Chapter 4.8: Compressors

Short type questions

1.	Define compression ratio for a compressor **Ans** Compression ratio = $\frac{\text{Absolute discharge pressure of last stage}}{\text{Absolute intake pressure}}$
2.	What are the different components of a compressed air system network? **Ans** The different components that are available in a compressed air network are ➢ Intake air filters ➢ Inter-stage coolers ➢ After coolers ➢ Air dryers ➢ Moisture drain traps ➢ Receivers
3.	List at least three different flow control methods adopted in a compressed air system? **Ans** Various flow control methods are ➢ Automatic On/Off control ➢ Load and Unload ➢ Multi-step control ➢ Throttling control
4.	Define “volumetric efficiency” of a compressor? **Ans** Volumetric efficiency = $\frac{\text{Free air delivery, } m^3/\text{min}}{\text{compressor displacement}}$
5.	What are the various instruments required for performance evaluation of compressed air systems by nozzle method? **Ans** Various instruments required are ➢ Thermometers or Thermocouple ➢ Pressure gauges or Manometers ➢ Differential pressure gauges or manometers ➢ Standard nozzle ➢ Psycho meter ➢ Tachometer/Stroboscope ➢ Electrical demand analyser
6.	Define specific power requirement? **Ans** The ratio of power consumption in kW to the volume delivered at ambient conditions.
7.	During the a leakage assessment test, compressor was loaded for 7 minutes and unloaded for 20 minutes. If the actual free air delivered is 200 CFM then evaluate quantity of leakage.

	Ans. % leakage $= \dfrac{\text{load time x 100}}{\text{load time + unload time}}$ $= \dfrac{7 \text{ x } 100}{7 + 20} = 26\%$ Leakage quantity = Actual FAD x % leakage = $= \dfrac{200 \text{ x } 26}{100} = 51.85$ cfm
8.	What happens to power consumption when the temperature of the inlet air to the compressor rises by $8^{o}C$? **Ans** Power consumption increases by 2%
9.	If the pressure setting of a compressor is reduced by 1 kg/cm^2g, what impact it will have on power consumption? **Ans** The power consumption reduces by 6-10%
10.	What are the acceptable pressure drops in mains header and that in distribution system in a compressed air network? **Ans** Typical acceptable pressure drop in industrial practice is 0.3 bar in mains header at the farthest point and 0.5 bar in distribution system.

Long type questions

1.	What is the procedure of conducting free air delivery test of compressor by nozzle method? **Ans** The compressor is started with the air from the receiver discharging to the atmosphere through the flow nozzle. It should be ensured that the pressure drop through the throttle valve should be equal to or twice the pressure beyond the throttle. After the system is stabilized the following measurements are carried out: • Receiver pressure • Pressure and temperature before the nozzle • Pressure drop across the nozzle • Speed of the compressor • KW, kWh and amps drawn by the compressor The above readings are taken for the 40%, 60%, 100% and 110% of discharge pressure values. The Free Air delivered (Qf) is given by: Free Air delivered Qf $= k \text{ x } \Pi \text{ x } \dfrac{d^2}{4} \text{ x } \dfrac{T_1}{P_1} \text{ x } \left[\dfrac{2(P3 - P4) \text{ x } (P3 \text{ x } Ra)}{T_3}\right]^{1/2}$ k : Flow coefficient – as per IS d : Nozzle diameter M T_1 : Absolute inlet temperature °K P_1 : Absolute inlet pressure kg/cm^2 P_3 : Absolute Pressure before nozzle kg/cm^2

	T_3 : Absolute temperature before nozzle °K R_a : Gas constant for air 287.1 J/kg k P_3-P_4 : Differential pressure across the nozzle kg/cm²
2.	Explain the simple method of free air delivery assessment of compressor in shop floor. Ans. Simple method of conducting the Free Air Delivery of the compressor is by receiver filling method. Though this is less accurate, this can be adopted where the elaborate nozzle method is difficult to be deployed. Steps: • Determine the volume of the connected receiver in m³. • Determine the volume of the piping between the compressors and receiver in m³, if significant. • Record the load/unload pressure settings of the compressors kg/cm². • Wait for the compressor to turn on, pressurize the receiver, and turn off or unload. • When the compressor turns off or unloads, start timing (it is assumed that the compressor unloads completely). • Note the receiver pressure. • Note the time it takes for the receiver pressure to drop and for the compressor to turn on or load up. • Repeat these steps over a reasonable period of time. The Free Air delivery is calculated as follows: $FAD = \frac{Q \text{ x } (P_F - P_1)}{(P_a \text{ x } t)}$ where, FAD - Free Air Delivery (m³/min) Q - Total volume of the receiver and pipeline connected from compressor to air receiver (m³) P_I - Initial Pressure of the receiver (kg/cm²) P_F - Final Pressure of the receiver (kg/cm²) Pa - Atmospheric Pressure, (kg/cm²a) t - Average filling time (min)

Numerical type questions

1.	In an engineering industry located in Southern India, there are 4 numbers of compressors installed for compressed air requirement. All the four will be in operation at any point of time. The rated capacities of compressors are 100 cfm each, whereas the actual output of each are given below: Compressor #1 : 80 cfm Compressor #2 : 75 cfm Compressor #3 : 90 cfm Compressor #4 : 95 cfm The power consumption of these compressors is 25 kW, 27 kW, 23 kW and 28 kW respectively. The compressor is continuously operated at 7 kg/cm²g pressure. During the measurements it was observed that the leakage losses constitute around 45% of the actual output of the compressors.

	Estimate the following a) Power loss due to leakage b) Estimate the power savings if 50% of the leakages are arrested *Note: The compressors have on and off control* **Ans.** a) Output of all four compressors : 80+ 75++90+95 : 340 cfm Power consumed by compressors : 25+27+23+28 : 103 kW Specific power consumption : 0.303 kW/cfm Leakage quantity : 45% of actual output : 0.45 x 340 : 153 cfm Equivalent power loss : 0.303 x 153 : 46.4 kW b) If 50% leakages are arrested i.e. 76.5 cfm, the power loss is 23.2 kW Hence power savings : 23.2 kW

2	**One Plant has one compressor of capacity 1680 m³/h. Free air delivery of the compressor is carried out by filling the receiver.** The test data is as follows: Receiver capacity : 10 m^3 Interconnecting pipe : 1 m^3 Initial pressure in receiver : 1.0 kg/cm^2a Inlet air pressure to compressor 1.0 kg/cm^2a Final pressure : 8.25 kg/cm^2a Time taken to fill the receiver : 3 minutes (180 seconds) Inlet air temperature : 30 ^oC Air temperature in the receiver : 40 ^oC Motor rpm (D1) : 1400 Motor pulley diameter (N1) : 300mm Compressor rpm (D2) : 700 rpm Compressor Pulley diameter (N2) : 600 mm Average duration of loading : 40 minutes in an hour Average duration of unloading : 20 minutes in an hour Power consumption during loading : 150 kW Power consumption during unloading : 25 kW Cost of energy : Rs. 5.00 per kWh A : Find the Free air delivery of the compressor and % output when compared to rated capacity. B: Evaluate hourly consumption of air. C: How much energy (kWh) that the compressor will consume in an hour and in a day. Also evaluate the cost of energy per day(24 hours operation). D: Evaluate the specific power (cfm/kW) during loading period and overall specific power after considering the loading & unloading of compressor. E: Plant was interested to reduce the unloading time of the compressor by reducing the pulley diameter of the motor. Evaluate the speed of the compressor required for 10 minutes

unloading and 50 minutes and accordingly evaluate the diameter of the pulley of the motor.

Equation: D1 x N1 = D2 x N2

F: Estimate the hourly power consumption, energy savings after replacement of the pulley and payback period. Consider the cost of pulley and belts is Rs 40000 and operating hours of the compressor is 8000 in a year. (consider during loading the power consumption is 120 kW and during unloading the power consumption was 20 kW)

Ans. Free Air Delivery in m^3/min is given by:

$$= \frac{\text{Volume in } m^3 \; \mathbf{x} \; (\text{Final pressure} - \text{Initial pressure}) \text{ in kg/cm}^2\text{a} \; \mathbf{x} \; \text{Inlet temp in K}}{\text{Time in minutes x Inlet air pressure in in kg/cm}^2\text{a x Outlet air temp in K}}$$

$$= \; : \frac{11 \quad x \quad (8.25\text{-}1) \quad x \quad (30+273)}{3 \quad x \quad 1 \quad x \quad (40+273)}$$

: 3.67 x 7.25 x 0.968

: 25.75 m^3/min

: 1545 m^3/h

: 914 cfm

% output is given by

: Actual FAD x 100 / Rated output

: 545 x 100 / 1680

: 92%

B: Hourly air consumption

Hourly consumption of air:

Average duration of loading	: 40 minutes in an hour
Average duration of unloading	: 20 minutes in an hour
% loading of the compressor	: 40 x 100/ (40+20)
	: 66.7% loading
Hourly consumption of air is given by	: % loading x actual out put
	: 0.667 x 1545
	: 1030 m^3/h
	: 609 cfm

C: Energy consumption:

% of loading of the compressor	: 66.7 %
% of unloading of the compressor	: 33.3 %

Hourly energy consumption is given by:

= (% loading x load power) **+** (% unloading x unload power)

: (0.667 x 150) + (0.333 x 25)

: 108.375 kWh

	Daily energy consumption	: 108.375 x 24
		: 2601 kWh
	Cost of energy per day	: 2601 x 5
		: Rs. 13005 /day
	D: Specific energy (cfm/kW):	
	During loading	: Actual FAD in cfm / Load power in kW
		: 914/150
		: 6.09 cfm/kW
	Over all specific energy is given by = Actual hourly air consumption in cfm / Actual energy per hour	
		: 609/108.37
		: 5.67 cfm/kW
	E: Speed of the compressor, Pulley size of the motor At present 609 cfm is obtained in 40 minutes when compressor is operating at 700 rpm. The same 609 cfm should be obtained in 50 minutes after changing of the pulley.	
	The speed of the compressor (proposed)N2	: 700 x 40 / 50
		: 560 rpm
	Proposed motor pulley diameter is D1	: N2 x D2/N1
		: 560 x 600 /1400
		: 240 rpm
	Caution: The proposed speed of the compressor is 560 cfm. Please refer the instruction manual of the compressor for the lowest speed that the compressor will operate with sufficient lubrication since the lubrication pump is directly connected to the compressor shaft. Other wise external pump for lubrication can be provided which may consume about 0.3 -0.4 kW. This should considered during the techno-economics evaluation	
	F. Power consumption & Payback period	
	Hourly consumption of air is given by	: (120 kW x (50/60)) + (20 kW x (10/60))
		: 103.33 kWh
	Energy savings	: 108.375 – 103.33 kW
		: 5 kW
	Annual energy savings	: 5 kW x 8000 h
		: 40 000 kWh
	Annual cost savings	: Rs. 40000 x 5 = Rs. 200, 000 i.e Rs 2.00 lakh
	Investment required	: Rs. 40, 000
	Payback period	: 0.2 years (2.4 months)

2.	A reciprocating two stage air compressor of 492 cfm capacity is operating in a manufacturing industry. The FAD test was conducted by Pump up Method. The following parameters were measured during the test. Receiver diameter : 1.78 m Receiver height : 0.8 m Volume of interconnecting pipelines : 0.09 m^3 Time taken to fill up the receiver : 1.48 minutes Initial pressure : Atmospheric Receiver pressure : 7.75 kg/cm^2 (g) Ambient temperature : 32 ^oC Compressed air temperature : 32 ^oC a. Calculate the actual FAD delivered by the compressor and express it in terms of percentage of design FAD. b. Also calculate the Isothermal efficiency and specific power consumption if the actual power consumption by the compressor is 89.7 kW. Assume motor efficiency as 90%. <u>a. Calculation of actual FAD of compressor</u> Volume of the receiver : ∏ x $(1.78)^2$ / 4 x 0.8 : 2.0 m^3 Volume of interconnecting pipelines : 0.09 m^3 Total volume : 2.09 m^3 Time taken to fill the receiver : 1.48 minutes Initial pressure : 1.0 kg/cm^2 a Receiver pressure : 8.75 kg/cm^2 a FAD : (8.75 – 1.0) x 2.09/ (1.0 x 1.48) : 10.94 m^3/min Rated FAD of the compressor : 492 cfm : 13.85 m^3/min Actual FAD as percentage of rated FAD : 79 % <u>b. Isothermal Efficiency</u> Compression ratio, r : 8.75 / 1.0 : 8.75 Isothermal Power, kW : 1.0 x 10.94 x 60 x ln (8.75)/36.7 : 38.8 Actual Power consumption, kW : 89.7 Isothermal Efficiency : 38.8 / (89.7 x 0.9) : 48.06 % Specific Power Consumption, kW/m^3/min: 89.7 / 10.94 = 8.2
3.	The following data are available for a single stage reciprocating air compressor. Receiver volume : 8.5 m^3 Time taken to fill up the receiver : 4 minutes

	Initial pressure	:	1 kg/cm^2, a
	Final pressure	:	3.5 kg/cm^2 a
	Cylinder bore	:	0.3 m
	Cylinder stroke	:	0.15 m
	Speed of motor	:	1445 rpm
	Speed of compressor	:	650 rpm
	No. of cylinders	:	1
	Compressor input power	:	18.5 kW
	No. of acting	:	single acting
	Calculate:		
	a. Free air delivery		
	b. Volumetric Efficiency		
	c. Isothermal Efficiency		
	d. Specific power consumption		
	a. Free air delivery		
	FAD	:	(3.5 – 1.0) x 8.5 / 4
		:	5.31 m^3/min
	b. Volumetric Efficiency		
	Compressor Displacement	:	$\prod$ x $(0.3)^2$ / 4 x 0.15 x 650
		:	6.89 m^3/min
	Volumetric Efficiency	:	FAD x 100 / Compressor Displacement
		:	5.31 x 100 / 6.89
		:	77.1 %
	c. Isothermal Efficiency		
	Compression Ratio	:	3.5
	Isothermal Power	:	1.0 x (5.31 x 60) x $\log_e$ (3.5 /36.7)
		:	10.88 kW
	Isothermal Efficiency	:	10.88 x 100 / 18.5
		:	58.8 %
	d. Specific Power Consumption	:	18.5 / 5.31
		:	3.48 kW / m^3/min