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Calculation of Coefficient of Performance for Refrigerant 404A

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***Abstract* - A refrigerant is a substance used to refrigeration system to maintain a constant temperature in different environmental chambers. In the present study refrigerant 404A is chosen as a refrigerant. The coefficient of performance is calculated for refrigerant 404A for the different conditions of ideal and real conditions. The aim of the project is to calculate the coefficient of performance of the given refrigerant 404A in excel sheet and to draw corresponding Pressure – enthalpy diagram for varying pressure and temperature of refrigerant 404A. The objective work is to The COP of refrigerant is measured theoretically for different conditions and draw P-h diagram and the relation will be formulated to calculate heat load, work input COP for different conditions.**

***keywords* - COP, refrigerant, heat load, work input.**

1. Introduction

The coefficient of performance or COP of a heat pump, refrigerator or air conditioning system is a ratio of useful heating or cooling provided to work required. Refrigeration is a process of eliminating heat from a low temperature reservoir and transferring it to a high temperature reservoir. The work of heat transfer in traditionally driven by mechanical means, but can also be driven by heat, magnetism, electricity, laser or other means.

Refrigeration has many applications including, but limited to household refrigerators, cryogenics, industrial freezers, and air condition.

[1] Vapour compression refrigeration in which the refrigerant undergoes phase changed, in one of the many refrigeration cycle and is the most broadly used method for refrigeration and air conditioning. $COP_R = \frac{Q_L}{W_{net,in}} = \frac{h_1 - h_4}{h_2 - h_1}$

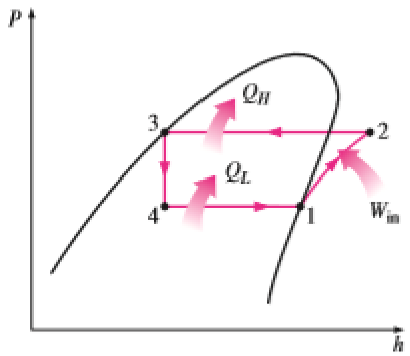

Figure 1.1:-Vapour compression refrigeration cycle

Another form of refrigeration that becomes economically attractive when there is a source of inexpensive thermal energy at temperature of 100 to 200ºC is absorption refrigeration.

$$COP_{absorption} = \frac{Desired\ output}{Required\ input} = \frac{Q_L}{Q_{gen}}$$

XU SHUXUEet al.(2013) [3],A thermodynamically analytical model on the two-stage compression heat pump system with vapor injection was derived. The optimal volume ratio of the high-pressure cylinder to the low pressure one has been discussed under both cooling and heating conditions. Based on the above research, the sample was developed and its experimental setup established. A comprehensive experiment for the prototype has been conducted, and the results show that, compared with the single-stage compression heat pump system, the cooling capacity and cooling COP can increase 5%-15% and 10-12%, respectively. Also, the heating capacity with the evaporating temperature ranging from 0.3 to 3ºC is 92-95% of that under the rate condition with the evaporating temperature of 7ºC, and 58% when the evaporation temperature is between 28ºC and 24ºC.

XIAOUI SHE et al. (2013) [4], proposed a new sub-cooling method for vapor compression refrigeration system dependent on expansion power recovery. To drive a compressor of sub-cooling cycle, expander output power is employed. Liquid refrigerant is sub-cooled by using evaporative cooler. This makes a hybrid refrigerant system. Analysis is to done by using different refrigerants and results shows that hybrid vapor compression refrigeration have more (C.O.P) than conventional vapor compression refrigeration system.

E HAJIDAVALLOO et al. [5] , in this paper to reduce the challenging problem of increase of coefficient of performance of air-conditioning system evaporatively cooled air condenser is used instead of air cooled condenser. Experimental results showthat evaporativecondenser has better performance than air cooled condenser.

3. FORMULATION AND CALCULATION

Calculation of temperature at given pressure range (0.511 to 2.041 bar) by solving below table using 3-degree curve fitting:

Table 4.5: Temperature-pressure table

T°C	P bar	P*T	P^2	P^2*T	P^3	P^3*T	P^4	P^5	P^6
-59	0.511	-30.149	0.26112	-15.406	0.13343	-7.87254	0.06818	0.03484	0.01780
-58	0.54	-31.32	0.29160	-16.913	0.15746	-9.13291	0.08503	0.04592	0.02479
-57	0.57	-32.49	0.32490	-18.519	0.18519	-10.55600	0.10556	0.06017	0.03430
-56	0.602	-33.712	0.36240	-20.295	0.21817	-12.21736	0.13134	0.07906	0.04760
-55	0.634	-34.87	0.40196	-22.108	0.25484	-14.01621	0.16157	0.10243	0.06494
-54	0.669	-36.126	0.44756	-24.168	0.29942	-16.16859	0.20031	0.13401	0.08965
-53	0.705	-37.365	0.49703	-26.342	0.35040	-18.57134	0.24703	0.17416	0.12278
-52	0.742	-38.584	0.55056	-28.629	0.40852	-21.24296	0.30312	0.22492	0.16689
-51	0.781	-39.831	0.60996	-31.108	0.47638	-24.29536	0.37205	0.29057	0.22694
-50	0.821	-41.05	0.67404	-33.702	0.55339	-27.66938	0.45433	0.37301	0.30624
-49	0.864	-42.336	0.74650	-36.578	0.64497	-31.60365	0.55726	0.48147	0.41599
-48	0.907	-43.536	0.82265	-39.487	0.74614	-35.81485	0.67675	0.61381	0.55673
-47	0.953	-44.791	0.90821	-42.686	0.86552	-40.67959	0.82484	0.78608	0.74913
-46	1	-46	1.00000	-46	1.00000	-46.00000	1.00000	1	1.00000
-45	1.049	-47.205	1.10040	-49.518	1.15432	-51.94443	1.21088	1.27022	1.33246
-44	1.101	-48.444	1.21220	-53.337	1.33463	-58.72387	1.46943	1.61784	1.78125
-43	1.154	-49.622	1.33172	-57.264	1.53680	-66.08241	1.77347	2.04658	2.36176
-42	1.209	-50.778	1.46168	-61.391	1.76717	-74.22124	2.13651	2.58304	3.12290
-41	1.266	-51.906	1.60276	-65.713	2.02909	-83.19265	2.56883	3.25213	4.11720
-40	1.325	-53	1.75563	-70.225	2.32620	-93.04813	3.08222	4.08394	5.41122
-39	1.386	-54.054	1.92100	-74.919	2.66250	-103.83752	3.69023	5.11465	7.08891
-38	1.449	-55.062	2.09960	-79.785	3.04232	-115.60823	4.40832	6.38766	9.25572
-37	1.515	-56.055	2.29523	-84.923	3.47727	-128.65884	5.26806	7.98111	12.09138
-36	1.583	-56.988	2.50589	-90.212	3.96682	-142.80560	6.27948	9.94042	15.73568
-35	1.653	-57.855	2.73241	-95.634	4.51667	-158.08352	7.46606	12.3414	20.40033
-34	1.726	-58.684	2.97908	-101.29	5.14189	-174.82410	8.87489	15.3181	26.43898
-33	1.801	-59.433	3.24360	-107.04	5.84173	-192.77694	10.52095	18.9482	34.12576
-32	1.878	-60.096	3.52688	-112.86	6.62349	-211.95162	12.43891	23.3603	43.87060
-31	1.958	-60.698	3.83376	-118.85	7.50651	-232.70181	14.69775	28.7782	56.34769
-30	2.041	-61.23	4.16568	-124.97	8.50215	-255.06465	17.35290	35.4173	72.28664
$\sum T$=-1335	$\sum P$= 34.393	$\sum PT$= -1413.3	$\sum P^2$= 45.66599	$\sum P^2 T$= -1749.9	$\sum P^3$= 67.7234	$\sum P^3 T$=- 2459.36628	$\sum P^4$= 108.426	$\sum P^5$= 182.841	$\sum P^6$= 319.592

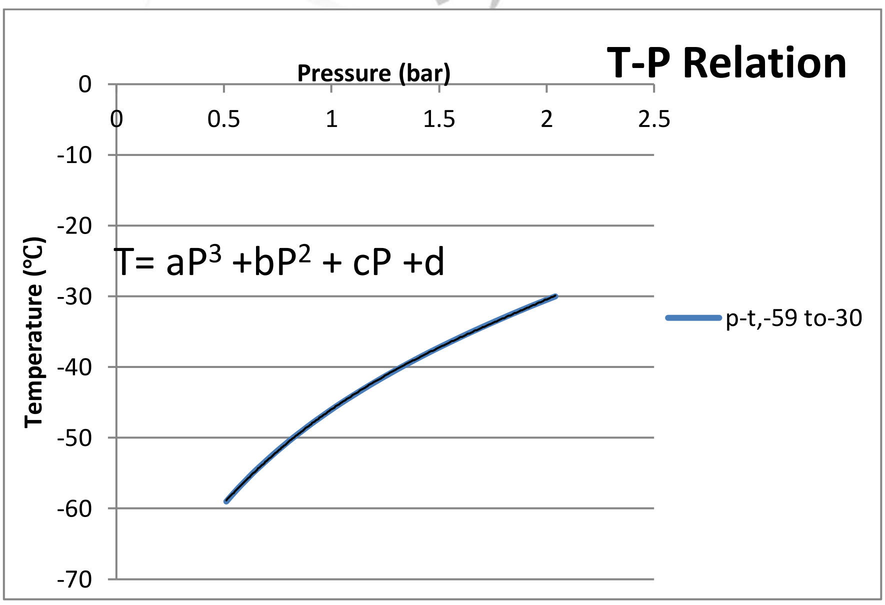

Figure 4.1:Graph of temperature v/s pressure relation (pressure range 0.511 to 2.041 bar)

Normal equation of table 4.5,
T= ap^3+ bP^2 + cP + d
$\sum T$=a$\sum P^3$+b$\sum P^2$+c$\sum P$+nd
$\sum PT$=a$\sum P^4$+b$\sum P^3$+c$\sum P^2$+d$\sum P$
$\sum P^2T$= a$\sum P^5$+b$\sum P^4$+c$\sum P^3$+d$\sum P^2$
$\sum P^3T$= a$\sum P^6$+b$\sum P^5$+c$\sum P^4$+d$\sum P^3$
$T= 3.3967P^3-19.163 P^2 + 49.256 P – 79.466$
Temperature – Enthalpy relation,
To find enthalpy of liquid at given temperature,
$h_l=0.00004 T^3 + 0.0036 T^2 + 1.4072 T + 199.7$

Calculation of entropy at variable temperature range (-85 to -70 ℃) by solving below equation using 2nd degree curve fitting.
Normal equations of table 4.6,
$S_g=aT^2 +bT + c$
$\sum S_g$=a$\sum T^2$ + b$\sum T$ + nc
$\sum T\ S_g$=a$\sum T^3$+b$\sum T^2$+c$\sum T$
$\sum T^2 S_g$= a$\sum T^4$+b$\sum T^3$+c$\sum T^2$
$S_g= -0.0001978 T^2 -0.03323 T + 0.31542$
Calculation of enthalpy of vapor at given temperature and at constant pressure(0.1 bar)
Below table is drawn constant pressure at 0.1 Bar referring to thermodynamic properties table of Refrigerant 404A by DuPont Suva [8].
Normal equations
$h_g=aT^2 +bT + c$
$\sum h_g$=a$\sum T^2$ + b$\sum T$ + nc
$\sum T\ h_g$=a$\sum T^3$+b$\sum T^2$+c$\sum T$
$\sum T^2 h_g$= a$\sum T^4$+b$\sum T^3$+c$\sum T^2$
$h_g= 0.0009 T^2 + 0.8222 T + 377.43$
Calculation of entropy at variable temperature and at constant pressure 0.1 Bar by solving below equation using 2nd degree curve fitting.
Curve fitting: Curve fitting is the process of constructing a curve, or mathematical function that has the best fit to a series of data points, possibly subject to constraints.
Normal equations,
$S_g=dT^2 + eT + f$
$\sum S_g$ = d$\sum T^2$ + e$\sum T$ + f
$\sum T\ S_g$= d$\sum T^3$+e$\sum T^2$+f$\sum T$
$\sum T^2 S_g$= d$\sum T^4$+e$\sum T^3$+f$\sum T^2$
$S_g= -0.000002008 T^2 + 0.003027 T + 1.9982$
To calculate enthalpy(h_g) and entropy (S_g) at given temperature and constant temperature we can refer to above table 4.9 for constant value a, b ,c ,d ,e, f and general equation 4.2.33 and 4.2.34.
$h_g= a T^2 + b T + c$
$S_g= d T^2 + e T + f$

4. Calculation of COP for R-404A
Data given by industry:
An industrial refrigerator with refrigerant 404A as working fluid is used to keep refrigerated space at -38°c by rejecting it's waste heat to cooling water that enters the condenser at 18°c at a rate of 0.2 kg/sec and leaves at 26°c. The refrigerant enters the condenser at 12 bar and 35°c. The inlet state of compressor is 1.2 bar and -45°c. Calculate a) COP ,b) mass flow rate of refrigerant ,c) heat load and d)work input. Compare all the three conditions saturated-isentropic, real condition and isentropic.
Sol^n,
Consider, water cooling system
Heat capacity of water =4.18 kJ/kg-K

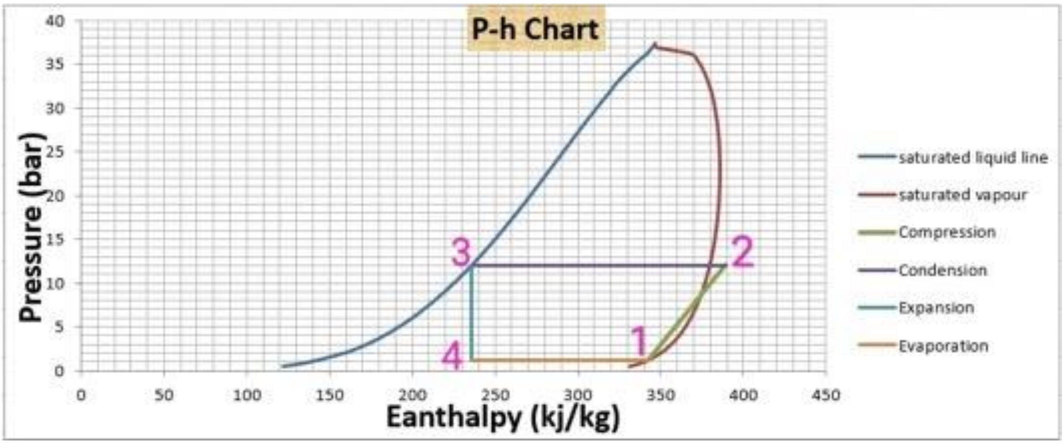

Figure 4.1:P-h chart

Case 1- saturated and isentropic condition

P_1=1.2 bar

P_2=12 bar

From temperature-pressure relation equation corresponding to 1.2 bar pressure

$T_1=3.396P_1^3-19.163P_1^2+49.256P_1-79.466$

$T_1=-42.08^oc$

$S_1=dT_1^2+eT_1+f$

$S_1=-0.000002T_1^2+0.0003T_1+1.7726$

S_1=1.6413kJ/kg-K

$h_1=aT_1^2+bT_1+c$

$h_1=0.0009T_1^2+0.8329T_1+375.33$

h_1=342.45kJ/kg

$S_1=S_2$=1.6413kJ/kg-K

$T_2=114.55S_2^2-70.593S_2-159.54$

$T_2=33.17^oc$

$h_2=aT_2^2+bT_2+c$

$h_2=0.0004T_2^2+0.9736T_2+356.75$

h_2=389.484kJ/kg

we know that pressure at point 2 is equal to point 3

$P_2=P_3$=12 bar

$T_3=0.0084P_3^3-0.3946P_3^2+8.9376P-41.254$

$T_3=23.69^oc$

$h_3=0.00004\ T^3 + 0.0036\ T^2 + 1.4072\ T + 199.7$

h_3=235.589kJ/kg

$h_3=h_4$=235.589kJ/kg

a. COP=$\frac{h_1-h_4}{h_2-h_1}$

   COP=2.27

b. Mass flow rate of refrigerant, $m_R=\frac{m_w(T_{outlet}-T_{inlet})*4.18}{h_2-h_3}$

   $m_R=\frac{0.2(26-18)*4.18}{389.484-235.589}$

   m_R=0.0435 kg/sec

c. Heat load =$m_R(h_1-h_4)$

   Q_l =4.6440kW

d. Work input, $W_{in}=m_R(h_2-h_1)$= 2.044 kW

Similarly calculations are done for the real condition of P_1=1.2 bar, $T_1=-45^oc$, P_2=12 bar, $T_2=35^oc$, $P_2=P_3$ and case 3-isentropic condition

P_1=1.2 bar

$T_1=-45^oc$

P_2=12 bar

5. Conclusion

Below table shows the comparison between all three conditions

Cases / Value by		Industry	Project	% error
Saturation and isentropic	COP	2.3	2.27	1.3
	m_R	0.0435	0.0435	0
	Q_L	4.666	4.644	0.47
	W_{in}	2.033	2.044	-0.54
Real	COP	2.035	2.04	-0.24
	m_R	0.0429	0.0429	0
	Q_L	4.475	4.495	-0.44
	W_{in}	2.199	2.193	0.27
Isentropic	COP	2.231	2.232	-0.04
	m_R	0.0442	0.0441	0.22
	Q_L	4.611	4.619	-0.17
	W_{in}	2.066	2.069	-0.145

Table 4.1: Result comparison table

From above table, it clearly shows that in all three conditions (i.e, saturated and isentropic, real, and isentropic) there is difference in the coefficient of performances, mass flow rate, heat load and work input at different conditions. Real case is more accurate so it can be preferred.

1. The COP is calculated for the refrigerant 404A and equation has been formulated to calculate the heat load, work input and to draw the P-h diagram for the different conditions.
2. The equation can be used for calculate heat load work input for different condition of pressure and temperature of refrigerant.
3. The results obtained are very useful in designing the refrigeration or air conditioning chamber for different specifications of customers.

6. References

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