# MODEL SOLUTIONS

## 16th NATIONAL CERTIFICATION EXAMINATION FOR ENERGY MANAGERS & ENERGY AUDITORS – September, 2015

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| **PAPER – 3: Energy Efficiency in Electrical Utilities** |
| **Date: 20.09.2015 Timings: 0930-1230 HRS Duration: 3 HRS Max. Marks: 150** |

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**Section – I: OBJECTIVE TYPE** **Marks: 50 x 1 = 50**

i) Answer all **50** questions
ii) Each question carries **one** mark
iii) Please hatch the appropriate oval in the OMR answer sheet with Black Pen or HB pencil

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| 1. | Which loss in a distribution transformer is dominating; if the transformer is loaded at 68% of its rated capacity<br><br>a) core loss b) <u>copper loss</u> c) hysteresis loss d) magnetic field loss |
| 2. | In a rolling mill, the loading on transformer was 1200 kVA with the power factor of 0.86. The plant improved the power factor to 0.98 by adding capacitors. What is the reduction in kVA<br><br>a) 1053 b) <u>147</u> c) 24 d) nil |

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| 3. | A 22 kW, 415 kV, 45A, 0.8 PF, 1475 RPM, 4 pole 3 phase induction motor operating at 420 V, 40 A and 0.8 PF. What will be the rated efficiency<br><br>a) 85.0% b) 94.5% c) 89.9% d) 88.2% |
| 4. | A 4 pole 50 Hz 3 phase induction motor has a full load slip of 5 %. The full load speed is:<br><br>a) 750 b) 1425 c) 1500 d) 1475 |
| 5. | In a no load test of a poly-phase induction motor, the measured power by the wattmeter consists of:<br><br>a) core loss b) copper loss<br>c) core loss, windage & friction loss d) stator copper loss, iron loss, windage & friction loss |
| 6. | If the observed temperature in air receiver is higher than ambient air temperature the correction factor for free air delivery will be:<br><br>a) less than one b) greater than one c) equal to one d)equal to zero |
| 7. | If the COP of a vapour compression system is 3.5 and the motor draws power of 10.8 kW at 90% motor efficiency, the cooling effect of vapour compression system will be:<br><br>a) 34 kW b) 37.8 kW c) 0.36 kW d) none of the above |
| 8. | Star – delta starter of an induction motor<br><br>a) reduces voltage by inserting resistance in rotor circuit<br>b) reduces voltage by inserting resistance in stator circuit |
| 9. | The adsorption material used in an adsorption air dryer for compressed air is |

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| | a) calcium chloride b) magnesium chloride c) <u>activated alumina</u> d) potassium chloride |
| 10 | If the speed of a reciprocating pump is reduced by 50 %, the head<br><br>a) is reduced by 50% b) is reduced by 12.5%<br>c) <u>remains same</u> d) none of the above |
| 11 | The unit of specific humidity of air is:<br><br><u>a) grams moisture/kg of dry air</u> b) moisture percentage in air<br>c) grams moisture/kg of air d) percentage |
| 12 | The cooling tower size is ______________ with the entering WBT when heat load, range and approach are constant.<br><br>a) directly proportional b) <u>inversely proportional</u> c) constant d) none of above |
| 13 | Calculate the density of air at 11400 mmWC absolute pressure and $65^0$C. (Molecular weight of air: 28.92 kg/kg mole and Gas constant:847.84 mmWC $m^3$/kg mole K)<br><br>a) 1.2 kg/$m^3$ b) 1.5 kg/$m^3$ c) <u>1.15 kg/$m^3$</u> d) none of the above |
| 14 | A spark ignition engine is used for firing which type of fuels:<br><br>a) high speed diesel b) light diesel oil c) <u>natural gas</u> d) furnace oil |
| 15 | A DG set consumes 70 litres per hour of diesel oil. If the specific fuel consumption of this DG set is 0.33 litres/ kWh at that load, then what is the kVA loading of the set at 0.8 PF?<br><br>a) 212 kVA b) <u>265 kVA</u> c) 170 kVA d) none of the above |
| 16 | The nomenclature T2,T5,T8 and T12 for fluorescent lamps are categorized based on<br><br><u>a) diameter of the tube</u> b) length of the tube<br>c) both diameter and length of the tube d) power consumption |

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| 17 | A hotel building has four floors each of 1000 $m^2$ area. If the interior lighting power allowance for the hotel building is 43000W, the Lighting Power Density (LPD) is:<br><br>a) 10.75 b) 0.09 c) 43 d) data insufficient |
| 18 | The percentage reduction in distribution loses when tail end power factor raised from 0.85 to 0.95 is<br><br>a) 10.1% b)19.9% c)71% d)84% |
| 19 | The inexpensive way to improving energy efficiency of a motor which operates consistently at below 40% of rated capacity is by ______.<br><br>a) operating in star mode b) replacing with correct sized motor<br>c) operating in delta mode d) none |
| 20 | Higher COP can be achieved with______.<br><br>a) lower evaporator temperature and higher condenser temperature<br>b) higher evaporator temperature and Lower condenser temperature<br>c) higher evaporator temperature and higher condenser temperature<br>d) lower evaporator temperature and Lower condenser temperature |
| 21 | Installing larger diameter pipe in pumping system results in<br><br>a) increase in static head b) decrease in static head<br>c) increase in frictional head d) decrease in frictional head |
| 22 | Friction losses in a pumping system is<br><br>a) inversely proportional to flow b) inversely proportional to cube of flow<br>c) proportional to square of flow d) inversely proportional square of flow |
| 23 | Installation of Variable frequency drives (VFD) allows the motor to be operated with<br><br>a) constant current b) lower start-up current c) higher voltage<br>d)none of the above |
| 24 | The indicator of cooling tower performance is best assessed by |

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| | a) wet bulb temperature b) dry bulb temperature c) range d) approach |
| 25 | L / G ratio in cooling tower is the ratio of<br><br>a) length and girth b) length and gradient of temperature<br>c) water mass flow rate and air mass flow rate d) water volume flow rate and air volume flow rate |
| 26 | Ignitors are used for starting<br><br>a) FTL b) CFL c) metal halide d) none of the above |
| 27 | Lower power factor of a DG set demands<br><br>a) lower excitation currents b) no change in excitation currents<br>c) higher excitation currents c) none of the above |
| 28 | Speed of the rotor of an induction motor is always<br><br>a) greater than its synchronous speed b) less than its synchronous speed<br>c) equal to its synchronous speed d)integer multiple of its synchronous speed |
| 29 | Trivector meter measures three vectors representing<br><br>a) active, reactive and maximum demand b) active, power factor and apparent power<br>c) active, harmonics and maximum demand d) active, reactive and apparent power |
| 30 | The capacitor size in kVAr required to improve power factor from 0.90 to unity for 900 kW Load will be<br><br>a) 720 kVAr b) 436 kVAr c) 485 kVAr d) none of the above |
| 31 | The actual measured load of 1000 k VA transformer is 400 k VA . Find out the total transformer loss corresponding to this load if no load loss is 1500 Watts and full load Copper Loss is 12,000 Watts |

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| | a) 1920 watts b) 1500 watts c) 3420 watt d) 13500 watts |
| 32 | Illuminance of a surface is expressed in<br><br>a) radians b) lux c) lumens d) LPD |
| 33 | What is the function of drift eliminators in cooling towers<br><br>a) maximize water and air contact b) capture water droplets escaping with air stream<br>c) enables entry of air to the cooling tower d) eliminates uneven distribution of water into the cooling tower |
| 34 | In a large compressed air system, about 70% to 80% of moisture in the compressed air is removed at the<br><br>a) air dryer b) after cooler c) air receiver d) inter cooler |
| 35 | If EER of One Ton Split AC is 3.5, what is its power rating?<br><br>a) 1.0 k W b) 1.5 kW c) 0.8 kW d) None of the above |
| 36 | A 100 kVAr capacitor rated for 415 Volts is connected across a load with 390 Volts normal supply. The effective kVAr will be<br><br>a)100 b) 93.98 c) 88.31 d) none of the above |
| 37 | Slip power recovery system is applicable in case of<br><br>a) squirrel cage induction motor. b) wound rotor motor c) synchronous motor d) DC shunt motor |
| 38 | FAD of a compressor means discharge at<br><br>a) standard temperature conditions at suction b) actual temperature conditions at suction<br>c) standard temperature conditions at delivery d) actual temperature conditions at delivery |
| 39 | The illuminance of a lamp at one meter distance is 10 $Lm/m^2$. What will be the corresponding value at 0.7 meter distance |

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| | a)14.28 b) 20.41 c) 10 d) None of these |
| 40 | Power factor Improvement will result in<br><br>a) reduction in active power b) reduction in active current<br>c) reduction in reactive power d) all the above |
| 41 | Humidification involves<br><br>a) reducing wet bulb temperature and specific humidity<br>b) reducing dry bulb temperature and specific humidity<br>c) increasing wet bulb temperature and decreasing specific humidity<br>d) reducing dry bulb temperature and increasing specific humidity |
| 42 | The fan system resistance is predominately due to<br><br>a) more bends used in the duct b) more equipments in the system<br>c) volume of air handled d) density of air |
| 43 | Flow control by damper operation in fan system will<br><br>a) increase energy consumption b) reduce energy consumption<br>c) reduce system resistance d) none of the above |
| 44 | In three phase transformer, the load current is 139.1A, and secondary voltage is 415V. The rating of the transformer would be ____________.<br><br>a) 50 kVA b) 57.72 kVA c) 100 kVA d) 173 kVA |
| 45 | Occupancy linked Control can be achieved using<br><br>a) ultrasonic sensors b) acoustic sensors c) infrared sensors d) all the above |
| 46 | Power factor is highest in case of<br><br>a) sodium vapour lamps b) mercury vapour lamps c) fluorescent lamps d) incandescent lamps |
| 47 | The percentage imbalance when line-line voltages are 415 V, 418 V and 408 V is<br><br>a) 1.047% b) 0.32% c) 1.44% d) none of the above |

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| 48 | A 50 hp motor with a full load efficiency rating of 90 percent was metered and found to be operating at 25 kW. The percent Motor Load is<br>a) 75% b) 50% c) 60% d) 25% |
| 49 | Time of the Day metering (TOD) is a way to<br><br>a) reduce the peak demand of the distribution company b) increase the revenue of the distribution company<br>c) increase the peak demand d) increase the maximum demand in a industry |
| 50 | Pumps of different sizes can run in parallel provided their…….. are similar<br><br>a) static head b) discharge head c) closed valve heads<br>d) none of these |

***…………. End of Section – I …………..***

## Section – II: SHORT DESCRIPTIVE QUESTIONS Marks: 8 x 5 = 40

(i) Answer all **Eight** questions
(ii) Each question carries **Five** marks

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| S-1 | The input power to a fan is 40kW for a 3125 Nm /hr fluid flow. The fan pulley diameter is 375mm. If the flow to be reduced by 15% by changing the fan pulley, what should be the diameter of fan pulley and power input to fan. |

Solution:

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| 1 | Input power to fan kW | 40 |
| 2 | Fluid flow $Nm^3/hr$ | 3125 |
| 3 | Diameter of Fan pulley (mm) | 375 |
| 4 | Governing Equation is $N_1D_1=N_2D_2$ | Eqn-1 |
| 5 | $N_2 = 0.85N_1$ | given |
| 6 | From Eqn-1 $D_2=(D_1)*(N_1/N_2)$; = $(375)*(N_1/0.85N_1)$ | 441.2mm |
| 7 | $(KW_1/KW_2) = (N_1^3/N_2^3)$; Hence, $KW_2=(N_2/N_1)^3*(KW_1) =(0.85 N_1/N_1)*(40)$ | 24.6KW |
| So Power requirement for fan will be 24.6 kW. | | |
| Fan pulley to be changed to 441.2 mm diameter. | | |

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| S-2 | The following single line diagram depicts the location of a 130 kW heater load and a 220 kW motor (which is 200 metres away from the 415V, LT bus). The main incoming line power factor of the system is 0.82 lag. Calculate the rating of capacitors to improve PF of main incoming line to 0.95 lag. |

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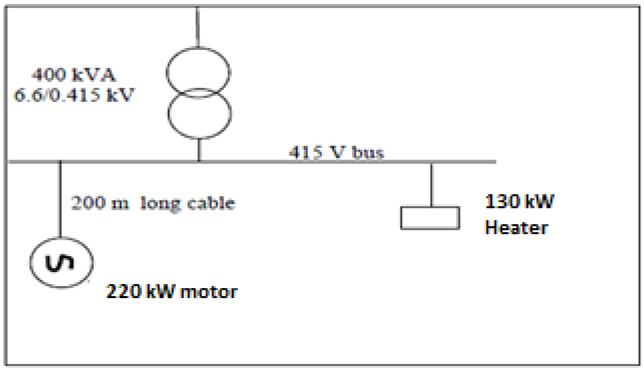
| | <br> |
| | Ans:<br>Total Inductive load requiring PF compensation=220kW (since the other 130 kW is a resistive load)<br>Operating PF cos φ1= 0.82 lag.<br>Desired PF cos φ2= 0.95 lag<br>kVAr required=kW((tan($\cos^{-1}\varphi_1$)-tan($\cos^{-1}\varphi_2$))<br>=220(tan ($\cos^{-1}$0.82)-tan ($\cos^{-1}$0.95))<br>=220( tan(34.92)-tan(18.19))<br>=220(0.698-0.329)<br>=220(0.369)<br>=81.2 kVAr |
| S-3 | State five possible methods of electrical demand management in a plant electrical system to minimize maximum demand. |
| | Ans<br>i. Rescheduling operation time period of loads<br>ii. Storage of products, in process material or utilities such as refrigeration |

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| | iii. Shedding of non-essential loads<br><br>iv. Reactive Power Compensation<br><br>v. Operation of Captive Power Generator |
| S-4 | Match the following with respect to energy efficient compressed air system. |
| | Ans<br><br>A1-B3; A2-B4; A3-B1; A4-B5; A5-B2 |
| S-5 | In a DG set, the generator is rated at 1000 kVA, 415V, 1390 A, 0.8 PF, 1500 RPM. The full load specific energy consumption of this DG set as measured by the energy auditor is 3.8 kWh per liter of fuel and air drawn by the DG set is 14 kg/kg of fuel. The energy auditor has recommended a waste heat recovery (WHR) system. Also the auditor indicated that the waste heat recovery potential is 1.98 x$10^5$ kCal/hr at the existing engine exhaust gas temperature of 483°C.<br><br>Estimate the exhaust temperature to chimney after installation of proposed WHR system. The specific gravity of fuel oil is 0.86 and specific heat of flue gas is 0.25 kCal/kg °C. |

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| A1 | After Cooler | B1 | Lower the dew point of the compressed air discharge |
| A2 | As cool as possible for maximum energy efficiency | B2 | Locate at the bottom of lines at required intervals |
| A3 | Refrigerant Drier | B3 | Remove heat of compression from last stage of compression |
| A4 | Air receiver | B4 | Compressor Air Intake |
| A5 | Compressed air line drain traps | B5 | Dampen flow pulsations and helps compressed air peak demands |

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| | Solution: |

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| 1 | Rated kVA of Diesel Generator (given) | 1000 |
| 2 | Rated kW @ 0.8 PF 1*(0.8pf) | 800 |
| 3 | Specific fuel consumption (kwh/lts) (given) | 3.8 |
| 4 | Specific gravity of fuel oil (given) | 0.86 |
| 5 | Oil consumption at full load in kg/hr((2*4)/3) (800/3.8)x 0.86 | 181 |
| 6 | Air supplied per kg of fuel (kg) (given) | 14 |
| 7 | Mass of flue gas per kg of fuel (14+1) | 15 |
| 8 | Mass of flue gas kg per hour (7*5) (15x 181) | 2715 |
| 9 | waste heat recovery potential kCal/hr (given) | 198000 |
| 10 | Delta T across waste heat recovery system (Heat kCal/hr)/(mass of flue gas kg/hr*specific heat, kcal/kg$^0$C) (198000/(2715x0.25) | 291.71 |
| 11 | Present Flue gas temp. or temp. before waste heat recovery system (given) | 483 |
| 12 | Exit flue gas temp. after waste heat recovery system (483 – 291.71) | 191.29 |

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| S-6 | List five energy saving measures for air conditioning system. |

Solution:

- Insulate all cold lines / vessels using economic insulation thickness to minimize heat gains.
- Optimize air conditioning volumes by measures such as use of false ceiling and segregation of critical areas for air conditioning by air curtains.

Minimize the air conditioning loads by measures such as

- roof cooling,
- roof painting,
- efficient lighting,
- pre-cooling of fresh air by air- to-air heat exchangers
- Variable volume air system
- Optimal thermo-static setting of temperature of air conditioned spaces
- Sun film application

Minimize the process heat loads by measures involving TR reduction and refrigeration temperature level reduction

- Flow optimization
- Heat transfer area increase to accept higher temperature coolant
- Avoid wastages by heat gains
- Avoid wastages by loss of chilled water
- Avoid wastages by ideal flows.
- Frequent cleaning and descaling of all heat exchangers

At refrigeration and AC plant area

- Minimize part load operations by matching loads and plant capacity on line; adopt variable speed drives for varying load.
- Ensure regular maintenance of all AC plant component as per manufacturers guide lines.
- Ensure adequate quantity of chilled water flows, cooling water flows
- Avoid by pass flow by closing valves of ideal equipments
- Adopt VAR system where economics permit as non CFC solutions
- Make efforts to continuously optimize condenser and evaporator parameters for minimizing specific energy consumption and maximizing capacity

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| S-7 | The total system resistance of a piping loop is 60 meters and the static head is 20 meters at designed water flow. Calculate the system resistance offered at 85%, 65% and 35% of water flow |
| | Solution:<br><br>Total System Resistance of piping loop: 60m<br>Static Head :20 m<br>So, Dynamic Head at designed water flow: 40 m |
| S-8 | Define Lux and Luminous efficacy. |
| | Ans<br><br>Lux (lx) is the illuminance produced by a luminous flux of one lumen, uniformly distributed over a surface area of one square meter. It is also defined as the International System unit of illumination, equal to one lumen per square meter.<br><br>Luminous efficacy is defined as the ratio of luminous flux emitted by a lamp to the power consumed by the lamp. Efficacy is energy efficiency of conversion from electricity to light form. |

Table for S-7 solution:

| Sl. No. | Flow % | Dynamic Head (m) $= 40x\ (\%flow)^2$ | Static Head (m) | Total Resistance (m) |
|---|---|---|---|---|
| 1 | 85.0% | 28.9 | 20 | 48.9 |
| 2 | 65.0% | 16.9 | 20 | 36.9 |
| 3 | 35.0% | 4.9 | 20 | 24.9 |

***……………. End of Section - II …………….***

## Section – III: LONG DESCRIPTIVE QUESTIONS Marks: 6 x 10 = 60

(i) Answer all **Six** questions
(ii) Each question carries **Ten** marks

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| L-1 | a) List the design improvements that have been incorporated in Energy Efficient motors to increase operating efficiency over standard motors?<br><br>b) The power input to a three phase induction motor is 45 kW. If the induction motor is operating at a slip of 2% and with total stator losses of 2.1 kW, find the total mechanical power developed |
| | Solution:<br><br>a) Following design modifications have been done in EEMs : Use of lower loss silicon steel<br>a. A longer core<br>b. Thicker wire<br>c. Thinner lamination<br>d. Smaller air gap between rotor ans stator<br>e. Use of copper<br>f. Superior bearings<br>g. Smaller fan<br><br>b)<br>Stator input: 45kW<br>Stator losses: 2.1 kW<br>Stator output: 45 - 2.1= 42.9 kW<br>OR Rotor Input= 42.9 kW<br><br>Slip= 2%<br>Mechanical Power Output = ( 1-S) x Rotor Input = (1-0.02) x 42.9<br><br>= 42.04 kW |

L-2

a) In a chemical industry, cooling water of 9000 $m^3$/hr and 6000 $m^3$/hr from two independent heat exchangers with temperature of 41$^0$C and 52$^0$C respectively are fed to one cooling tower after proper mixing at top basin. If measured heat rejection by the cooling tower is 45000TR, calculate effectiveness and evaporation loss of the cooling tower at 32$^0$C WBT.

b) In an air conditioning duct 0.5 m x 0.5 m, the average velocity of air measured by vane anemometer is 28 m/s. The static pressure at suction of the fan is -20 mmWC and at the discharge is 30 mmWC. The three phase induction motor draws 10.8 A at 415 V with a power factor of 0.9. Find out efficiency of the fan if motor efficiency = 90% (neglect density correction)

Solution:

a)

| Sl. No. | Particulars | Stream 1 | Stream 2 |
|---|---|---|---|
| 1 | Flow Rate ($m^3$/hr) (given) | 9000 | 6000 |
| 2 | Temp. $^0$C (given) | 41 | 52 |
| 3 | Mix. Flow Rate ($m^3$/Hr) (Sl.1 +2) | 15000 | |
| 4 | Mix. Hot Water Temp. $^0$C [(Flow1 * Temp. 1) + (Flow 2 *Temp. 2)]/ (Flow1 + Flow 2) | 45.4 | |
| 5 | Heat Rejection (TR) (given) | 45000 | |
| 6 | Range of Cooling Tower $^0$C: (Heat Rejection TR * 3024) / (Flow $M^3$/hr * 1000) | 9.072 | |
| 7 | WBT $^0$C (given) | 32 | |
| 8 | Cold Water Temp. $^0$C (Mix. Hot Water Temp. – Range) | 36.328 | |
| 9 | Approach $^0$C (Cold Water Temp. – WBT) | 4.328 | |
| 10 | Effectiveness (Range/ (Range + Approach)) | 67.7 | |
| | Evaporation Loss ($m^3$/hr) | 208.2 | |

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| 11 | = 0.00085*1.8*Mix. Flow $m^3$/hr*Range | |

b)

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| 1 | Area of the Duct: (0.5*0.5) $m^2$ | 0.25 |
| 2 | Avg. velocity (m/s) (given) | 28 |
| 3 | Air Flow ($m^3$/s) (Sl. 1* Sl. 2) | 7 |
| 4 | Suction static Pr. (mmWC) (given) | -20 |
| 5 | Discharge Static Pr. (mmWC) (given) | 30 |
| 6 | Power drawn by the motor (kW): (1.732 * 415*10.8*0.8/1000) | 6.99 |
| 7 | Air Power kW: = Flow ($m^3$/s)* (Dis. Pr – Suc. Pr.) mmWC /102 | 3.43 |
| 8 | Power to fan Shaft kW (Motor Drawn power * Motor eff. of 90%) | 6.29 |
| 9 | Fan Static Eff. (%) = Air Power*100%/Shaft Input | 54.57 |

L-3 One of the process industries has installed 18 MW cogeneration plant. The Cogeneration plant maximum condenser load is 7 MW and the extraction steam of 57 TPH is used for process and also for vapour absorption machine. The condenser heat load is 550 Kcal/kg of steam and the steam rate is 5 kg/KW for condenser power. The heat load of VAM in 127 Kcal/min/TR and the capacity of VAM is 1100 TR. Estimate cooling tower heat load in Kcal/hr. If the tower is designed for 8°C range, calculate the water flow in cooling tower. The design approach temperature of the CT is 5°C.

Ans. Condenser load = 7 MW

Steam rate for condenser = 5 kg/KW

Total steam required for condenser power = 7000 X 5 = 35000 Kg/hr.

Condenser heat load = 35000 x 550 = 19250000 Kcal/hr.

Heat load of VAM = 1100 x 127 x 60 = 8382000 Kcal/hr.

Total heat load = 19250000 + 8382000 = 27632000 Kcal/hr.

Range of tower = 8deg C
Cooling water Flow required=27632000/8=3454000 lts or 3454 m3

**L-4** Compare the performance of centrifugal chiller with vapour absorption chiller using the data given below:

| Sl. No. | Parameter | Centrifugal Chiller | VAM |
|---|---|---|---|
| 1 | Chilled water flow ($m^3/h$) | 192 | 183 |
| 2 | Condenser water flow ($m^3/h$) | 245 | 360 |
| 3 | Chiller inlet water temperature ($^0C$) | 13 | 14.5 |
| 4 | Condenser water inlet temperature ($^0C$) | 28 | 32 |
| 5 | Chiller outlet water temperature ($^0C$) | 7.8 | 9.2 |
| 6 | Condenser water outlet temperature ($^0C$) | 36.2 | 40.7 |
| 7 | Chilled water pump consumption (kW) | 32 | 31 |
| 8 | Condenser water pump consumption (kW) | 38 | 52 |
| 9 | Cooling tower fan consumption (kW) | 9 | 22 |

If the compressor of centrifugal chiller consumes 220 kW, the steam consumption for VAM is 1620 kg/Hr. calculate the following:

i) Refrigeration load delivered (TR) for both systems?
ii) Condenser Heat load (TR) for both systems?
iii) Compare auxiliary power consumption for both systems, give reason?
iv) If electricity cost is Rs.5.0/kWh and steam cost is Rs.0.35/kg compare the operating cost for both systems.

Solution:

Compression Chiller vs VAM

| Sl. No. | Parameter | Centrifugal Chiller | VAM |
|---|---|---|---|
| 1 | Refrigeration load delivered (TR) = Mass of Chilled water flowx Specific heat * | 330.16 | 320.73 |
| 2 | Condenser heat load delivered (TR) = Mass of condenser water flow x Specific heat * | 664.35 | 1035.71 |
| 3 | Auxiliary Power Consumption (kW) = | 79 | 105 |
| 4 | The auxiliary power consumption in case of VAM system is higher because heat rejection in VAM condenser is comparatively higher than centrifugal chiller with | | |
| 5 | Total Energy Consumption: | 284 kW<br><br>(Auxiliary Power of 79kW and Chiller | Auxiliary Power of 105 kW and Steam consumption of 1620 |
| 6 | Operating Energy Cost per Hour of Operation | Rs. 1420/-<br><br>(284 * 5 = Rs. 1420/-) | Rs 1092/-<br><br>(105 * 5 = Rs. 525/- plus 1620 * 0.35 = Rs. 1092/-) |

L-5 In a diary plant 3 numbers of cooling water pumps, identical in characteristics are installed in parallel to supply cooling. During normal operation two of the pumps are operational while one pump is on standby. All pump combinations develop a discharge pressure of 3.4 kg/cm$^2$ (a). The installed water flow meter at the common header during an energy audit reads the following:

| Operating Pump No. | Flow Rate ($m^3$/hr) |
|---|---|
| Pump No 1 & 2 | 525 |
| Pump No 2 & 3 | 555 |
| Pump No 3 & 1 | 540 |

The power drawn by motors of cooling water pump 1, 2 & 3 are 30 kW, 33 kW & 31 kW respectively. While the operating motor efficiency for pump no. 1 & 2 is 92% the motor efficiency for pump no. 3 is 91.5%. If the water level in suction of all pumps is 3 meter below pump central line calculate the following:

i) Individual pump efficiencies
ii) Specific energy consumption (kWh/$m^3$)
iii) Which is the best operating pump combination

Solution:

Let flow of pump 1,2 &3 be X, Y and Z respectively.

From given:

X + Y = 525 ---------(1)
Y + Z = 555---------(2)
X + Z = 540 ---------(3)

Subtracting eqn (1) from eqn (2):

Z - X= 30 --------(4)

Adding eqn (3) and eqn (4):

2Z = 570
Z= 285

Putting Z value in eqn (2) and (3):

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| | Y = 270 and X = 255<br><br>Therefore, individual pump flow rates are: 255 $m^3$/hr, 270$m^3$/hr and 285 $m^3$/hr respectively. |

| Pump Ref: | 1 | 2 | 3 |
|---|---|---|---|
| **A)** Flow Rate ($M^3$/hr) *(calculated)* | 255 | 270 | 285 |
| **B)** Discharge Head (m) =3.4 kg/$cm^2$ (a) = 2.4 kg/$cm^2$ (g) =24 m *(given)* | 24 | 24 | 24 |
| **C)**Suction Head (m) (g) *(given)* | -3 | -3 | -3 |
| **D)**Total Head (Discharge Head - Suction Head)* *(B-C)* | 27 | 27 | 27 |
| **E)**Liquid kW [flow ($m^3$/s)*total head (m)*density (1000 kg./$m^3$) * 9.81 (m/$s^2$)/1000] | 18.76 | 19.87 | 20.97 |
| **F)**Power Drawn by motor kW *(given)* | 30 | 33 | 31 |
| **G)**Motor eff. % *(given)* | 92.0% | 92.0% | 91.5% |
| **H)**Pump input power kW (FxG) | 27.6 | 30.4 | 28.4 |
| **I)**Pump eff. % (E/H) | 67.97 % | 65.36 % | 73.83 % |
| **J)** Specific Energy Consumption (kWh/$M^3$) (F/A) | 0.1176 | 0.1222 | 0.1087 |

Pump No. 1 & 3 are the best performing operating combination.

Note:
*The total head has been calculated subtracting Discharge Gauge pressure from suction gauge pressure. The candidates can also calculate total head as difference of absolute pressures as follows:

Discharge Head= 3.4 kg/$cm^2$ (a)
Suction Head = 1- 0.3 kg/$cm^2$ = 0.7 kg/$cm^2$
Total Head Developed = 3.4 – 0.7 = 2.7 kg/$cm^2$ = 27 m

| | |
|---|---|
| L-6 | a) Calculate the ventilation rate for an engine room of 20m length, 10.5m width and 15m height; if the recommended Air Changes per Hour (ACH) |

is 25.

b) Air at 30,000 $m^3$/hr and at 1.2 kg/$m^3$ density is flowing into an air handling unit of an inspection room. The enthalpy difference between the inlet and outlet air is 2.38 kcal/kg. If the motor draws 26.5 kW with an efficiency of 90%, find out the kW/TR of the refrigeration system. (1 Cal = 4.18 J.).

Solution:

a) Ventilation Rate:

| | |
|---|---|
| Room Length (m) | 20 |
| Room Height (m) | 15 |
| Room Width (m) | 10.5 |
| Air Changes per Hr (ACH) | 25 |
| ventilation rate ($m^3$/Hr) = Length (m) * Height (m) * Width (m) * ACH | 78750 |

b)

| | |
|---|---|
| Refrigeration tonnes | $Q \times \rho x (h_2-h_1)$<br>30000 x 1.2 x (2.38) kcal/kg<br>85680 kcal/hr |
| TR | 85680 /3024<br>28.3 TR |
| Power input to the compressor | 26.5 x 0.9= 23.85 kW |
| kW/TR | 28.3/23.85 = 1.19 |

***-------- End of Section - III -----***