CHAPTER 6 – PROBLEMS

1. A general heat engine has a total heat input of 1.3 kJ and a thermal efficiency of 35%. How much work will it produce? (0.455 kJ)
2. A heat engine has a heat input of \(3 \times 10^4\) Btu/hr and a thermal efficiency of 40%. Calculate the power it will produce.
3. The thermal efficiency of a general heat engine is 40% and it produces 30 hp. At what rate is heat added to this engine? (53.0 Btu/s)
4. A residential heat pump has a coefficient of performance of 1.4. How much heating effect will this heat pump produce when it is supplied with 5 hp of power?
5. The coefficient of performance of a residential heat pump is 1.6. Calculate the heating effect when this heat pump uses 2 kW of electrical power. (3.2 kW)
6. A commercial heat pump removes 10 kBTu/hr from the source, rejects 15.09 kBTu/hr to the sink, and requires 2 hp of power. What is this heat pump's coefficient of performance?
7. A refrigerator in a grocery store is to produce a 10 kBTu/hr cooling effect and it has a coefficient of performance of 1.35. How much power will be required to operate this refrigerator? (2.17 kW)
8. A food freezer is to produce a 5 kW cooling effect and its COP is 1.3. How much power is required to operate this freezer?
9. A refrigerator used to cool a computer requires 3 kW of electrical power and has a COP of 1.4. What is the cooling capacity of this refrigerator?
10. A heat engine that propels a ship produces 500 Btu/min of work while rejecting 300 Btu/min of heat. What is its thermal efficiency?
11. A heat engine that pumps water out of an underground mine accepts 500 kJ of heat and produces 200 kJ of work. How much heat does it reject? (300 kJ)
12. A general heat engine with a thermal efficiency of 40% rejects 1000 Btu/lbm of heat. How much heat does it consume?
13. A heat pump has a COP of 1.7. Determine the heat transfer to and from this heat pump as it consumes 50 kJ of work. (35 kJ, 85 kJ)
14. A heat pump with a COP of 1.4 is to produce a 100 kBTu/hr heating effect. How much power does this device require?
15. A food refrigerator produces a 15 kBTu/hr cooling effect while rejecting 22 kBTu/hr of heat. What is its COP? (2.14)
16. An air conditioner produces a 2 kW cooling effect while rejecting 2.5 kW of heat. What is its COP?
17. An automotive air conditioner produces a 1 kW cooling effect while using 0.75 kW of power. What is the rate of heat rejection in the condenser? (1.75 kW)
18. Prove that a refrigerator's COP cannot exceed that of a completely reversible refrigerator that uses the same thermal-energy reservoirs.
19. Prove that the COP of all completely reversible refrigerators must be the same when the thermal-energy reservoirs are the same.
20. Derive an expression for the COP of a completely reversible refrigerator in terms of the thermal-energy reservoir absolute temperatures.
21. Derive an expression for the COP of a completely reversible heat pump in terms of the thermal-energy reservoir absolute temperatures. \([T_h / (T_h - T_i)]\)
22. A completely reversible heat engine operates with a source reservoir at 1500 °R and a sink reservoir at 500 °R. At what rate must heat be supplied to this engine for it to produce 5 hp of power?

23. A completely reversible refrigerator is driven by a 10 kW compressor and operates with thermal-energy reservoirs at 250 K and 300 K. Calculate the rate of cooling provided by this refrigerator. (50 kW)

24. A completely reversible refrigerator operates with thermal-energy reservoirs at 450 °R and 540 °R. How many kilowatts of power are required for this refrigerator to produce a 15 kBtu/hr cooling effect?

25. A completely reversible heat pump has a COP of 1.6 and a sink-reservoir temperature of 300 K. Calculate the temperature of the source-reservoir and the rate of heat transfer to the sink-reservoir when 1.5 kW of power is supplied to this heat pump. (113 K, 4.0 kW)

26. An inventor claims to have devised a cyclic heat engine for use in space vehicles that operates with a nuclear-fuel energy-source whose temperature is 1000 °R and a sink-reservoir which radiates heat to deep space at 550 °R. He also claims that this engine produces 5 hp while rejecting heat at a rate of 15 kBtu/hr. Is this claim valid?

27. You are an engineer in an electrical-generation station. You know that the flames in the boiler reach a maximum temperature of 1200 K and that cooling water at 300 K is available from a nearby river. What is the maximum efficiency your plant will ever achieve? (0.75)

28. As the engineer of the previous problem, you also know that the metallurgical temperature limit for the blades in the turbines is 1000 K before they incur excessive creep. What is now the maximum efficiency of this plant?

29. Supposedly, the efficiency of a completely reversible heat engine can be doubled by doubling the temperature of the energy source-reservoir. Justify this claim. (this claim is invalid)

30. A manufacturer of ice cream freezers claims that his product has a coefficient of performance of 1.3 while freezing ice cream at 250 K when the temperature of the surroundings is 300 K. Is this claim valid?

31. A heat pump designer claims to have a heat pump whose COP is 1.8 when heating a building whose interior temperature is 300 K and the temperature of the atmosphere surrounding the building is 260 K. Is this claim valid? (claim is valid)

32. An inventor claims to have developed a heat pump that produces a 200 kW heating effect for a 293 K heated zone while only using 75 KW of power and a source-reservoir whose temperature is 273 K. Is this claim valid?

33. A heat engine operates with a source-reservoir at 1280 K and a sink-reservoir at 290 K. What is the maximum work per unit of heat input this engine can produce? (0.77)

34. A heat engine has thermal-energy reservoirs at 1260 °R and 510 °R. What is the maximum work per unit of heat input this engine can produce?

35. From a work production perspective, which are the more valuable, (a) thermal-energy reservoirs at 675 K and 325 K or (b) thermal-energy reservoirs at 273 K and 303K? (option a is more valuable)
36. Determine the minimum amount of work required per unit of heat transfer from the source-reservoir to drive a refrigerator whose thermal-energy reservoirs are at 27 K and 303 K.

37. Determine the minimum amount of work required per unit of heat transfer from the source-reservoir to drive a heat pump with thermal-energy reservoirs at 460 °R and 535 °R.

38. An inventor claims to have a heat engine whose thermal efficiency is 50% when operating with thermal-energy reservoirs at 1260 °R and 510 °R. Is this claim valid?

39. An inventor claims to have a heat pump with a COP of 1.7 when operating with thermal-energy reservoirs at 273 K and 293 K. Is this claim valid? (claim is valid)

40. Based upon an atmospheric temperature of 300 K which one of these two energy reservoirs, (a) 1 GJ at 500 K or (b) 0.9 GJ at 550 K, is the more valuable for work production?

41. Based upon an atmospheric temperature of 300 K which one of these two energy reservoirs is most desirable for operating an air conditioner, (a) one at 320 K or (b) one at 340 K? (option a requires the least amount of work input)

42. Your geologist has found two sources of coal. One contains two million kg of low-quality coal (18 MJ/kg) that burns at 600 K and the other contains 1.7 million kg of high-quality coal (22 MJ/kg) that burns at 650 K. Presuming everything else is equal, which coal source should you proceed to develop?