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MECHANICAL ENGINEERING
P.E. THERMAL AND FLUID SYSTEMS
PRACTICE EXAM

001. Strain hardening occurs when:

- (A) The ultimate tensile strength can be estimated from the Brinell hardness number.
- (B) A material has been stressed beyond the yield strength to some point in the plastic region, and then the load is removed.
- (C) A part is cyclically loaded so the stress is kept below the endurance limit, thus having a nominally infinite life.
- (D) Maximum shear stress theory predicts the shear strength as one half of the tensile yield strength.

002. The compressibility factor, Z :

- (A) Is the ratio of inertial forces to viscous forces in a flow field.
- (B) Allows finding the dew point temperature along the 100% relative humidity line in a psychrometric chart
- (C) Is typically neglected when the Mach number is small.
- (D) Accounts for the deviation of real gases from ideal-gas behavior.

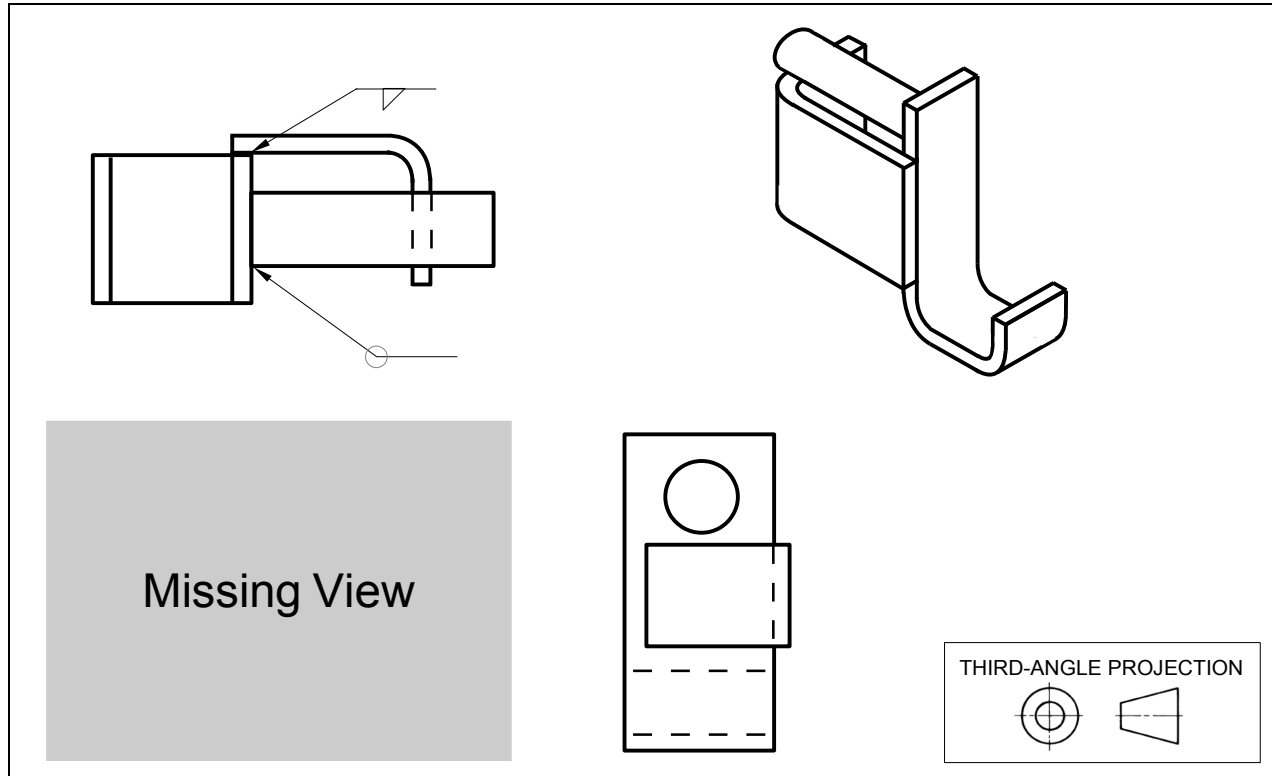
003. A remotely located facility has no easy access to electricity. They are considering purchasing a gas turbine plant to provide mechanical power to a group of pumps. The pumps require a power input of 450 hp to operate properly. The table provides some data for the gas turbine system, which is expected to have a useful life of 10 years.

Purchase and Installation Cost	\$235,000
Yearly Maintenance Cost, years 1 through 4	\$9,000
Yearly Maintenance Cost, years 5 through 10	\$12,500
Fuel	Natural Gas
Fuel Costs	\$2.25 per million Btu
Fuel Heating Value	20,000 Btu per pound

The thermal efficiency (percentage of energy in the fuel that is converted to useful mechanical energy) for the gas turbine plant is 55%. Using an interest rate of 8%, the present worth of the yearly maintenance costs is most nearly:

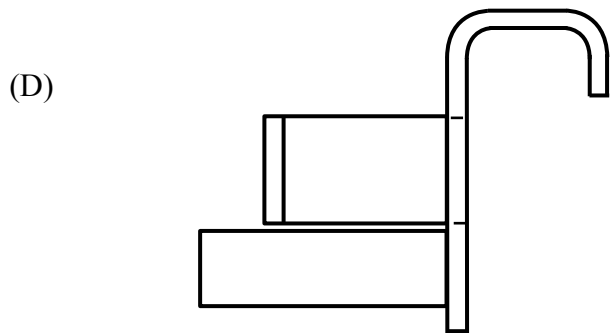
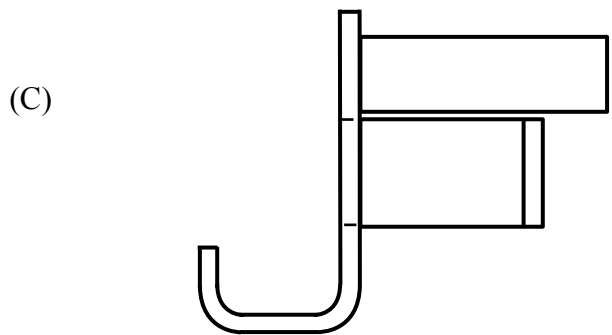
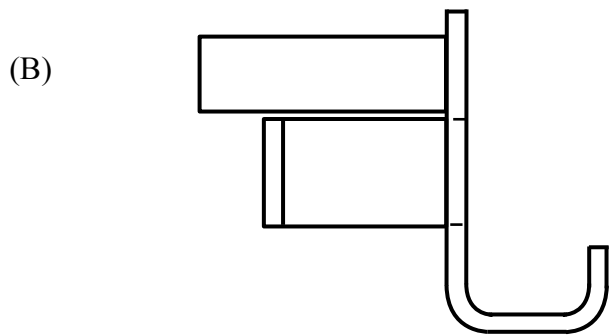
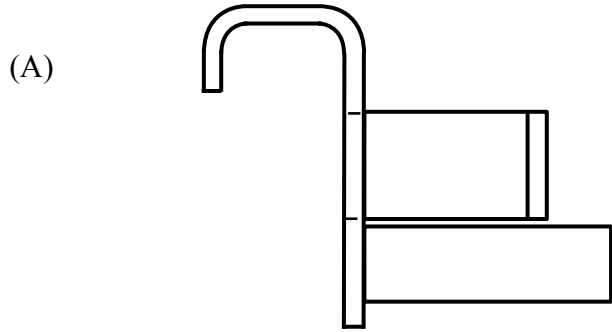
- (A) \$55,700
- (B) \$72,300
- (C) \$111,000
- (D) \$307,300

004. Part of the fabrication drawing for a machine part is shown below. The drawing includes an isometric view, and three orthogonal views. One of the orthogonal views has been covered with a shaded region.



Four alternatives for the missing view are shown in the next page.

The view that should be placed on the shaded area is most nearly:



005. A supplier to the automotive industry uses the same 3D metal cutting machine to make two different parts: A, and B. The table below summarizes how much each part costs to fabricate. Also shown is the profit the supplier makes when selling the part to its customers.

	Part A	Part B
Cost to Fabricate (\$)	20	10
Profit (\$)	50	30

The machine has the capacity to produce up to 100 parts per day. For profitability, the total number of parts made per day must be at least 70. You may assume that every part made is sold. The company can spend at most \$1200 per day in making these parts. The number of parts A and B that must be made daily to maximize profits is most nearly:

- (A) 30 of part A, and 70 of part B.
- (B) 70 of part A, and 30 of part B.
- (C) 50 of part A, and 20 of part B.
- (D) 20 of part A, and 80 of part B.

006. A cooling chamber in a pharmaceutical manufacturing process is normally 30°F lower than the ambient plant temperature. A process upset resulted in a momentary rise of the chamber temperature such that the temperature difference, in °F, with the ambient was reduced by 75% before returning to normal. The lowest temperature difference with ambient plant temperature, in °C, experienced in the chamber during the process upset is most nearly:

- (A) -13.6
- (B) 4.2
- (C) 7.5
- (D) 22.5

007. A vacuum of 25 kPa is measured at a location where the elevation is 3000 m, where the atmospheric pressure is 70.7 kPa. The absolute pressure (mmHg) at that location is most nearly:

- (A) 0.343
- (B) 45.7
- (C) 70.7
- (D) 343

008. The shaft of a cylindrical viscometer is 6 ft 7 in long. The shaft diameter is 1.6 inches. The fluid-filled gap is 0.0079 inches and contains SAE 10W-40 oil at 105°F (dynamic viscosity = 80 cP). If the shaft rotates at 1200 rpm, the shear stress (pound-force per square feet) in the fluid film halfway between the two solid surfaces is most nearly:

- (A) 10.7
- (B) 21.3
- (C) 42.6
- (D) 85.2

009. A Pitot static tube in an air flow stream indicates a static pressure of 17 psig and a stagnation pressure of 25 psig. The Mach number for the flow at the location of the Pitot static tube is most nearly:

- (A) 0.58
- (B) 0.70
- (C) 0.75
- (D) 0.85

010. A normal shock wave travels at 600 m/s through stagnant 20 °C air. The velocity (m/s) induced behind the shock wave is most nearly:

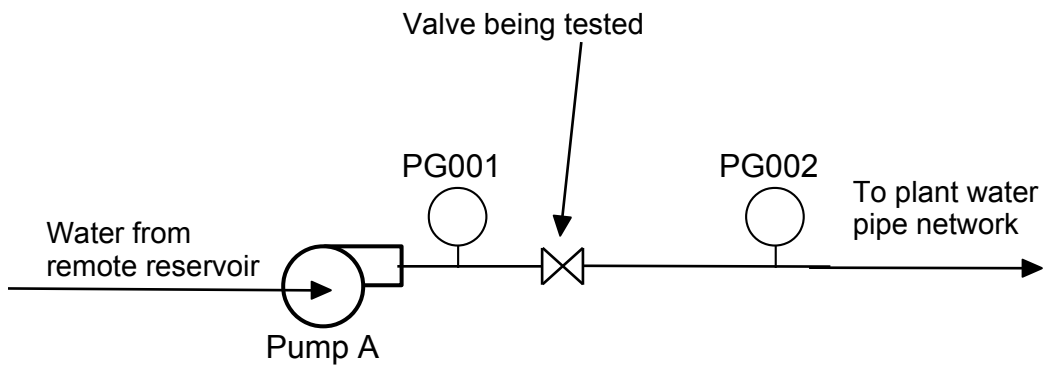
- (A) 264
- (B) 337
- (C) 343
- (D) 600

011. A vacuum cleaner is capable of creating a vacuum of 0.3 psi just inside the hose. The maximum velocity (m/s) that could be expected in the hose is most nearly:

- (A) 58
- (B) 34
- (C) 191
- (D) 11

012. A valve manufacturer uses the rig shown below to test their valves. The working fluid is water (kinematic viscosity = 1.12 cSt, density = 62.4 lb/ft³). The flow rate is 400 gallons per minute, and all piping is 4-in, schedule 40, steel pipe (ID = 4.026 in). The test section (between pressure gauges PG001 and PG002) is 1,000 feet long of horizontal, straight pipe. For the test conditions, the Moody friction factor is known to be 0.018. Upon achieving steady state flow, the pressure readings are 70 psig for PG001 and 25 psig for PG002. For the valve being tested, the equivalent length in feet is most nearly:

- (A) 0
- (B) 110
- (C) 220
- (D) 1,000



013. A solid copper sphere with a diameter of 1 inch is initially at a spatially uniform temperature of 150°F before being inserted into a stream of air at 80°F. A thermocouple at the surface of the sphere indicates a temperature of 130°F after 1 minute and 10 seconds. The heat transfer coefficient, in $\text{Btu}/(\text{ft}^2\text{h}^\circ\text{F})$ is most nearly:

- (A) 12
- (B) 120
- (C) 558
- (D) 955

014 A 6-inch thick brick wall separates the hot gas inside an industrial furnace from the ambient air and its surroundings, which are at 77°F. The brick wall has a known thermal conductivity of $0.7 \text{ Btu ft}/(\text{ft}^2\text{h}^\circ\text{F})$ and a surface emissivity of 0.8. During steady operation of the furnace, the surface temperature of the outer face of the wall was measured as 212°F. Assuming a convective heat transfer coefficient between the outer face of the wall and the surrounding air of $3.5 \text{ Btu}/(\text{ft}^2\text{h}^\circ\text{F})$, the temperature of the inner face of the wall (°F) is most nearly:

- (A) 212
- (B) 352
- (C) 550
- (D) 700

015. A spherical container with thin walls is initially full of liquid nitrogen at -320°F . The diameter of the container is 20 inches and it is covered with a 1 inch thick vacuum-mat insulating blanket having a thermal conductivity of $3.3 \times 10^{-6} \text{ Btu in}/(\text{s} \cdot \text{ft}^2 \cdot ^{\circ}\text{F})$. The ambient temperature around the container is 81°F , and the convection coefficient between the outer surface of the insulating blanket and the surrounding air is known to be $3.5 \text{ Btu}/(\text{h} \cdot \text{ft}^2 \cdot ^{\circ}\text{F})$. A small vent in the container allows the escape of the nitrogen gas produced by boil-off. A table with selected data for N_2 is provided for your possible use. Under the conditions described, the time (hours) required to lose 10% of the liquid mass of nitrogen in the tank is most nearly:

- (A) 22.9
 (B) 25.0
 (C) 27.9
 (D) 32.9

Saturation Properties for N_2					
Temp. ($^{\circ}\text{F}$)	Volume (ft^3/lbm)		Enthalpy (Btu/lbm)		Δh_{vap}
	Liquid	Vapor	Liquid	Vapor	
-340	0.018770	13.945	-61.973	29.220	91.193
-320	0.019899	3.3841	-52.282	33.272	85.554
-300	0.021311	1.1821	-42.289	36.292	78.581

The thermal resistance for conduction across a spherical shell of inner and outer radius r_1 and r_2 , respectively is:

$$R_{\text{cond}} = \frac{1}{4 \pi k} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

The thermal resistance for convection at a spherical surface of radius r

$$R_{\text{conv}} = \frac{1}{h 4 \pi r^2}$$

016. A solar water heater directs solar energy towards a horizontal pipe carrying water. The effect of the solar energy can be approximated as a constant heat flux on the pipe outer surface of $640 \text{ Btu}/(\text{h}\cdot\text{ft}^2)$. The pipe diameter is 2.36 inches and it is negligibly thin-walled. The water flow rate through the pipe is $80 \text{ lbm}/\text{h}$ with an inlet temperature of 68°F and a discharge temperature of 120°F . Using a dynamic viscosity for water of $1.16 \times 10^{-5} \text{ lbf}\cdot\text{s}/\text{ft}^2$ and a thermal conductivity for water of $0.378 \text{ Btu}/(\text{h}\cdot\text{ft}\cdot^\circ\text{F})$, the pipe surface temperature ($^\circ\text{F}$) at the discharge location is most nearly:

- (A) 174
- (B) 196
- (C) 212
- (D) 250

017. A carbon steel (1% C) very large flat plate, $\frac{1}{2}$ -inch thick is at an initial temperature of 1100°F when it is suddenly plunged in a water bath with water at 60°F . You may assume a convective heat transfer coefficient of $1800 \text{ Btu}/(\text{h}\cdot\text{ft}^2\cdot^\circ\text{F})$. Under these conditions, the Biot number is most nearly:

The following table has selected data for carbon steel, for your possible use.

- (A) 0.07
- (B) 1.4
- (C) 17
- (D) 5009

Thermophysical Properties, Carbon Steel (1% C)		
Thermal Diffusivity (in^2/s)	Density (lbm/ft^3)	Specific Heat ($\text{Btu}/(\text{lbm}\cdot^\circ\text{F})$)
0.02	490	0.11

018. A 12-in thick brick exterior wall is used in an office building with no insulation or added internal finish. On a winter day, the following temperatures were measured: inside air temperature, 70°F ; outside air temperature, 15°F ; inside surface temperature, 56°F ; outside surface temperature; 20°F . Assuming a thermal conductivity of 0.7 Btu/(h·ft·°F) for the brick wall, the convection heat transfer coefficient (Btu/(h·ft²·°F)) for the inner side of the wall, is most nearly:

- (A) 0.9
- (B) 1.8
- (C) 3.6
- (D) 7.2

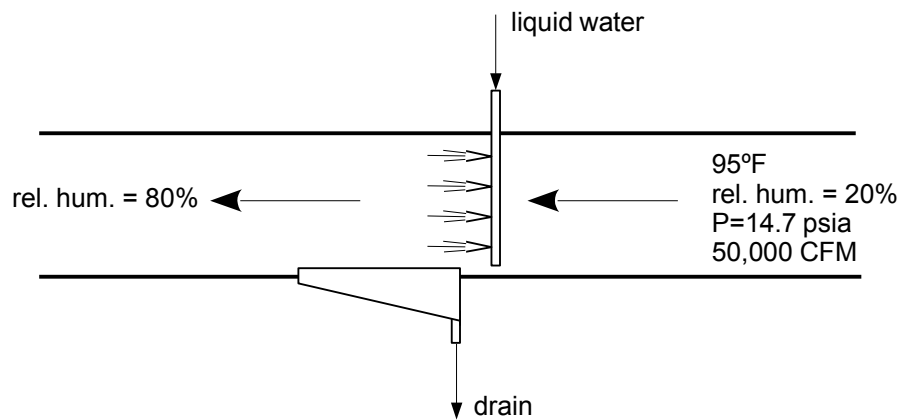
019. A cylindrical, atmospheric-pressure tank with a diameter of 10 m has one inlet pipe and one outlet pipe. The tank is used for the storage of liquid jet fuel. During simultaneous loading and unloading, liquid jet fuel is delivered to the tank at a rate of 1 m³/s through the inlet pipe. If the level inside the tank is to rise at a rate no greater than 0.5m/minute, the lowest flow rate (gpm) at which the jet fuel must be drawn from the tank through the outlet pipe is most nearly:

- (A) Cannot be determined
- (B) 35
- (C) 2,070
- (D) 5,476

020. An air stream of 50,000 CFM enters an evaporative cooler where it is sprayed with a mist of cool water. During steady state operation, approximately 70% of the water sprayed evaporates and mixes with the air while the remaining water is collected in a basin and drained. For the conditions shown in the figure, the required input of liquid water (gpm) is most nearly:

- (A) 2.40
- (B) 3.42
- (C) 4.55
- (D) 5.80

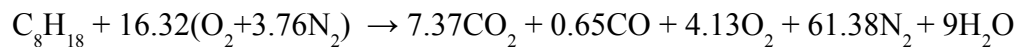
Note: A psychrometric chart is provided for your possible use in page 63



021. An ideal Diesel cycle uses air ($R=0.3704 \text{ psia} \cdot \text{ft}^3/(\text{lb} \cdot \text{°R})$, $c_p=0.240 \text{ Btu}/(\text{lb} \cdot \text{°R})$, $k=1.4$) and at the start of the compression process the working fluid is at 80°F and 14.7 psia . If the maximum absolute pressure achieved in the cycle is 58 bar , the compression ratio is most nearly:

- (A) 58
- (B) 18
- (C) 8
- (D) 2.7

022. Octane is burned in a constant pressure burner and the combustion equation for the actual process is:



The percent excess air being used is most nearly:

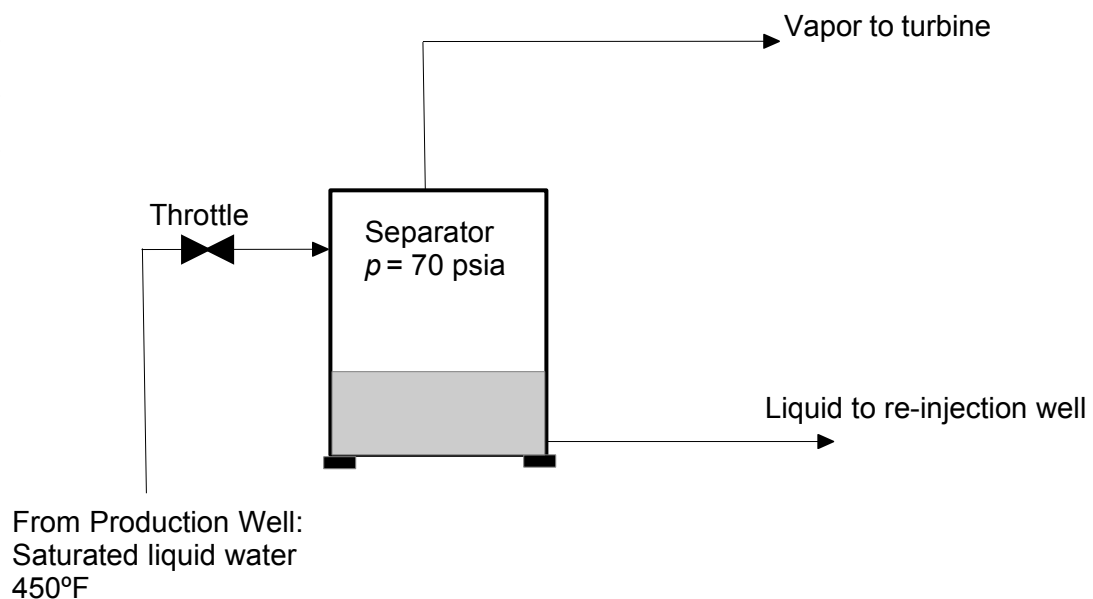
- (A) 1475
- (B) 131
- (C) 16
- (D) 31

023. In an ideal Dual-Compression, Dual-Expansion Refrigeration Cycle with ammonia, the flash intercooler operates at a pressure of 30 psia. At the discharge of the low pressure stage compressor, the superheat is 160°F. The condenser pressure for the high pressure stage is 100 psia. The ammonia mass flow through the low pressure cycle is 1,000 pounds-mass per hour. The ammonia mass flow (pounds-mass per hour) through the high pressure cycle is most nearly:

- (A) 320
- (B) 550
- (C) 765
- (D) 1,310

024. A geothermal power plant uses geothermal water extracted as high-pressure saturated liquid at 450°F. This water is throttled down to a pressure of 70 psia before entering a separator tank. This sudden pressure drop results in the “flashing” of the liquid into a liquid-vapor mixture. In the separator tank the resulting vapor is separated from the liquid and directed to a turbine. On a mass basis, the percentage of geothermal water that is sent in vapor form to the turbine is most nearly:

- (A) Cannot be determined
- (B) 17%
- (C) 32%
- (D) 94%



025. A simple ammonia vapor compression refrigeration system has a load of 5 tons. The evaporator temperature is 5°F. The ammonia leaves the expansion device with a quality of 30% and enters the compressor as saturated vapor. The required flow rate of ammonia (pounds-mass per hour) is most nearly:

- (A) 50
- (B) 75
- (C) 150
- (D) 200

026. Near the earth's equator, the water close to the surface of the ocean remains warm year-round, due to solar heating. At greater depths, the water remains relatively cold. It is proposed to take advantage of this temperature difference and build a power plant absorbing heat from the warm water near the surface and rejecting the waste heat to the deep, cold water. Assuming the surface and deep water are at 24°C and 3°C, respectively, the maximum possible thermal efficiency (%) of such a plant is most nearly:

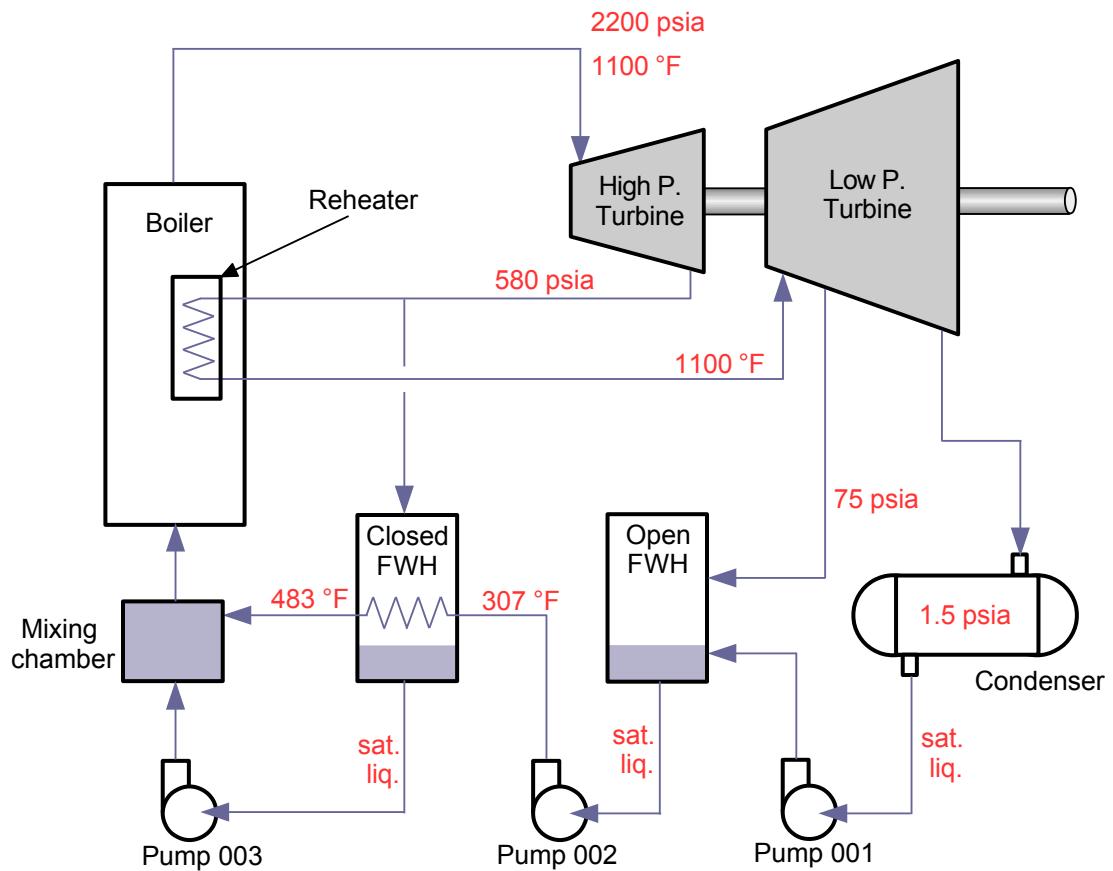
- (A) 7.0
- (B) 9.0
- (C) 12.5
- (D) 87.5

027. A heat pump is used for heating a house during winter. The house is to be maintained at 78°F at all times. When the outdoor air temperature is 25°F the heat losses from the house are estimated to be 55,000 Btu/h. If the outdoor air is used as the heat source, the theoretical minimum power (hp) required to run this heat pump under the conditions described is most nearly:

- (A) 1.5
- (B) 2.1
- (C) 5.4
- (D) 8.0

028. The steam power plant shown operates as an ideal reheat-regenerative Rankine cycle. Steam enters the high pressure turbine at 2200 psia and 1100°F. The condenser pressure is 1.5 psia. Some steam discharged from the high pressure turbine at 580 psia is sent to the closed feed water heater (FWH) and the rest is sent to the boiler for reheat and further expansion in the low pressure turbine. Additional information is given in the figure. The percentage of the high pressure turbine steam discharge that is diverted to the closed FWH is most nearly:

- (A) 7%
- (B) 17%
- (C) 27%
- (D) 37%

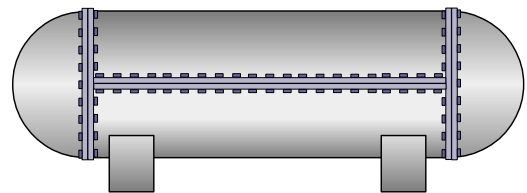


029. An atmospheric pressure air stream of 300 CFM at 65°F, with a humidity ratio of 55 grains of moisture per pound of dry air is to be cooled by flowing over a coil. Condensation is to be avoided, so the cooling process shall end with the air at a temperature 5°F above the dew point. Under these conditions, the maximum allowable dry-bulb temperature drop for the air (°F) is most nearly:

- (A) 3
- (B) 9
- (C) 19
- (D) 51

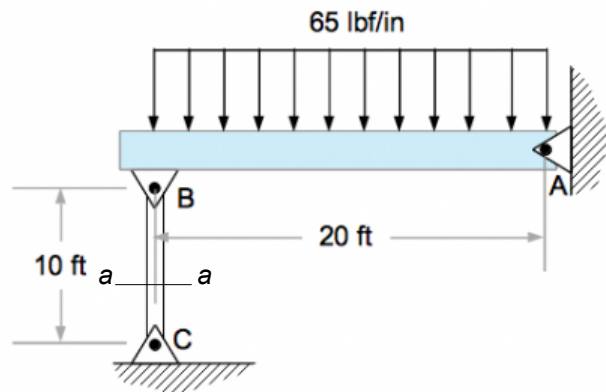
030. The gas storage tank is fabricated by bolting together two half-cylindrical thin shells and two hemispherical shells as shown. The tank is designed for an internal operating pressure of 3 MPa. It is desired to have a principal stress of 150 MPa in the hemispherical shells at this pressure. The tank has an inner diameter of 4 m. The required minimum thickness (mm) of the hemispherical shells is most nearly:

- (A) 3
- (B) 9
- (C) 20
- (D) 51



031. The A-36 steel rod (modulus of elasticity, $E = 29,000$ ksi) BC has a diameter of 2 inches and is used as a strut to support beam AB. For the configuration shown in the figure, the normal stress (ksi) at section $a - a$ across rod BC is most nearly:

- (A) 2.4
- (B) 4.8
- (C) 1,240
- (D) 2,480



032. An industrial boiler installation is to be performed in conformance with the ASME Controls and Safety Devices for Automatically Fired Boilers (CSD-1) Standard (relevant portion reproduced below, with permission from ASME). Per the standard, under what circumstances can a single safety shutoff valve be used in the gas supply line?

- (A) If the input is greater than 5,000,000 Btu/h and it is not possible to use two valves in series.
- (B) If the input is lower than 5,000,000 Btu/h and the valve has a proof of closure interlock function.
- (C) If the input is greater than 5,000,000 Btu/h and the valve has a proof of closure interlock function.
- (D) None. This is not allowed by the standard.

CF-180 Safety Shutoff Valves

(a) Each main burner supply line shall be equipped with a safety shutoff valve(s) that shall comply with the applicable provisions of ANSI Z21.21/CSA 6.5, Automatic Valves for Gas Appliances, ANSI Z21.78/CSA 6.20, Combination Gas Controls for Gas Appliances, or UL 429, Standard for Electrically Operated Valves.

(b) The burner supply line shall be equipped as indicated below for the applicable input classification or any greater input classifications:

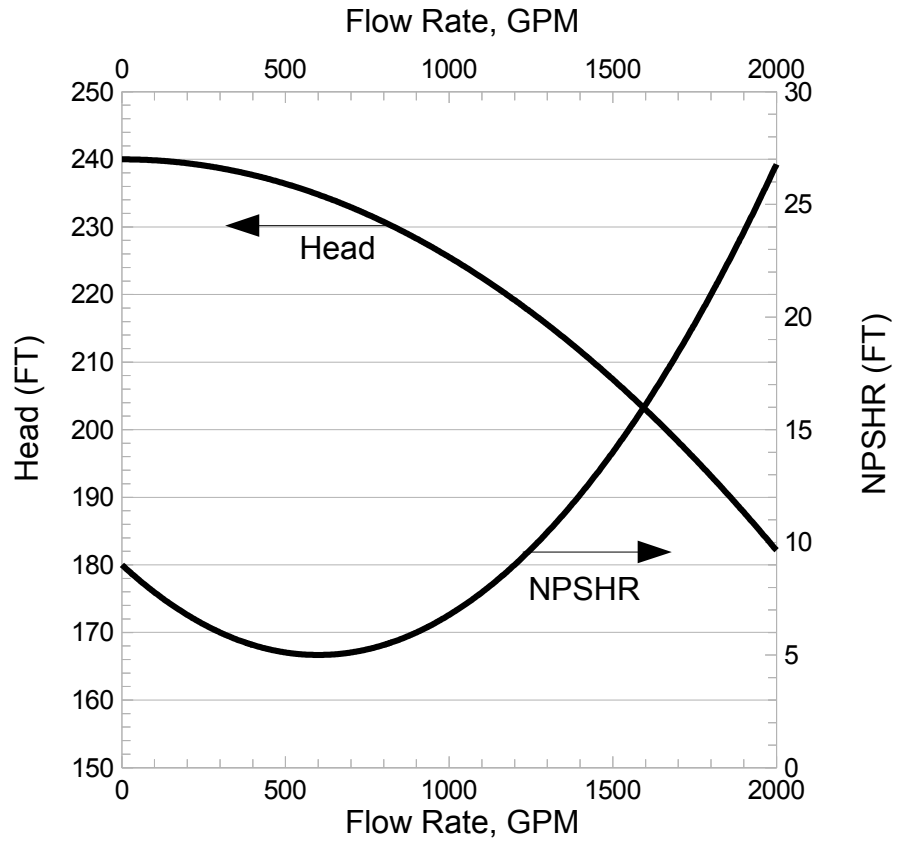
(1) For boiler units having inputs less than or equal to 5,000,000 Btu/hr (1 465 356 W), the main burner supply line shall be equipped with at least two safety shutoff valves in series that may be in a single valve body or one safety shutoff valve with a valve seal overtravel (proof of closure) interlock function. If the two safety shutoff valves are in a single valve body, the two safety shutoff valve seats shall be in series and shall have independently operated valve shafts.

(2) For boiler units having inputs greater than 5,000,000 Btu/hr (1 465 356 W) and less than 12,500,000 Btu/hr (3 663 389 W), the main burner supply line shall be equipped with at least two safety shutoff valves in series that may be in a single valve body. At least one of the two safety shutoff valves shall incorporate a valve seal overtravel (proof of closure) interlock function. If the two safety shutoff valves are in a single valve body, the two safety shutoff valve seats shall be in series and shall have independently operated valve shafts.

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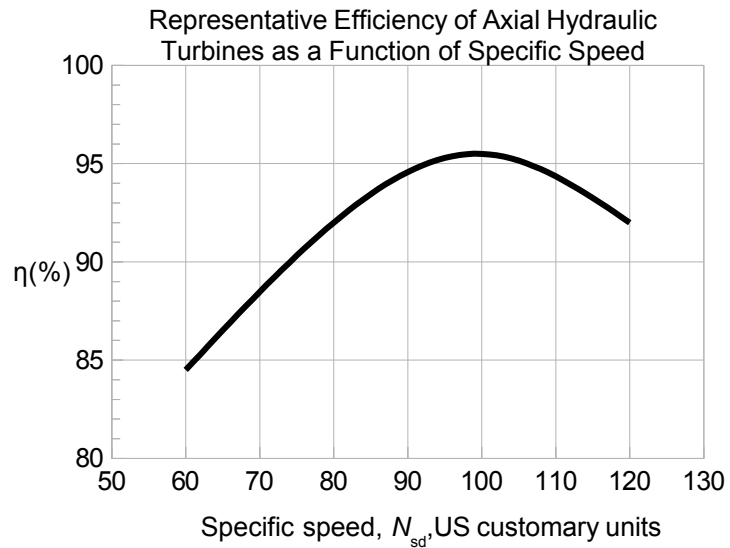
033. A pressurized, insulated hot water tank stores heated liquid water at 25 psi (absolute) and 180°F. A pump is used to take water from the tank at a rate of 1100 gpm. The pump performance curves are provided below. Neglecting friction and minor losses, the maximum height (feet) above the water surface of the suction reservoir this pump can be located without experiencing cavitation is most nearly:

- (A) 8
- (B) 21
- (C) 34
- (D) 224



034. An axial flow hydraulic turbine develops 5,000 hp at the shaft when operating with a head of 40 ft. A plot showing the variation of axial flow turbine efficiency with specific speed is provided for your possible use. If the turbine is to operate at peak efficiency, the rotational speed (rpm) is most nearly:

- (A) 300
- (B) 140
- (C) 100
- (D) 96

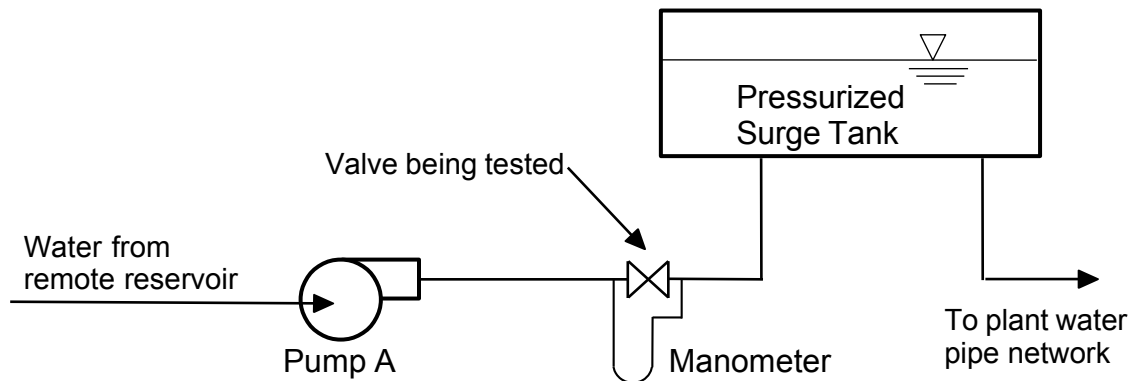


Note: Turbine specific speed is given by:
$$N_{sd} = \frac{\omega \text{ (rpm)} \sqrt{\dot{W}_{shaft} \text{ (bhp)}}}{[h_a \text{ (ft)}]^{5/4}}$$

where ω (rpm) is the rotational speed in rpm, \dot{W}_{shaft} (bhp) is the shaft horsepower, and h_a (ft) is the head in feet available to the turbine.

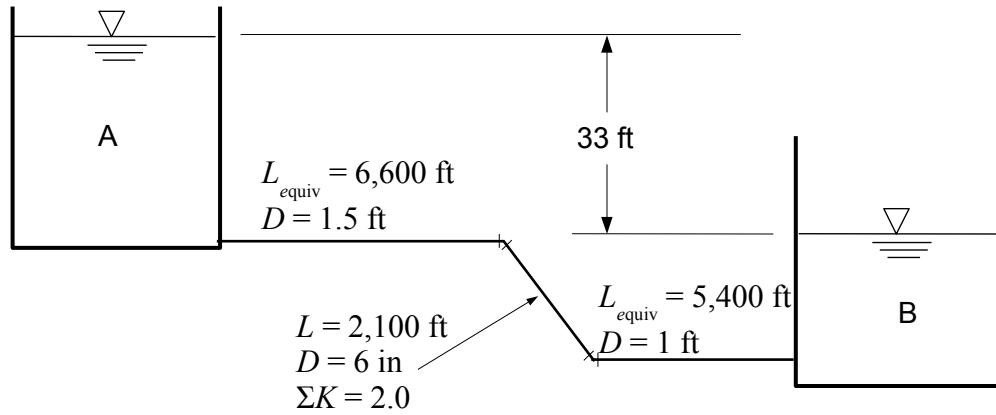
035. A valve manufacturer uses the test rig shown below to determine the loss coefficient K for their valves. The working fluid is water (kinematic viscosity, $\nu = 1.12$ cSt, density, $\rho = 62.4$ lb/ft³). The flow rate is 400 gallons per minute, and all piping is 4-in, schedule 40, steel pipe (ID = 4.026 in). A differential U-tube manometer measures the pressure drop across the valve as 8.5 inches of mercury. The loss coefficient K for the valve, is most nearly:

- (A) 8.5
- (B) 12
- (C) 6
- (D) 24



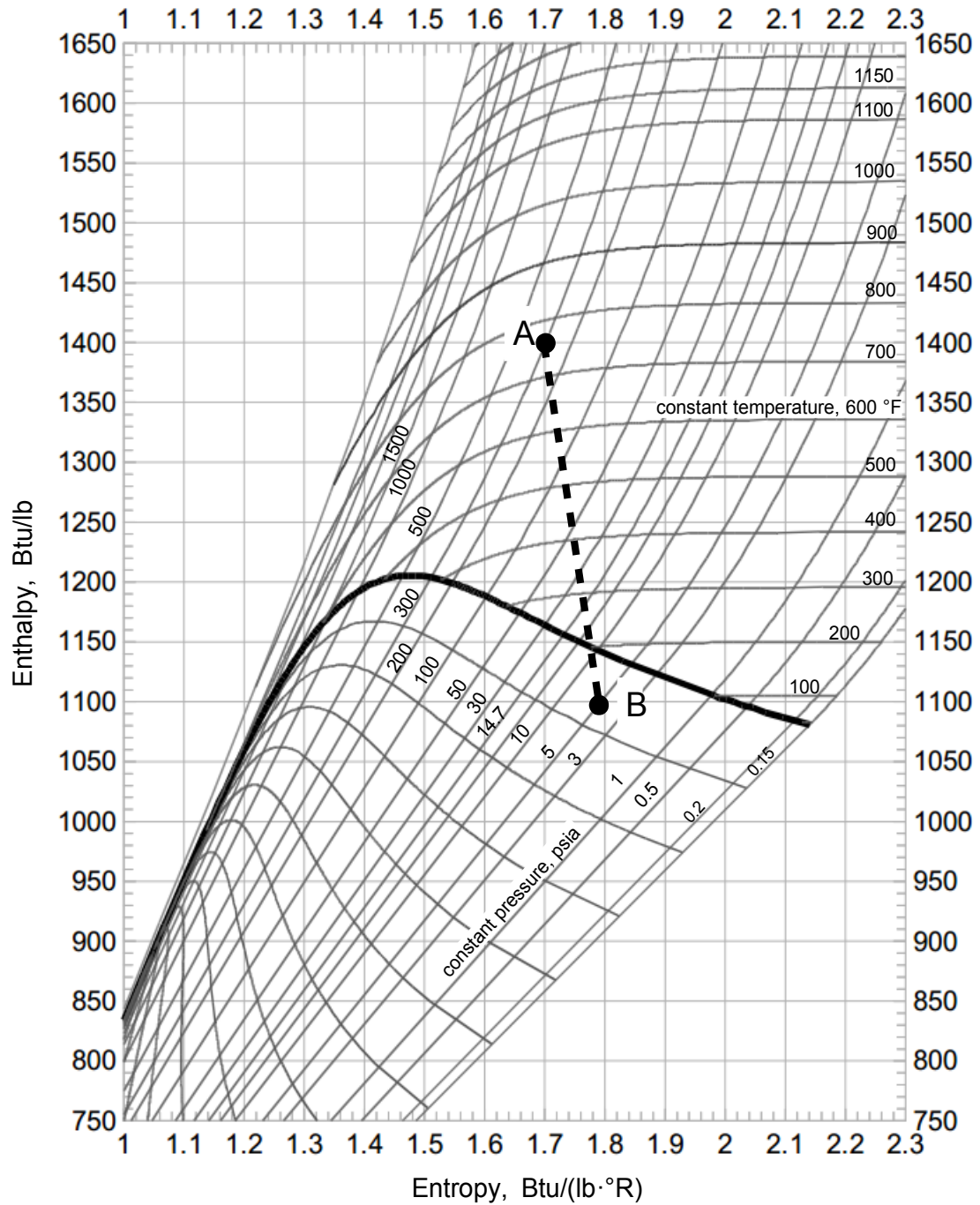
036. The two reservoirs are connected by three piping segments in series. Assume a Darcy friction factor of 0.03 throughout all piping. For the middle segment, the pipe length is 2,100 ft and the sum of the minor loss coefficients $\Sigma K = 2.0$. For the other two segments, the equivalent length is provided in the figure. The flow rate (gpm) is most nearly:

- (A) Cannot be determined
- (B) 0.77
- (C) 165
- (D) 345



037. Points A and B in the Mollier diagram below represent respectively the inlet and outlet of a steam turbine operating at steady state. There is only one inlet and one outlet. The isentropic efficiency of this turbine is most nearly:

- (A) 21%
- (B) 63%
- (C) 71%
- (D) 85%



038. Water enters the tubes of a small parallel flow heat exchanger at 74 °F at a rate of 30 gpm. On the shell side 10,700 lb/h of a heat transfer oil enters at 175 °F. The heat transfer surface area is 94 ft², and the overall heat transfer coefficient is 200 Btu/(h·ft²·°F). For this heat exchanger, the number of transfer units (*NTU*) is most nearly:

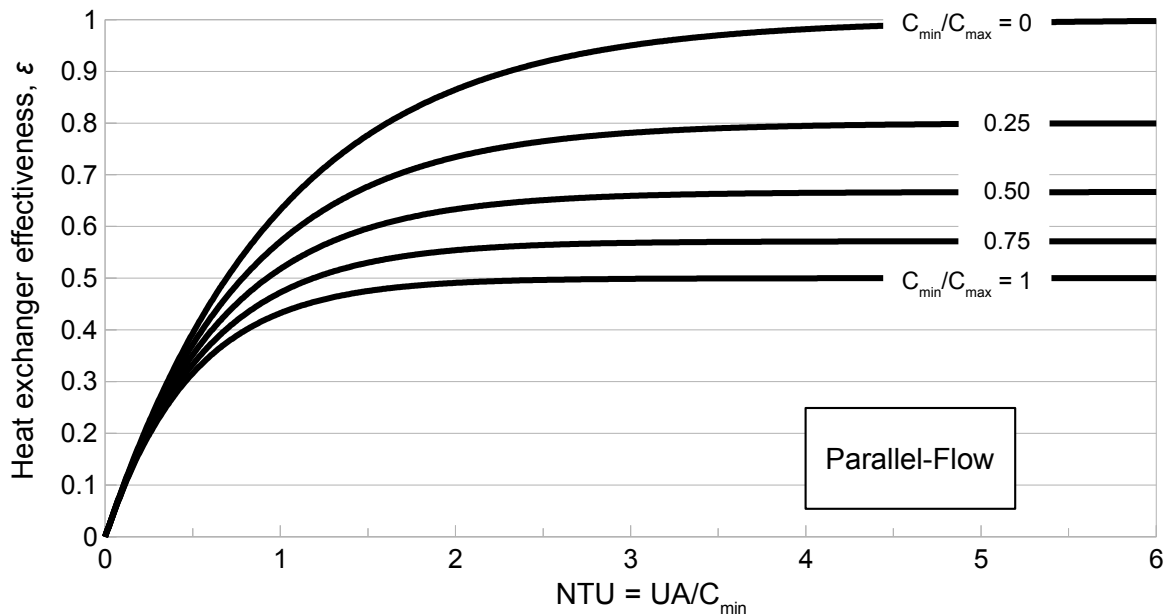
- (A) Cannot be determined
- (B) 2.5
- (C) 3.0
- (D) 3.5

If needed, you may use the following values for specific heat *c*, and density, ρ :

$$c_{oil} = 0.7 \text{ Btu}/(\text{lb}\cdot^\circ\text{F}) \quad \rho_{oil} = 81.1 \text{ lb}/\text{ft}^3$$

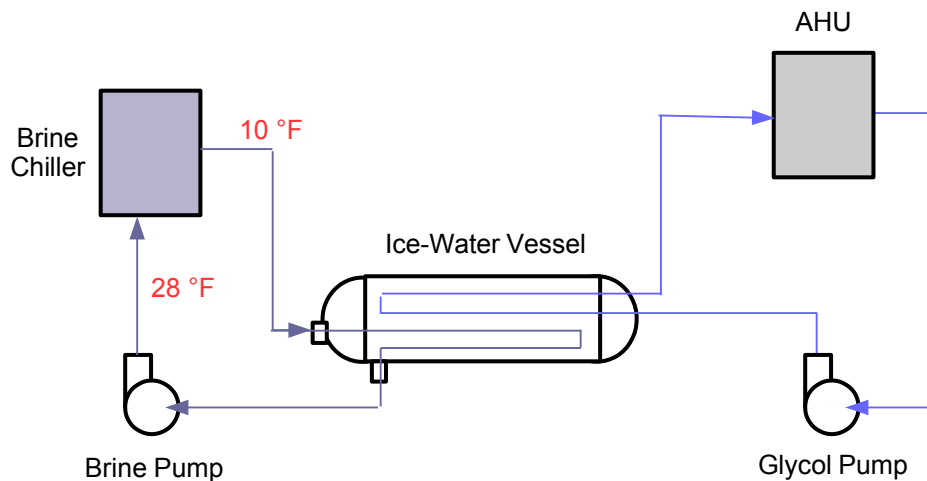
$$c_{water} = 1.0 \text{ Btu}/(\text{lb}\cdot^\circ\text{F}) \quad \rho_{water} = 62.4 \text{ lb}/\text{ft}^3$$

Also, this is a plot of heat exchanger effectiveness for your possible use:

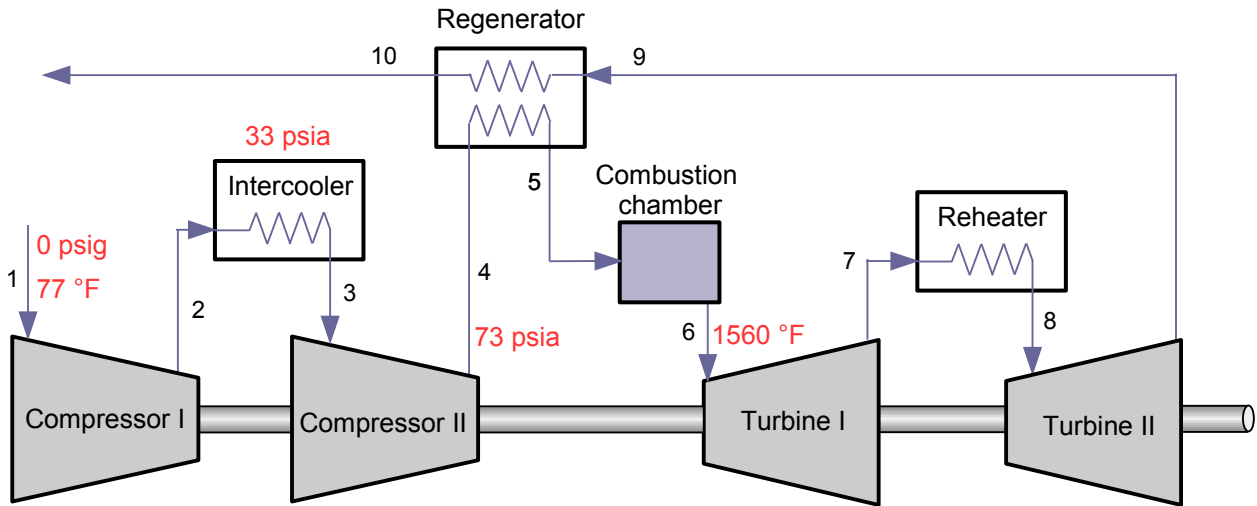


039. During the night, when electricity costs are low, an office building uses a chilled brine (specific heat, $0.88 \text{ Btu}/(\text{lbm}\cdot^\circ\text{F})$; density, $67 \text{ lbm}/\text{ft}^3$) to freeze water stored in a large, perfectly insulated vessel. During the freezing process, the water in the tank goes from 5% ice by mass to 95% ice by mass and it takes 5 hours of continuous operation of the brine system. During the day (as the building is occupied and the brine system is inactive) the stored ice is used to chill glycol which is pumped to the air handling unit (AHU) and provide conditioned air to the offices. The design cooling load of the AHU is $700,000 \text{ Btu}/\text{h}$ and it must provide this continuously during a period of 10 hours. At the design condition, the water is 95% ice by mass and goes to 5% ice by mass over the 10 hours. At the design condition, the required brine flow rate (gpm) is most nearly:

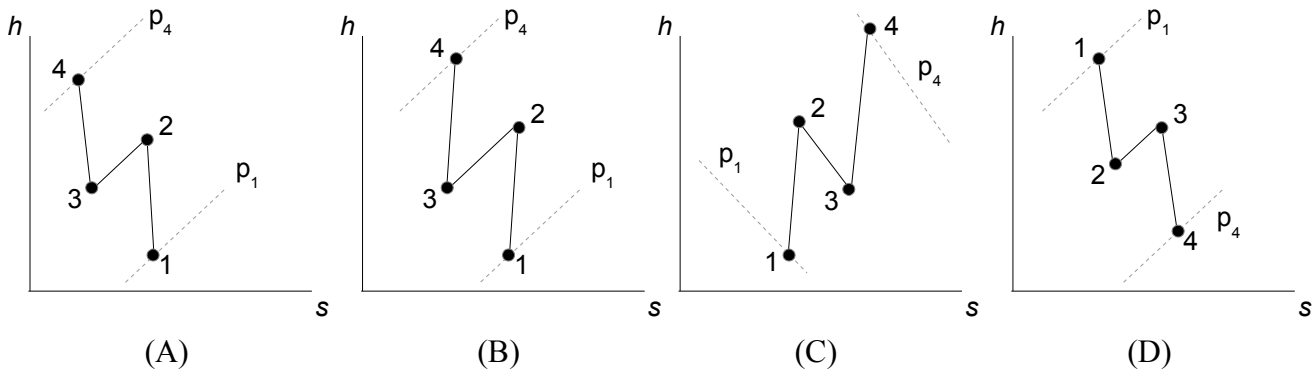
- (A) 15
- (B) 25
- (C) 95
- (D) 165



040. A gas turbine power plant uses two-stage compression with intercooling and two-stage turbine expansion with reheat as shown. The discharge of the second compressor is at 73 psia. Assume ambient pressure is 15 psia. The intercooler pressure is 33 psia.



Select the correct representation of the two-stage compression with intercooling process in an h - s diagram:





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The afternoon portion of the test starts in the next page.

201. Rank in the correct order the processes involved in the ideal Rankine cycle.

Correct order:

1. Isentropic compression
2. _____
3. _____
4. _____

The other processes are (in the actual test you would drag and drop the choices into the right blank space above):

Isobaric heat rejection

Isobaric heat addition

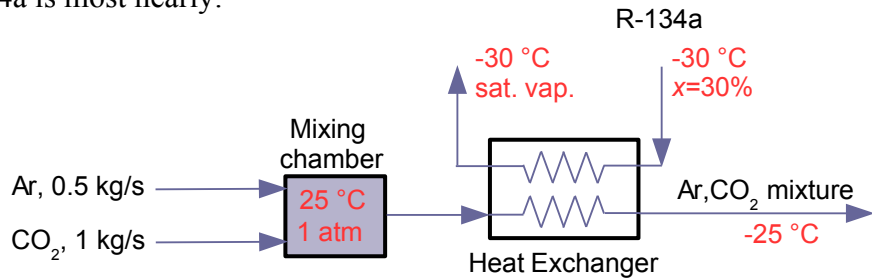
Isentropic expansion

202. A certain coal has the following analysis on a mass basis: 82 percent C, 5 percent H₂O, 2 percent H₂, 1 percent O₂, and 10 percent ash. The coal is burned with 50 percent excess air. The air–fuel ratio (kg of air/kg of fuel) is most nearly:

- (A) 10.2
- (B) 15.3
- (C) 25.1
- (D) 30.7

203. Carbon dioxide – specific heat: $0.85 \text{ kJ}/(\text{kg}\cdot\text{K})$ – and argon – specific heat: $0.52 \text{ kJ}/(\text{kg}\cdot\text{K})$ – are both at 25°C , 1 atm and are mixed steadily in an adiabatic mixing chamber, as shown. The resulting gas mixture is cooled to -25°C in a heat exchanger downstream of the mixing chamber. The cooling medium in the heat exchanger is a stream of refrigerant R-134a which enters the heat exchanger as a liquid-vapor mixture with 30% quality at -30°C and is discharged as a saturated vapor at -30°C . The required flow rate (kg/s) of R-134a is most nearly:

- (A) 0.36
- (B) 0.74
- (C) 1.50
- (D) 1.95



The following table has selected data for R-134a for your possible use:

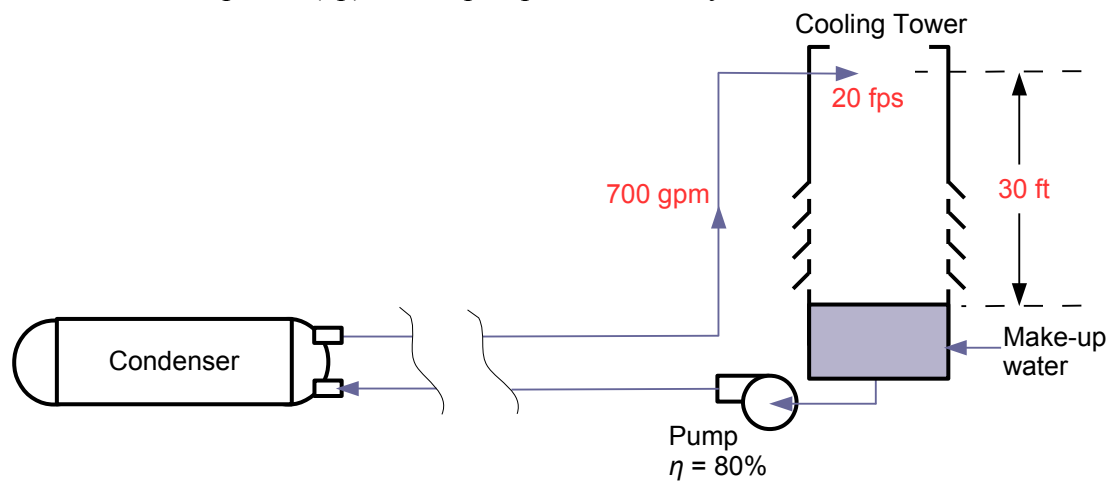
Saturation Properties for R-134a							
Temp. (°C)	Absolute Pressure (kPa)	Volume (m ³ /kg)		Enthalpy (kJ/kg)		Entropy (kJ/kg·°C)	
		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
-34	69.560	0.000714	0.27090	7.57	229.65	0.0320	0.9606
-30	84.430	0.000720	0.22580	12.65	232.17	0.0530	0.9558
-26	101.730	0.000727	0.18946	17.76	234.68	0.0738	0.9514

204. Water leaves the condenser of a power plant at a rate of 1,600 gpm and enters a wet cooling tower at 95°F. The water is cooled in the tower down to 70°F by ambient air that enters the tower at 68°F, and 60 percent relative humidity and leaves saturated at 86°F. The required flow rate (pounds-mass per hour) of air through the tower is most nearly:

- (A) 1,600
- (B) 413,500
- (C) 797,000
- (D) 838,000

205. The pump draws 700 gpm of water from the basin at the bottom of the cooling tower and sends it through the condenser of a steam power plant and then to the spray nozzles at the top of the tower. All piping is schedule 40, nominal 6-in steel pipe (ID=6.065 in). The total length of pipe is 800 ft. All the elbows, tees, valves, and fittings are well represented by a total loss coefficient $\Sigma K = 20$. The water pressure drop across the condenser is 10 psi. The spray nozzles at the top of the tower are 30 ft above the free surface of the basin and the water velocity at the nozzles is 20 ft/s. Neglecting any changes in the water properties with temperature, assuming a Darcy friction factor of 0.03, and assuming a pump efficiency of 80%, the brake horsepower (hp) for the pump is most nearly:

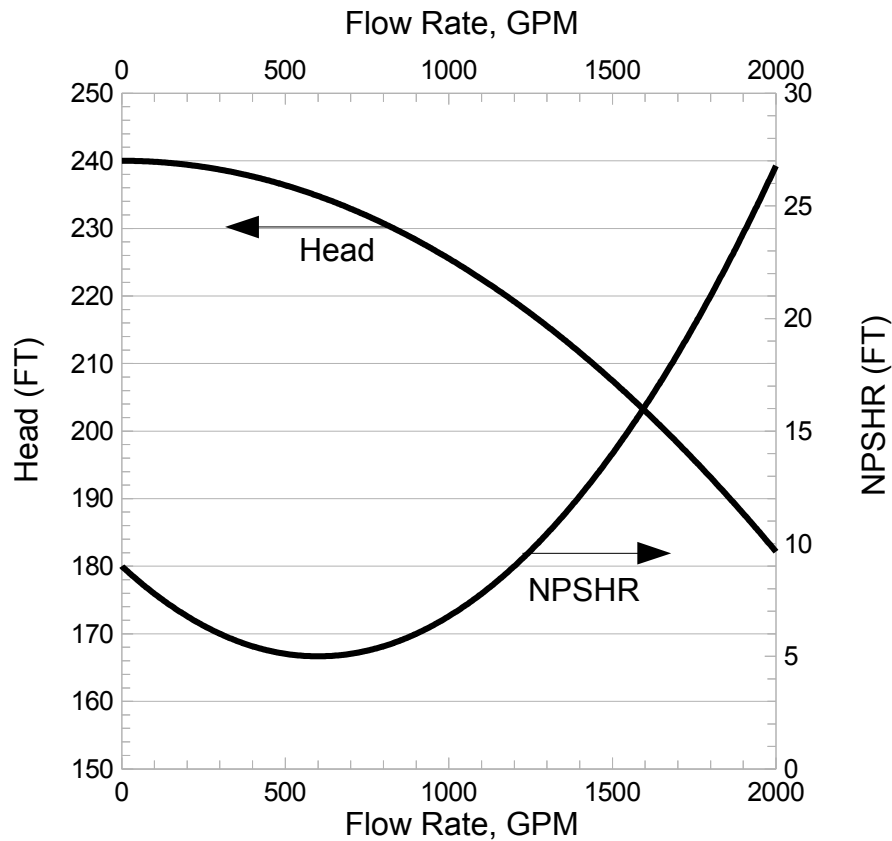
- (A) 15
- (B) 22
- (C) 27
- (D) 32



206. When the shaft horsepower supplied to a certain centrifugal pump is 25 hp, the pump discharges 700 gpm of water while operating at 1800 rpm with a head rise of 90 ft. If the pump speed is reduced to 1200 rpm, the new head rise is most nearly _____ feet

207. A pump is used to deliver water from a ground-level, atmospheric reservoir to a municipal water tower, also at atmospheric pressure. The height of the water surface in the tower is 170 feet. Normally the pump (whose performance curve is shown below) delivers a flow rate of 1200 gpm and minor losses are negligible. For this distribution system in normal operation, the friction head loss (ft) is most nearly:

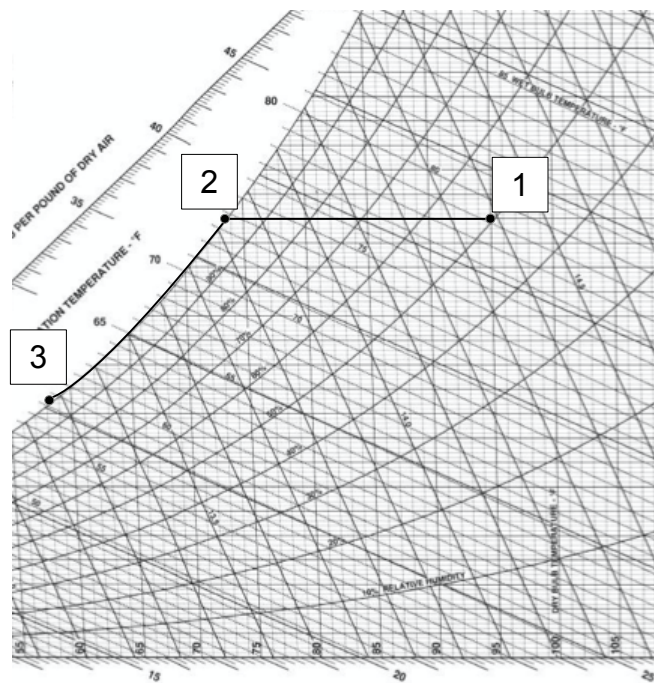
- (A) 9
- (B) 50
- (C) 170
- (D) 220



208. The sketch shows process 1-2-3 in a psychrometric chart.

Select all that apply:

- A. In process 1-2 the relative humidity decreased.
- B. The dry-bulb temperature at State 2 is the dew-point temperature of State 1.
- C. In process 1-2 the humidity ratio remained constant.
- D. In process 2-3 the sensible heat ratio is less than 1.
- E. In state 3, the wet bulb temperature is lower than the dry bulb temperature.
- F. The amount of condensation formed in process 2-3 is approximately the same as the amount formed in process 1-2.

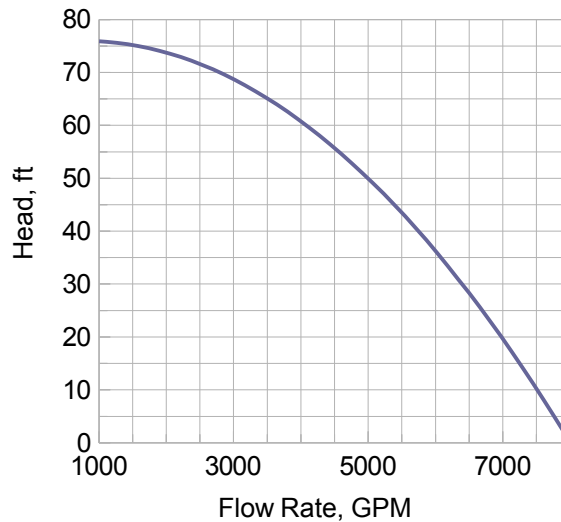


209. Water is pumped between two atmospheric pressure reservoirs in a pipeline with the following characteristics:

Pipeline Characteristics	
Pipe ID, D (in)	12
Total length, L (ft)	230
Darcy friction factor, f	0.03
Total of minor loss coefficients, ΣK	2.5
Static head, $z_{\text{destination}} - z_{\text{source}}$ (ft)	50

The system is served by two identical pumps in parallel, running simultaneously. The characteristic curve for each pump is given below. The water flow rate (gpm) in the pipeline is most nearly:

- (A) 1,000
- (B) 1,700
- (C) 2,200
- (D) 4,400

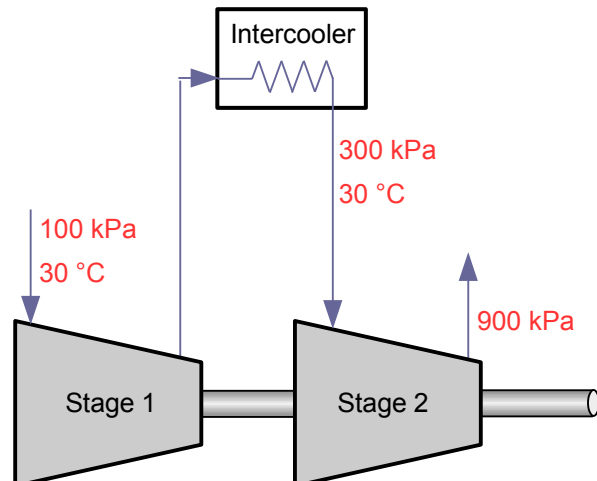


210. A heat transfer oil at 430°F (density = 40 lbm/ft³) flows into a manifold where the flow is divided into 4 branches labeled *A*, *B*, *C*, and *D*. All piping is schedule 40 seamless steel pipe. The flow entering the manifold is 10,000 lbm/h, and the flow rates for branches *A*, *B*, and *C*, are known to be 1000, 2000, and 3000 pounds per hour, respectively. If the velocity in all branches is not to exceed 5.5 feet per second, the smallest nominal pipe diameter (in) for branch *D*, is most nearly:

- (A) ¼
- (B) ½
- (C) ¾
- (D) 1

211. Air (with a mass flow rate of 0.3 kg/s) is compressed in a two-stage turbocompressor with intercooling, as shown. The isentropic efficiency of each stage is 85%. With the conditions shown in the figure, the heat removed (kW) by the intercooler is most nearly:

- (A) 10
- (B) 19
- (C) 29
- (D) 40



212. Ethane (C_2H_6) is burned with 20 percent excess air during a combustion process. Assuming complete combustion and a total pressure of 14.7 psia, the dew-point temperature ($^{\circ}F$) of the products is most nearly:

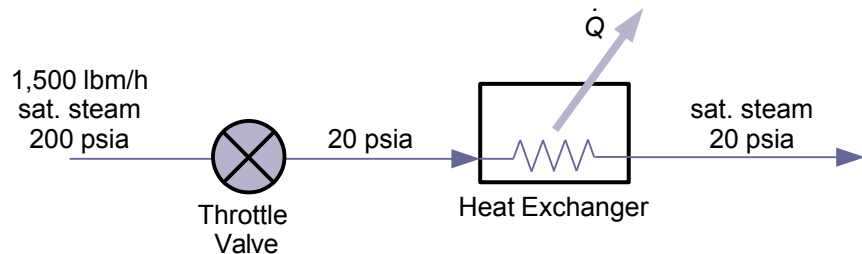
- (A) 127
- (B) 133
- (C) 139
- (D) 145

213. Octane (C_8H_{18}) is burned with dry air. The volumetric analysis of the products on a dry basis is given in the table below. Under these conditions, the air-fuel ratio (kg air/kg fuel) used, is most nearly:

(A) 4.76	CO_2	10.02%
(B) 14.22	O_2	5.62%
(C) 16.32	CO	0.88%
(D) 19.76	N_2	83.48%

214. A stream of 1,500 lbm/h of saturated steam at 200 psia is throttled down to 20 psia and then cooled in a heat exchanger so that it becomes saturated steam again. Under these conditions, the rate at which the steam must be cooled (Btu/h) in the heat exchanger is most nearly:

- (A) 645
- (B) 6,450
- (C) 64,500
- (D) 643,400

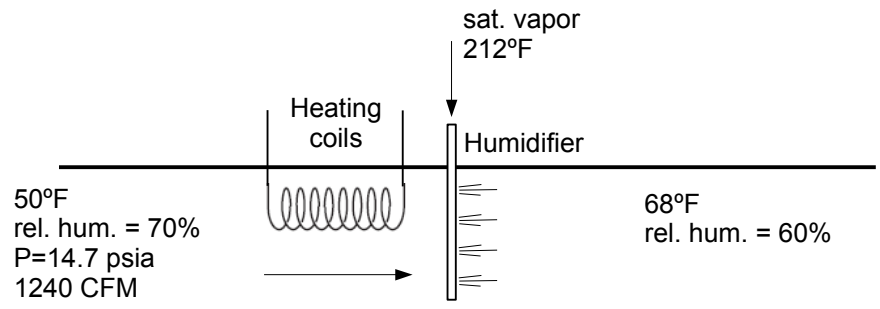


215. A heating section consists of a 15-in.-diameter duct that houses a 4-kW electric resistance heater. Air enters the heating section at 14.7 psia, 50°F, and 40% relative humidity with a velocity of 25 ft/s. The air exit temperature (°F) is most nearly:

- (A) 54
- (B) 57
- (C) 61
- (D) 66

216. An air-conditioning system operates at a total pressure of 1 atm and consists of a heating section and a humidifier that supplies wet steam (saturated water vapor) at 212°F. Air enters the heating section at 50°F and 70 percent relative humidity at a rate of 1240 CFM, and it leaves the humidifying section at 68°F and 60 percent relative humidity. The rate at which water is added (lbm/h) to the air in the humidifying section is most nearly:

- (A) 0.32
- (B) 6.5
- (C) 12.5
- (D) 19.5



217. During an air-conditioning process, 900 CFM of conditioned air at 65°F and 30 percent relative humidity is mixed with 300 CFM of outside air at 80°F and 90 percent relative humidity at a pressure of 1 atm. The relative humidity of the resulting mixture is most nearly:

- (A) 30%
- (B) 45%
- (C) 53%
- (D) 90%

218. The specific volume of saturated liquid ammonia at -50°F is 0.023 ft³/lbm, and the viscosity is 6.527×10^{-6} lbf·s/ft². If the Reynolds number is 1,500,000 at a location within a 3-in ID pipe, the mass flow rate (lbm/h) of ammonia is most nearly:

- (A) 62
- (B) 743
- (C) 3,713
- (D) 223,000

219. Air at 10°C and 80 kPa enters the diffuser of a jet engine steadily with a velocity of 85 m/s. The inlet area of the diffuser is 0.4 m^2 . The air leaves the diffuser with a velocity that is very small compared with the inlet velocity. The temperature ($^{\circ}\text{C}$) of the air leaving the diffuser is most nearly:

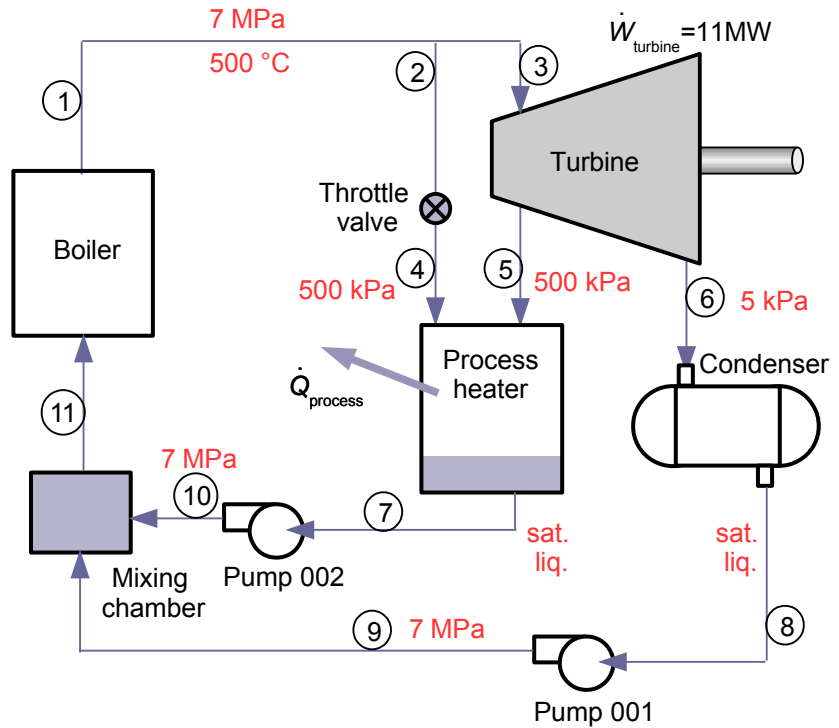
- (A) 14
- (B) 20
- (C) 293
- (D) 303

220. Steam at 250 psia and 700°F steadily enters a well-insulated nozzle whose inlet area is 0.2 ft^2 . The mass flow rate of steam through the nozzle is 10 lbm/s. Steam leaves the nozzle at 200 psia with a velocity of 900 ft/s. The exit temperature ($^{\circ}\text{F}$) of the steam is most nearly:

- (A) 600
- (B) 662
- (C) 700
- (D) 962

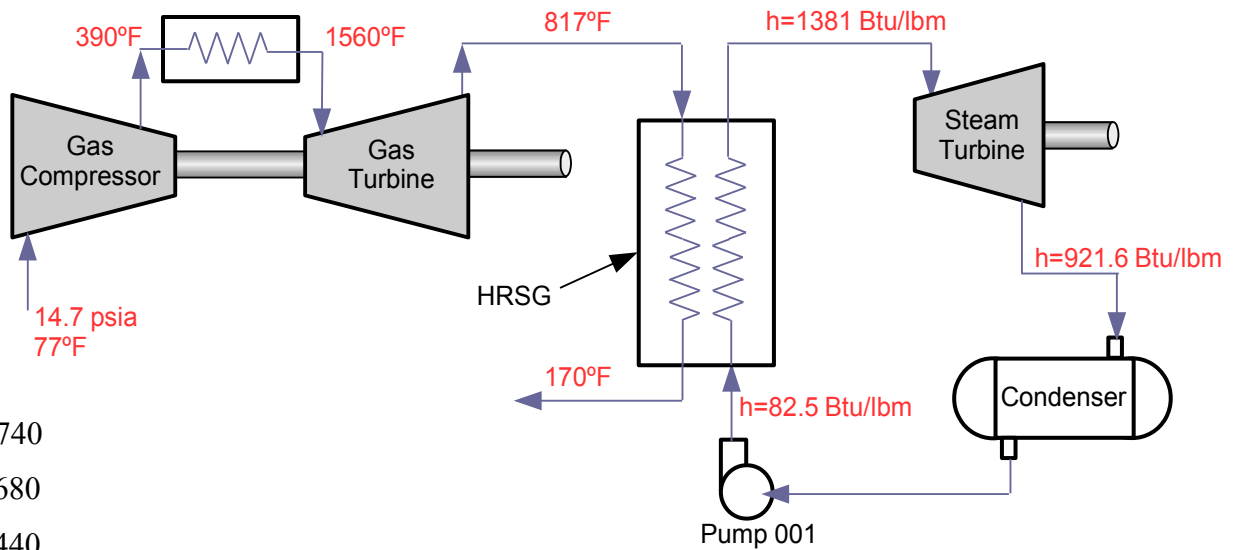
221. Consider the cogeneration steam plant shown in the figure. The flow rate of steam at the boiler outlet is 15 kg/s. The flow rate extracted at location 2 is 1.5 kg/s. The power produced by the isentropic turbine is 11 MW. The streams labeled 4 and 5 are fed into a heat exchanger used as a heater for a manufacturing process. Additional information is provided in the figure and table below. The heat transfer rate (kW) delivered to the manufacturing process is most nearly:

Location	Mass Flow (kg/s)	Enthalpy (kJ/kg)
1	15	3411.4
2	1.5	3411.4
3	13.5	3411.4
4	-	3411.4
5	-	2739.3
6	-	2073.0
7	-	640.09
8	-	137.75
9	-	144.78
10	-	647.19
11	15	-



- (A) 9,540
- (B) 12,680
- (C) 26,410
- (D) 45,560

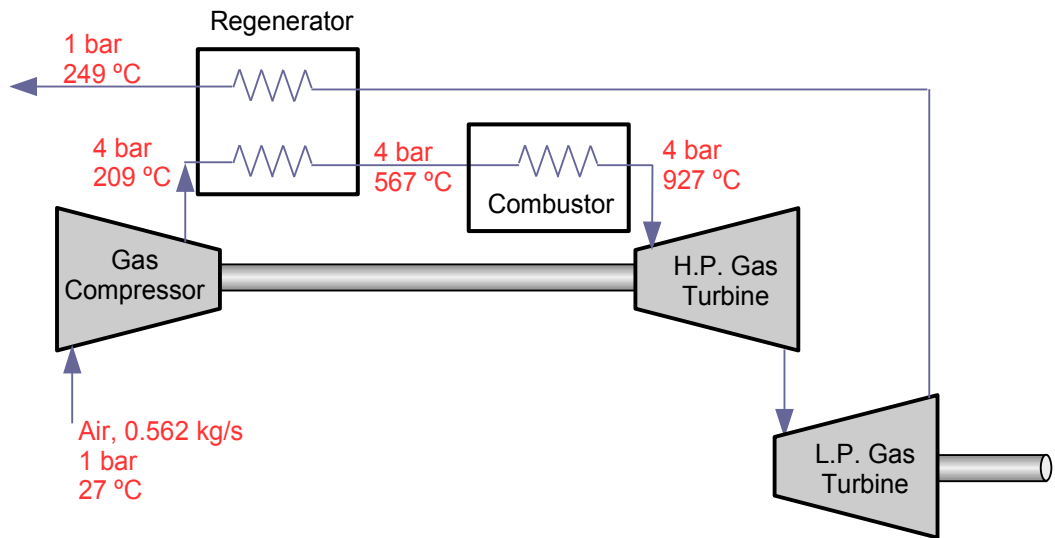
222. In the combined gas and steam turbine (CGST) power plant shown, the inlet to the gas compressor is air at 14.7 psia and 77°F. The pressure ratio for the gas system is 5. There is a perfectly-insulated heat recovery steam generator (HRSG) using the gas turbine exhaust as a heat source to boil and superheat the water in the steam cycle. The mass flow rate for the steam cycle is 741,800 lbm/h and the power consumption by the water pump is negligible. Additional information is provided in the figure. Under these conditions, the heat addition rate (Million Btu/h) in the combustion chamber of the gas cycle system is most nearly:



- (A) 1,740
- (B) 2,680
- (C) 3,440
- (D) 5,110

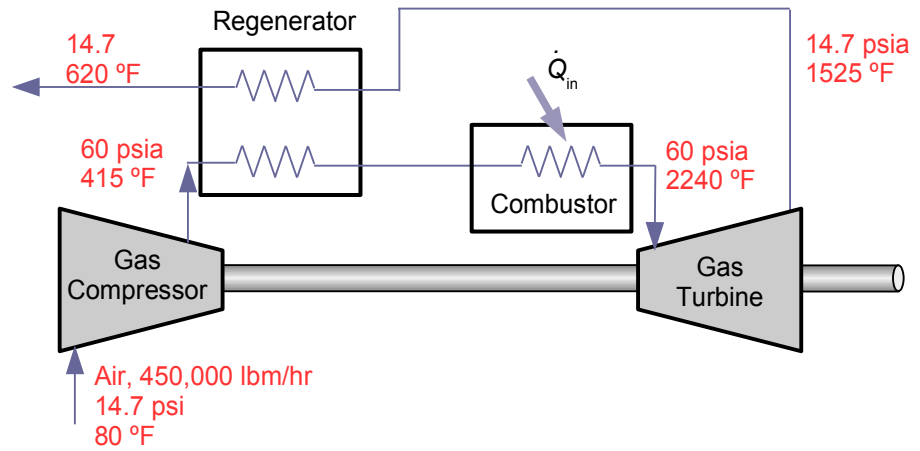
223. A regenerative gas turbine power plant is shown below. Air enters the compressor at 1 bar, 27°C with a mass flow rate of 0.562 kg/s and is compressed to 4 bar. The figure contains additional information. All the power developed by the high-pressure turbine is used to run the compressor. The low-pressure turbine provides the net power output. Each turbine has an isentropic efficiency of 87% and the temperature at the inlet to the high-pressure turbine is 927°C. The pressure (kPa) at the inlet of the low pressure turbine is most nearly:

- (A) 95
- (B) 185
- (C) 205
- (D) 250

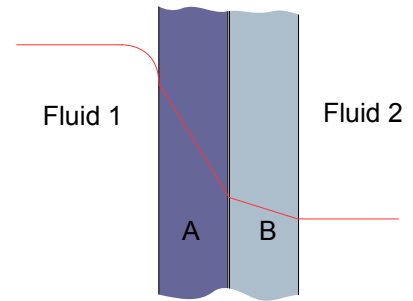


224. A regenerative gas turbine power plant is shown below. Air enters the compressor at 14.7 psi, 80°F with a mass flow rate of 450,000 lbm/h. The heat added by the combustor is 89,100,000 Btu/h. The figure contains additional information. Under these conditions, the regenerator effectiveness is most nearly:

- (A) 75%
- (B) 80%
- (C) 85%
- (D) 90%



225. Fluid 1 (hot) and Fluid 2 (cold) are separated by a composite wall made of two layers. Layer A is made of material A and Layer B is made of a different material, B. The thickness of Layer A is the same as that of Layer B. The red line represents the temperature distribution across the fluids at steady state.



For steady state, select all that apply:

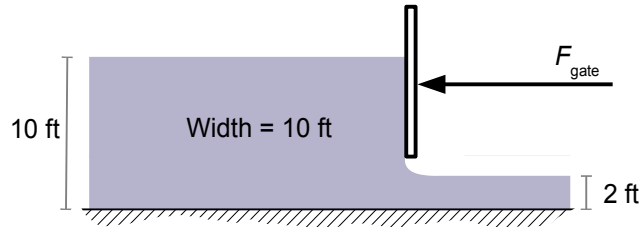
- A. The convection coefficient at the interface between the wall and Fluid 2 is zero.
- B. The thermal conductivity of Material A is lower than that of Material B.
- C. The heat transfer rate across Layer A is greater than that across Layer B.
- D. The conduction resistance across Layer A is higher than the convective resistance between Fluid 1 and the wall

226. An ideal Otto cycle has a compression ratio of 8. At the beginning of the compression process, air is at 100 kPa and 17°C, and 800 kJ/kg of heat is transferred to the air during the constant-volume heat-addition process. Using cold-air-standard assumptions (constant specific heat values at room temperature), the mean effective pressure (kPa) is most nearly:

- (A) 338
- (B) 404
- (C) 621
- (D) 800

227. A 10 ft wide sluice gate in a 10 ft wide canal is lifted so that the height of the water surface immediately downstream is 2 ft. The water surface height upstream of the gate is 10 ft. When the gate is in the position shown, a force F_{gate} of 18,300 lbf is measured. Under these conditions, the water flow rate in the canal (million gallons per day) is most nearly:

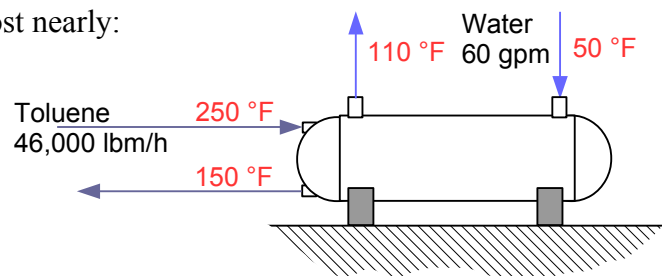
- (A) 169
 (B) 251
 (C) 388
 (D) 475



Hint: A submerged vertical (real or imaginary) surface of height h is subjected to a resultant force F due to hydrostatic pressure, given by: $F_{\text{res}} = (1/2)\rho g h A$ where A is the surface area, ρ is the density of the fluid and g is the gravitational acceleration.

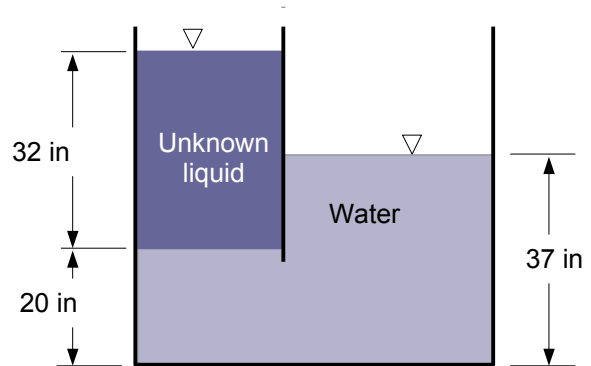
228. The figure shows a heat exchanger used as a cooler for hot liquid toluene (specific heat 0.41 Btu/lbm/°F) in a chemical process plant. The coolant is a stream of 60 gpm of water at 50°F, which is then discharged at 110°F. Over the course of several years, the insulation on the heat exchanger has been degraded so the amount of heat lost to the ambient from the heat exchanger vessel is no longer negligible. The figure provides the process data. Under these conditions, the rate at which heat is lost (Thousand Btu/h) to the ambient is most nearly:

- (A) 0
 (B) 42
 (C) 62
 (D) 84



229. The top part of a water tank is divided into two compartments, as shown in the figure. Now a fluid with an unknown density is poured into one side, and the water level rises a certain amount on the other side to compensate for this effect. Assume the liquid does not mix with water. Based on the final fluid heights shown on the figure, the density (lbm/in^3) of the fluid added is most nearly:

- (A) 0.019
- (B) 0.036
- (C) 0.072
- (D) 0.144



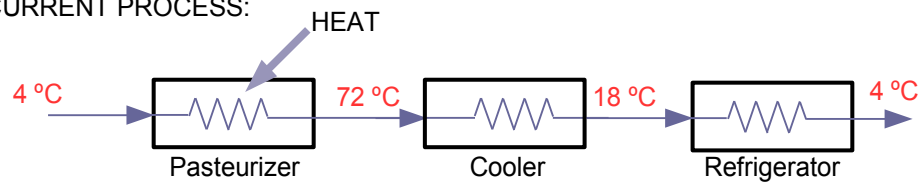
230. Air is compressed steadily by a compressor from 14.7 psi and 68°F to 175 psia and 570°F at a rate of 3200 lbm/h . The power input (brake horsepower) to the compressor is 175 hp. The compressor is intentionally cooled by fins on the surface of the compressor. The rate at which the compressor is cooled (Btu/h) is most nearly:

- (A) 44,620
- (B) 59,730
- (C) 79,860
- (D) 88,540

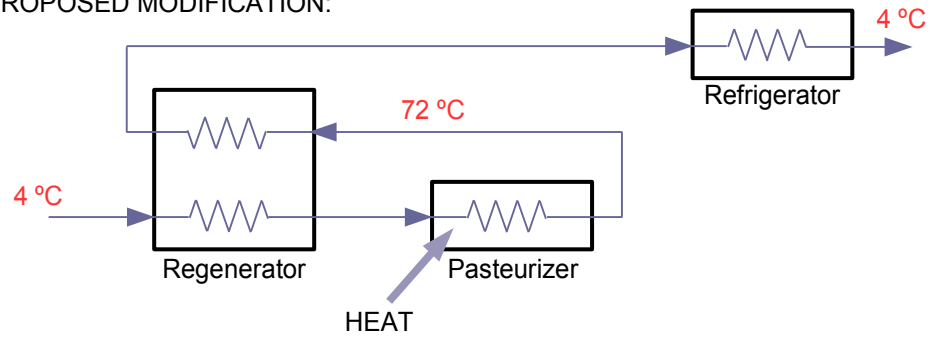
231. In a dairy plant, milk (specific heat, $3.77 \text{ kJ}/(\text{kg}^\circ\text{C})$; density $1035 \text{ kg}/\text{m}^3$) at 4°C is pasteurized continuously at 72°C at a rate of $12 \text{ L}/\text{s}$ for 24 hours a day. The milk is heated to the pasteurizing temperature in an electric heater (a pasteurizer). The pasteurized milk is then cooled to 18°C in another heat exchanger with cold water before it is finally refrigerated back to 4°C . To save energy and money, the plant is considering replacing the cooler with a regenerator that has an effectiveness of 82 percent. The current and proposed processes are shown in the figure. If the regenerator is installed, the reduction of the daily heating requirement (kWh) for the pasteurizing heater is most nearly:

- (A) 2,610
- (B) 4,680
- (C) 62,700
- (D) 74,800

CURRENT PROCESS:

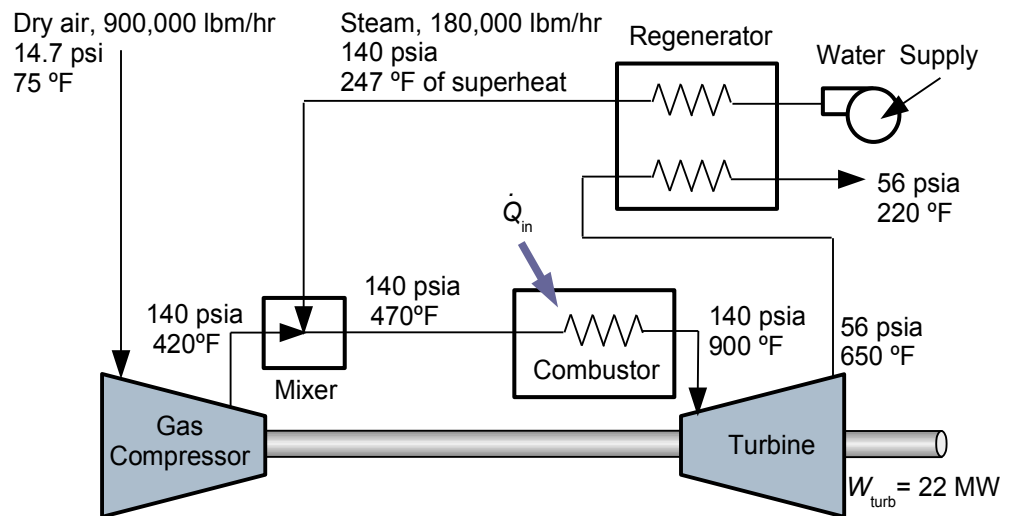


PROPOSED MODIFICATION:



232. In a steam-injected gas turbine, a heat recovery steam generator (HRSG) produces superheated steam which is mixed with the dry air (specific heat, 0.25 Btu/lbm/°F , molecular weight 29 lbm/lbmol) from the compressor. The steam-air mixture is then heated in the combustor and sent to the turbine to produce power. For the purposes of this analysis, the steam may be modeled as an ideal gas with specific heat 0.47 Btu/lbm/°F and molecular weight 18 lbm/lbmol. For the conditions shown, the mol fraction of steam in the mixture at the combustor inlet is most nearly:

- (A) 0.2
- (B) 0.24
- (C) 0.52
- (D) 0.8



233. A counterflow, concentric tube heat exchanger is used to cool the lubricating oil (specific heat 0.5 Btu/(lbm °F)) for a large bank of stationary Diesel engines. The flow rate of cooling water through the inner tube (1-in diameter) is 400 pounds per hour, while the flow rate of oil through the outer annulus (1.77-in diameter) is 200 pounds per hour. The oil and water enter the heat exchanger at temperatures of 210°F and 85°F respectively. The film coefficients are 400 and 7 Btu/(h ft² °F) for the water and oil sides, respectively. The tube length (ft), for a desired oil discharge temperature of 140°F, is most nearly:

- (A) 35
- (B) 50
- (C) 65
- (D) 70

234. A heat transfer oil at 320°F is available for heating 20,000 pounds per hour of water from 60°F to 185°F. The heating will be performed in a shell and tube heat exchanger with the oil in the shell side. The convective coefficient for the oil is 70 Btu/h/ft²/°F on the outside surface of the tubes and 540 Btu/h/ft²/°F for the water on the inside surface of the tubes. Ten tubes pass the water through the shell. Each thin-walled tube is 1-in ID and makes eight passes through the shell. Use a shell-and-tube correction factor $F=0.87$. The discharge temperature for the oil is 210°F. The length (ft) of each tube is most nearly:

- (A) 10.4
- (B) 108
- (C) 125
- (D) 1250

235. Hot exhaust gases, which enter a finned-tube, cross-flow heat exchanger at 350°C and leave at 120°C, are used to heat water at a flow rate of 0.9 kg/s from 30°C to 125°C. For these conditions, the overall heat transfer coefficient is known to be $U = 100 \text{ W}/(\text{m}^2 \cdot \text{K})$. If needed, you may use the following property values for specific heat c , and density, ρ , which may be treated as constants:

$$\begin{array}{ll} c_{\text{gas}} = 1000 \text{ kJ}/(\text{kg} \cdot \text{K}) & \rho_{\text{gas}} = 0.686 \text{ kg}/\text{m}^3 \\ c_{\text{water}} = 4197 \text{ kJ}/(\text{kg} \cdot \text{K}) & \rho_{\text{water}} = 972 \text{ kg}/\text{m}^3 \end{array}$$

Under these conditions, the heat transfer effectiveness is most nearly:

- (A) 72%
- (B) 82%
- (C) 92%
- (D) Cannot be determined

236. The condenser in a large power plant is a shell-and-tube heat exchanger, consisting of a single shell and 30,000 tubes, each executing two passes. The tubes are of thin wall construction with 1-in ID. Saturated steam condenses to saturated liquid water on the outer surface of the tubes with an associated convection coefficient of $1940 \text{ Btu}/(\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F})$. The condenser duty is $6.82 \times 10^9 \text{ Btu}/\text{h}$ while using 238 million pounds per hour of cooling water available at 68°F. The pressure in the shell (steam) side is 1.8 psia. Under these conditions, the shell-and-tube correction factor is most nearly:

- (A) 0.7
- (B) 0.8
- (C) 0.9
- (D) 1.0

237. A facility has a steam power plant that can be modeled as an ideal simple Rankine cycle with saturated vapor at the turbine discharge and saturated liquid at the condenser discharge. The facility will lower the condenser pressure without changing the boiler inlet pressure.

Select all that apply:

- A. The pump work input will decrease.
- B. The turbine work output will increase.
- C. The heat supplied by the boiler will remain the same.
- D. The moisture content at the turbine discharge will increase.
- E. The moisture content at the turbine discharge will decrease.

238. A cooling tower has a cooling capacity of 100 tons. If the tower operates at capacity in ambient conditions of 70°F and 60% relative humidity with air at 95°F and 80% relative humidity at the discharge, the amount of water evaporated (lbm/day) is most nearly:

- (A) 845
- (B) 9,310
- (C) 14,510
- (D) 20,300

239. Air at 1 MPa and 600°C enters a converging nozzle with a velocity of 150 m/s. The back pressure is 0.4 MPa. The mass flow rate (kg/s) through the nozzle for a nozzle throat area of 50 cm² is most nearly:

- (A) 4.6
- (B) 5.1
- (C) 7.1
- (D) 7.6

240. The air entering a conditioned space is supplied at 56°F, 55 r.h. The space is kept at 75°F and 50% r.h. The total sensible load for the space is 129,000 Btu/h and the total moisture evaporation rate in the space is 25 lbm of water per hour. Based on the sensible load, the air flow (cfm) required for this space is most nearly:

- (A) 1,130
- (B) 2,260
- (C) 6,300
- (D) 12,600



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