Refrigeration

useful for a number of industrial processes

- treatment and preservation of foods and pharmaceuticals, large-scale production of protein drugs, lubricating oil purification, separation of volatile components

OBJECTIVES

- to examine common types of refrigeration processes in use
- to describe these processes thermodynamically

Refrigeration

Process

- evaporation of a liquid at steady-state
- vapor returned to liquid state for re-evaporation

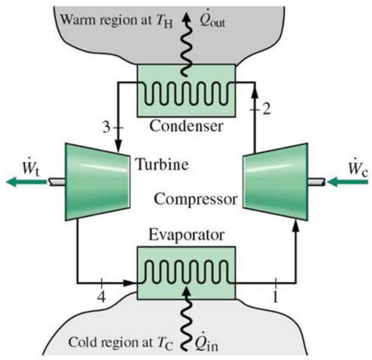
measure of process effectiveness

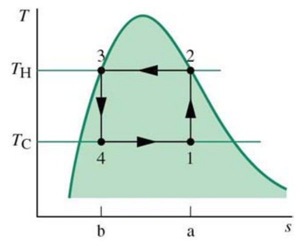
- coefficient of performance, C.O.P.

$$\text{COP} = \frac{\text{heat absorbed at lower T}}{\text{net work}}$$

Carnot Cycle

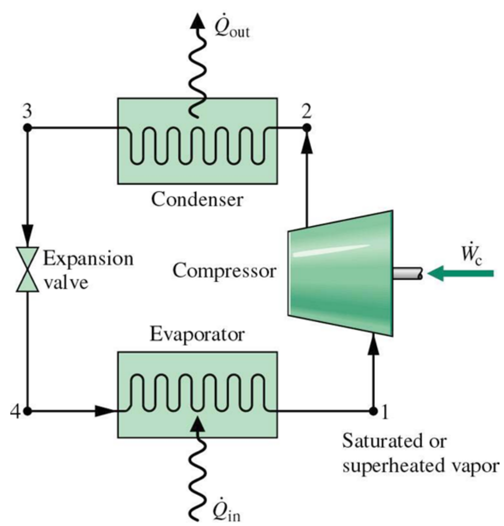
represents an ideal case
operate in reverse of heating cycle





$$COP = \frac{T_c}{T_H - T_C}$$

Rankine Refrigeration Cycle



Choice of Refrigerant

criteria

- nontoxic,nonflammable, nonexplosive
- compatible with other materials
- proper thermodynamic and physical properties
  - » high latent heat
  - » low specific vapor volume
  - » low viscosity
  - » reasonably low vapor pressure for T_C conditions
  - » easily detected if leaking
  - » low heat capacity of liquid
  - » high heat capacity of vapor
- limited choices
  - » ammonia, HFC, propane

Refrigerant R134a Properties

TABLE B.5.1 *(continued)*
Saturated R-134a

		Enthalpy, kJ/kg			Entropy, kJ/kg-K		
Temp. (°C)	Press. (kPa)	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapo s_g
−70	8.3	119.47	235.15	354.62	0.6645	1.1575	1.8220
−65	11.7	123.18	234.55	357.73	0.6825	1.1268	1.8094
−60	16.3	127.53	233.33	360.86	0.7031	1.0947	1.7978
−55	22.2	132.37	231.63	364.00	0.7256	1.0618	1.7874
−50	29.9	137.62	229.54	367.16	0.7493	1.0286	1.7780
−45	39.6	143.18	227.14	370.32	0.7740	0.9956	1.7695
−40	51.8	148.98	224.50	373.48	0.7991	0.9629	1.7620
−35	66.8	154.98	221.67	376.64	0.8245	0.9308	1.7553
−30	85.1	161.12	218.68	379.80	0.8499	0.8994	1.7493
−26.3	101.3	165.80	216.36	382.16	0.8690	0.8763	1.7453
−25	107.2	167.38	215.57	382.95	0.8754	0.8687	1.7441
−20	133.7	173.74	212.34	386.08	0.9007	0.8388	1.7395
−15	165.0	180.19	209.00	389.20	0.9258	0.8096	1.7354
−10	201.7	186.72	205.56	392.28	0.9507	0.7812	1.7319
−5	244.5	193.32	202.02	395.34	0.9755	0.7534	1.7288
0	294.0	200.00	198.36	398.36	1.0000	0.7262	1.7262
5	350.9	206.75	194.57	401.32	1.0243	0.6995	1.7239
10	415.8	213.58	190.65	404.23	1.0485	0.6733	1.7218
15	489.5	220.49	186.58	407.07	1.0725	0.6475	1.7200
20	572.8	227.49	182.35	409.84	1.0963	0.6220	1.7183
25	666.3	234.59	177.92	412.51	1.1201	0.5967	1.7168
30	771.0	241.79	173.29	415.08	1.1437	0.5716	1.7153
35	887.6	249.10	168.42	417.52	1.1673	0.5465	1.7139
40	1017.0	256.54	163.28	419.82	1.1909	0.5214	1.7123
45	1160.2	264.11	157.85	421.96	1.2145	0.4962	1.7106

Refrigerant R134a Properties

TABLE B.5.2
Superheated R-134a

Temp. (°C)	*v* (m^3/kg)	*u* (kJ/kg)	*h* (kJ/kg)	*s* (kJ/kg-K)	*v* (m^3/kg)	*u* (kJ/kg)	*h* (kJ/kg)	*s* (kJ/kg-K)
	50 kPa (−40.67)				100 kPa (−26.54)			
Sat.	0.36889	354.61	373.06	1.7629	0.19257	362.73	381.98	1.7456
−20	0.40507	368.57	388.82	1.8279	0.19860	367.36	387.22	1.7665
−10	0.42222	375.53	396.64	1.8582	0.20765	374.51	395.27	1.7978
0	0.43921	382.63	404.59	1.8878	0.21652	381.76	403.41	1.8281
10	0.45608	389.90	412.70	1.9170	0.22527	389.14	411.67	1.8578
20	0.47287	397.32	420.96	1.9456	0.23392	396.66	420.05	1.8869
30	0.48958	404.90	429.38	1.9739	0.24250	404.31	428.56	1.9155
40	0.50623	412.64	437.96	2.0017	0.25101	412.12	437.22	1.9436
50	0.52284	420.55	446.70	2.0292	0.25948	420.08	446.03	1.9712
60	0.53941	428.63	455.60	2.0563	0.26791	428.20	454.99	1.9985
70	0.55595	436.86	464.66	2.0831	0.27631	436.47	464.10	2.0255
80	0.57247	445.26	473.88	2.1096	0.28468	444.89	473.36	2.0521
90	0.58896	453.82	483.26	2.1358	0.29302	453.47	482.78	2.0784
100	0.60544	462.53	492.81	2.1617	0.30135	462.21	492.35	2.1044
110	0.62190	471.41	502.50	2.1874	0.30967	471.11	502.07	2.1301
120	0.63835	480.44	512.36	2.2128	0.31797	480.16	511.95	2.1555
130	0.65479	489.63	522.37	2.2379	0.32626	489.36	521.98	2.1807

Example

Refrigerant R134a is used in an ideal refrigeration cycle, that operates between a cold reservoir at 0ºC and a hot reservoir at 25ºC. Saturated vapor enters the compressor at 0ºC and saturated liquid leaves the condenser at 25ºC. The mass flowrate of refrigerant is 0.08 kg/s. Determine the compressor power, the refrigeration capacity, the coefficient of performance and compare this coefficient of performance to that of a Carnot cycle.

Example

The same refrigeration cycle as in the last example is used, but now the compressor has an efficiency of 80%. Calculate the compressor power, the refrigeration capacity, and the coefficient of performance.

Cascade Designs

2 or more refrigeration cycles employing different refrigerants