SPATIO-TEMPORAL MONITORING OF STRATOSPERIC OZONE FOR BIG CITIES IN PAKISTAN AND ITS EFFECTS ON HUMANS AND CLIMATE

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ABSTRACT: Remote sensing and geographic information system (RS & GIS) are dominant techniques for understanding the spatial-temporal patterns of earth and its atmosphere. Pakistan does not fabricate any of the ozone depleting substances (ODSs) but stringent regulatory regime exists to check imports of these substances, with a system of licensing and quotas for import of HCFCs (Hydrochloro fluorocarbons) in place. The main consumer of HCFCs (about 75%) is manufacturing sector consisting of 36 industries located in Karachi and Lahore. Servicing sector uses about 25% of the total HCFCs consumption in Pakistan. The Global Positioning System (GPS) points of the industrial locations are taken and mapped with the help of RS (Remote sensing) and GIS (Geographical information system) techniques. A case study of mega city Lahore has been discussed for HCFCs emissions from manufacturing and wastage stages, from 2005 to 2013. During these stages, significant emissions of HCFC 141b have been observed increasing at rate of 7.11% (slope: 7331.2, y-intercept 103058 Kg) per year. Ozone could induce adverse impacts to human health. Cardiovascular disorders, fibrosis and damage to lungs are the swear problems faced due to long term exposure. Pakistan has been at the forefront in its endeavors to phase out ODSs. In Phase-I of the HCFC phase-out management plan (HPMP), Pakistan has successfully phased out 80 ozone depletion potential tons (ODPT) of HCFC 141b. Various alternatives have also been found to achieve performance better than HCFC 22. The R 744 is available for commercial sized systems. It is expected that the target will be achieved by the end of 2040 by implementing alternatives against HCFC 22.

Keywords: Chlorofluorocarbons, Ozone depleting substances, Hydrochlorofluorocarbons, hydrochlorofluorocarbons phase out management plan, Remote sensing and geographical information system, Ozone and alternatives.

(Received 15-03-2016 Accepted 15-01-2018)

INTRODUCTION

Ozone plays an important, diverse role in the life of human beings. The concentration of atmospheric ozone is approximately 90% contained in the ozone layer. It varies over wide limits at a given spatial location, with time. It protects the earth from ultraviolet harmful radiation from the Sun (Zahid and Rasul, 2010). Stratospheric ozone results by the destruction and production taking place in photochemical processes (Haq *et al.*, 2014). Chlorofluorocarbons (CFCs) and their alternatives such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) are generally used as refrigerants and aerosol propellants because of their first-rate characteristics (Xiang *et al*., 2014). The reactive elements such as Fluorine (F), Chlorine (Cl) and Bromine (Br) are released from CFCs during solar ultraviolet radiations in the stratosphere contributing to ozone depletion. CFCs and their alternatives intensely absorb infrared radiations which lead to greenhouse effect. The usage of HCFCs is controlled under the Montreal Protocol as they belong to Ozone Depleting Substances ODSs (Gao *et al*., 2001).The category HCFC 141b is widely used in manufacturing industries whereas HCFC 22 is used mainly in servicing sector. Ozone is not packed into a single layer rather it is fully dispersed in the atmosphere. Satellite sensors and ground based equipment can assess the total ozone for an entire column of the atmosphere (Sivasakthivel *et al*., 2011).

The average amount of ozone in the atmosphere corresponds to 300 DU (Dobson unit) (Velders *et al*., 2011). 100 DU forms one ml thick ozone layer when compressed. The ozone concentration drops to an average of about 100 DU which is termed as the "Antarctic Ozone Hole" (Rinsland *et al*., 2009).

Depletion of ozone contributes to global warming. The anomalous behavior of temperature calculated over a couple of decades can be related to total ozone depth (Mahmood *et al*., 2016). Indicators of climate change such as increase in temperature,

variability of precipitation, incidence of extreme weather events and deterioration in air quality levels, have direct as well as indirect consequences on human health (Merem *et al*., 2012).

Climate and weather are often thought to be a product of the lower atmosphere, that is, the troposphere and ozone is found in stratosphere. On contrary most of greenhouse gases accumulate in lower atmosphere like chlorofluorocarbons (CFCs) and hydro-chlorofluorocarbons (HCFCs) and they contribute in destruction of stratospheric ozone. Hence, links can be deduced between climatic variations due to greenhouse effect and Ozone depletion which itself is a greenhouse gas (Kovats *et al.,* 2000).

Short-term exposure to Ozone leads to high mortalities for adults from cardiovascular and respiratory diseases, such as asthma, throat infections, chronic obstructive pulmonary disease (COPD). Long-term ozone exposure is associated with lung functioning reduction, fibrosis and cardiopulmonary blocking diseases (Crouse *et al*., 2015). Therefore, O_3 concentrations levels in the troposphere are supposed to be associated with the health risks (Andrady *et al*., 2016). Pakistan successfully phased out the first generation of ozone depletion substances *i.e.* chlorofluorocarbons (CFC), carbon tetra chloride (CCl_4), halons, methyl bromide by December 2009 and is now heading toward the elimination of second generation *i.e.* hydrochlorofluorocarbons (HCFC).

The main objective of the study was to phase out the second generation of ozone depleting substances.

MATERIALS AND METHODS

A survey was conducted to establish the baseline of HCFCs usage in Pakistan which highlights the future projections of its estimation. Federal Board of Revenue (FBR) and United Nation (UN) Comrade provide the HCFCs consumption data. Recent study is designed to address the climate change impacts on ozone concentration and to measure the HCFCs concentrations (Zahid and Rasool, 2010).

Under the first stage of conversion funded by Multilateral Fund (MLF) industries converted CFCs to HCFCs. Approximately 36 industries are estimated with their branches both in Karachi and Lahore. There are number of cottage industries that use HCFCs in very small quantities like in thermobaric, flexible and spray sub-sectors. About 8,500 servicing workshops scattered all over Pakistan. 25% of HCFCs is used in servicing sector (Ye *et al*., 2001).

HCFC 141b is used in a number of applications including thermos-ware polyurethane (PU) insulation foams, PU Sandwich Panels, Spray Foam, Flexible Foam, Commercial Refrigeration and Pipe PU Insulation. HCFC 142b has only one application in manufacturing of Extruded Polystyrene Board. HCFC 22 is used in manufacturing of domestic, commercial air conditioning and in servicing sector. HCFCs have been replaced in five industrial units such as United Refrigeration Industries Hyderabad, HNR Company (Haier) Lahore, Varioline Intercool Lahore, Pakistan. Shadman Electronics Karachi and Dawlance Karachi to achieve 10% reduction by 2015 in the first phase (Haq *et al*., 2014).

As per reported data, baseline for Pakistan is 247.4 ODPT (Ozone Depleting Potential Target). Maximum allowable total consumption target in ODPT and reduction is depicted in table 1 below. Out of baseline 79.1 ODPT has been phased out in Stage-I while remaining 168.3 ODPT has been planned in remaining stages. Out of 168.3 ODPT, the share of HCFCs in manufacturing is 113.8 ODPT while remaining 54.5 ODPT is in servicing sector.

Table-1. Pakistan ODPT targets and reduction limit from 2013 – 2040.

Year	ODPT Targets	Steps
2013	247.4	Freeze
2015	222.66	10% reduction
2020	160.80	35% reduction
2025	80.40	67.5% reduction
2030	6.20	97.5% reduction
2040	0.00	100% reduction

With regard to the number of workshops/enterprises currently using HCFC and its categorization against annual product-wise consumption. Table 2 describes the Annual Consumption of ODSAs in manufacturing and servicing sectors during 2012-2015.

Table-2. Annual Consumption of ODSAs in manufacturing and servicing sectors during 2012-2015.

Sectors/ Sub-sectors	2012	2013	2014	2015
Refrigeration				
-Domestic	717	747	780	810
-Commercial and large commercial	201	218	236	274
-Industrial	35	37	39	41
-Transport	2	2	2	2
Sub-Total	**954**	**1003**	**1057**	**1126**
Air Conditioning				
-Stationary	335	342	424	573
-Mobile	621	366	367	676
Sub-Total	**956**	**708**	**791**	**1250**
Foam				
-Domestic Refrigeration	212	230	443	715

2.1 HCFC-22 Phase out strategy in servicing sector: This strategy totally bans on import of products, equipment's using or containing HCFCs, their blends such as air conditioning equipment's and foam manufacturing materials. It prohibits the investment in building the new plants consuming HCFCs. It sanctions the uncontrolled release of HCFCs during servicing. Strict mitigation should be done on import quota system. Policies for proper handling, transportation, storage of hydrocarbons, emission, monitoring, reporting and awareness rising with private sector should be done. Import duty relaxation will be provided on non-HCFCs based products and higher duties on HCFCs based products and raw materials (Zhao., 2011).

RESULTS AND DISCUSSION

A comprehensive strategy of action plan includes a list of possible projects and their estimated expenditures to achieve the required phase out targets while preparing the HCFC Phase-out Management Plan (HPMP) for Pakistan. The identified projects shall be implemented in stages. Presently there are a number of non-ODP substitutes that exist for several HCFCs uses. These substitutes vary in key respects including available maturity of the technologies, cost effectiveness, energy efficiency and other environmental considerations (Montzka *et al*., 2015). This mainly includes programmatic review of the entire process and inclusive plan to be implemented in number of stages until specific HCFCs phase out activities for meeting the initial freeze and 10% reduction step understage-1.

The strategic objectives of this plan is to ensure that the Pakistan's obligation is met in terms of the Montreal Protocol's control measures by reducing HCFCs consumption in manufacturing and servicing sectors (Iversen *et al*., 2006). In Pakistan, the conditions and constraints of this plan comprise of that the industry & business related to HCFCs must be developed in a sustainable manner. Employment must be kept in all related industries, particularly in small entrepreneurs' that play a major role in the refrigeration servicing sectors. Even more employment may be created as a result of successful implementation of the program. The requirement of HCFCs refrigerants appropriate for quality servicing sector must be ensured for servicing and maintenance of the existing HCFCs based on air conditioners during the period until the complete phase out is implemented as per schedule. Recognizing the period of HCFCs phase out in the servicing sector and frequent change out of business in the Small Manufacturing Enterprises (SMEs) sectors, an effort shall be made to ensure training of technicians on regular basis (Aslam *et al*., 2017).

Geospatial analysis of industries in Pakistan consuming HCFCs: RS &GIS techniques help to view the trends and changes occurring due to use of HCFCs and their impact (Al-Mahdi *et al*., 2013). The figure 1 shows the location of refrigerants and foam sector industries in Pakistan. It can be seen easily the difference in the size of industries and consumption of HCFCs. They are mapped by using the statistical data of ozone cell and our spatial survey for the GPS points of industrial locations. Then both are joined to map the location and consumption of HCFCs (Anjum *et al*., 2016).

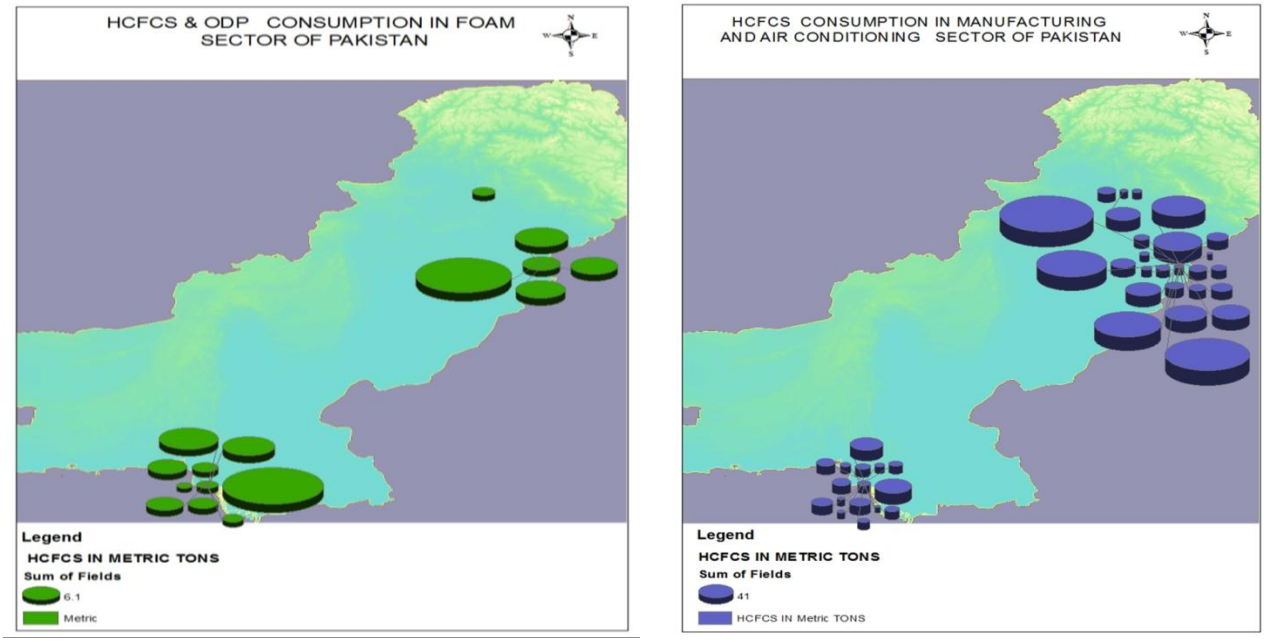

Figure-1: Locations of refrigerants and foam sector industries in Pakistan

The major clusters (75%) of refrigerant and foam industries are located in Karachi and Lahore. Figures 2 and 3 depict the maps which provide the closer view of the refrigerant and foam sector industries present in these areas.

The closer view of separate maps of Lahore and Karachi are prepared to present the more accurate picture of the refrigerant and foam sector industries. The following maps are showing the details.

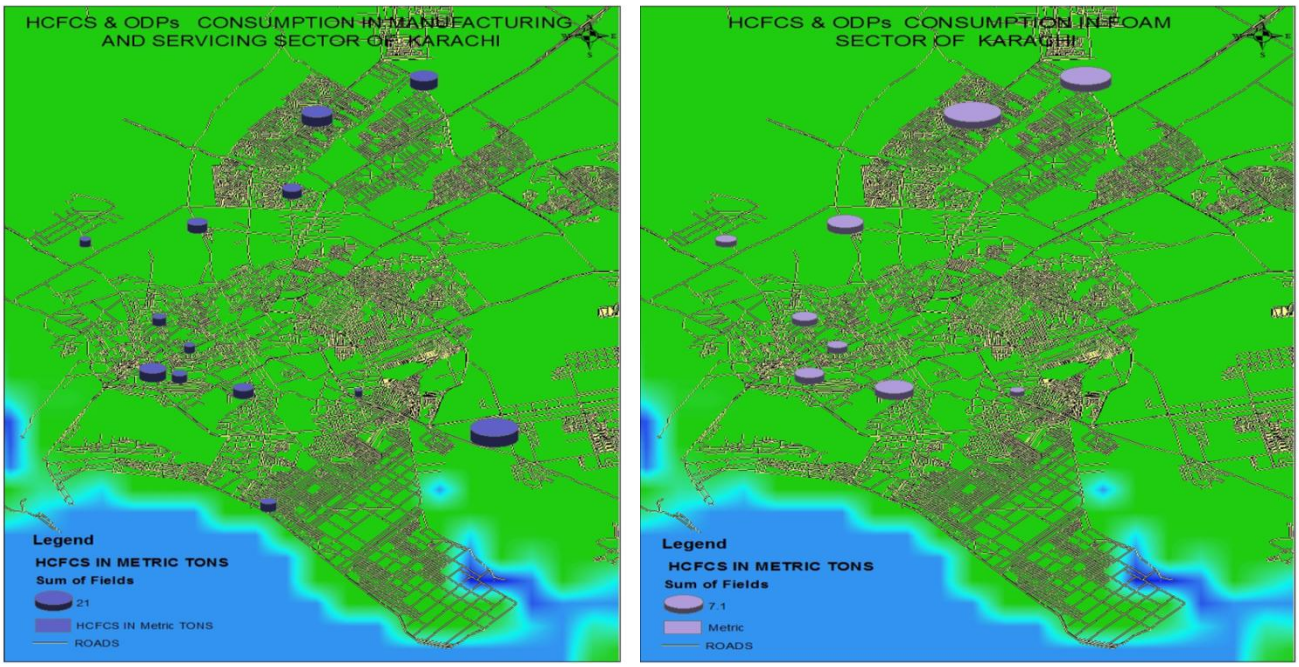

Figure-2: Hydrochlorofluorocarbons consumption in manufacturing, servicing and foam sectors in Karachi

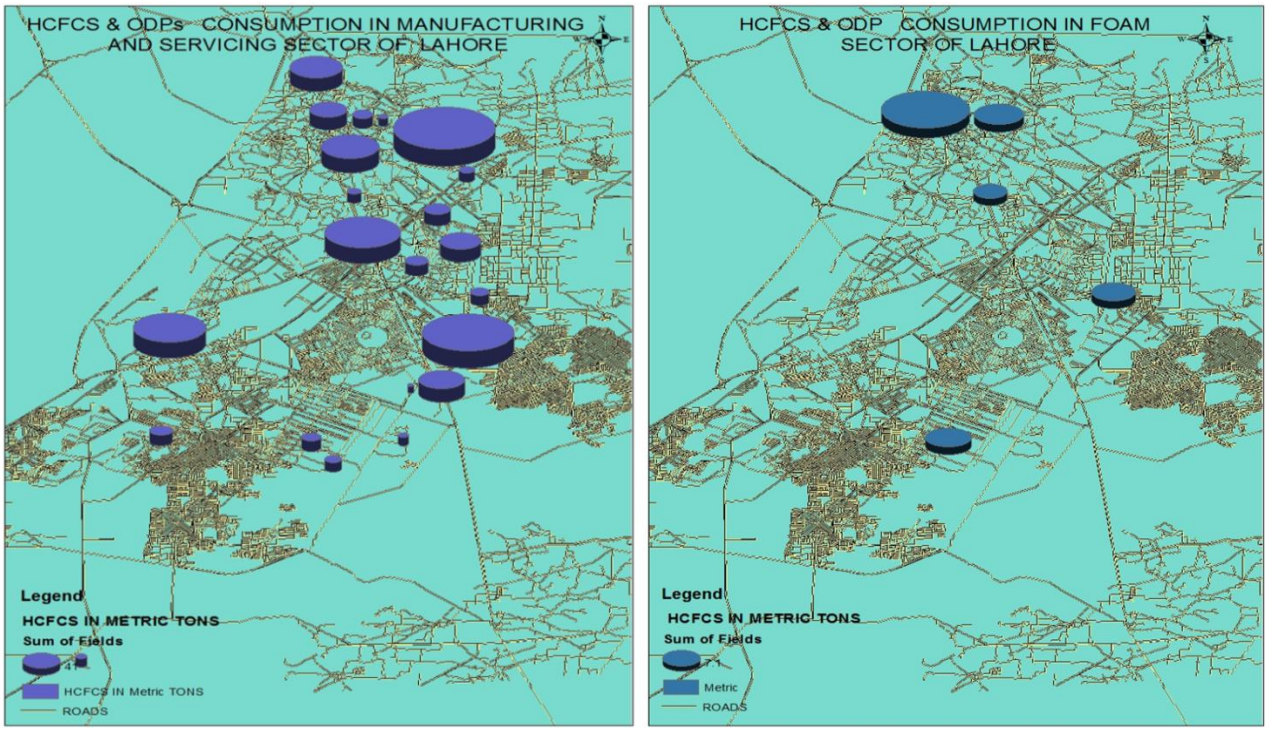

Figure-3: Hydrochlorofluorocarbons consumption in manufacturing, servicing and foam sectors in Lahore

HCFC-141b emissions in mega city Lahore: A field survey, based on Stratified Random Sampling (SRS) method and other parameters described in (Haq *et al*., 2016), has been conducted for estimation of refrigerant HCFC 141b from manufacturing and wastage stages in mega city Lahore during 2005-2013. Both stages of manufacturing and wastage have contributed significant emissions of HCFC 141b, increasing at rate of 7.11% (slope: 7331.2, y-intercept 103058 kg) per year, during the period.

Table-3. HCFC 141b emissions and related ODPT contribution from manufacturing and wastage stages in mega city Lahore during 2005-2013.

Year	Manufactured refrigerators containing HCFC-141b	Disposed off refrigerators containing HCFC-141b	Emissions (kg)	ODPT *(CFC-11 eq.)*
2005	431748	1255	93418	10.277
2006	537711	1150	116293	12.796
2007	606458	1090	131134	14.425
2008	659368	1003	142552	16.734
2009	750007	867	152112	16.722
2010	703194	650	151972	16.899
2011	703194	490	153621	16.896
2012	774165	342	157263	17.294
2013	782510	299	159060	17.494

Servicing sector considerations: The number of workshops, scattered all over the country, is estimated to have increased by almost 50% between 2001 and 2009. As a result, the consumption in the servicing sector has been on increase. Around 75% of HCFC 22 and 33% of all HCFCs used in Pakistan are currently consumed by the servicing sector. Two main reasons for this are aging air conditioning units in the country that are more vulnerable to leakage, and new HCFC-22 based air-conditioners (locally manufactured as well as imported mainly from China and Thailand) which, when installed, will scale up the servicing demand of HCFC-22. This sector requires special attention to ensure sustainable implementation of the HCFC phase out programme (Velders *et al*., 2007).

Institutional / legal activities: Government of Pakistan is enforcing rules and regulations laid down under the Pakistan Environment Protection Act, 1997. Ozone cell is monitoring the import of HCFCs, and all the importers are required to seek permissions to import of HCFCs from the Ministry of commerce in coordination with the ozone cell. A quota system for the import and control of HCFCs will be implemented as soon as the licensing system is finalized. In due process, all commercial and industrial importers of HCFCs are being registered. Also, a new trade policy is being implemented to ban the import of HCFC based equipment.

The ozone cell shall examine present legal and institutional system for ODS management and improve where necessary for HCFC Management. In this course it shall consult and coordinate with stakeholders including ministry of commerce and trade, trade associations, commercial Importers, manufacturers etc. As part of institutional work, the action to be taken by ozone cell includes to establish a help desk for assistance to stakeholders, design and establish website for guidance of stakeholders, masses and info seekers, make institutional arrangement for an easy access to alternative supplies, coordinate HCFC plan with climate change, chemical management and energy policies, identify additional regulatory measures for HCFC management and implementation.

In addition, the regular monitoring and periodic evaluation of communication strategy activities is a must. The NOU has a strong track record of awareness-raising and outreach, which will certainly benefit HCFC, related communication strategy activities. For monitoring and evaluation of HPMP, the following is proposed:

- NOU will convene an informal working group, comprising of a few key stake holders that meet occasionally to review and advise the NOU on awareness and outreach activities.
- An external evaluation of communication strategy and outreach activities, undertaken after activity implementation in 2011, 2012, recommends improvements for 2013 and beyond.

Suitability review of alternatives: The manufacturing sector uses HCFC 141b in the refrigeration sector PU foam. HCFC 141b application is in both domestic as well as commercial refrigeration sub sectors. In the foam sector HCFC141b is used in the rigid PU, spray, flexible and integral skin foam sub-sectors. HCFC 22 is used in the manufacturing of cooling system of domestic and commercial air conditioners and servicing sector. A number of viable substitute technologies for phasing out of HCFC's have been identified in the foam and

refrigeration sectors. The following technologies have been adopted for various sectors / sub-sectors after consultation with the enterprise as mentioned in the following Table 4.

Table-4. Adopted HCFCs alternative technologies for various sectors and sub-sectors.

Sector/Sub-Sectors	Adopted Alternatives
Refrigeration Sector	
-Domestic Refrigeration PU Foam	Cyclopentane
-Commercial Refrigeration PU Foam	Cyclopentane
-Domestic A/C	R410A
-Commercia lA/C	R410A
Foam Sector	
-Rigid Foam	Cyclopentane
-Spray Foam	Water Based / (Water / CO_2) / Methyl Format
-Flexible Molded Foam	Water Based / (water/CO_2) / Methyl Format

The table below compares characteristics of already known alternative refrigerants to HCFC-22. Replacements which are widely used are R-417A, R-422A and R-422D. Actually these all replacements are the mixtures of HFCs and hydrocarbons. This certifies the oil flow in the refrigeration cycle. These all alternatives not truly reflect the newly designed HVAC equipment. They have limited market experiences and their performance is not satisfactory. The system with already mineral oil lubricant may not provide appropriate lubrication. This results in poor durability on wearing surfaces in the compressor.

R 404A and R 507A are suitable for low-temperature application only. They are not appropriate for air-conditioning application. R 290 is used as an alternative against HCFC 22 for vending machines. It is highly flammable and used only for small equipment's only. R 600a is a common is a refrigerant used for domestic refrigerators. Ammonia (R 717) is highly toxic to environment and it poses serious threat for health. If inhaled it may leads to respiratory disorders like asthma, coughing or lungs problem. It is widely used in big chillers but its toxicity may minimize its use. Carbon dioxide (R-744) also contributes to respiratory problems. Short term or long term exposure may be fatal. It reduces the capacity of hemoglobin to combine with oxygen. This leads to lungs cancer and shortness of breath. CO_2 is one of the greatest contributors in global warming. Its usage must be limited. Itis consumed by mobile air-conditioners. Heat pump is used to heat water. Carbon dioxide is present as a refrigerant in heat pumps and is becoming wide spread. The efficiency of heating process is quite high but efficiency is quite low for refrigeration. This draw back minimizes its usage in air-conditioning applications. R-1234yf having low-GWP and HFCs are mainly used for MAC applications. Thermal efficiency, volumetric efficiency and operating pressure are the factors important to determine performance of refrigerants.

Table-5. Characteristics of Alternative Refrigerants to HCFC-22.

Refrigerant	Component	GWP (100y)	Safety Class	Temp. glide(K)	Condensing Temp.at26 Bar(oC)	Suitable AC application
HCFC-22	HCFC	1810	A1	0	63	All
HFC-134a	HFC	1,430	A1	0	80	Screw chiller
R-407C	HFCs	1,800	A1	7.4	58	All
R-410A	HFCs	2,100	A1	0	43	All
R-404A	HFCs	3,900	A1	0.7	55	Commercial refrigeration
R-507A	HFCs	4,000	A1	0	54	Commercial refrigeration
R-290	Propane	20	A3	0	70	Room AC
R-1270	HC Propylene	20	A3	0	61	-
R-600a	HC Isobutane	20	A3	0	114	Domestic refrigerators
R-717	Ammonia	0	B2	0	60	Screw chiller
R-744	CO_2	1	A1	0	-11	Mobile air conditioners, heat pump for water heater

Ozone layer protection mission goes on in Pakistan: Pakistan is fully devoted to global efforts for the conservation of environment. Pakistan magnificently met 2010 targets set by the Montreal Protocol for the phasing out of Ozone Depleting Substances (ODS).

Pakistan has already transformed its industry in the foam, refrigeration, metal cleaning and fire-fighting sectors from ODS-based technology into Ozone friendly technology. This was implemented by the agencies like UNIDO, UNEP, UNDP and World Bank. The 2015 targets set for the phasing out of HCFC enhanced

programme is met through the implementation of five projects in residential and commercial refrigeration sector. The HCFCs having higher Global Warming Potential (GWP) were replaced with the substances having very low GWP to preserve not only the ozone layer but also to reduce the impact globally.

Conclusion: Phasing out HCFCs from industrial sector was a difficult endeavor but by adopting alternatives we can get rid off from all ozone depleting substances. Our contributions to the global warming potential will be reduced which leads towards less influence on climate change.

Acknowledgments: We acknowledge the contribution of Ministry of Climate Change, Govt. of Pakistan for providing financial assistance to complete the research work and also thanks to the officials of the ministry for their continuous assistance during the execution of research work.

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