DETERMINATION OF OPTIMUM INTER-STAGE PRESSURE OF MULTI-STAGE VAPOUR COMPRESSION REFRIGERATION SYSTEM WITH ISOBUTANE R-600A

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ABSTRACT

The drawbacks of high discharge temperatures related with single stage refrigeration cycles can be overcome by accepting multi-stage compression with inter-cooling between the stages. This is also helps to improve the overall volumetric efficiency and power saving. This paper also considers minimum work of compression and minimum energy losses during inter-stage and gas cooling for identifying inter-stage pressure. This article present a detailed analysis, that is based on experimental data, of the multi stage working conditions of a two-stage vapour compression refrigeration system equipped with a compound compressor, which is operates with the most typical inter-stage configurations in medium and low capacity commercial refrigeration applications. The experimental analysis is performed by two methods, approximate as well as exact, and evaporating and condensing temperature range between −20°C to +20°C, using Isobutane R-600a as a refrigerant. Optimum inter-stage working temperature, pressure and COP are obtained in these tests.

Keywords: *Isobutane, Vapor compression Refrigeration, Multi-stage system*

1. Introduction

The worldwide excitement against global warming and control of greenhouse gas emissions, perhaps, impacts from the refrigeration and air conditioning sector as strong as it does for the power generation industry. This is reasonable because, for example, even though supermarket refrigeration donates to only about 3–4% of primary energy consumption, its involvement to global warming is much greater due to direct emissions of refrigerants from refrigeration systems.

A vapour compression refrigeration is an improved air refrigeration system in which a suitable working substance termed as refrigerant is used. It condenses and evaporates at temperature and pressure closed to the atmospheric condition. The refrigerants usually used for this purpose are Ammonia (NH_3), Carbon dioxide (CO_2), and Sulphur dioxide (SO_2). The refrigerant used, does not leaved the system, but is circulated throughout and evaporating in evaporate the refrigerant absorbs its latent heat from the brine, (salt water) which is used for circulating it around the cold chamber. While condensing, it gives out its latent heat to the circulating water of cooler. The vapour compression refrigeration system is therefore a latent heat pump, as it pumps its latent heat from the brine and delivers it to the cooler.

The vapour compression refrigeration system is now days used for all purpose refrigeration. It is generally used for all industrial purpose from a small domestic refrigerator to a big Air Conditioning plant.

Single stage system means there is a single component used in vapour compression system like as a single

- Compressor
- Condenser (heat rejection device)
- Capillary tube (expansion device)
- Evaporator(heat transfer device)

The Single stage vapour compression system has mainly four component listed above. It has been shown that the C.O.P. of air refrigeration cycle is quite low. Since heat transfer is not reversible. Therefore to achieve C.O.P. of the refrigeration system closes to ideal value. The phase change cycle is the suitable choice. Phase change cycle means if the refrigerant under goes a change of phases during the cyclic process it is said to be phase change cycle.

In vapour compression system the used refrigerant are Ammonia (NH_3), Carbon dioxide (CO_2), Sulphur dioxide (SO_2) or Halocarbon refrigerant are used which are easily evaporative and easily condensed vapour compression refrigeration system is now a day’s used for all purpose refrigeration.

Manoar Prasad developed a new formula to obtain the optimum inter-stage pressure for R-12 refrigeration system with a flash intercooler. He developed a graphical method for analyzing a two-stage refrigeration system based on the iterative scheme for the evaluation of optimum inter-stage pressure [1981] . Prasad et al studied two stage ammonia refrigeration system with intercooler for analyzing optimum intermediate pressure [1983].

Dan Manole reviewed the current practices in selecting the inter-stage pressure and temperature values in two stage refrigeration system and then pointed out the potential to further increase the system efficiency [2006]. Arora, and Kaushik conducted exergy analysis of two-stage vapour compression refrigeration (VCR) system for evaluating optimum inter-stage temperature (pressure) for refrigerants HCFC22, R410A and R717[2009]

1.1 Mechanism of Single Stage Vapour Compression Refrigeration System

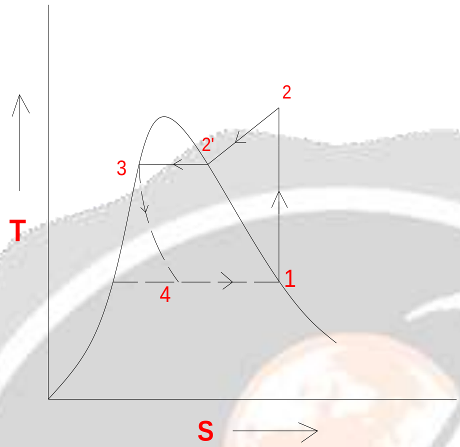


Figure-1: T-S Diagram of Vapour Compression Refrigeration System

- Process 1-2 (Isentropic compression): In this process vapour refrigerant is compressed in to the compressor up to 2, isentropically.
- Process 2-3 (Heat rejection process): In this process superheated refrigerant is condensed in two stage superheated to saturated vapour and saturated vapour to saturated liquid.
- Process 3-4 (Isentropic expansion): In this process liquid refrigerant is throttled to low pressure and low temperature liquid refrigerant. In this process enthalpy at point 3&4 will be same.
- Process 4-1: (Heat addition process): In this process heat transfer take place low pressure and low temperature liquid refrigerant converted into vapour refrigerant.

1.1.1 Advantages of multistage over single stage vapour compression system:

The advantages of multistage system over single stage system are as follows:

a) Energy saving: In case of multistage vapour compression system is reduced due to cooling of compressed gas before being compressor in the succeeding stage.

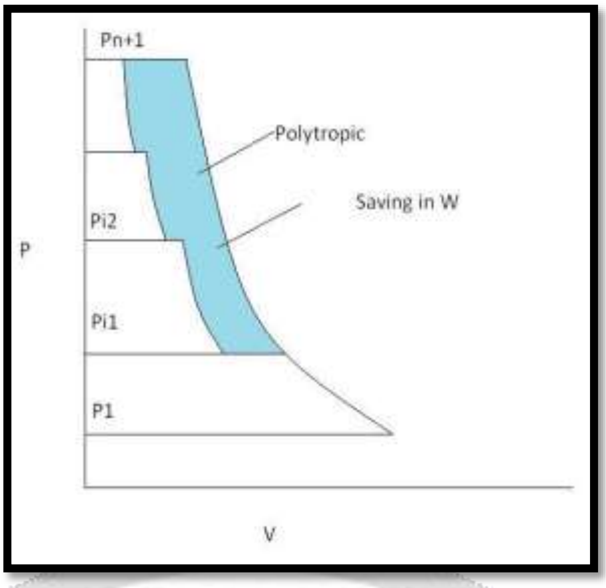


Figure-2: P-V Diagram of Multi Stage Vapour Compression Refrigeration System

It improve volumetric efficiency for a given pressure ratio.

b) Saving of material: If single stage system is used the cylinder wall thickness.

$t = P_2d/2hs$

Where, d=diameter of cylinder

P_2 = upper pressure limit

hs = hoop stress

For multistage the diameterof the high pressure cylinder will be much smaller diameter of single stage cylinder.

$d_{HP} << d$

$t_{HP}=P_2*d_{HP}/2hs << t$

c) Leakage across piston: Since the pressure difference is (p2-p1) in a single stage is greater than (pi1-p1) or (p2-piN) in multistage the leakage in the letter is accepted to be much less.

d) Temperature reductiondue to multistage: The compressor pressure p1 at the end of one stage is less than that of p2this gives the temperature.

Ti1=T1(pi1/p1)^(n-1/n) <t1(p2/p1)^(n-1/n)

e) Flash chamber: when the high pressure liquid refrigerant from the condenser pass through the expansion valve some part of liquid refrigerant evaporates on the expansion valve. This partial evaporation of liquid refrigerant is called flash or flashing. The flash chamber is an insulated container and it separates the liquid and vapour due to centrifugal action.

1.2 Multistage Vapour compression system

The simple vapour compression refrigeration system in which the low pressure vapour refrigerant from evaporator is compressed in asingle stage (single compressor) and then deliver to condenser at a high pressure but some time the vapour refrigerant is required to be deliver at avery high pressure as in the case if low temperature refrigerating system. In such cases either we should compress the refrigerant by employing a single stage compressor with a high pressure ratio between condensers or evaporatoror compressor it in two or more compressor is called multistage compression.

1.2.1 Optimum Interstage pressure:

COP of a refrigeration system is improved if multistage isemployed. The magnitude of betterment is controlled by the number of stages and the subsequent intermediate pressures, these results from the reduction in the requirement of compression work.

If p1 and pN+1 are lower and upper pressure limits of an N-stage compression system employing perfect gas as theworking medium, the intermediate pressures p2,p3,…….,pN are related by,

(p1/ p2) = (p2/ p3) = (p3/p4)=…………(pN/pN+1)= (p1/pN+1)^(1/N).

1.2.2 Effect of pressure change on COP:

1. Evaporator pressure decrease by p1,p2 remaining same. The decrease in pressure p1 causes the state 5-1shifted to 5'-1'. The numerical values show that the change in refrigeration effect is not very large while the work input to compressor to increase. The cop & capacity is lower compared to normal cycle
2. Condenser pressure increase: increase in p2 by p, p1 remaining same. In this situation the refrigerating effect is reduce by an area of T-S diagram under the process 5-5"on the other hand the compressor work is increase by an area 2-2"-4'-4. Further

the work 1/p has been increased by an amount much less than that in the proceeding case the C.O.P. in this case is accepted to be higher than that in the former case.

3. In this case when p1 decreases and p2 increases the capacity and C.O.P. are reduced compare to normal cycle.

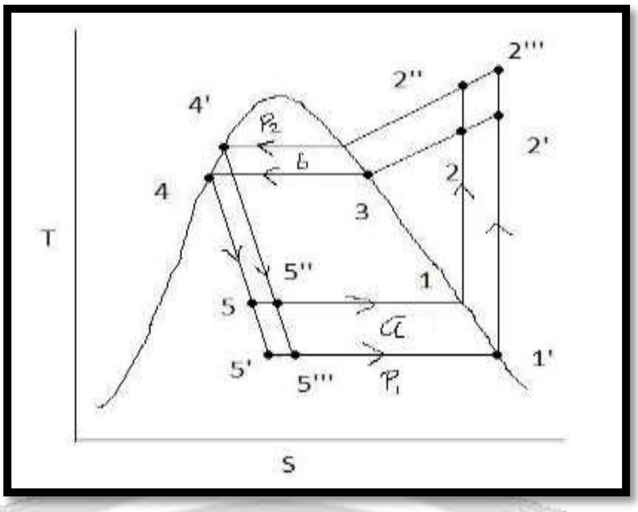


Figure-3: Effect of Suction and Discharge Pressure on COP of VCR System

a) For temperature in the range of -46°C to -101°C, cascade systems are preferable.
b) In this system, two independent systems combined together in such a way that the evaporator of high temperature system becomes the condenser of low temperature system, but the working media of two system are separated from each other.
c) The intermediate heat exchangers are also called as cascade heat exchanger or condenser.

2. ISO-BUTANE (R-600a):

Isobutane, also known as methyl propane, is an isomer of butane. It is the simplest alkane with a tertiary carbon. Concerns with depletion of the ozone layer by Freon gases have led to increased use of Isobutane as a gas for refrigeration systems, especially in domestic refrigerators and freezers, and as a propellant in aerosol sprays. When used as a refrigerant or a propellant, isobutane is also known as R-600a. Some portable camp stoves use a mixture of isobutane with propane, usually 80:20. Isobutane is used as a feedstock in the petrochemical industry, for example in the synthesis of isooctane. Its UN number (for hazardous substances see shipping) is UN 1969. Isobutane is the R group for the amino acid leucine.

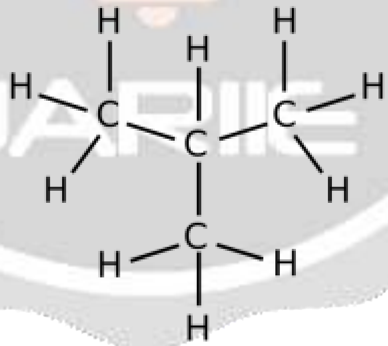


Figure -4: Chemical formula of Isobutane.

2.1 Exact and Approximate methods:

2.1.1 Exact Analysis: In this method the superheat range of multistage compression system is considered.

S2=S3+Cpln (T2/T3)
h2=h3+Cp(T2 -T3)
S4=S4’+Cpln (T4/T4’)
m3=(h2-h7)/(h3-h5)
w=(h2-h1)+m3(h4-h3)
cop=(h1-h7)/w

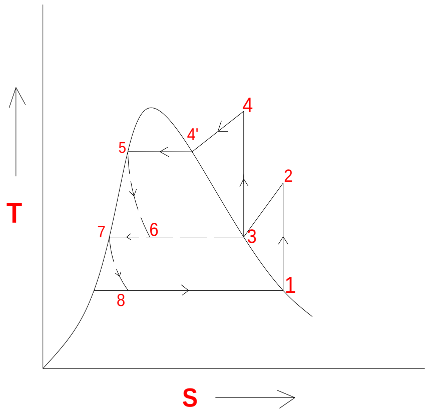


Figure-5: T-S Diagram of Multi-Stage VCR System for Exact Analysis

2.1.2 Approximate Method: In this method superheat range of multistage compression system ignored during analysis.

h2=Ti(s1-s7)+h7
h4'=T5(s3-s7)+h5
m3=(h2-h7)/(h3-h5)
w=(h2-h1)+m3(h4-h3)
COP=(h1-h7)/w

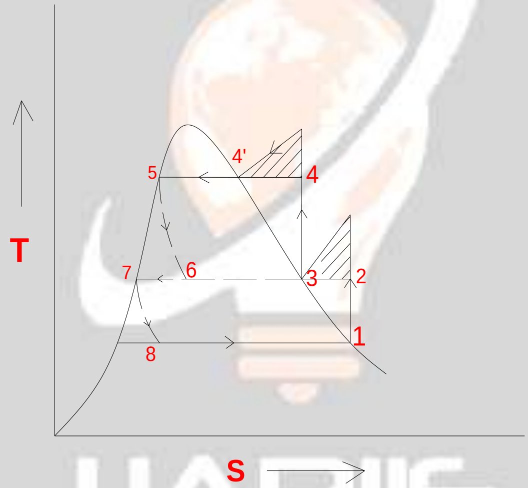


Figure-6: T-S Diagram of Multi-Stage VCR System for Approximate Analysis

Table -1: At Various Temperature ranges, COP and Intermediate Pressure of Multi-Stage VCR System (Exact Analysis)

EXACT ANALYSIS OF TEMP. RANGE (-20 to 20ºc)					
T3 (ºC)	**P (bar)**	**W (kj/kg)**	**Qc (kj/kg)**	**COP**	**m_3**
-18	0.78	69.6186	369.8209	5.3121	1.3108
-16	0.85	68.2144	365.3767	5.3563	1.2934
-14	0.92	66.887	360.9155	5.3959	1.2761
-12	1	65.6045	356.4292	5.433	1.2589
-10	1.1	64.3956	351.9283	5.4651	1.2419
-8	1.2	63.2279	347.4056	5.4945	1.2249
-6	1.3	62.0999	342.8597	5.5211	1.208
-4	1.4	61.0697	338.2956	5.5395	1.1913

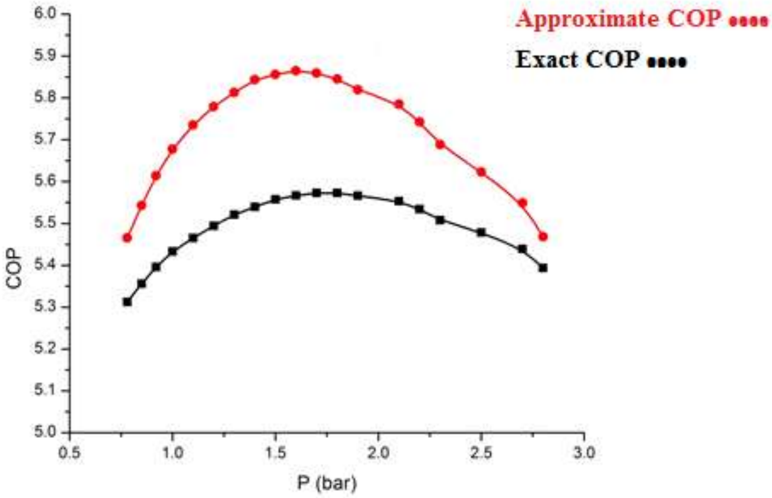
-2	1.5	60.0463	333.7073	5.5575	1.1746
0	1.6	59.1174	329.0947	5.5668	1.158
2	**1.7**	**58.2221**	**324.4659**	**5.5729**	**1.1416**
4	1.8	57.3883	319.8077	5.5727	1.1252
6	1.9	56.6147	315.1287	5.5662	1.1089
8	2.1	55.9001	310.43	5.5533	1.0928
10	2.2	55.2427	305.7075	5.5339	1.0767
12	2.3	54.6415	300.9599	5.5079	1.0608
14	2.5	54.0655	296.187	5.4783	1.0484
16	2.7	53.5725	291.3915	5.4392	1.0299
18	2.8	53.1316	286.5759	5.3937	1.0133

Table-2: At Various Temperature ranges, COP and Intermediate Pressure of Multi-Stage VCR System (Approximate Analysis)

APPRO. ANALY. TEMP. RANGE (-20 to 20ºc)				
Ti(ºC)	P(bar)	m3	W(kJ/kg)	COP
-18	0.78	1.3101	67.662	5.4657
-16	0.85	1.2927	65.9159	5.5431
-14	0.92	1.2754	64.2873	5.6141
-12	1	1.2583	62.7802	5.6775
10	1.1	1.2411	61.3578	5.7357
-8	1.2	1.2242	60.1116	5.7793
-6	1.3	1.2074	58.9803	5.8131
-4	1.4	1.1906	57.8931	5.8434
-2	1.5	1.174	56.9813	5.8564
0	**1.6**	**1.157**	**56.1099**	**5.8652**
2	1.7	1.141	55.3761	5.8593
4	1.8	1.1246	54.7139	5.8451
6	1.9	1.1084	54.1511	5.8195
8	2.1	1.0922	53.6587	5.7853
10	2.2	1.0761	53.2347	5.7426
12	2.3	1.0602	52.9079	5.6884
14	2.5	1.0443	52.6775	5.6227
16	2.7	1.0285	52.5105	5.5492
18	2.8	1.0128	52.4079	5.4681

3. Results

Following graph is shows that the differences between Exact COP and Approximate COP for a given temperature range -20^{o}c to +20 ^{o}c.



3.1 The decision as to which refrigerant should be used in a refrigerating system is based on the major criteria of safety, costs and protection of the environment. But against the scenario of constantly increasing energy prices, the energy consumption of a system also plays an increasingly important role. Ideally, the chosen refrigerant should have excellent thermodynamic properties, high chemical stability and good physical characteristics.

3.2 Furthermore, it should have no or only a negligible impact on the environment while also being in expensive and available worldwide.

4. References

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