VAPOUR COMPRESSION SYSTEM, VCR

ME441, TFE Laboratory, UG Course + RAC Laboratory, RAC_1 of 2+Vapour Compression Unit_with_Single_Stage+R134a

Thermal and Fluid Engineering Laboratory

HPL_IITB

- ***Aim***
  - ✓ Understand the design and operation of a ***Vapour Compression Refrigeration System***
- ***Objective***
  - ✓ ***Verify Energy Balance in a Single Stage VCR System***

    @ various evaporator loads
  - ✓ ***Plot the variation of***
    - ***Overall COP V/s Evaporator Temperature, $t_{evp.sat}$***
    - ***Refrigerant flow rate V/s Overall COP***
    - ***Superheat V/s Evaporator Temperature, $t_{evp.sat}$***
    - ***Refrigeration Load & Power Input V/s Evaporator Temperature, $t_{evp.sat}$***
- ***Outline of the Presentation***
  - ✓ Theory: Simple VCR Cycle and Components
  - ✓ Discussion on P A Hilton experiment set up
  - ✓ Experimental set up components and their working functions
  - ✓ Discussion on the fundamental principle behind the single stage vapor compression
  - ✓ Advantages and disadvantages
  - ✓ The parameters to be measured
  - ✓ Discussion on p-h diagram of R134a refrigerant and possible interpretations

APPARATUS

P A Hilton R714/28333 Refrigeration Laboratory Unit

Component Description

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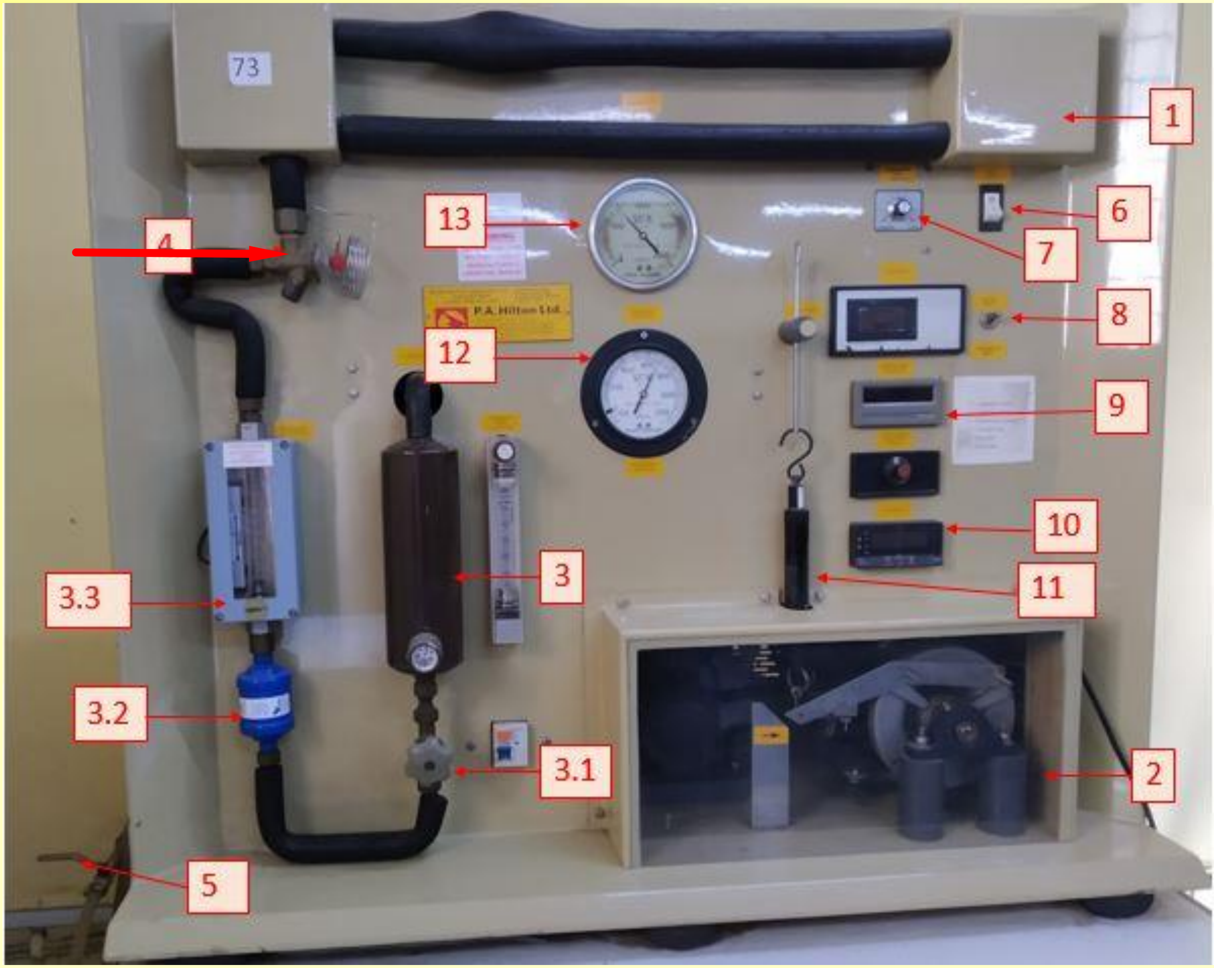
1	*Evaporator with Electric Heater*
2	*Compressor with External Motor*
3	*Water Cooled Condenser with Sight Glass*
3.1	*Isolation Valve*
3.2	*Filter cum Dryer*
3.3	*Rotameter for Refrigerant Liquid*
4	*Thermostatic Expansion Valve, TEV*
5	*Condenser Cooling Water Valve*
6	*Main Switch: Power Supply to the Unit*
7	*Evaporator Input Control: EVP Power*
8	*Watt Meter & Toggle Switch* *Enables Measuring Motor and EVP Power*
9	*Temperature Indicator & Section Switch:* *Enables Measuring Temperatures*
10	*Tachometer: Indicates Compressor Speed*
11	*Dynamometer: Enables Measuring Torque*
12	*Evaporator Pressure Gauge*
13	*Condenser Pressure Gauge*
14	*Rotameter for Condenser Cooling Water*



PROCESS SCHEMATIC

P A Hilton R714/28333 Refrigeration Laboratory Unit

Component Description in Layout

HPL_IITB

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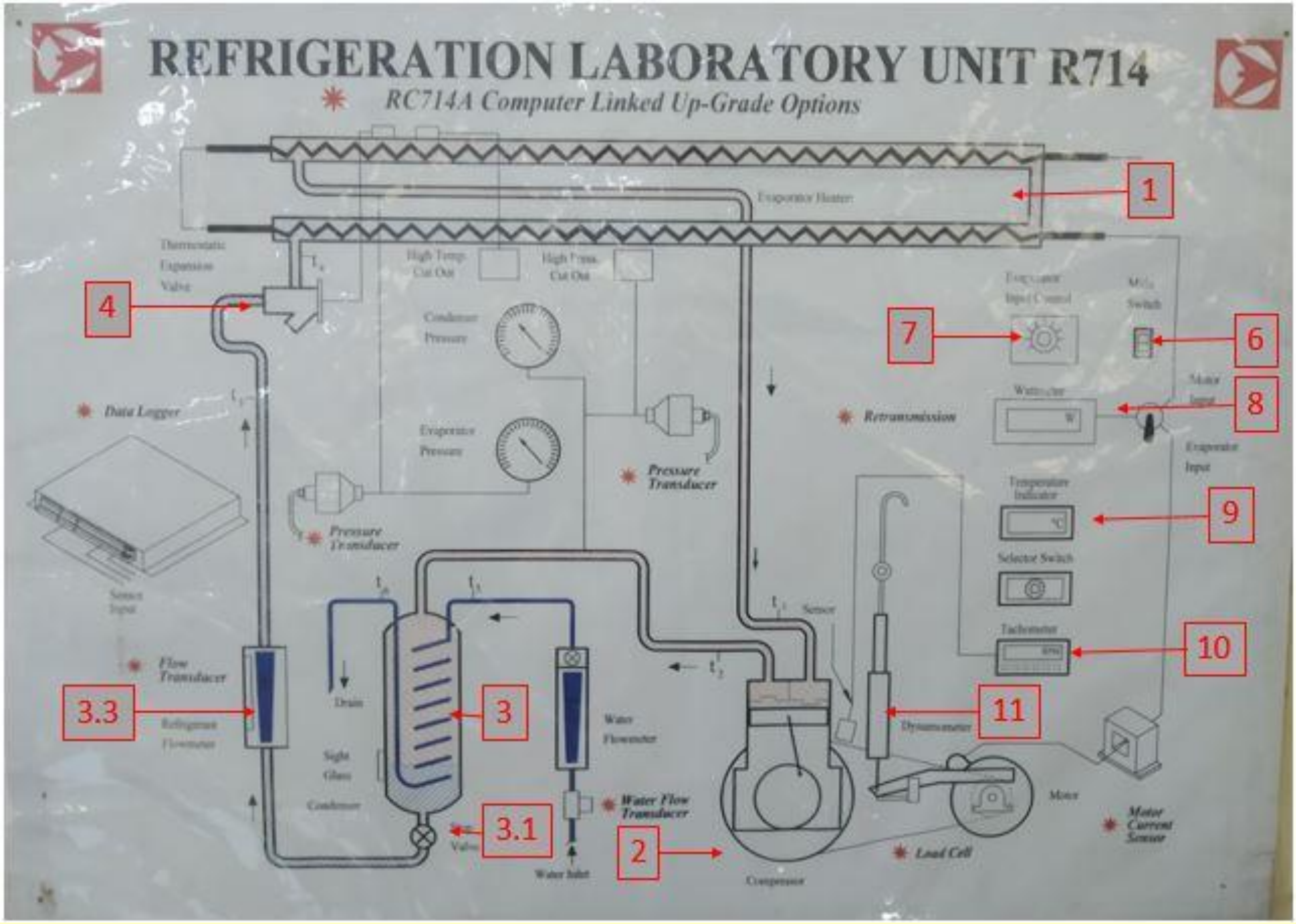

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P A Hilton R714/28333 Refrigeration Laboratory Unit

Important Parts: Evaporator, EVP

- ***A Tubular Evaporator, 1, is Deployed in this Experimental Setup***
  - ✓ Heat load to the evaporator is provided by an Electric Heater, within the evaporator,1
  - ✓ Additional heat load to the evaporating refrigerant is due to the heat gain through the insulation around the evaporator

- ***Heat Load through the Electric Heater can be Varied by Turning Knob 7***
  - ✓ This varies the power input to the electric heater and as a result the evaporator load

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P A Hilton R714/28333 Refrigeration Laboratory Unit

Important Parts: Open Type Compressor with External Motor

- ***Power from the Motor is Transmitted to the Compressor Using a Belt Drive***
  - ✓ Diameter of the pulley mounted on the motor and the diameter of the pulley mounted on the compressor govern the compressor speed
    - ***Speed of the motor and the pulley diameter ration (1.98 in the resent case) decides the speed of the compressor***

- ***Compressor Power Measurement can be Enabled by Measuring the Following:***
  - ✓ Motor Speed, Torque on the Motor Shaft
- ***Motor Speed is Measured Using Tachometer***
- ***Torque on the Motor Shaft is Measured Using the Dynamometer***
  - ✓ Adjusting the sharp edge of the lever end of the dynamometer with the marked arrow next to it and then reading the tension in the force measuring gauge
  - ✓ Multiplying the force with the length of the arm gives the torque
  - ✓ Using the torque and motor rpm the power delivered by the motor can be calculated

- ***Electrical Power Input to the Motor can be Read from the Wattmeter***

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P A Hilton R714/28333 Refrigeration Laboratory Unit

Important Parts: Condenser, CND, Water Cooled

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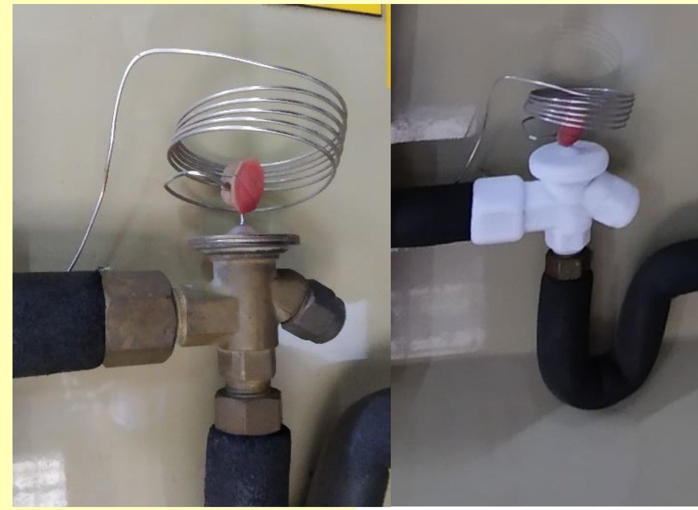
- ***Water Cooled Condenser, WCC***
  - ✓ Desuperheats, condenses and subcools compressed refrigerant exiting the compressor
- ***Water Cooled Condensers Typically Offer Lower Condensing Temperatures as Compared to Air Cooled Condensers***
  - ✓ Cooling water inlet temperature is typically lower than ambient air temperature
  - ✓ Heat transfer coefficient with water is better than that with ambient air
- ***Water Cooled Condensers Typically are More Compact***
  - ✓ Heat transfer coefficient with water is better than that with ambient air
  - ✓ In the present system the area of condenser coil, $A_{he.cnd} = 0.075\ m^2$
- ***Water Flow Through the WCC can be Measured Using the Rotameter***
  - ✓ Range of the rotameter is from 4 to 50 g/s & Least Count is 2 g/s
  - ✓ Water flow for the experiments are typically set at 30 g/s
    - ***After setting a value the water flow may vary due to variation in tap water pressure***

APPARATUS

P A Hilton R714/28333 Refrigeration Laboratory Unit

Important Parts: Thermostatic Expansion Valve , TEV

- ***TEV Regulates the Refrigerant Flow***
  - ✓ from the Condenser Outlet to the Evaporator Inlet



- ***TEV Regulates the Refrigerant Flow to Maintain Super Heat at the Outlet of the Evaporator or Inter of the Compressor***
  - ✓ Designed to keep the superheating of the refrigerant at a constant level
  - ✓ Amount of superheat can be set by setting the adjustment screw provided in the TEV
    - ***Normally this is factory set and it is not recommended to be tampered with at site***

- ***Bulb Type Temperature Sensor Located at the Outlet of the Evaporator is Connected to the Valve by a Capillary***
  - ✓ Increase in superheat above the set value, increases the pressure in the sensor and the valve opens up to regulate the refrigerant flow
- ***TEV is Expected to Work as an Adiabatic Expansion Device***
  - ✓ It should be ideally insulated to avoid the frosting seen in the setup

THEORY

ME 441 Lab Manual

Vapour Compression Refrigeration System, VCRS

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- ***VCRS is the Most Commonly Used Refrigeration System***
  - ✓ Refrigeration/cooling effect is achieved due to evaporation of the refrigerant in the evaporator
    - ***Evaporation takes place at low temperatures and its vapour pressure is low***
  - ✓ This low pressure refrigerant is compressed in the compressor
    - ***Higher pressure refrigerant at the outlet of the compressor is then condensed in the condenser***
  - ✓ Condensation at higher pressure takes place as higher temperature
    - ***Enabling heat transfer to is the surrounding of suitable heat sink***
  - ✓ Condensed refrigerant from the outlet of the condenser is throttled through the Expansion Device and let in to the evaporator
- ***VCRS Works on the Vapour Compression Cycle (VCC) it Consist of Four Steps***
    - ***Isobaric heat extraction in the evaporator***
    - ***Isentropic compression***
    - ***Isobaric heat rejection in condenser***
    - ***Isenthalpic expansion in expansion device***
- ***VCC Introduces Two Irreversibilities as Compared to Carnot Cycle***
  - ✓ Irreversibility due to non-isothermal heat rejection & that due to isenthalpic throttling
- ***Due to These Irreversibilities, the Cooling Effect Reduces and Work Input Increases***
  - ✓ COP of the VCRS reduces as compared to Carnot cycle

OBSERBVATION TABLE

ME 441 Lab Manual

Vapour Compression Refrigeration system, VCRS

Sr #	Measurements	Units	1	2	3	4	5	6
1	p_c	kN/m^2	800	850	950	970	975	1050
2	p_e	kN/m^2	100	125	175	200	225	250
3	t_1	^oC	7.0	-0.1	2.2	5.2	6.1	9.6
4	t_2	^oC	65.0	72.7	63.2	68.8	60.2	70.1
5	t_3	^oC	29.6	30.5	32.5	34.2	34.3	36.4
6	t_4	^oC	-29.0	-23.7	-15.3	-10.6	-8.2	-5.2
7	t_5	^oC	28.2	27.5	27.6	28	26.8	28.1
8	t_6	^oC	30.9	31.1	32.7	33.5	33.0	35.0
9	m_w	g/sec	30.0	30	32	32	32 0	34

OBSERBVATION TABLE

ME 441 Lab Manual

Vapour Compression Refrigeration system, VCRS

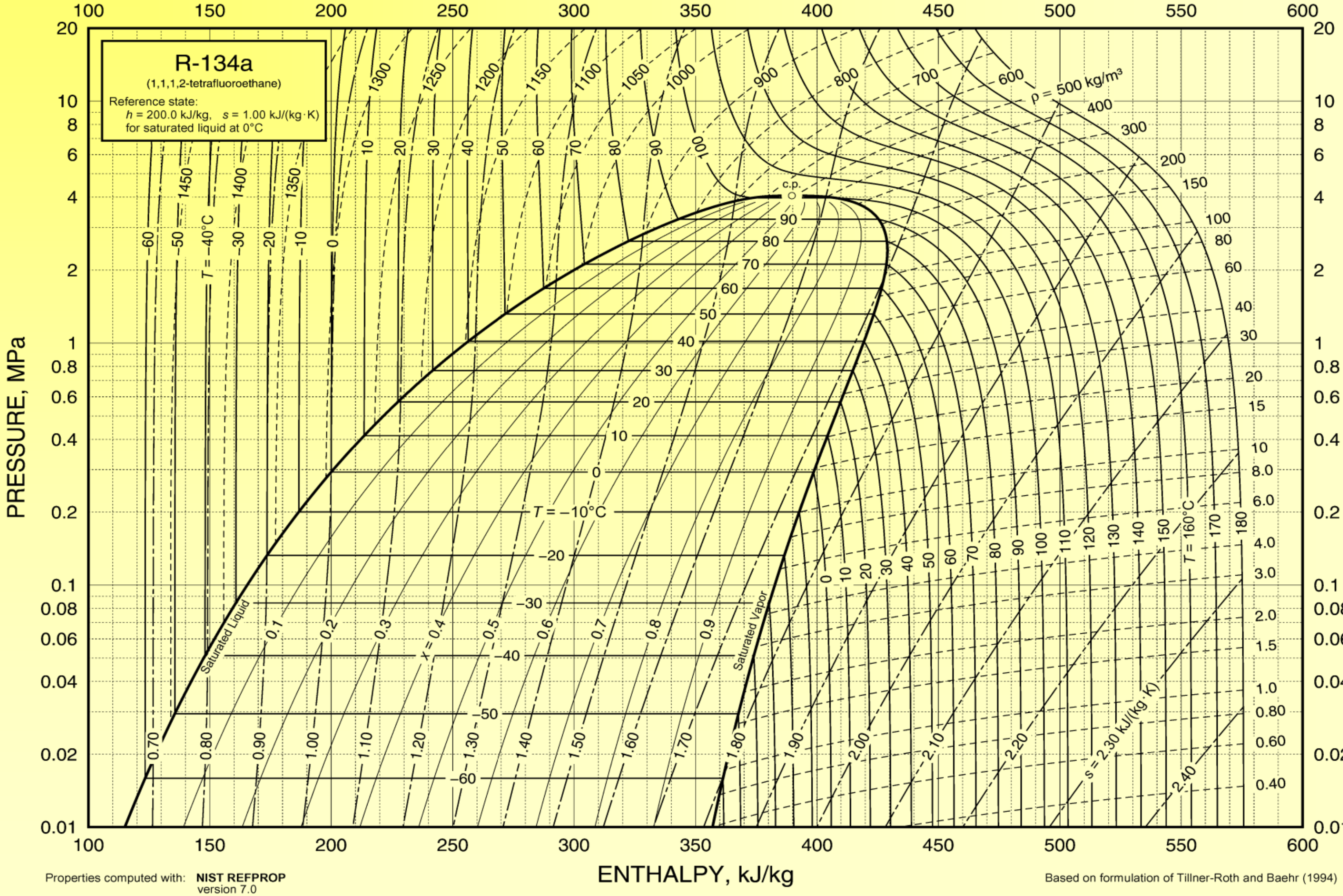
HPL_IITB

Sr #	Measurements	Units	1	2	3	4	5	6
10	m_r	g/s	1.9	2.2	3.2	3.8	4.2	4.5
11	Qe_{el}	W	126	210	400	505	603	686
12	Qm_{el}	W	343	373	424	451	458	493
13	F	N	10.0	10.5	12.0	12.5	13.0	14.0
14	n_c	rpm	742	743	743	743	743	743
15	n_m	rpm	1470	1472	1472	1473	1472	1473

p – h CHART

ASHRAE HBF 2017, Ch 30, P 30.17, Fig 8 + Safety Group A1, GWP-AR5 1300, ODP 0

R-134a, HFC, 1,1,1,2-Tetrafluoroethane, CH_2FCF_3



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- ***Refrigeration Load***

  $Q_e = m_r (h_1 – h_4)$

- ***Shaft Power***

  $P_s = T\omega$ $\omega = 2\pi N_m/60$ $T = F \times 0.165$ (arm length for dynamometer)

- ***Friction Power***

  $P_f = 0.165 \times F_f \times \omega$ $F_f = 5N$

- ***Indicated Power***

  $P_i = P_s - P_f$

- ***COP Based on Electrical Power or Overall COP***

  $COP_{ep} = Q_e/Qm_{el}$

- ***COP Based on Shaft Power***

  $COP_{ep} = Q_e/P_s$

- ***COP Based on Indicated Power***

  $COP_{ip} = Q_e / P_i$

- ***Volumetric efficiency***

  $\eta_{vol} = (m_r \times v_1) / V_{swept}$ $V_{swept} = 43.0\ cm^3/rev \times$ *rps of compressor*

- ***Heat Balance***

  $W_{in} = P_i \times \eta_{vol}$

  $Q_{cnd} = m_w C_p (t_6 - t_5)$

  $W_{in} + Q_e = Q_{cnd}$ **(Verify Energy Balance)**

REFRIGERANTS

ASHRAE HBF 2013, Ch 29, 30

Refrigerant	Name	ODP	GWP$_{100}$	p_r at 7.2°C bar	p_r at 54.4°C bar	p_r critical bar	$t_{r.critical}$ °C	Issues
R-22	Dichloroflurومethane	0.04	**1790**	6.3	21.3	50.0	96.1	High GWP
R-134a	Tetrafluoroethane	0	**1370**	3.8	14.6	40.6	101.1	High GWP
R-290	Propane	0	~20	5.9	19.1	42.5	96.7	Flammable
R-600	Butane	0	~20	1.3	5.5	38.0	152.0	Flammable
R-407C	R-32/125/134a (23/25/52)	0	**1700**	6.4	24.0	46.3	86.0	High GWP
R-410A	R-32/125 (50/50)	0	**2100**	10.0	34.0	49.0	71.4	High GWP
R-717	Ammonia	0	< 1	5.6	22.0	113.3	132.3	Toxic
R-744	Carbon Dioxide	0	1	42.1	*SH*	**73.8**	**31.0**	High pr, Low $t_{critical}$
R-718	Water/Steam			0.010	0.140	220.6	373.3	Very low pressure, low density