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Effect of inter-stage pressure on the performance of a two stage refrigeration cycle using inter cooler

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Abstract

Effect of inter-stage pressure on the performance of a two stage refrigeration cycle using inter cooler is studied based on thermodynamic modelling. Six common refrigerants are selected for the analyses. These are R134a, R22 and R143a as synthetic refrigerants and propane, carbon dioxide and nitrous oxide as natural refrigerants. The designed input range is -50°C to -30°C for evaporator temperature and 40°C to 60°C for heat rejection temperature. Three classical relations for estimating inter-stage pressure in a two stage refrigeration system are selected and the performance is evaluated against optimized inter-stage pressure corresponding to the best COP. Results show that for trans-critical cycles, the deviation of optimized inter-stage pressure with the classical ones is considerable, while for sub-critical cycles, COP is very less sensitive to inter-stage pressure. Further, comprehensive analysis of CO_2 based trans-critical refrigeration system is presented for a wider range covering -50°C to 10°C evaporation temperature and 35°C to 60°C gas cooler outlet temperature. A correlation for estimating optimum inter-stage and gas cooler pressure for the same is also formulated. With gradual increase in focus towards adoption of natural refrigerants like CO_2, the effect of inter stage pressure is expected to be an important consideration in warmer climatic condition.

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Keywords: Two stage cycle; Inter-stage pressure ;Trans-critical; COP; Inter cooler.

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Nomenclature

$Pevap$	Evaporator pressure (kPa)	η	Efficiency of compressor
Pg	Condenser/Gas cooler pressure (kPa)	e	Effectiveness of inter cooler
$Tevap$	Evaporator temperature (^oC)	RE	Refrigeration effect ($KJ \cdot Kg^{-1}$)
Tg	Condenser/Gas cooler outlet temperature (^oC)	COP	Coefficient of performance
Ts	Intermediate temperature (^oC)	h	Specific enthalpy ($KJ \cdot Kg^{-1}$)
$Pint$	Inter stage Pressure (kPa)		
LP	Low Pressure	**Subscripts**	
WD	Work required by compressor ($KJ \cdot Kg^{-1}$)	i	isentropic
HP	High Pressure		
To	Ambient temperature (^oC)		

1. Introduction

The performance of a single stage vapour compression cycle deteriorates at high heat rejection and low evaporation temperatures. Classically this is overcome by employing multi staging. One of the options is to utilize inter cooling using external fluid between the compression stages to reduce the specific volumes and the discharge temperatures, which as a consequence reduces the work input to the compressor. Selection of the inter-stage pressure is crucial for enhancing the performance of such systems. A few thumb rules exist for choosing approximately the right inter-stage pressure for the subcritical systems [1]. However, such relations do not hold good for trans-critical cycles [2].

Natural refrigerants like CO_2 & N_2O has low critical temperature (just above 30^oC) and such cycles need to be run as trans-critical, in warm climatic conditions. Moreover, natural refrigerants such as air, water, ammonia, carbon dioxide, nitrous oxide, isobutene, propane etc. are ecologically safer, have zero ODP and low GWP and are, therefore, gaining importance [3, 4]. Both synthetic refrigerants (R134a, R22 and R143a) and natural refrigerants (propane, CO_2 and N_2O) are chosen for the analysis. Some salient properties of selected refrigerant are listed in Table 1. Among the chosen natural refrigerants, CO_2 is in focus for many researchers. This may be attributed to the many favourable properties of CO_2.

Table1. Properties of refrigerants

Refrigerant	Type	Critical Temperature ($^o C$)	Critical Pressure (MPa)	ODP	GWP
R134a	Artificial	101.06	4.05	0	1300
R22	Artificial	96.14	4.99	0.005	1700
R143a	Artificial	72.70	3.76	0	4300
Propane	Natural	96.74	4.25	0	3
Carbon Dioxide	Natural	31.1	7.37	0	1
Nitrous Oxide	Natural	36.37	7.24	0	310

In this paper, the effect of inter-stage pressure on the performance of a two stage refrigeration cycle is investigated for selected refrigerants which operates in sub and trans-critical cycle. The system performance is evaluated over a range of condensing/gas cooler temperature ($40\,^o C$ to $60\,^o C$) and evaporator temperature ($-50\,^o C$ to $-30^o C$). Further, finding from our study that trans-critical cycle is more sensitive with respect to inter- stage pressure and that CO_2 as a refrigerant is gaining importance worldwide, the same is studied in more detail. Various other operating parameters like inter-stage pressure, gas cooler pressure and compressor discharge temperature for both stages are investigated thoroughly to see their effect on system COP. Finally, two correlations for estimating optimum gas cooler and inter-stage pressure for the tested range of evaporators (-50^oC to 10^oC) and gas cooler outlet temperatures (35^oC to 60^oC) are presented.