CO_2 as Refrigerant in HVAC, Supermarket and Cold-chain Application

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- Background and Motivation
- Introduction
- Why CO_2 as Refrigerant
- Technical Challenges and Opportunities
- Recent Developments
- Conclusion

Background and Motivation

- Present scenario the global warming is the major concern worldwide, due to the continuous increment of CO_2 level in the environment.

- The power plants, chemical, manufacturing industries and the automobile application are the major cause for the same.

- Now a days, various protocols and norms have been in implementation stage to either reduce the CO_2 level or to capture the CO_2 produce during the process.

Background and Motivation

- Research are going on to capturing the CO_2, however, the storage of the captured CO2 is the major challenge.
- It leaves a question whether the capturing of CO_2 with storage is a really a feasible and economical solution?
- At this stage, HVAC sector are in the transition phase due to control the ozone depletion and global warming respectively.
- In other hand, the challenges associated with the storage of CO2 captured and, the use of CO2 as a refrigerant in HVAC application could be an appreciable solution.

Introduction

- CO_2 is a natural refrigerants, favourable thermo-physical properties and having lowest warming potential (GWP).
- Many research going on worldwide for different application in HVAC sector.
- Cold chain is one of the major sector where the use of CO2 as refrigerant can be appreciated, especially for the referred vehicles and cold storage for NH_3 charge reduction.

Indian Cold Chain Infrastructure [1]

Cold-chain is an environment controlled logistics chain, ensuring uninterrupted care from source-to-user, consisting only of storage and distribution related activities in which the inventory is maintained within predetermined ambient parameters. Cold chain does not alter the essential characteristics of the produce or product handled.

Infrastructural GAP in India Cold Chain [1]

Type of Infrastructure	Infrastructure Requirement	Infrastructure Created	All India Gap
Reefer Vehicles	61,826	9,000	52,826
Cold Storage	351,41,373 MT	318,23,700 MT	32,76,962 MT
Pack-house	70,080	249	69,831
Ripening Chamber	9,131 nos.	812 nos.	8,319 nos.

The data clearly indicate the huge scope and demand of HVAC for Infrastructure development of India.

Why CO_2 as refrigerant

CO_2 has favourable and excellent thermo-physical properties and it is most suitable as lowest GWP.

The detail comparison of properties with different refrigerants are shown in table 2.

It is being already in use as refrigerant in the colder climate countries like northern Europe, Canada, some part of USA, etc. especially, for the heating application.

Table 2. Environmental, Thermo physical and safety Standard for Refrigerants (UNEP 2014b

Refrigerant	GWP	ODP	Critical Point	Safety
R22	1780	0.04	96.1	A1
R134a	1360	0	101.1	A1
R32	704	0	78.1	A2L
R152a	0	148	113.3	A2
R1234yf	0	<1	94.7	A2L
R1234ze	0	<1	109.4	A2L
R407C	0	1600	86.0	A1
R290	0	20	96.7	A3
R600a	0	20	134.6	A3
R1270	0	20	91.1	A3
R717	0	<1	132.3	B2L
R744 (CO_2)	0	1	31.1	A1

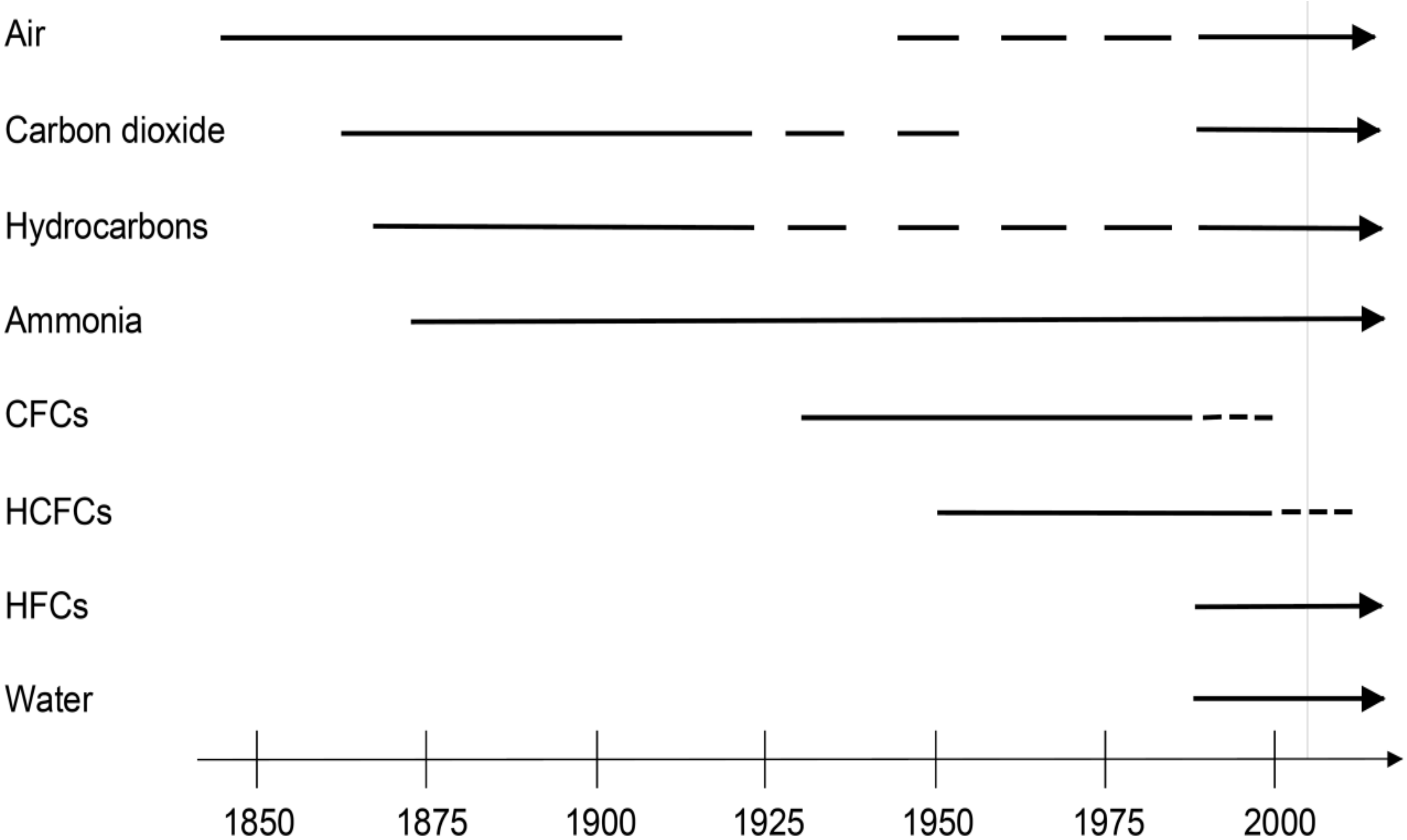


Figure: Historical introduction of refrigerants (Lorentzen & Pettersen, 1993)

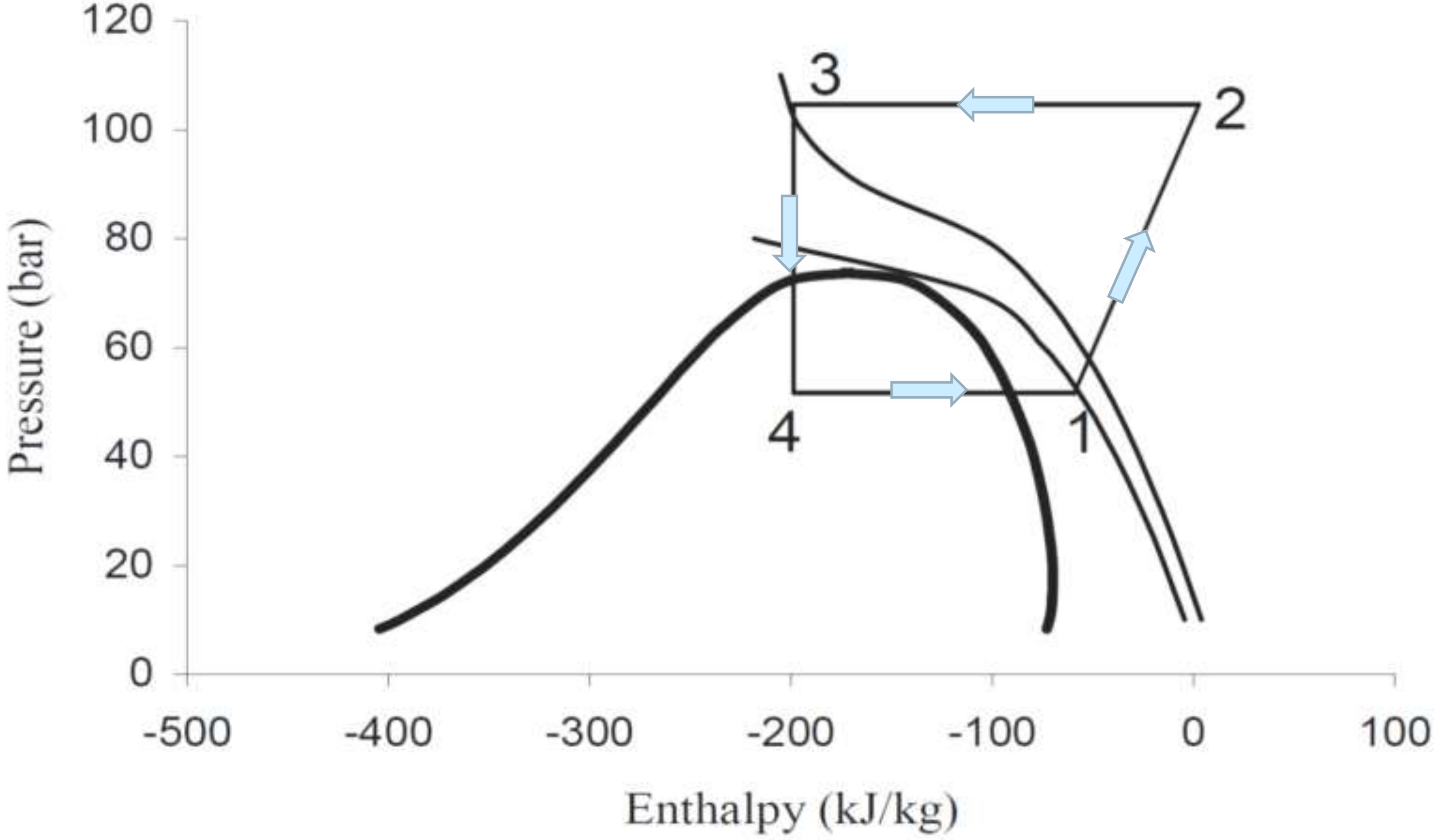


Fig: CO_2 Trans-Critical Cycle

CO_2 trans-critical system offers several application as mobile air conditioning, heat pump, simultaneous heating and cooling.

Advantages of trans-critical CO_2 systems is the high temperature lift . However, system performance deteriorates at high heat rejection temperature.

Apart from that….

The majority of work reported are heating application, in Indian condition need cooling application, has own challenges, to use in warmer climatic conditions.

The environmental temperature in India vary drastically from place to place. The optimum operating conditions for CO_2 system will also vary.

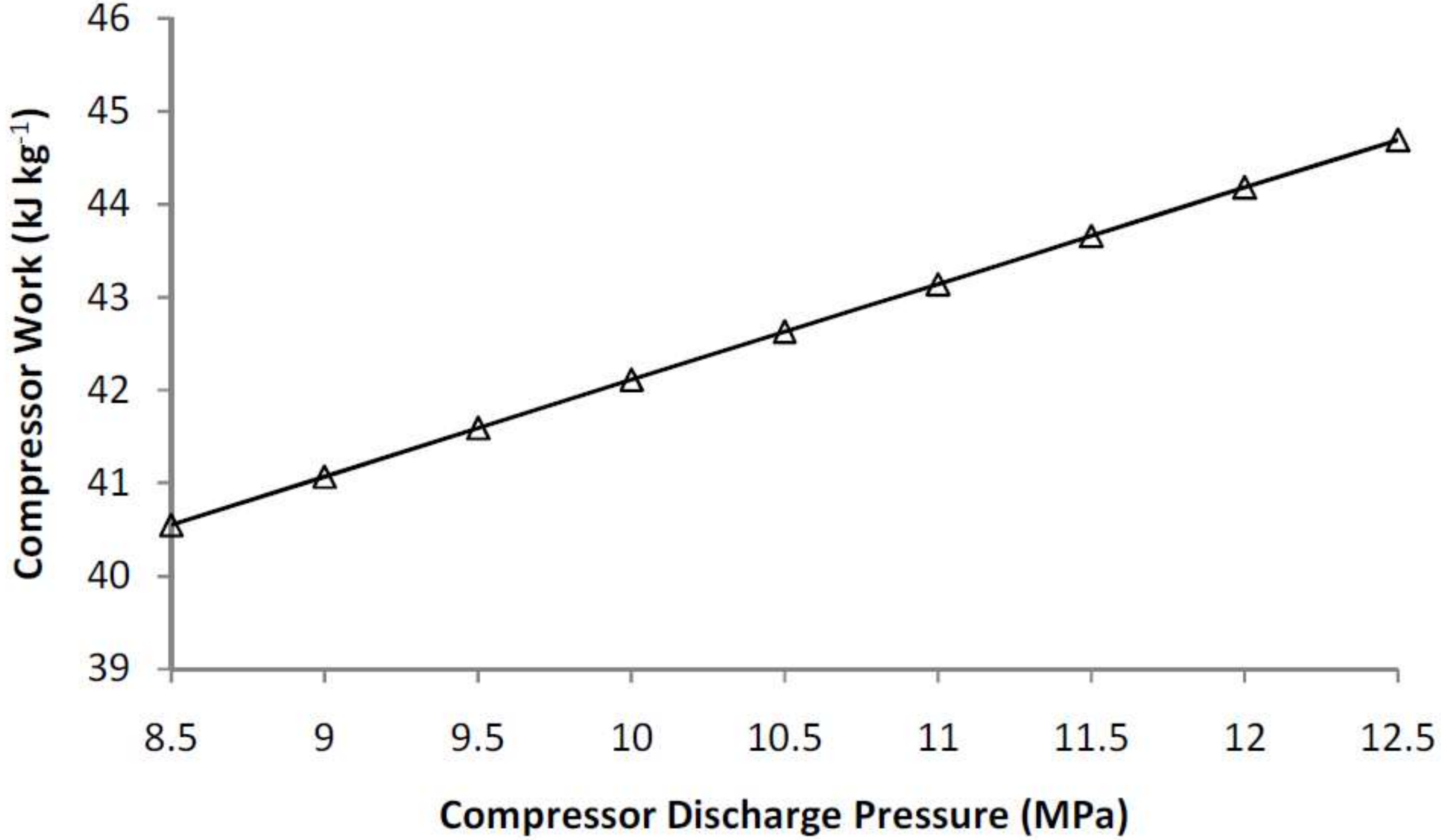
The high heat rejection temperature is major challenge, hence the gas cooler is the most sensitive component of the overall system and its design is very much crucial

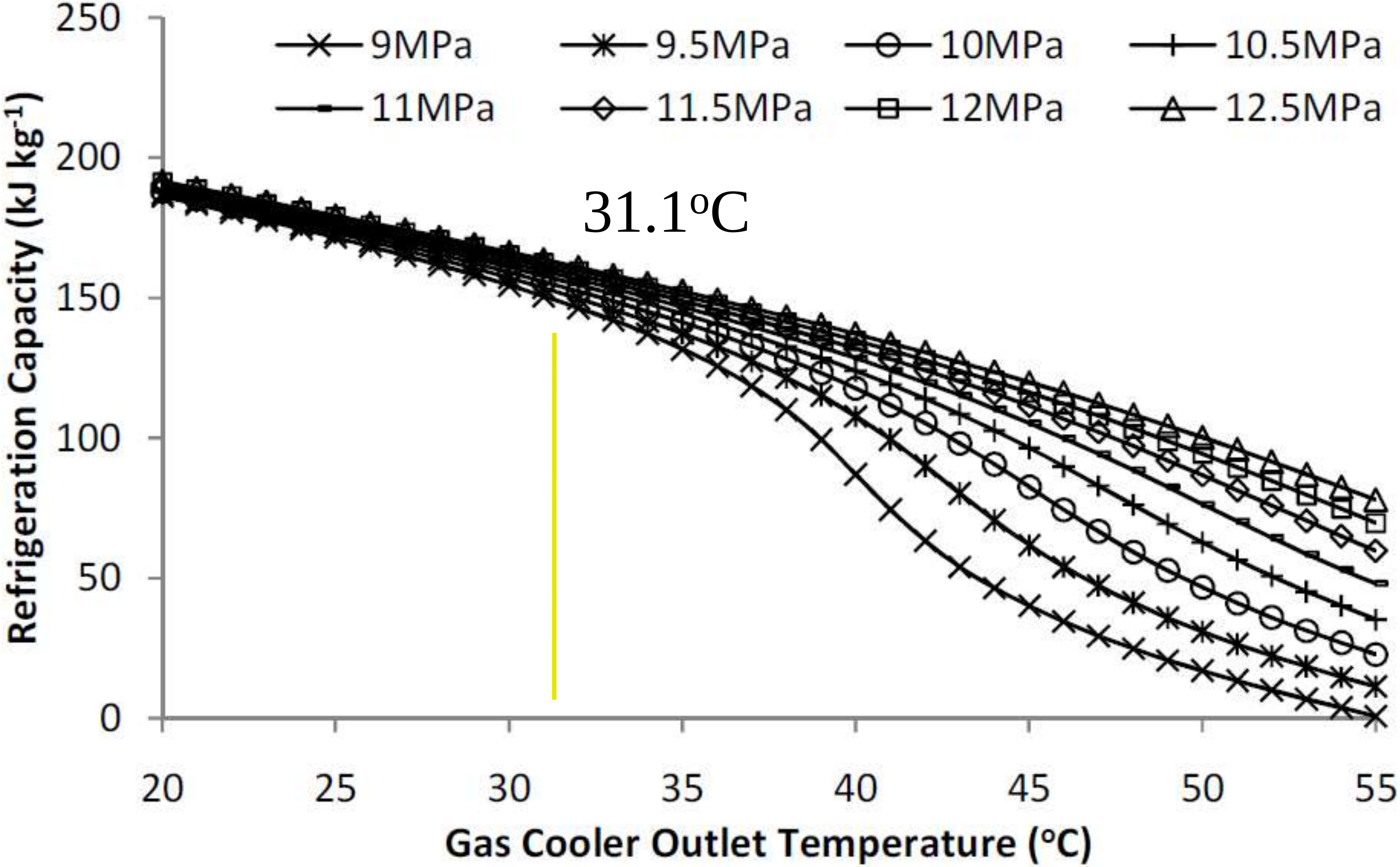
Each temperature zones required to have a specific design of components with optimum operating conditions.

It is required to analyze and optimize the performance of the system at different clusters of the temperature zones

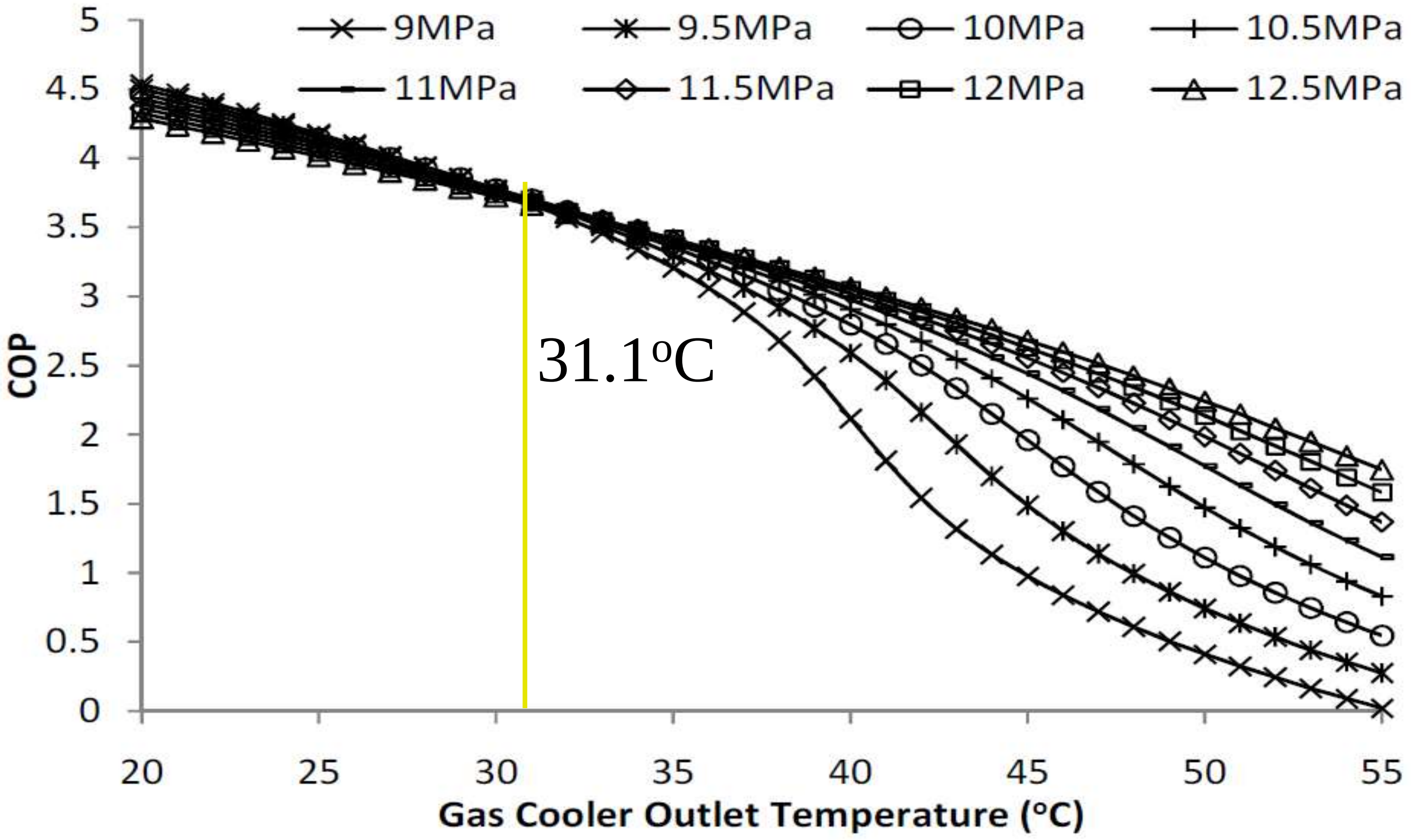
Design of the components and selection of the operating conditions must look to optimize the performance of the system

The present work focuses on the design and optimization of gas cooler for trans-critical CO_2 refrigeration system in Indian context


46
45
44
43
42
41
40
39
Compressor Work (kJ kg-1)
8.5
9
9.5
10
10.5
11
11.5
12
12.5
Compressor Discharge Pressure (MPa)



9MPa
9.5MPa
10MPa
10.5MPa
11MPa
11.5MPa
12MPa
12.5MPa
31.1oC
Refrigeration Capacity (kJ kg-1)
Gas Cooler Outlet Temperature (°C)
0
50
100
150
200
250
20
25
30
35
40
45
50
55


9MPa
9.5MPa
10MPa
10.5MPa
11MPa
11.5MPa
12MPa
12.5MPa
COP
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
20
25
30
35
40
45
50
55
Gas Cooler Outlet Temperature (°C)
31.1°C

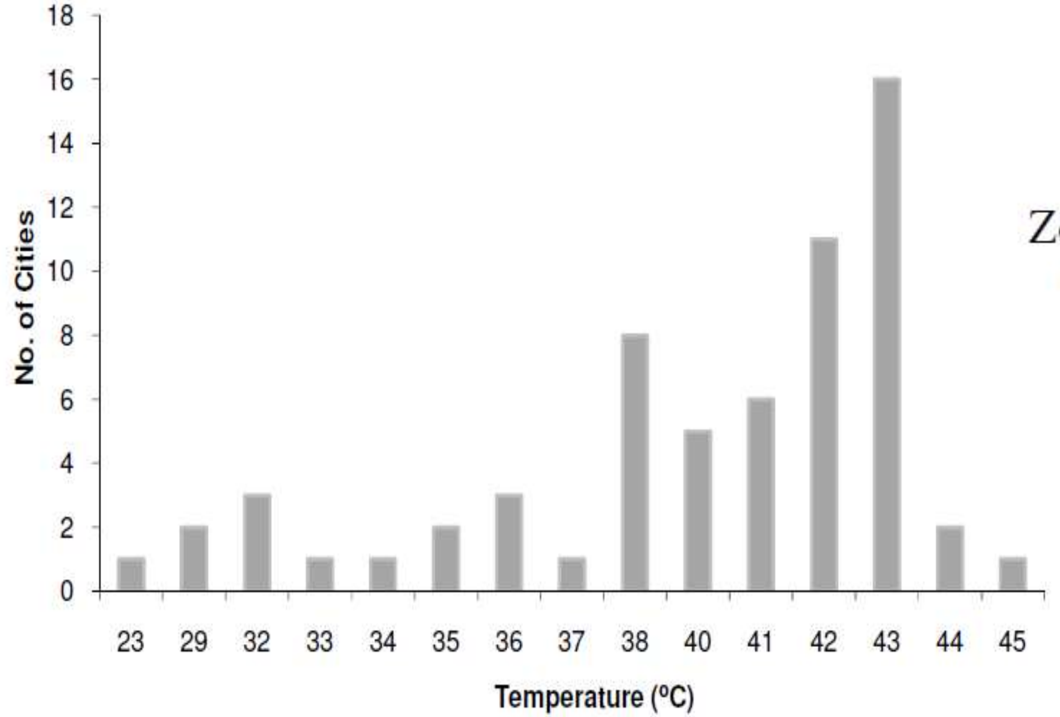
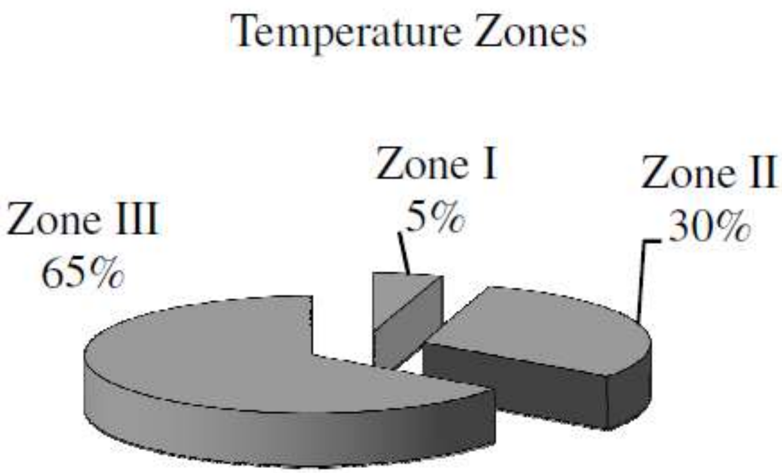


Figure 3.5: Number of cities in India and its design temperatures



Temperature Zones	No. of major cities	Design Temperature
Zone I	3	<=29.4°C
Zone II	19	> 29.4°C<= 40°C
Zone III	41	> 40°C<= 45°C

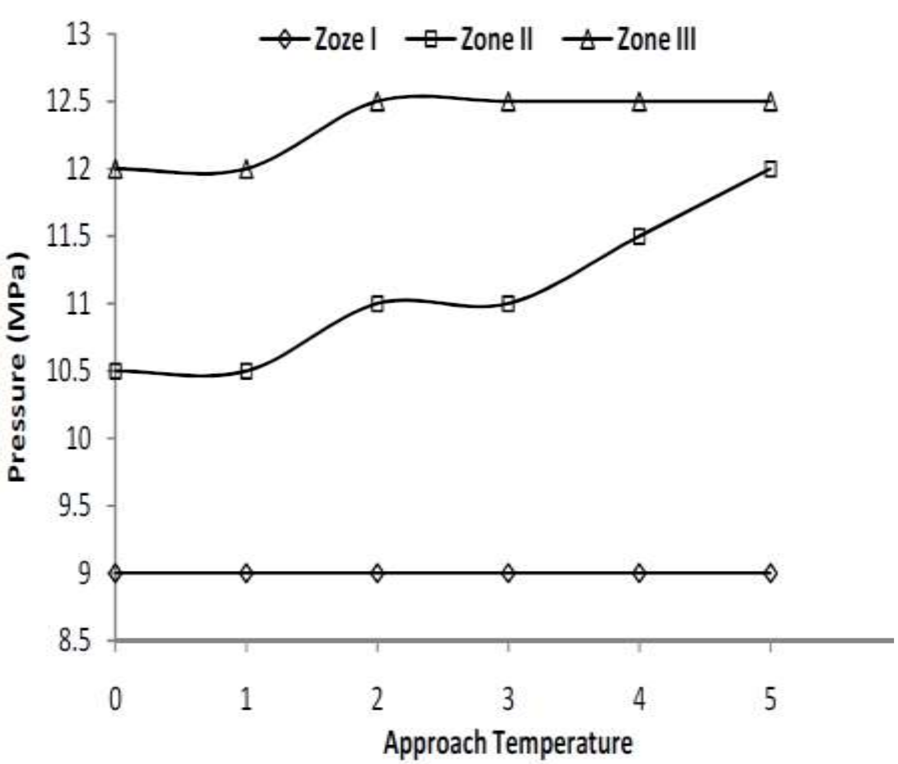


Figure : Pressure at which the maximum COP achievable at different AT

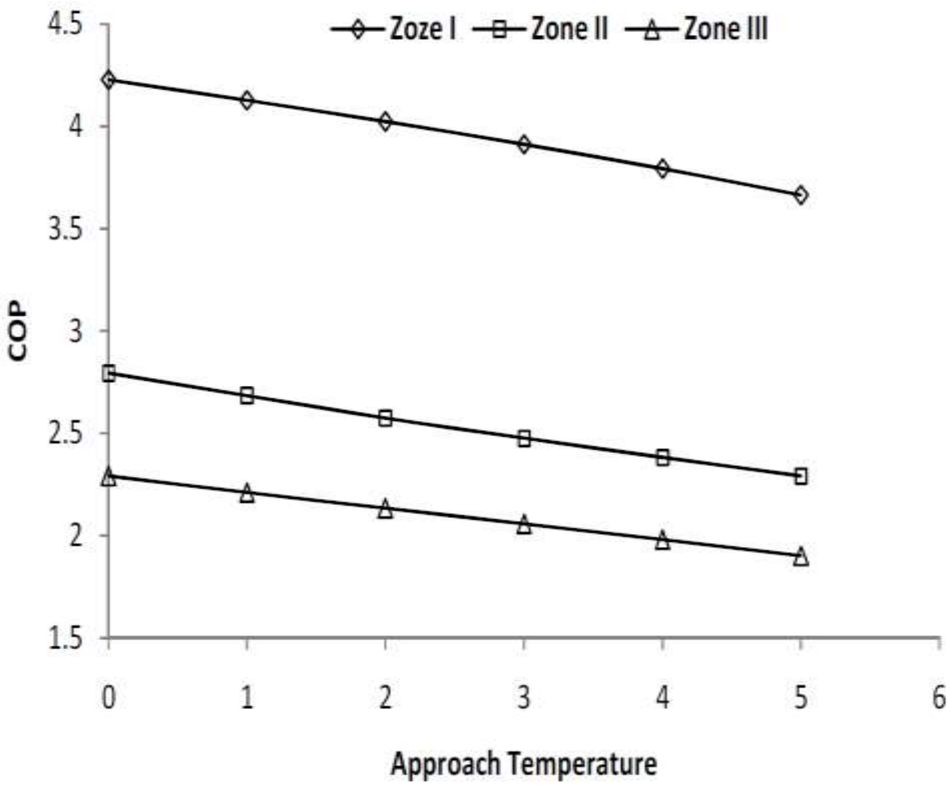


Figure: Variation of maximum possible COP with AT and different zones

Development of the CO_2 system

CO_2 cascade refrigeration systems

R744–R717 cascade refrigeration system

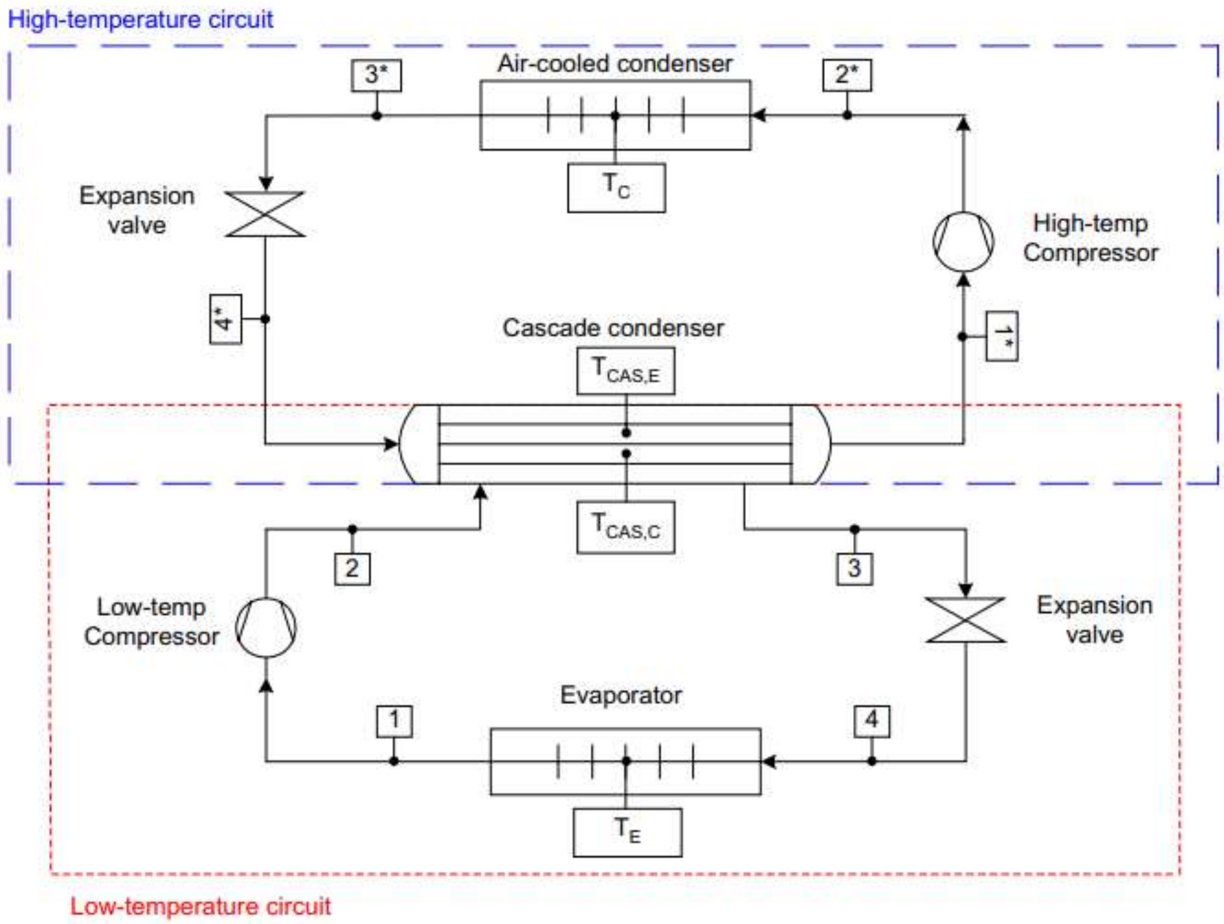


Fig. – Schematic of a two-stage cascade refrigeration system.

Ref.: H.M. Getu et. al.

R744–R717 cascade refrigeration system

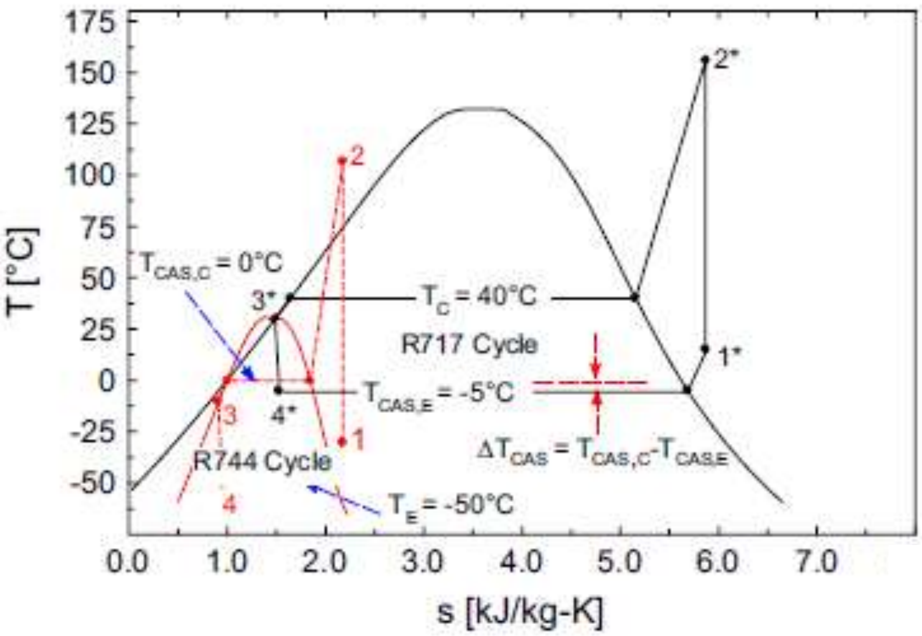


Fig : Carbon dioxide and ammonia cycles on T–s property plots.

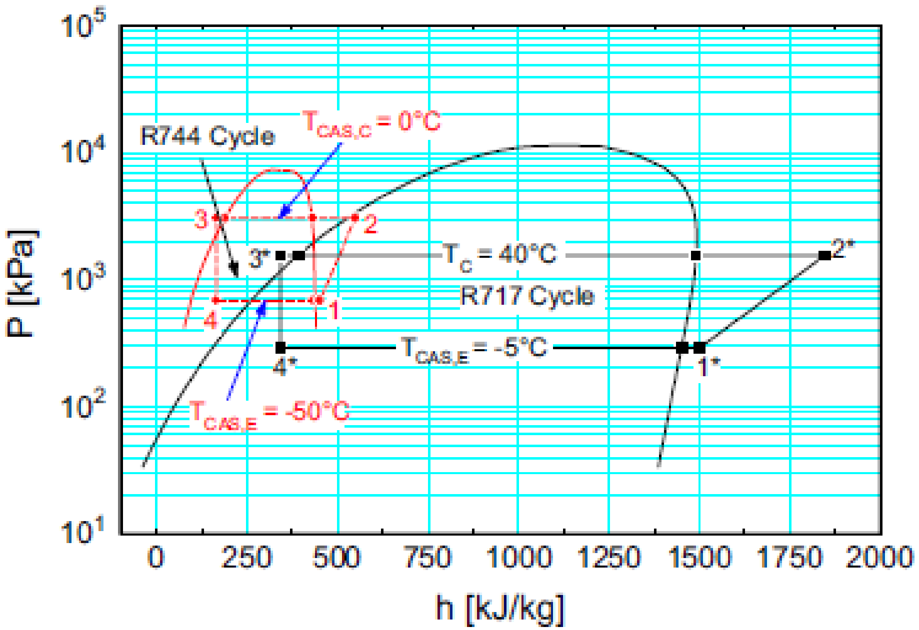


Fig : Carbon dioxide and ammonia cycles on P–h property plots.

Ref.: H.M. Getu et. al.

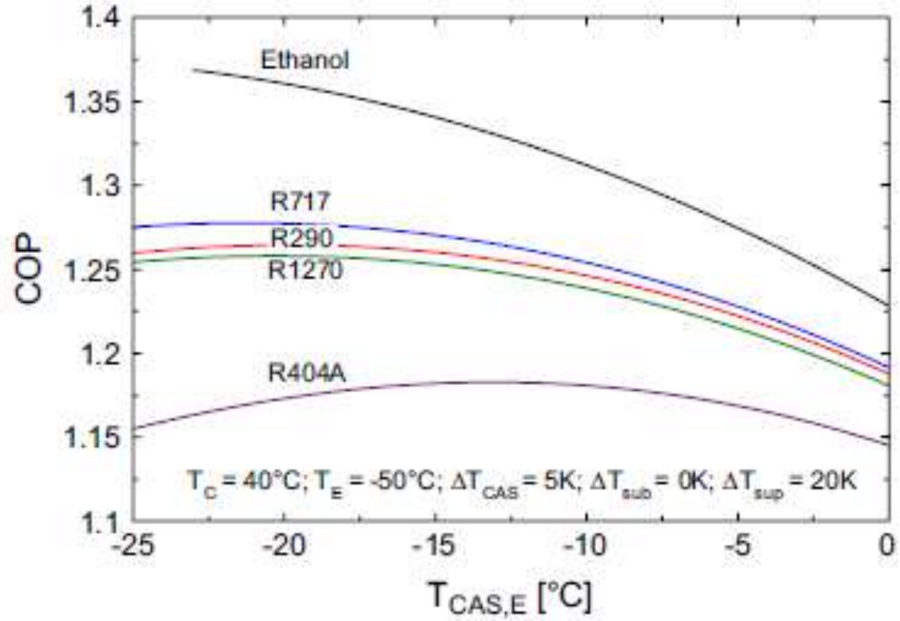


Fig. : Variation of system performance for a subcooling of 0 K and superheat of 20 K.

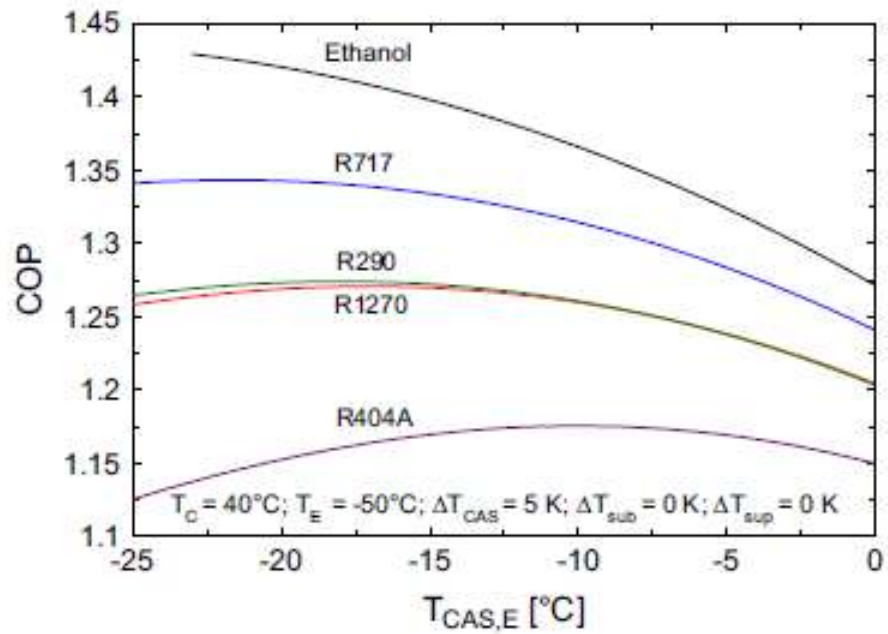


Fig.: Variation of system performance for a subcooling of 0 K and superheat of 0 K.

Ref.: H.M. Getu et. al.

Fig.: Variation of system performance for a subcooling of 10 K and superheat of 20 K.

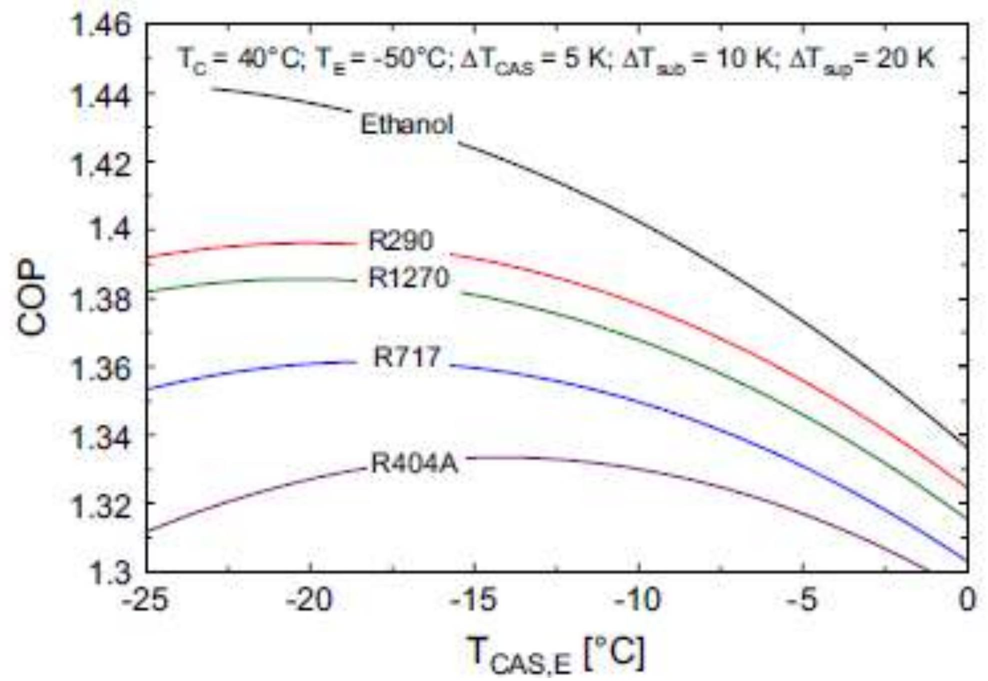
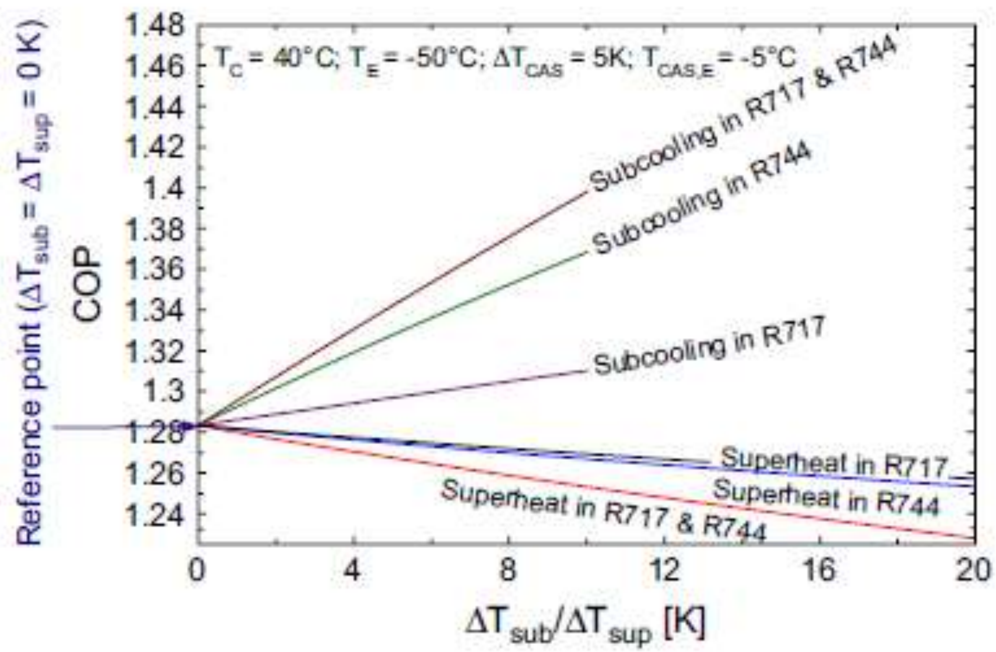


Fig.: Effect of superheating and subcooling on system and individual cycles.



Ref.: H.M. Getu et. al.

CO_2 Trans-critical booster systems

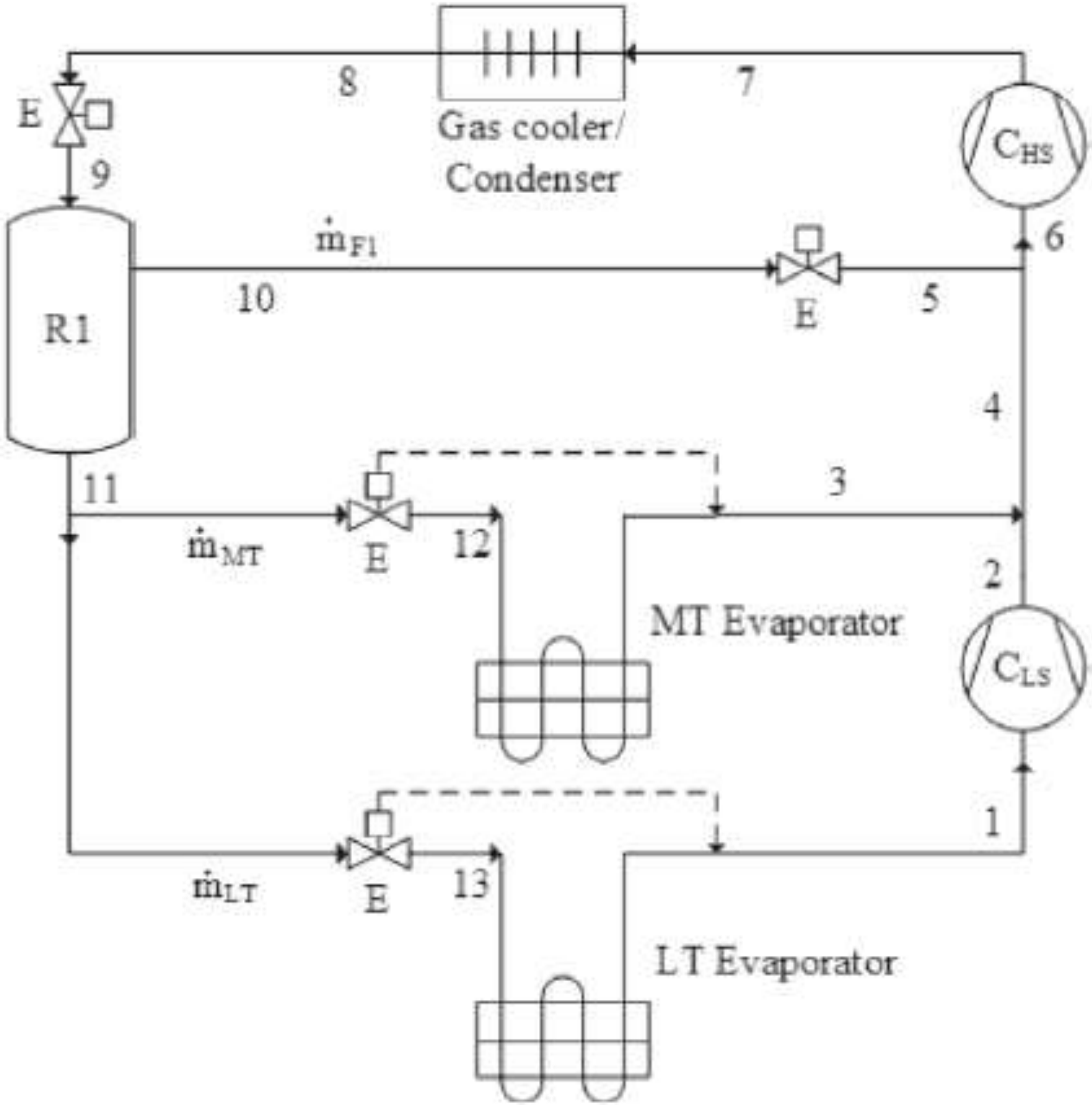


Fig.: Standard CO2 booster system (BC1).

Ref.: N. Purohit et. al.

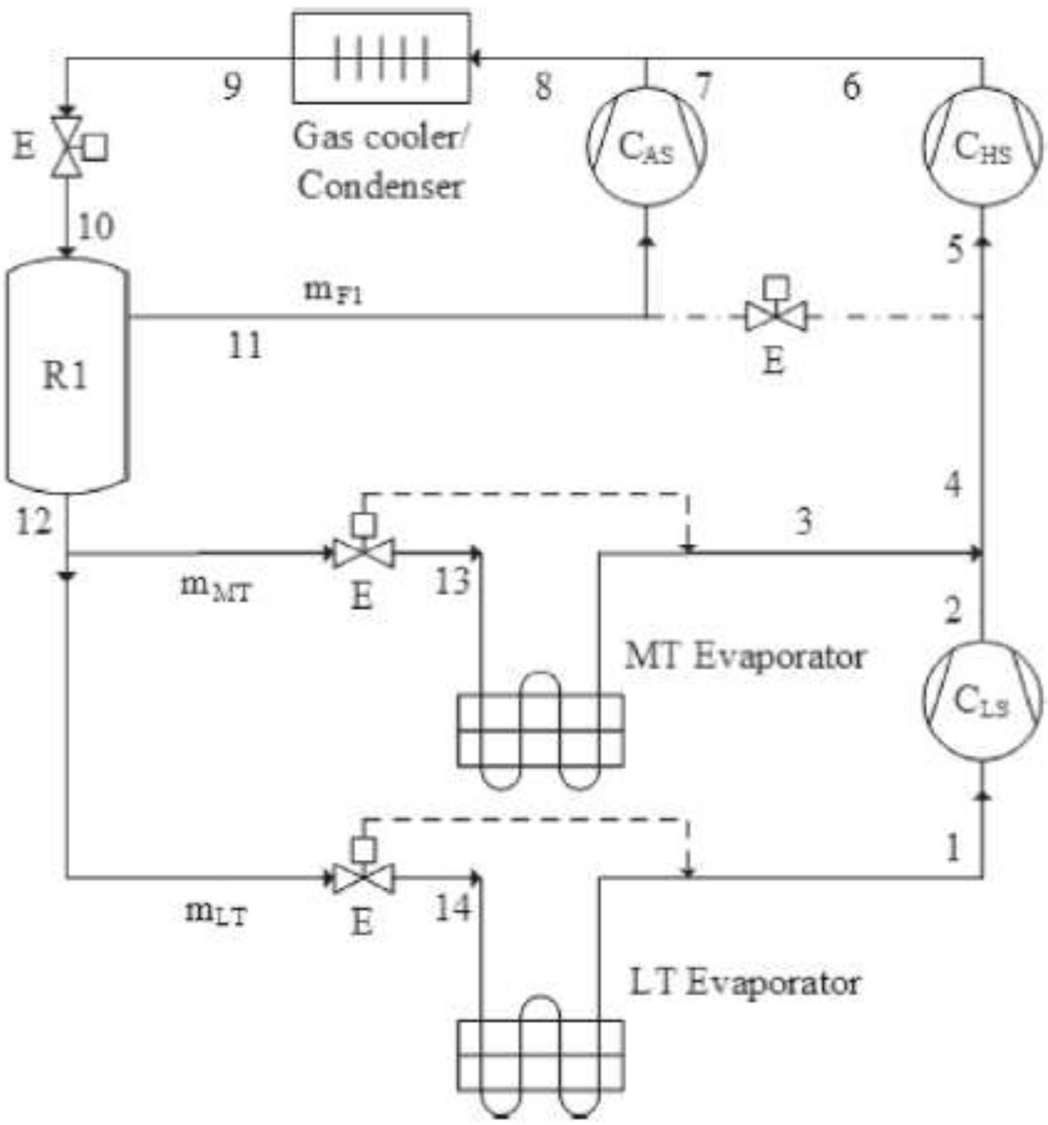


Fig. : CO2 booster system with parallel compression (BC2).

Ref.: N. Purohit et. al.

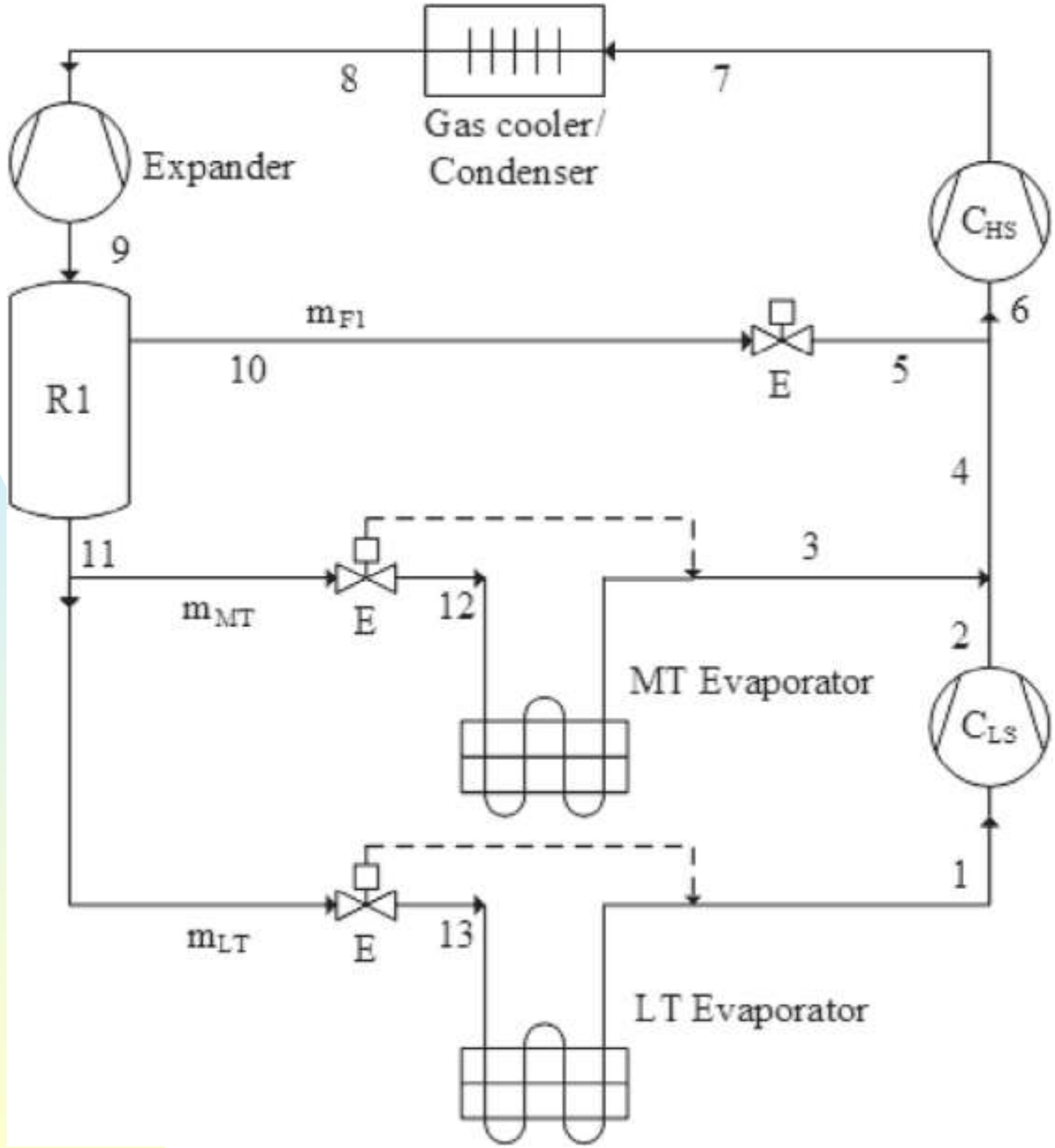


Fig.: CO2 booster system with work recovery expander (BC4).

Ref.: N. Purohit et. al.

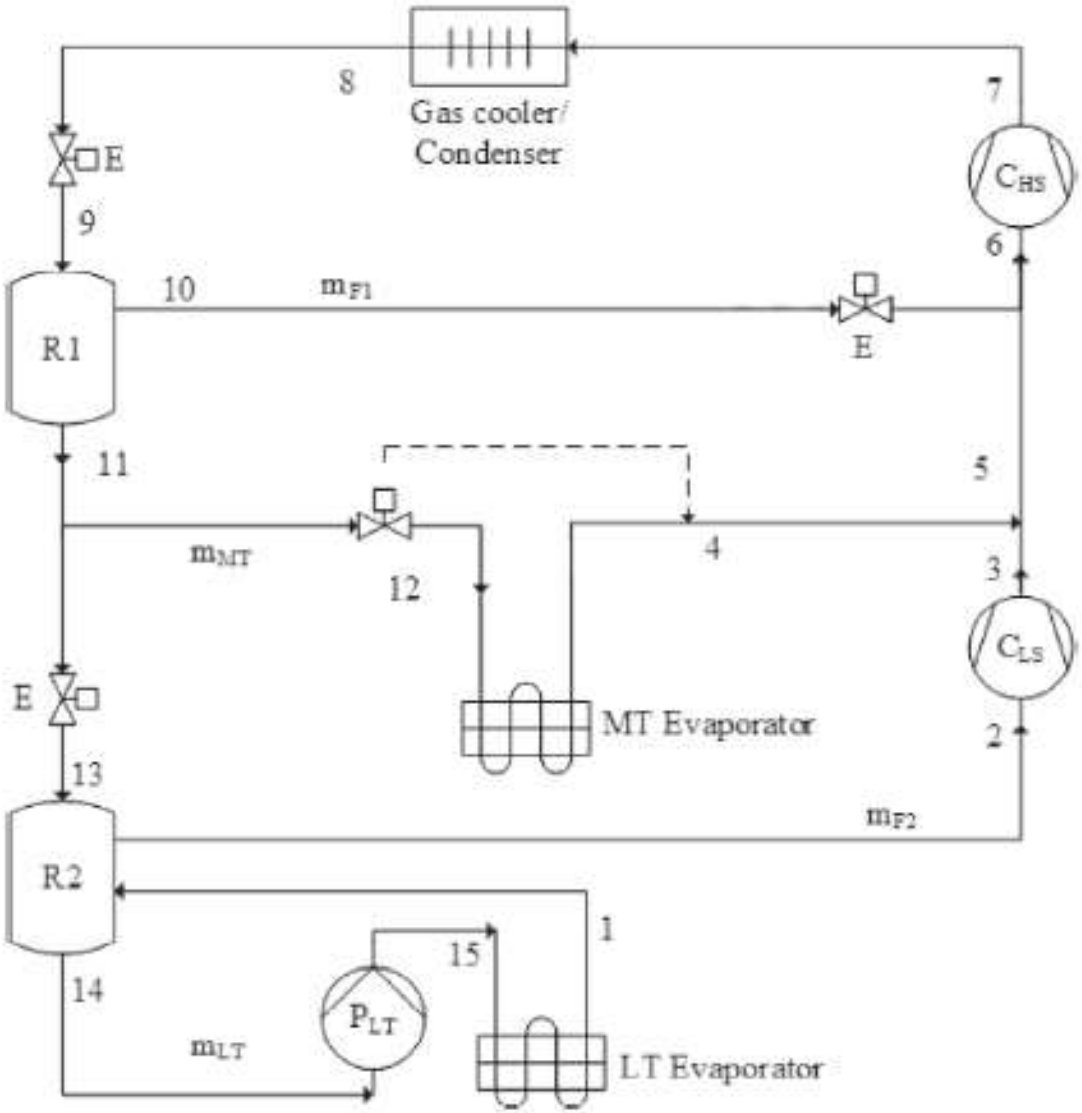


Fig.: CO2 booster system with flooded LT evaporator (BC3).

Ref.: N. Purohit et. al.

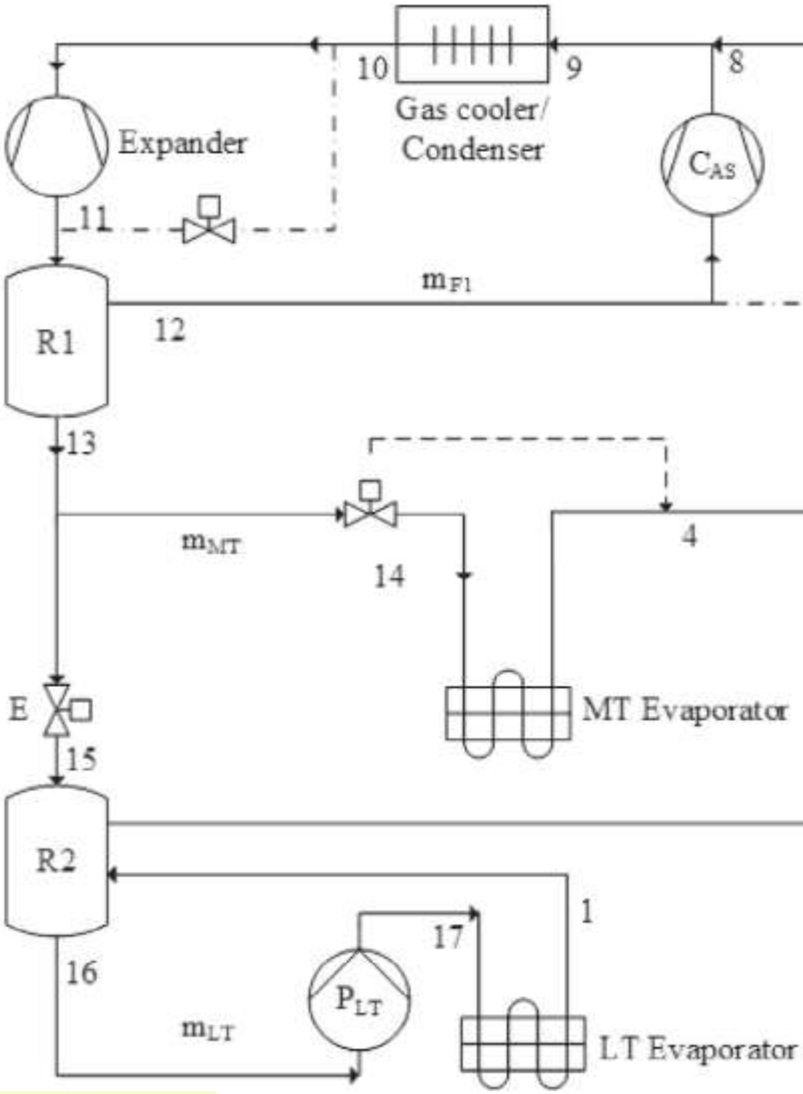


Fig.: CO2 booster system with parallel compression along with flooded LT evaporator and work recovery expander (BC5).

Ref.: N. Purohit et. al.

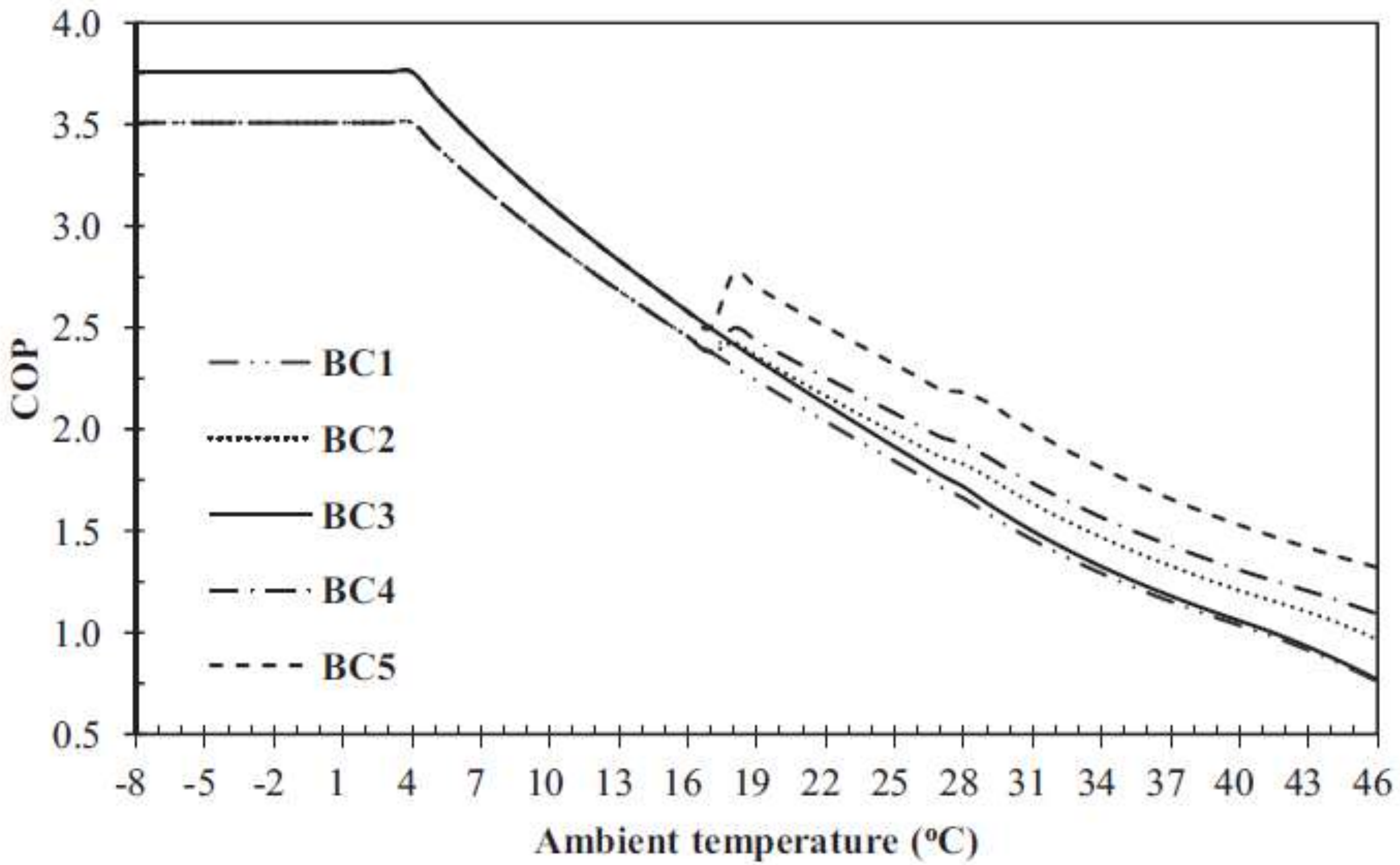


Fig. : COP of the investigated systems at various ambient temperatures.

Ref.: N. Purohit et. al.

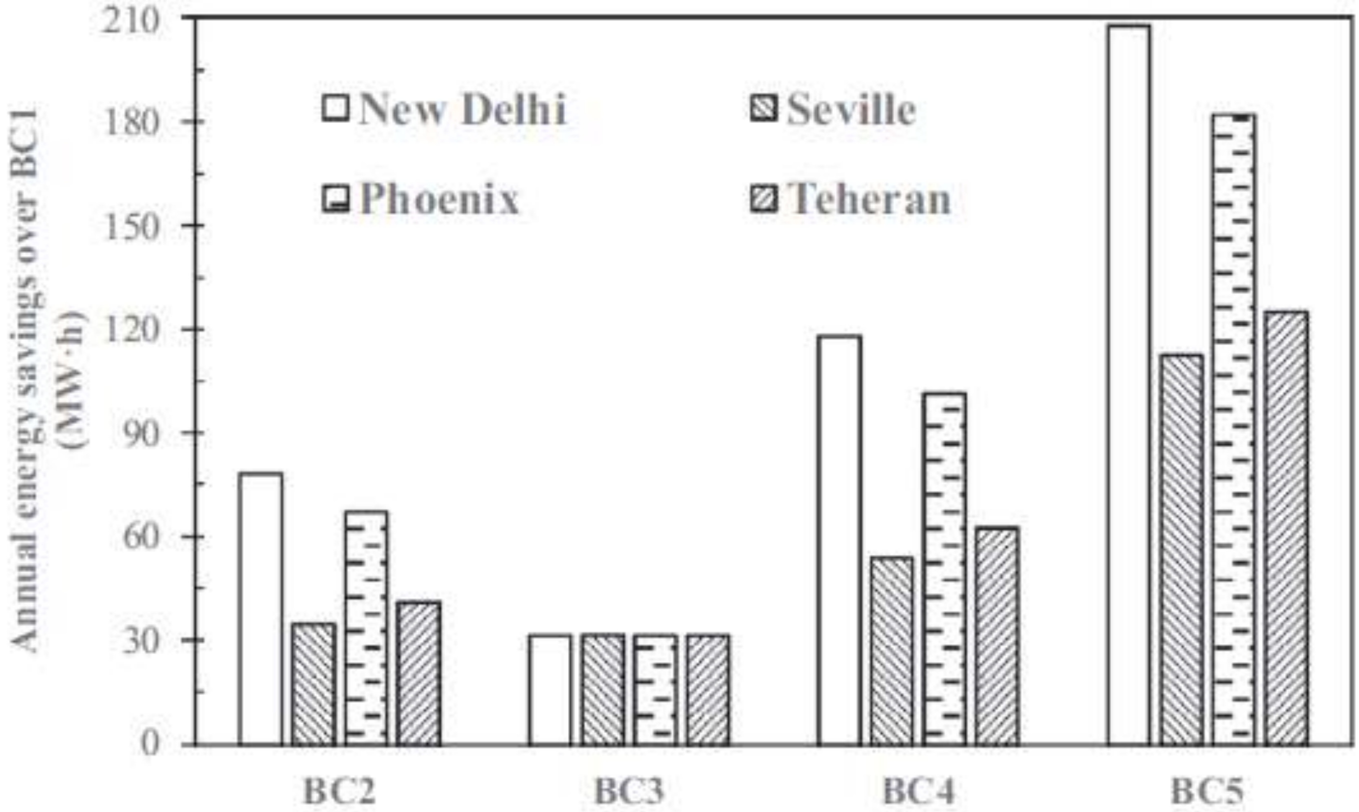


Fig. : Annual energy savings over and above BC1 for systems investigated.

BC5 followed by BC4, BC3 and BC2 are found to be better solution over BC1.

Ref.: N. Purohit et. al.

CO_2 Trans-critical refrigeration plant with dedicated mechanical Subcooling.

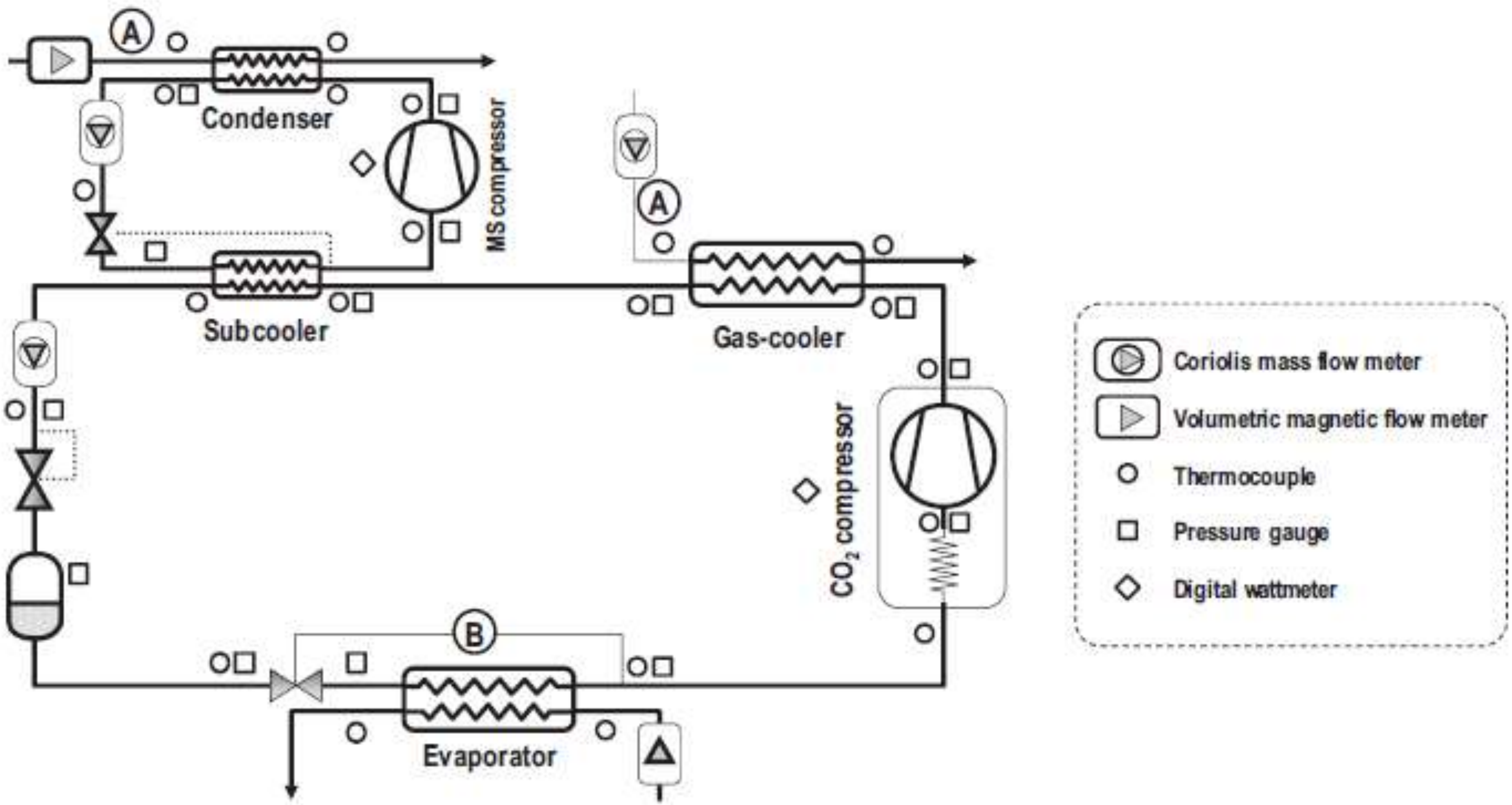


Fig: Schematic diagram of CO2 transcritical refrigeration plant with dedicated mechanical subcooling.

Ref.: R. Llopis et. al.

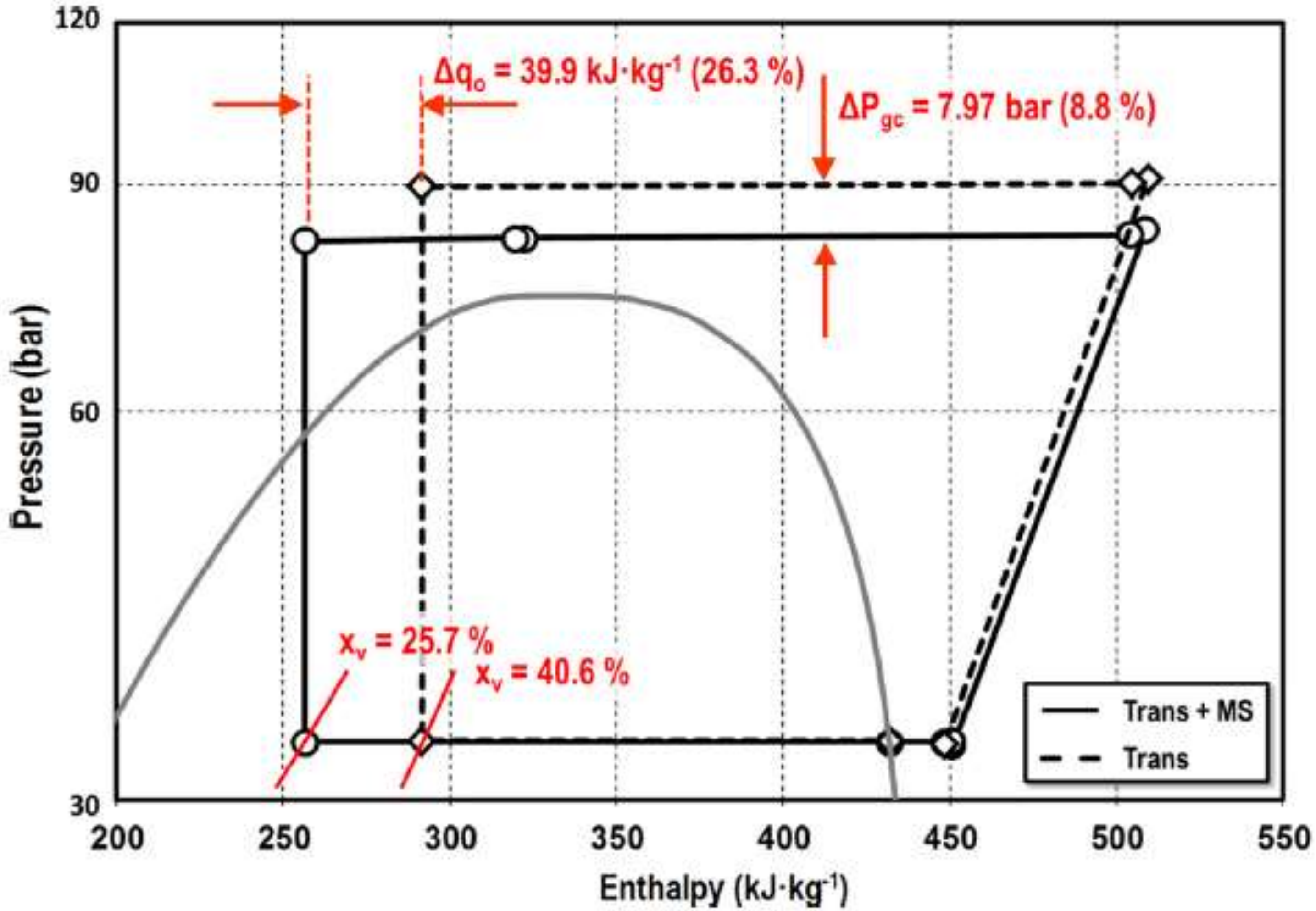


Fig.: CO2 pressure–enthalpy diagram with and without MS at TO = 0.0 °C, Tw,in = 30.2 °C.

Ref.: R. Llopis et. al.

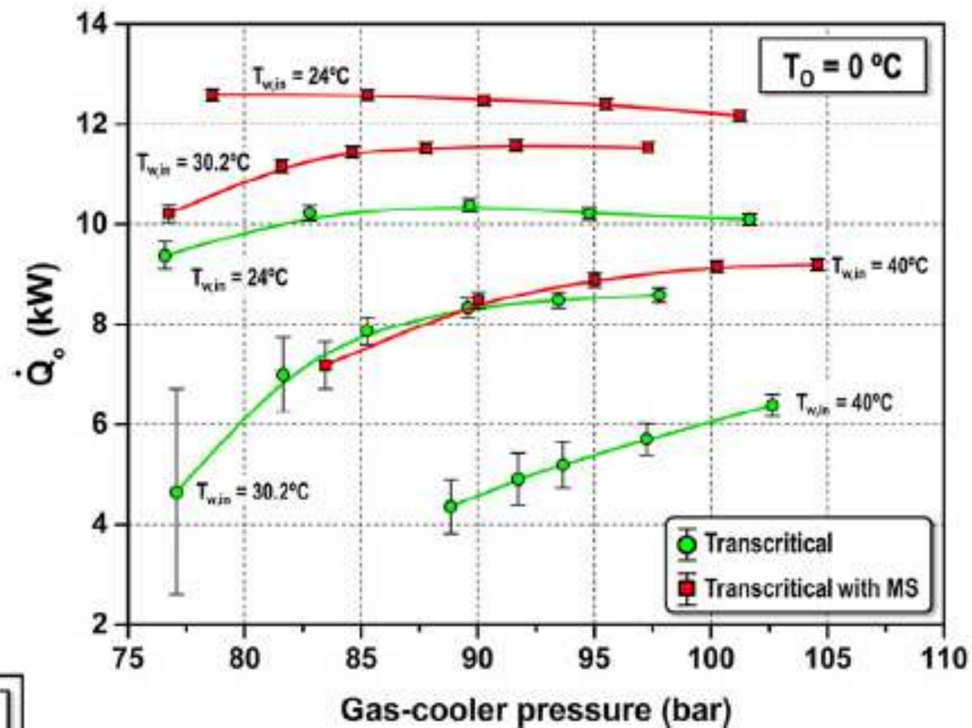


Fig. : Cooling capacity with and without MS at To = 0.0 °C.

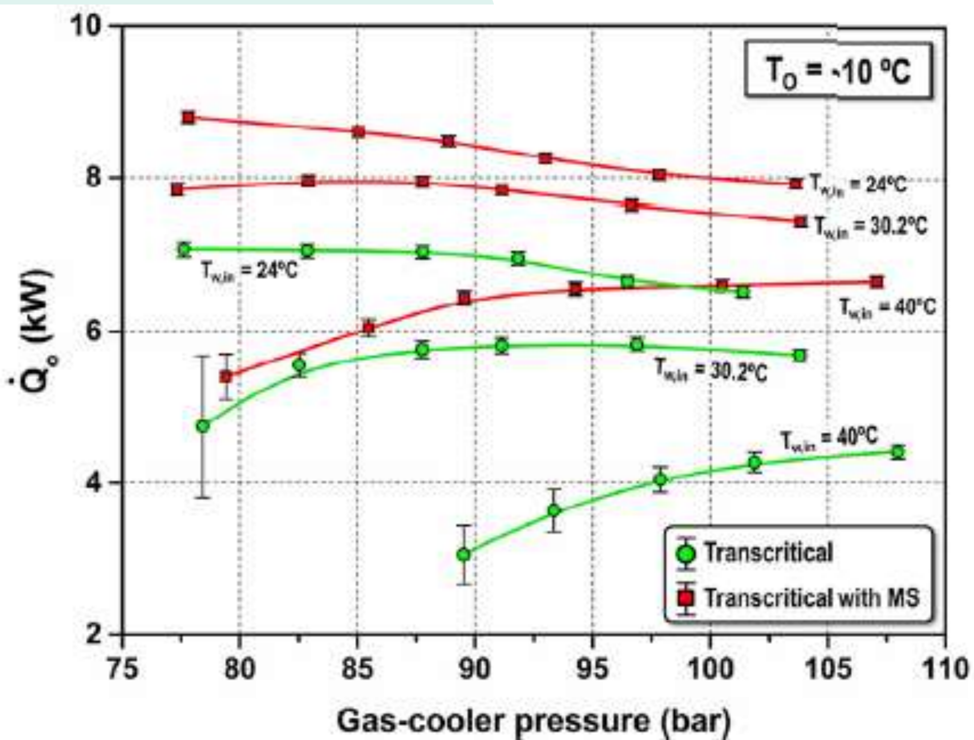


Fig: Cooling capacity with and without MS at To = −10.0 °C.

Ref.: R. Llopis et. al.

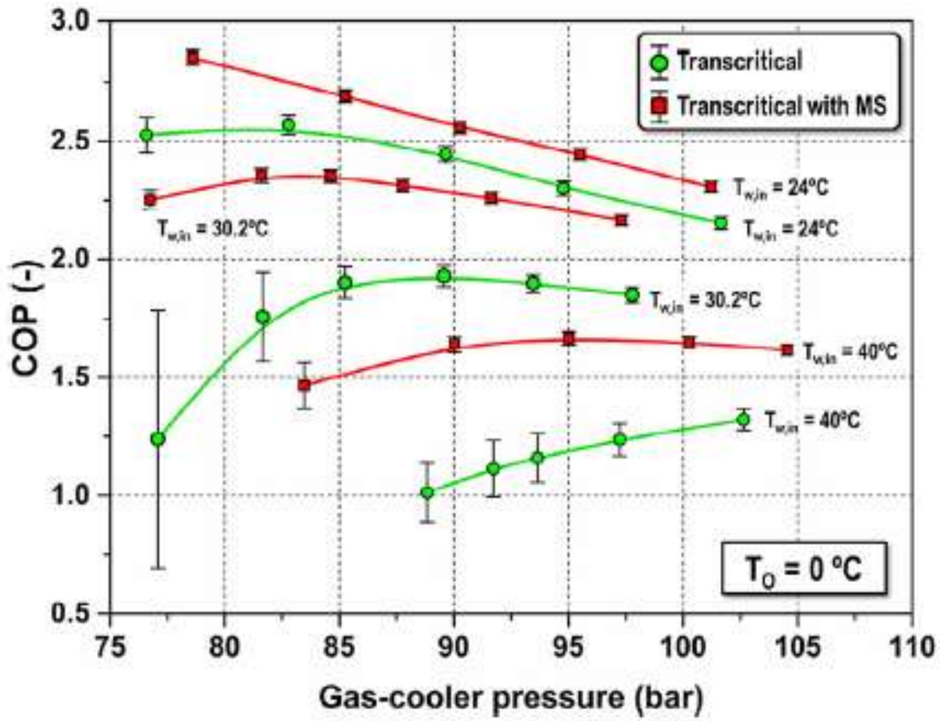


Fig. 19: COP with and without MS at TO = 0.0 °C.

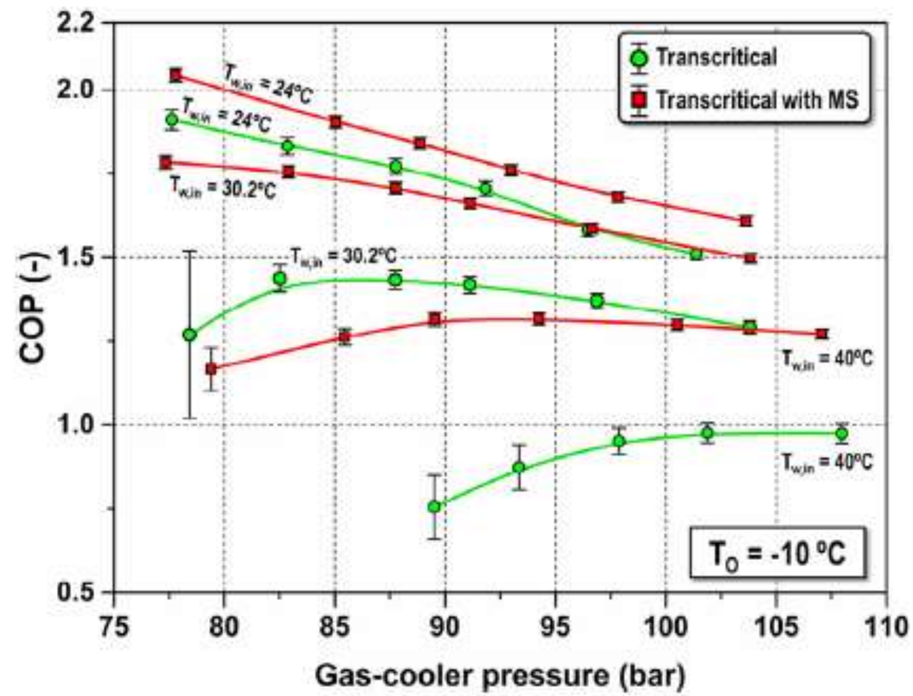


Fig. : COP with and without MS at TO = −10.0 °C.

Ref.: R. Llopis et. al.

Conclusions

- ✓ CO_2 may be consider as an ecologically safe and natural refrigerant for the next generation of HVAC industries.
- ✓ It can also be considered as a utilization of captured CO2 from the different sources.
- ✓ There are challenges and opportunities associated with the CO_2 refrigeration system, therefore, many research groups are actively working on this systems to make it feasible.
- ✓ Still many more application of CO_2 as refrigerant is to be explored in future for Indian HVAC industries.

References

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