 2030. To make natural refrigerants and hydrocarbons more competitive, manufacturers are looking for ways to reduce charges, making them safer for general and residential/commercial use. This has led to more natural refrigerant applications, with older R-22 systems retiring and businesses seeking alternative refrigerants. As HFCs are phasing out, more ice rinks and larger plants are transitioning to ammonia or carbon dioxide.

3b. Natural Refrigerant History:

Ice harvesting dates back centuries, but it wasn't until the 1800s that real refrigerant systems emerged. Jacob Perkins' patent in the 1830s for a vapor compression refrigeration system used hydrocarbon refrigerant ether, while Charles Tellier built on Perkins's system using methyl ether. Advancements in standard vapor compression systems, such as carbon dioxide (R-744) in the 1860s, ammonia-based systems by David Boyle and Carl Von Linde, and methyl chloride (R-40) in France, laid the foundation for modern-day halocarbon refrigerants.

In the early twentieth century, industrial refrigeration experienced rapid growth, with ammonia being the preferred refrigerant. However, its toxicity caused hesitation in residential and commercial sectors. Wealthy homeowners used various refrigerants, including ammonia, methyl chloride, sulfur dioxide, and propane. Hydrocarbons were considered safest and least frequented, but lobbying from ice companies and union laborers led to strict safety regulations, requiring alternative refrigerants.

In the 1930s, General Motors and DuPont Corporation collaborated to develop affordable, safe, and efficient refrigerants. Thomas Midgley Jr. invented Chlorofluorocarbons and Hydrochlorofluorocarbons, leading to R-12 and R-22. A better synthetization method in the 1950s boosted demand, reducing hydrocarbon usage worldwide.

In the 1980s, American scientists discovered that Chlorine from CFCs and HCFCs weakens the atmosphere. When exposed to UV irradiation, the Chlorine atom detaches from CFC molecules, creating a Chlorine oxidized molecule. This molecule moves to the stratosphere, where the Ozone layer protects Earth from harmful UVB wavelengths. The Montreal Protocol, signed by over 100 nations, aimed to protect the Ozone layer and phase out the responsible chemicals.

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In 1989, the Montreal Protocol marked the beginning of the end for CFC and HCFC refrigerants worldwide. Industrialized countries, like America, began to phase out CFC refrigerants first, with R-12 phased out in the early 1990s. HCFC refrigerants, such as R-22 and R-502, were given more time to phase out.

Hydrofluorocarbons (HFCs) were initially proposed as a replacement for CFCs and HCFCs due to their safety, cost-effectiveness, and non-ozone-damaging properties. However, HFCs are now criticized for their increased Global Warming Potential (GWP). Natural refrigerants, which began in the 19th century, are climate-friendly and will continue to grow as technology advances. They offer peace of mind, no phase-downs, and are a low-risk investment for business owners [15].

4. **Software Analysis:** Here All natural refrigerants analysis for 1.5-ton Air conditioner done by software analysis to observe outcomes. Software details summarize are in below.

Cool Pack Software (Version 1.50):

Cool Pack is a collection of simulation programs that can be used for designing, dimensioning, analysing, and optimizing refrigeration systems. The simulation programs in Cool Pack are divided into six categories - each represented by a tab in the Toolbar above. It can get an overview of the programs in a category by clicking on its Toolbar tab and clicking on the icons in the Toolbar that starts the individual programs. The objective of the project was to develop this simulation model to be used for energy optimization of refrigeration systems. The users of these models would be refrigeration technicians, engineers, students, etc. in short, all the persons with influence on the present and future energy consumption of refrigeration systems.

The Cool Pack programs cover the following simulation purposes:
- Refrigerant properties calculations (property plots, thermodynamic & Thermo physical data, refrigerant comparisons)
- Refrigeration Cycle analysis – e.g., comparison of one- and two-stage cycles
- Air Conditioning System dimensioning – calculation of component sizes from general dimensioning criteria
- System simulation – calculation of operating conditions in a system with known components
- System Evaluation of operation – evaluation of system efficiency and suggestions for reducing the energy consumption
- System Component calculations – calculation of component efficiencies
- Transient simulation of cooling of an object – e.g., for evaluation of cooling down periods

It has done its best to make the programs in Cool Pack as robust, error-free, relevant, and as easy to use as possible [16].

4.a: Natural refrigerants Analysis using Cool Pack Software:

Table 1: Most useful Natural Refrigerants Characteristics for 1.5TON AC

Natural Refrigerants Characteristics for 1.5TON System Table 1	Ammonia (R-717)	Carbon Dioxide (R-744)	**Propane R290**	**Isobutane R600a**	**Propylene R1270**	Water (R-718)
Te [°C]	10°C	10°C	10°C	10°C	10°C	10°C
Tc [°C]	50°C	31.05°C	50°C	50°C	50°C	50°C
Qe [kW]	5.275	5.275	5.275	5.275	5.275	5.275
Qc [kW]	6.155	6.271	6.246	6.198	6.251	6.201
Qe [kJ/kg]	1035.704	92.975	249.983	248.361	255.017	2309.730
Qc [kJ/kg]	1208.437	110.531	295.988	291.809	302.219	2715.247
COP	6.00	5.30	5.43	5.72	5.40	5.70
W [kJ/kg]	172.733	17.556	46.005	43.448	47.202	405.517
Pressure Ratio	3.306	1.640	2.705	3.118	2.636	10.060
m [kg/s]	0.00509316	0.05673370	0.02110145	0.02123926	0.02068492	0.00228382
Specific volume flow rate, V [m^3/h]	3.7651	1.3177	5.5075	12.9894	4.5682	874.5934
W [kW]	0.880	0.996	0.971	0.923	0.976	0.926
Displacement [m^3/h] at 90% volumetric efficiency	4.1834	1.6863	6.1194	14.4327	5.0758	971.7704

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Table 2: Natural Refrigerants restricted Characteristics for 1.5TON AC

Natural Refrigerants Characteristics for 1.5TON System Table 2	Nitrogen (R-728)	Oxygen (R-732)	Argon (R-740)	Nitrous Oxide (R-744A)	Sulfur Dioxide (R-764)	Krypton (R-784)
Te [°C] Tc [°C]	The value must between -210⁰C & -146.95⁰C Not suitable in domestic air conditioner unit	The value must between -218.8⁰C & -118.869⁰C Not suitable in domestic air conditioner unit	The value must between -189.3⁰C & -122.45⁰C Not suitable in domestic air conditioner unit	Not available in the Cool Pack Software Refrigerant list	Not available in the Cool Pack Software Refrigerant list	Not available in the Cool Pack Software Refrigerant list
Qe [kW]	5.275	5.275	5.275	5.275	5.275	5.275

Table 3: Natural Refrigerants restricted Characteristics for 1.5TON AC

Natural Refrigerants Characteristics for 1.5TON System Table 3	Air (R-729)	Methylamine (R-630)	Ethylamine (R-631)	Hydrogen (R-702)	Helium (R-704)	Neon (R-720)
Te [°C] Tc [°C]	The value must between -206.8⁰C & -140.65⁰C Not suitable in domestic air conditioner unit	Not available in the Cool Pack Software Refrigerant list	Not available in the Cool Pack Software Refrigerant list	Not available in the Cool Pack Software Refrigerant list	Not available in the Cool Pack Software Refrigerant list	Not available in the Cool Pack Software Refrigerant list
Qe [kW]	5.275	5.275	5.275	5.275	5.275	5.275

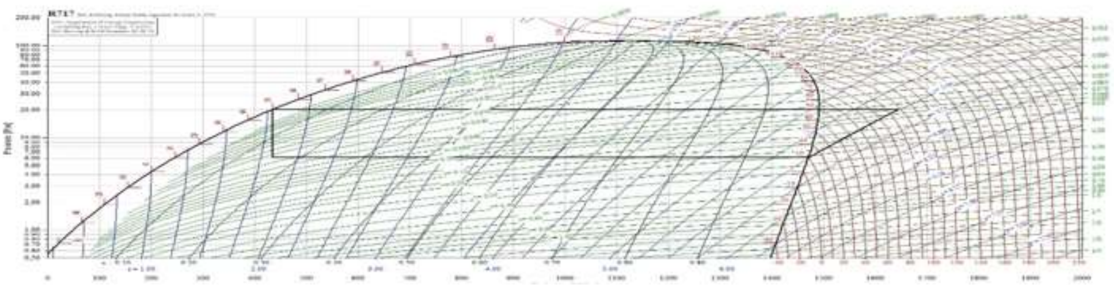
4.b: Natural refrigerants Analysis using EES Software:

Table 4: Most useful Natural Refrigerants Characteristics for 1.5TON AC by EES Software

Natural Refrigerants Characteristics for 1.5TON System Table 4	Ammonia (R-717)	Carbon Dioxide (R-744)	**Propane R290**	**Isobutane R600a**	**Propylene R1270**	Water (R-718)
Te [°C]	10⁰C	10⁰C	10⁰C	10⁰C	10⁰C	10⁰C
Tc [°C]	50⁰C	**31.05⁰C**	50⁰C	50⁰C	50⁰C	50⁰C
COP	5.975	5.903	**5.397**	5.702	5.368	5.701
W [kW]	0.8827	0.5957	0.977	0.925	0.9824	0.9251

Here all results are almost identical with Cool Pack software data.

Here from this EES result author have cross checked Cool Packed data which is Actively accurate result reflected by EES software and both software also validated on our laboratory scale.



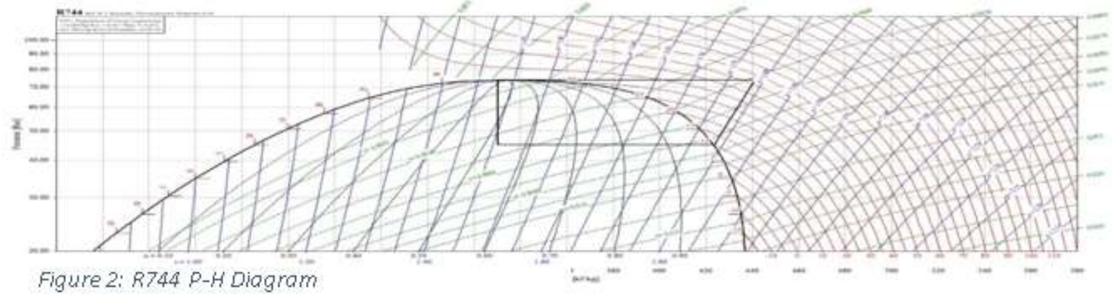


Figure 2: R744 P-H Diagram

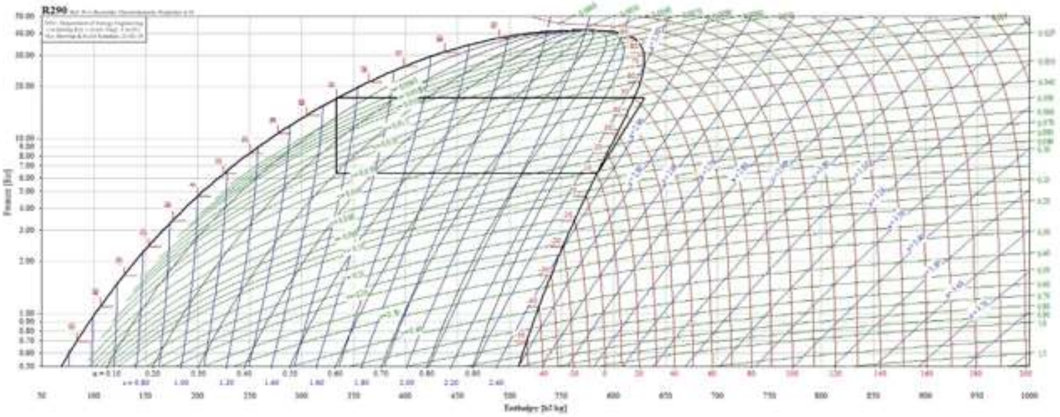


Figure 3: R290 P-H Diagram

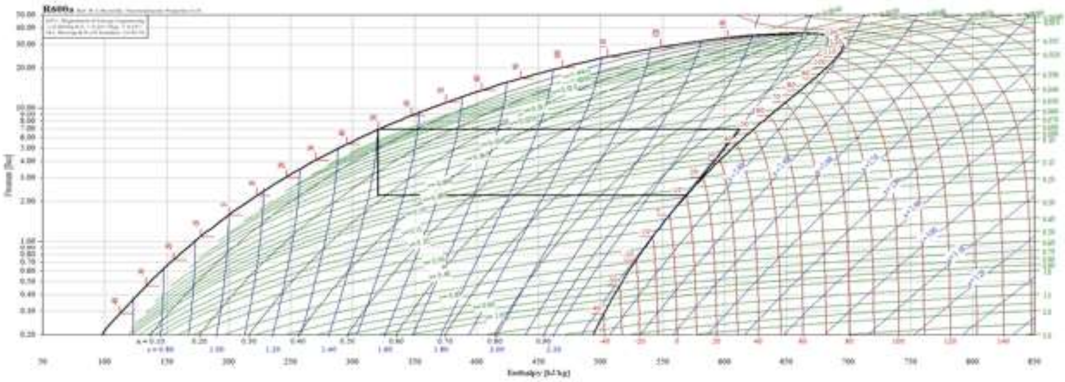


Figure 4: R600a P-H Diagram

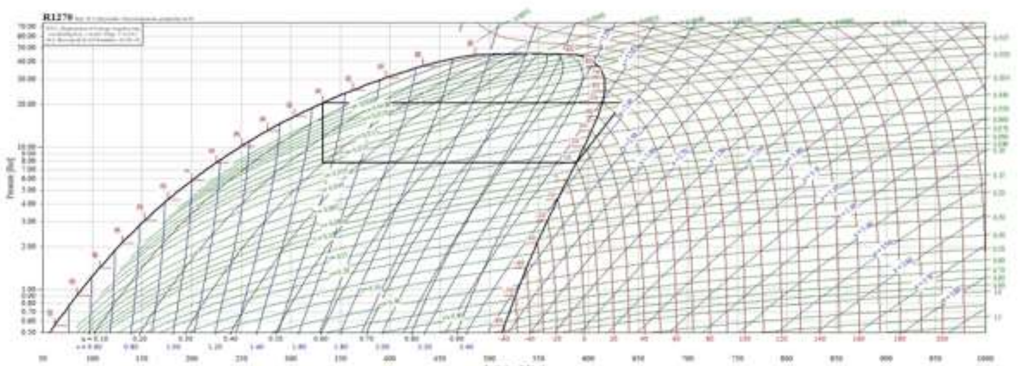


Figure 5: R1270 P-H Diagram

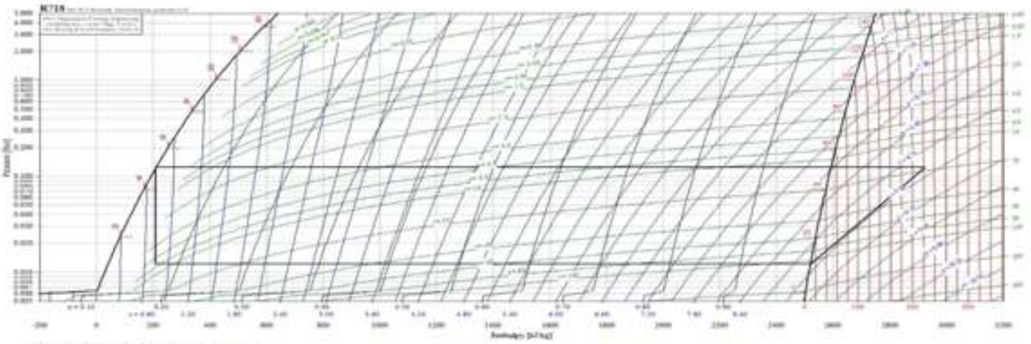


Figure 6: R718 P-H Diagram

Result & Discussion:

Natural refrigerants are substances that exist naturally in the environment. With zero ozone depletion potential (ODP) and very low or zero global warming potential (GWP), they are considered the definitive solution to the environmental damage caused by synthetic refrigerants.

The most widespread natural refrigerants used in HVAC/R applications today are carbon dioxide (CO2, R-744), hydrocarbons such as propane (R-290), isobutane (R-600a) and propylene (R-1270), and ammonia (NH3, R-717). Other natural refrigerants are water (H2O, R-718) and air (R-729), used only for special applications, or Sulphur dioxide (SO2) and methyl chloride (CH3Cl), which are no longer used.

The main characteristics of the most commonly used natural refrigerants are summarized in the following above table. Here 18 numbers natural refrigerants are analysis by cool pack software and shown in table 1 to 3. Table 2 & 3 not suitable for domestic air conditioner temperature zone as pert analysis report.

Among of eighteen natural refrigerants, we have received outcomes of only six natural refrigerants and observed least power consumption using Ammonia and 2nd lowest power consumption by isobutane (R-600a) but some drawbacks observed from its P-H diagram. Third lowest power consumption by propane (R-290). Due to high toxicity Ammonia at present overlooking by all air conditioner brand. And mentioned 2nd and 3rd (R290 & R600a) are highly acceptable range and author already published one paper over details study by using R290 refrigerants for different climatic zone [17]. One another natural refrigerants, Propylene R1270 is also under this competitive study but need further details analysis.

Conclusions:

So, in the present situation, the Refrigerant industry must shift toward natural refrigerants to prevent environmental damage to mother earth and also to provide a sustainable future. As per the IPCC report Global warming index should be restricted to 1.5^0C and the application of solar air conditioners will take a leading role towards a sustainable environment because of the complete use of natural resources for the human indoor comfort index at the summer session. This reverse cycle of R600a using solar thermal superheating is also applicable in winter sessions by increasing temperature to ambient temperature to maintain indoor air comfort.

The content of this work consists of the types of parameters influencing the performance of all natural refrigerants and covers it through software analysis. Finally concluded R600a is the best suitable option as a domestic air conditioner refrigerant irrespective of its in-flammability if we overcome the drawbacks which reflect from P-H diagram. Table one shows R600a is the best alternative Refrigeration over highly toxic ammonia from its power consumption point of view but P-h diagram shows Compressor across this refrigerant is not in a 100% gaseous phase which is mandatory criteria for compressor working longevity.

Result also cross checked by EES Software which outcome almost same with Cool Pack software data.

Future scope of this work towards the proper design to overcome of R600a, Compressor across phase state problem with attention on least power consumption with respect to various tonnage capacity domestic air conditioner system and then R600a will use for Different Climatic zone for total Power saving opportunities in India.

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