Department of Mechanical Engineering, The University of Hong Kong

BBSE3004 Air Conditioning and Refrigeration

Experiment 2: Energy Performance of Air-Conditioning System

Objectives

This laboratory exercise is designed to allow students to learn the fundamentals of vapor compression refrigeration cycle in an air-conditioning system. The students will apply the First Law of thermodynamics to analyze the performance of the air-conditioning system tested. The coefficient of performance (COP) of the test system will be determined based on (1) the refrigeration cycle and (2) measured cooling effect and electrical power input.

Introduction

An ideal single-stage vapor compression refrigeration cycle used to produce cooling is illustrated in the p-h diagram shown in Figure 1. The major equipment components and corresponding thermodynamic processes are:

Compressor: 1-2 isentropic compression
Condenser: 2-3 constant-pressure condensation
Expansion valve: 3-4 constant-enthalpy expansion
Evaporator: 4-1 constant-pressure evaporation

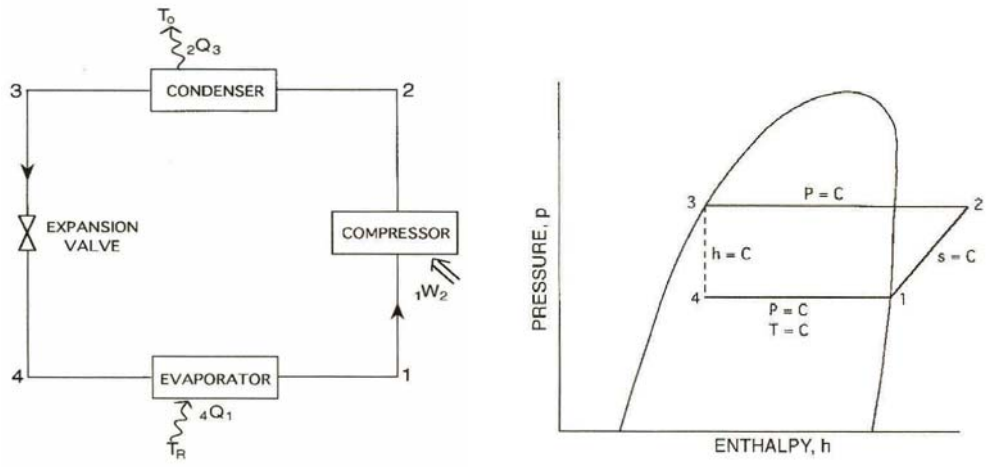


Figure 1. Ideal single-stage vapor compression refrigeration cycle (Ref. ASHRAE 2001)

Air cooling can be achieved by use of a chilled water circuit as a medium to transfer the heat from air to the refrigerant. The schematic is shown in Figure 2.

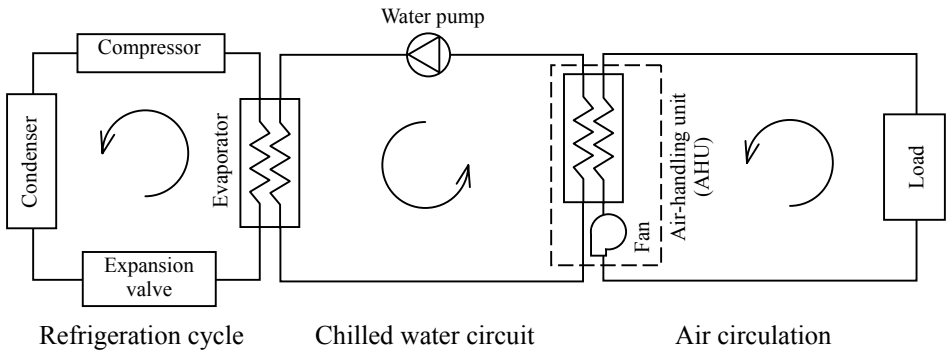


Figure 2. Simple air-conditioning system with chilled water circuit

Theory

Coefficient of performance (COP) is commonly used to represent the energy performance of a refrigeration cycle. COP is a ratio of cooling effect to compressor work,

$$COP = \frac{{}_4Q_1}{{}_1W_2} = \frac{\dot{m}(h_1 - h_4)}{\dot{m}(h_2 - h_1)} = \frac{h_1 - h_4}{h_2 - h_1} \quad (1)$$

where ${}_4Q_1$ = cooling effect (kW)
${}_1W_2$ = compressor work (kW)
h_i = enthalpy of refrigerant at particular temperature and pressure in state i (kJ/kg)
$\dot{m}$ = mass flow rate of refrigerant (kg/s)

Alternatively, if the states of refrigerant, i.e. temperature and pressure, are not available, COP can be estimated by the ratio of the cooling effect on the air side to the electrical power input for the compressor,

$$COP = \frac{\text{Cooling effect on air}}{\text{Compressor electrical power}} = \frac{\dot{V}\,\rho\,Cp(T_i - T_o)}{PF\,V_L\,I\,/\,1000} \quad (2)$$

where $\dot{V}$ = volumetric flow rate of air (m^3/s)
ρ = density of air (kg/m^3)
Cp = specific heat of air ($kJ/kg \cdot {}^oC$)
T_i = temperature of air entering AHU (^oC)
T_o = temperature of air exiting AHU (^oC)
V_L = 3-phase line voltage (V)
I = load current (A)
PF = power factor

Equipment and Instruments

- Environmental chamber
- Chiller plant (34 kW cooling capacity, refrigerant R407C)
- Air-handling unit (AHU)
- Anemometer
- Air temperature & humidity sensor
- Power analyzer

Test Procedures

1. Start chiller plant and air-handling unit until the environmental chamber reach a steady state at 12^{o}C.
2. Record the following measurements at 2-minute intervals for 20 minutes:
   - Pressure of the condensing refrigerant (P_c)
   - Pressure of the evaporating refrigerant (P_e)
   - Temperature of air entering the AHU (T_i)
   - Temperature of air exiting the AHU (T_o)
   - Speed of airflow through AHU (V)
   - 3-phase electrical current of the compressor (I_R, I_Y, I_B)
   - 3-phase electrical voltage of the compressor (V_R, V_Y, V_B)
   - Power factor (PF)
3. Stop chiller plant and AHU.

Data Analysis

1. Show the refrigeration cycle in the pressure-enthaply diagram of R407C (Appendix A), assuming that it is an ideal cycle at the measured condensing pressure and evaporating pressure.
2. Calculate COP based on the refrigeration cycle.
3. Calculate COP based on measured cooling effect and electrical power input.

Results & Discussions

1. Report the measurements and calculated results.
2. Discuss any discrepancy found in comparison between the two COP's obtained.

Laboratory Report

Each student should prepare their own report based on the data and information obtained during the experiment. While the results from the observations and measurements can be shared among the members in the same student group, each student shall generate information to show his/her own understanding and ideas. Students making direct copy of the information in other's report (plagiarism), if found, will be disqualified.

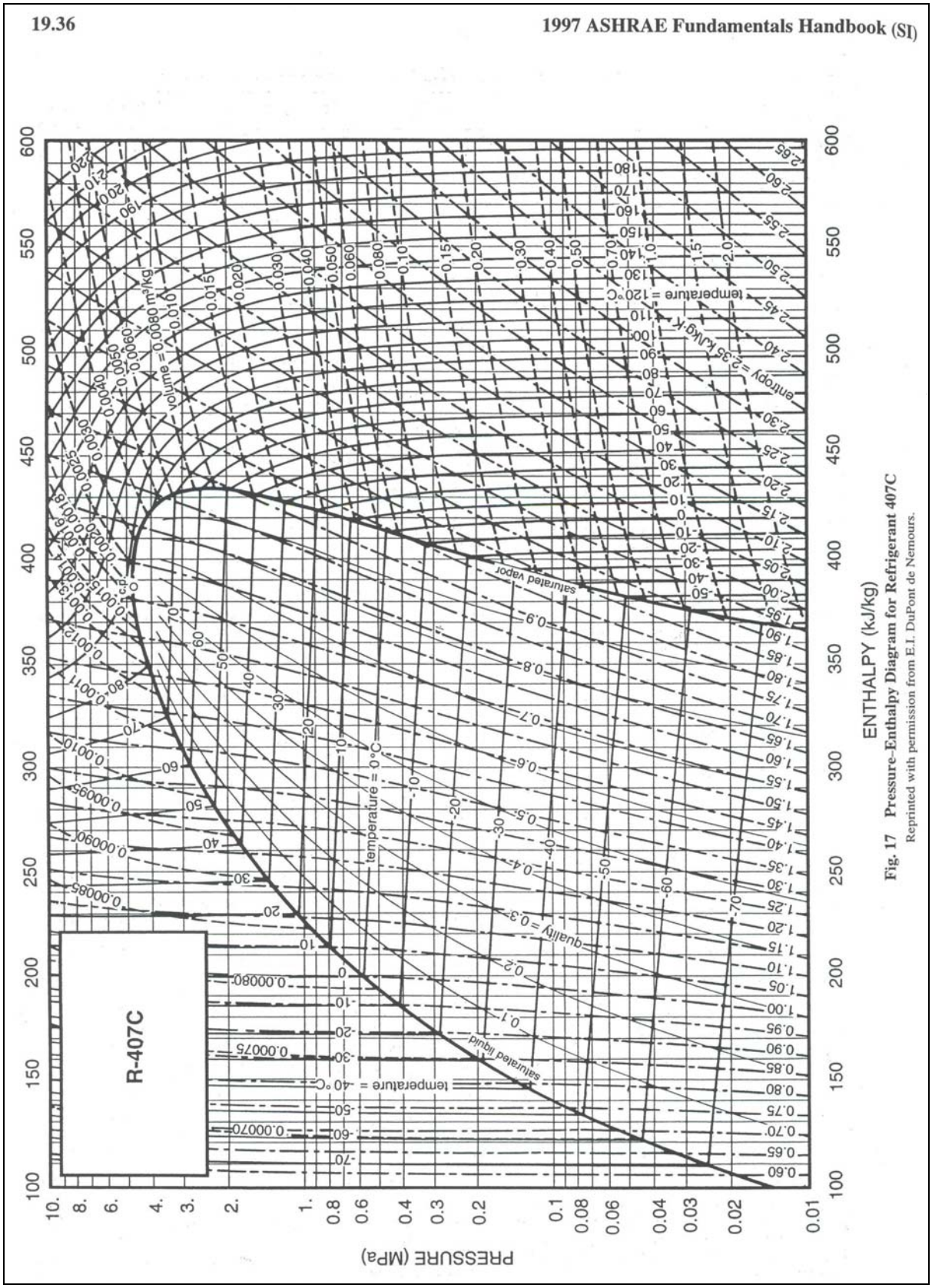
The laboratory report shall be submitted to the lecturer within FOUR weeks after completion of the experiment.

References

1. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), 2001, *ASHRAE Handbook Fundamentals*, SI Edition.

2. Air-conditioning & Refrigeration Institute (ARI), 2003, *Standard 210/240 Unitary Air- Conditioning and Air-source Heat Equipment* (http://www.ari.org/std/_individual/210.240-2003.pdf)

Appendix A. Pressure-enthalpy diagram of R407C



Appendix B. Thermophysical properties of R407C

Refrigerant 407C [R-32/125/134a (23/25/52)] Properties of Liquid on the Bubble Line and Vapor on the Dew Line

Absolute Pressure, MPa	Temperature*, °C		Density, kg/m³	Volume, m³/kg	Enthalpy, kJ/kg		Entropy, kJ/(kg·K)		Specific Heat c_p, kJ/(kg·K)		c_p/c_v	Velocity of Sound, m/s		Absolute Pressure, MPa
	Bubble	Dew	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Vapor	Liquid	Vapor	
0.01000	−82.79	−74.95	1496.9	1.897	91.30	365.97	0.5293	1.9442	1.245	0.662	1.180	1025.	149.1	0.01000
0.02000	−72.79	−65.14	1468.5	0.9907	103.81	372.02	0.5934	1.9078	1.257	0.685	1.179	968.	151.9	0.02000
0.04000	−61.48	−54.06	1435.6	0.5176	118.11	378.83	0.6627	1.8739	1.271	0.714	1.180	908.	154.6	0.04000
0.06000	−54.16	−46.88	1413.8	0.3539	127.48	383.20	0.7061	1.8553	1.282	0.734	1.182	869.	156.2	0.06000
0.08000	−48.59	−41.42	1397.1	0.2701	134.64	386.48	0.7384	1.8427	1.291	0.751	1.184	841.	157.2	0.08000
0.10000	−44.04	−36.97	1383.2	0.2190	140.53	389.13	0.7643	1.8333	1.298	0.765	1.187	818.	157.9	0.10000
0.10132b	−43.77	−36.70	1382.3	0.2163	140.89	389.29	0.7658	1.8328	1.299	0.766	1.187	816.	157.9	0.10132
0.12000	−40.17	−33.18	1371.2	0.1844	145.58	391.35	0.7861	1.8258	1.305	0.778	1.189	798.	158.4	0.12000
0.14000	−36.78	−29.85	1360.6	0.1594	150.03	393.28	0.8050	1.8196	1.312	0.790	1.192	781.	158.8	0.14000
0.16000	−33.75	−26.89	1351.1	0.1405	154.02	394.99	0.8217	1.8143	1.318	0.801	1.195	766.	159.1	0.16000
0.18000	−31.00	−24.20	1342.3	0.1256	157.65	396.51	0.8367	1.8098	1.324	0.811	1.197	752.	159.4	0.18000
0.20000	−28.48	−21.73	1334.2	0.1137	161.00	397.90	0.8504	1.8058	1.329	0.821	1.200	740.	159.5	0.20000
0.22000	−26.15	−19.45	1326.7	0.1038	164.11	399.16	0.8630	1.8022	1.335	0.830	1.203	728.	159.7	0.22000
0.24000	−23.98	−17.33	1319.6	0.09552	167.02	400.33	0.8746	1.7989	1.340	0.839	1.206	717.	159.8	0.24000
0.26000	−21.95	−15.34	1312.9	0.08847	169.75	401.41	0.8855	1.7960	1.345	0.847	1.208	707.	159.8	0.26000
0.28000	−20.03	−13.46	1306.5	0.08240	172.34	402.42	0.8957	1.7933	1.349	0.855	1.211	697.	159.9	0.28000
0.30000	−18.22	−11.69	1300.5	0.07712	174.80	403.36	0.9053	1.7908	1.354	0.863	1.214	688.	159.9	0.30000
0.32000	−16.49	−10.00	1294.7	0.07247	177.14	404.25	0.9144	1.7885	1.359	0.871	1.217	680.	159.9	0.32000
0.34000	−14.85	−8.39	1289.1	0.06835	179.38	405.09	0.9231	1.7863	1.363	0.879	1.220	672.	159.9	0.34000
0.36000	−13.28	−6.86	1283.8	0.06467	181.53	405.88	0.9313	1.7843	1.368	0.886	1.222	664.	159.8	0.36000
0.38000	−11.78	−5.39	1278.6	0.06137	183.59	406.63	0.9392	1.7824	1.372	0.893	1.225	656.	159.8	0.38000
0.40000	−10.33	−3.98	1273.6	0.05838	185.58	407.34	0.9467	1.7806	1.376	0.900	1.228	649.	159.7	0.40000
0.42000	−8.94	−2.62	1268.7	0.05567	187.50	408.02	0.9539	1.7789	1.380	0.907	1.231	642.	159.6	0.42000
0.44000	−7.60	−1.31	1264.0	0.05320	189.36	408.67	0.9609	1.7772	1.385	0.914	1.234	636.	159.5	0.44000
0.46000	−6.30	−0.04	1259.5	0.05094	191.16	409.29	0.9676	1.7757	1.389	0.921	1.237	629.	159.4	0.46000
0.48000	−5.05	1.18	1255.0	0.04885	192.91	409.88	0.9741	1.7742	1.393	0.928	1.240	623.	159.3	0.48000
0.50000	−3.84	2.36	1250.7	0.04693	194.61	410.45	0.9803	1.7728	1.397	0.934	1.242	617.	159.2	0.50000
0.55000	−0.95	5.18	1240.3	0.04272	198.65	411.77	0.9951	1.7695	1.407	0.950	1.250	603.	158.9	0.55000
0.60000	1.74	7.80	1230.4	0.03919	202.46	412.97	1.0089	1.7665	1.416	0.966	1.257	589.	158.6	0.60000
0.65000	4.26	10.26	1221.0	0.03618	206.05	414.07	1.0217	1.7637	1.426	0.981	1.265	577.	158.2	0.65000
0.70000	6.64	12.58	1212.0	0.03359	209.47	415.07	1.0339	1.7611	1.436	0.997	1.273	565.	157.8	0.70000
0.75000	8.90	14.78	1203.4	0.03133	212.72	416.00	1.0453	1.7587	1.445	1.012	1.280	553.	157.4	0.75000
0.80000	11.05	16.87	1195.0	0.02934	215.84	416.85	1.0562	1.7564	1.455	1.027	1.288	543.	157.0	0.80000
0.85000	13.10	18.86	1187.0	0.02758	218.83	417.65	1.0665	1.7542	1.464	1.042	1.297	532.	156.5	0.85000
0.90000	15.06	20.77	1179.1	0.02601	221.71	418.38	1.0764	1.7522	1.474	1.056	1.305	522.	156.1	0.90000
0.95000	16.94	22.59	1171.5	0.02460	224.49	419.06	1.0858	1.7502	1.483	1.071	1.314	513.	155.6	0.95000
1.00000	18.75	24.35	1164.1	0.02333	227.18	419.69	1.0949	1.7483	1.493	1.086	1.322	504.	155.1	1.00000
1.10000	22.17	27.67	1149.8	0.02111	232.31	420.83	1.1121	1.7446	1.512	1.116	1.340	487.	154.1	1.10000
1.20000	25.37	30.77	1136.0	0.01925	237.16	421.81	1.1281	1.7412	1.532	1.147	1.359	470.	153.1	1.20000
1.30000	28.37	33.67	1122.8	0.01767	241.77	422.66	1.1432	1.7380	1.552	1.178	1.379	455.	152.0	1.30000
1.40000	31.21	36.41	1109.9	0.01630	246.17	423.38	1.1575	1.7348	1.573	1.210	1.400	440.	151.0	1.40000
1.50000	33.90	39.01	1097.4	0.01511	250.40	424.00	1.1710	1.7318	1.594	1.243	1.423	427.	149.9	1.50000
1.60000	36.46	41.47	1085.2	0.01406	254.46	424.53	1.1839	1.7288	1.616	1.277	1.447	413.	148.7	1.60000
1.70000	38.90	43.82	1073.2	0.01313	258.39	424.96	1.1962	1.7258	1.639	1.313	1.472	401.	147.6	1.70000
1.80000	41.24	46.07	1061.4	0.01230	262.19	425.30	1.2081	1.7229	1.664	1.350	1.499	389.	146.5	1.80000
1.90000	43.49	48.22	1049.8	0.01155	265.89	425.56	1.2195	1.7200	1.689	1.389	1.528	377.	145.3	1.90000
2.00000	45.65	50.29	1038.3	0.01087	269.48	425.75	1.2305	1.7172	1.716	1.431	1.559	365.	144.1	2.00000
2.10000	47.73	52.27	1026.9	0.01025	272.99	425.87	1.2411	1.7142	1.744	1.475	1.592	354.	143.0	2.10000
2.20000	49.73	54.19	1015.6	0.00969	276.42	425.91	1.2515	1.7113	1.774	1.522	1.628	344.	141.8	2.20000
2.30000	51.67	56.04	1004.3	0.00917	279.78	425.88	1.2616	1.7084	1.805	1.572	1.666	333.	140.6	2.30000
2.40000	53.55	57.82	993.0	0.00869	283.08	425.79	1.2714	1.7054	1.840	1.625	1.709	323.	139.4	2.40000
2.50000	55.37	59.54	981.8	0.00825	286.32	425.62	1.2810	1.7023	1.876	1.683	1.755	313.	138.2	2.50000
2.60000	57.14	61.22	970.5	0.00783	289.51	425.39	1.2903	1.6992	1.916	1.746	1.805	303.	136.9	2.60000
2.70000	58.86	62.83	959.2	0.00745	292.66	425.09	1.2995	1.6961	1.959	1.815	1.860	293.	135.7	2.70000
2.80000	60.53	64.41	947.8	0.00709	295.77	424.72	1.3086	1.6928	2.006	1.890	1.921	284.	134.5	2.80000
2.90000	62.16	65.93	936.3	0.00675	298.85	424.28	1.3175	1.6894	2.058	1.973	1.988	274.	133.2	2.90000
3.00000	63.74	67.41	924.7	0.00643	301.91	423.76	1.3262	1.6860	2.115	2.065	2.064	265.	132.0	3.00000
3.20000	66.80	70.25	900.9	0.00585	307.97	422.48	1.3435	1.6787	2.251	2.283	2.244	246.	129.4	3.20000
3.40000	69.71	72.94	876.0	0.00531	314.01	420.85	1.3605	1.6707	2.427	2.565	2.479	228.	126.8	3.40000
3.60000	72.50	75.49	849.6	0.00483	320.10	418.79	1.3775	1.6618	2.665	2.945	2.798	210.	124.1	3.60000
3.80000	75.18	77.91	821.0	0.00437	326.32	416.20	1.3948	1.6518	3.009	3.490	3.256	191.	121.3	3.80000
4.00000	77.75	80.19	789.1	0.00393	332.81	412.89	1.4126	1.6400	3.556	4.342	3.972	173.	118.4	4.00000
4.20000	80.24	82.33	751.5	0.00350	339.86	408.43	1.4319	1.6254	4.570	5.874	5.259	154.	115.3	4.20000
4.40000	82.67	84.30	702.1	0.00303	348.17	401.74	1.4546	1.6048	7.125	9.498	8.286	134.	111.7	4.40000
4.6528c	86.08	86.08	506.0	0.00198	375.52	375.52	1.5298	1.5298	∞	∞	∞	0.	0.0	4.6528

*temperatures are on the ITS-90 scale b = one standard atmosphere c = critical point