Chapter 3.3: Compressed Air System

Part–I: Objective type questions and answers

1.	Which of the following type does Screw compressor belongs to? a) Positive displacement compressor b) Dynamic compressors c) Both a & b d) None of the above
2.	The compressor capacity of a reciprocating compressor is directly proportional to __ a) Speed b) Pressure c) Volume d) All
3.	Vertical type reciprocating compressors are used in the capacity range of _____ a) 50 – 150 cfm b) 200 – 500 cfm c) Above 10ooo cfm d) 10 – 50 cfm
4.	The specific power consumption of non lubricated compressor compared to lubricated type is ____ a) Lesser b) Same c) Higher d) None
5.	The discharge temperature of two stage compressor compared to single stage one is ____ a) Lesser b) Same c) Higher d) None
6.	The compression ratios for axial flow compressors are ____. a) Lesser b) Higher c) moderate d) None
7.	The volumetric efficiency of the compressor ______ with the increase in altitude of place a) increases b) decreases c) does not change d) None
8.	The ratio of isothermal power to actual measured input power of a compressor is known as: a) Isothermal efficiency b) Volumetric Efficiency c) Barometric efficiency d) None
9.	The basic function of air dryer in a compressor is: a. prevent dust from entering compressor b. storage and smoothening pulsating air output c. reduce the temperature of the air before it enters the next state to increase efficiency d. to remove remaining traces of moisture after after-cooler
10.	For every 4°C raise in air inlet temperature of an air compressor, the power consumption will increases by_____ a) 2% b) 1% c) 3% d) 4%
11.	The percentage increase in power consumption of a compressor with suction side air filter and with the pressure drop across the filter of 200 mmWc is ____ a) 1.0% b) 3% c) 2.4% d) 1.6%
12.	Which of the statement is “True” for centrifugal compressors? a) The compressor should not be operated at full load b) The compressor should be operated at shut off pressure c) The compressor should not be operated with inlet-guide vane control

	d) The compressor should not be operated close to the surge point
13.	Identify the correct statement for air compressors. a. For every 5.5°C drop in the inlet air temperature, the increase in energy consumption is by 2%. b. For every 4 °C rise in the inlet air temperature, the decrease in energy consumption is by 1% c. For every 4 °C rise in the inter air temperature, the increase in energy consumption is by 1% d. The energy consumption remains same irrespective of inlet air temperature
14.	Reduction in the delivery pressure of a Compressor working at 7 bar, by 1 bar would reduce the power consumption by a) 6 to 10 % b) 2 to 3 % c) 12 to 14 % d) None of the above
15.	The acceptable pressure drop at the farthest point in mains header of an industrial compressed air network is: a)0.3 bar b) 0.5 bar c) 1.0 bar d) 2 bar
16.	The likely estimate on equivalent power wastage for a leakage from 7 bar compressed air system through 1.6 mm orifice size is ____ a) 0.2 kW b) 3.0 kW c) 0.8 kW d) 12 kW
17.	From the point of lower specific energy consumption, which of the following compressors are suitable for part load operation? a) Two stage reciprocating compressors b) Centrifugal compressors c) Two stage screw compressor d) Single stage screw compressor
18.	From base load operation and from achieving best specific energy consumption point of view, which of the following compressors are suitable? a) Single stage reciprocating compressors b) Centrifugal compressors c) Two stage reciprocating compressor d) Multi stage reciprocating compressor
19.	Which of the following parameters are not required for evaluating volumetric efficiency of the compressor? a) Power b) Cylinder bore diameter c) Stroke length d) FAD
20.	If the compressor of 200 cfm loads in 10 seconds and unloads in 20 seconds, the air leakage would be_____ a) 67 cfm b) 100 cfm c) 10 cfm d) 133 cfm

Part – II: Short type questions and answers

1.	Give major classifications of compressors and the basic principle of its working. The major classifications of compressors are positive displacement and dynamic type. Positive displacement can be further divided in to (a) Reciprocating (b) Rotary. Dynamic compressors divided into Radial and Axial. In case of positive displacement compressors increase the pressure of air/gas by reducing the volume. Dynamic compressors increase the air or gas velocity, which is then converted to increase the pressure.

2.	If the compressor of 200 m^3/min loads in 10 seconds and unloads in 20 seconds, calculate the amount of air leakages in the system. The system leakage is calculated by: System leakage in ‘m^3/min’ = $\frac{QxT}{(T+t)}$ Where Q = Actual free air being supplied during trial in m^3/min T = Load time in minutes t = Unload time in minutes = 200 x 10 / (10 + 20) = 67 m^3/min
3.	Briefly describe about ‘rotary compressor’? Rotary compressors have rotors in place of pistons and give a continuous, pulsation free discharge. They operate at high speed and generally provide higher throughput than reciprocating compressors. They are directly coupled to the prime mover and require lower starting torque as compared to reciprocating machines. Also they require smaller foundations, vibrate less, and have a lower number of parts which are subject to wear.
4.	What are the limitations of a centrifugal compressor operation? The major limitation of a centrifugal compressor is that is operates at peak efficiency at design point only and any deviation from the operating point is detrimental to its performance. When selecting centrifugal compressors, close attention should be paid during system design to ensure that at high pressure, with the consequent reduction in flow, the surge point is not reached.
5.	What is a surge point and how do you prevent surging, in centrifugal compressors? Surge point is the point on the performance curve where a further decrease inflow (typically in the region of 50-70 % of rated capacity) causes instability, resulting in a pulsating flow, which may lead to overheating, failure of bearings due to thrust reversals, or excessive vibration. Bypass valves advents are commonly used to prevent surging.
6.	What is the function of an air receiver? The main purpose of a receiver is to act as a pulsation damper, allowing intermittent high demands for compressed air to be met from a small compressor set, resulting in lesser energy consumption.
7.	Calculate the free air delivery (FAD) of a compressor for the following observed data: Receiver capacity: 0.25 m^3 Initial pressure: 1 kg/cm^2 (g) Final pressure: 13 kg/cm^2 (g) Initial temperature: 22 ^oC Final temperature: 42 ^oC Additional holdup volume: 0.05 m^3 Compressor pump up time: 3.9 minutes Q = $\frac{P_2 - P_1}{P_0} \times \frac{V}{t} \times \left(\frac{273+t_1}{273+t_2}\right)$

	$= \frac{13-1}{1.026} \times \frac{(0.25+0.05)}{3.9} \times \left(\frac{273+22}{273+42}\right)$ $= 0.837\ m^3/min$
8.	Explain about the importance of optimal Pressure settings of a compressed air network The power consumed by a compressor depends on its operating pressure and rated capacity. They should not be operated above their optimum operating pressure as this not only wastes energy, but also leads to excessive wear, leading to further energy wastage. The volumetric efficiency is also less at higher delivery pressure. The possibility of down setting the delivery pressure should be explored by careful study of pressure requirements of various equipment and pressure drop between generation point and utilization point. The pressure switches must be adjusted such that the compressor cut-in and cuts-off at optimum levels.
9.	List the components of a compressed air system. The various components of a compressed air system are: • Intake air filters • Inter-stage coolers • After coolers • Air-dryers • Moisture traps • Receivers
10.	Why inter-coolers are required for multi-stage reciprocating compressors? The intercoolers reduce the temperature of air/gas discharged between stages. Ideally, the intake temperature at each stage should be the same as that at the first stage (referred to a perfect cooling), so that the volume of air to be compressed does not increase and hence reduced power consumption.
11.	What are the likely effects of using very cold water in intercoolers for reciprocating compressors? Use of very cold water can result in condensation which may result in water entering the cylinder, thereby reducing valve life, accelerating wear and scoring of piston, piston rings and cylinder. The condensed water may also wash away the oil film on the cylinder and cause rust which will result in abrasion during compressor operation and significantly reduce efficiency.
12.	Give the empirical relation to evaluate the volumetric efficiency. $\text{Volumetric efficiency} = \frac{\text{Free air delivered } m^3/min}{\text{Compressor displacement}}$ $\text{Compressor Displacement} = \frac{(\Pi) \times (D^2) \times (L) \times (S) \times (\chi) \times (n)}{4}$ D = Cylinder bore, metre L = Cylinder stroke, metre S = Compressor speed rpm χ = 1 for single acting and 2 for double acting cylinders n = No. of cylinders

13.	List the means of capacity control for reciprocating compressors. ▪ On/off control ▪ Load and unload control ▪ Multi-step control
14.	List the advantages of keeping the discharge pressure for reciprocating compressors at minimum. ▪ Lower power consumption ▪ Less load on the piston rods and hence reduced maintenance costs ▪ Lower leakage losses
15.	What are the different types of pressure regulators available for air compressor system? ▪ Pilot operated type ▪ Direct acting type ▪ Self – relieving type
16.	What are the most common types of compressed air dryers used? a. Heat – less dryer (absorption) b. Adsorption dryer c. Chiller dryer (refrigerated dryers)
17.	Can you explain how temperature of inlet air affects the energy consumption of an air compressor? As a thumb rule "for every 4 °C rise in inlet air temperature results in a higher energy consumption by 1% to achieve equivalent output". Hence cool air intake leads to a more efficient compression.
18.	Which type of energy efficient dryer can be opted if a user in a plant requires compressed air at atmosphere dew point of -40°C? Desiccant regenerative type dryer can be opted if a user in a plant requires compressed air at atmosphere dew point of -40°C.
19.	What is the effect of increase in altitude on the performance of single stage reciprocating compressors? With the increase in altitude, there will be reduction in air pressure, which results in increase in compression ratio, leading to higher discharge temperature and reduced efficiency.
20.	What are the methods of capacity control in centrifugal air compressors? Centrifugal compressors operate best at the design point. They are prone to surging at flow rates less than 50% of the rated capacity. The following types of controls are employed in centrifugal compressors. a) Modulating controls: Modulating (throttling) inlet controls allows the output of a compressor to be varied to meet flow requirements. Throttling is usually accomplished by closing down inlet vane, thereby restricting inlet air to the compressors. The amount of capacity reduction is limited by the potential for surge and minimum throttling capacity. b) Variable speed drives: Efficient way of compressor capacity control is application of variable speed drives to match compressor output to meet varying load requirements is by speed control

Part – III: Long type questions and answers

1. Explain the simple steps that can be followed in shop – floor for quantification of compressed air leakages.

The following steps can be followed for quantification of compressed air leakages.

- Shut off compressed air operated equipments (or conduct test when no equipment is using compressed air).
- Run the compressor to charge the system to set pressure of operation
- Note the sub-sequent time taken for 'on load' and 'off load' cycles of the compressors. For accuracy, take ON & OFF times for 8 – 10 cycles continuously. Then calculate total 'ON' Time (T) and Total 'OFF' time (t).
- The system leakage is calculated as
- % leakage = T × 100 / (T + t)

(or) System leakage (cmm) = Q × T / (T + t)

Q = Actual free air being supplied during trial, in cubic meters per minute (cmm)

T = Time on load in minutes

T = Time unload in minutes

2. In an automobile industry one compressor of rated capacity of 1000 cfm is operated to evaluate leakage quantity in the plant during a holiday when no equipment was using compressed air. FAD test was also carried out before conducting leakage test and found that the compressor is delivering out put of 90% of rated capacity.

The observations on leakage test are:

a) Compressor was on load for 08 minutes

b) Compressor was unloaded for 48 minutes

c) Compressor was consuming 144 kW

Evaluate

a) Free air delivery

b) Specific power consumption

c) % leakage in compressed air system

d) Leakage quantity

e) Power lost due to leakage

Compressor capacity : 1000 cfm

a. Operating capacity (FAD) : 90% of rated capacity

: 0.90 x 1000 cfm

: 900 cfm

b. Specific power consumption

Actual power consumption : 144 kW

Actual output : 900 cfm

Specific power consumption : 900/144

: 6.25 cfm / kW

c. % Leakage in the system

Load time (T) : 08 minutes

Un load time (t) : 48 minutes

	% leakage in the system : $\frac{T}{(T+t)} x100$: $\frac{08}{(08+48)} x100$: 14.2% d. Leakage quantity : 0.142 x 900 : 127.8 cfm e. Power lost due to leakage : $\frac{Leakage\,quality}{Specific\,energy}$: $\frac{127.8}{6.25}$: 20.45 kW
3.	In a chemical industry reciprocating compressor of two stages was tested for free air delivery. The test details are as follow: a) Receive capacity : 5 m^3 b) Initial pressure : 1 kg/cm^2 g c) Final pressure : 7.0 kg/cm^2 g d) Connecting pipe volume and moisture separator volume : 0.5 m^3 e) Compressor pump up time : 5 minutes f) Motor power consumption : 37 kW g) Temp. of air in the receiver : 36 °C h) Ambient air temperature : 30 °C Evaluate the FAD (free air delivery), and specific power consumption. <u>Actual free air delivery</u> $Q = \frac{p_2 - p_1}{p_0} x \frac{V}{T} x \left(\frac{273+t_1}{273+t_2}\right)$ Q = m^3/min, P2 = Final pressure in kg/cm^2 a = 8 kg /cm^2 a P1 = Initial pressure in kg/cm^2 a = 2 kg / cm^2 a P0 = Absolute pressure kg/cm^2 a = 1.026 kg/cm^2 a V = Receiver+connecting pipe volume in m^3 = 5 + 0.5 = 5.5 m^3 T = Time taken to fill the receiver in minutes t1 = Ambient temp. in °C = 30 °C t2 = Final temp. is received °C = 36 °C

	FAD (Q) = $\frac{(8-2)}{1.026} x \frac{5.5}{5} x \frac{(273+30)}{(273+36)}$ = 6.3 m^3/min = 378 m^3/h = 236 cfm Specific power consumption kW/cfm = 0.156 cfm/kW = 6.37
4.	Explain about the air compressor modulation by optimal pressure settings. Very often in an industry, different types, capacities and makes of compressors are connected to a common distribution network. In such situations, proper selection of a right combination of compressors and optimal modulation of different compressors can conserve energy. Where more than one compressor feeds a common header, compressors have to be operated in such a way that the cost of compressed air generation is minimal. ▪ If all compressors are similar, the pressure setting can be adjusted such that only one compressor handles the load variation, whereas the others operate more or less at full load. ▪ If compressors are of different sizes, the pressure switch should be set such that only the smallest compressor is allowed to modulate (vary in flow rate). ▪ If different types of compressors are operated together, unload power consumptions are significant. The compressor with lowest no load power must be modulated. ▪ In general, the compressor with lower part load power consumption should be modulated. ▪ Compressors can be graded according to their specific energy consumption, at different pressures and energy efficient ones must be made to meet most of the demand.
5.	Explain the simple method of capacity assessment of air compressors. • Isolate the compressor along with its individual receiver being taken for test from main compressed air system by tightly closing the isolation valve or blanking it, thus closing the receiver outlet. • Open water drain valve and drain out water fully and empty the receiver and the pipe line. Make sure that water trap line is tightly closed once again to start the test. • Start the compressor and activate the stop watch. • Note the time taken to attain the normal operational pressure P_2 (in the receiver) from initial pressure P_1. • Calculate the capacity as per the formulae given below : **Actual Free air discharge** $Q = \frac{P_2 - P_1}{P_0} \times \frac{V}{T} \text{ NM}^3 / \text{Min.}$ Where P_2 = Final pressure after filling (kg/cm^2 a) P_1 = Initial pressure (kg/cm^2a) after bleeding P_0 = Atmospheric Pressure (kg/cm^2 a) V = Storage volume in m^3 which includes receiver, after cooler, and delivery piping T = Time take to build up pressure to P_2 in minutes

	The above equation is relevant where the compressed air temperature is same as the ambient air temperature, i.e., perfect isothermal compression. In case the actual compressed air temperature at discharge, say t_2 ^{0}C is higher than ambient air temperature say t_1 ^{0}C (as is usual case), the FAD is to be corrected by a factor $(273 + t_1) / (273 + t_2)$.