Modeling Exercises

I. Rankine Cycle Modeling and Analysis

Exercise 1:

A Rankine cycle comprises of boiler, a single stage turbine, condenser and a feed water pump shown in the model below. The boiler generates steam at 5400 kg/hr (1.5 kg/s) with 1000 kg/hr coal feed rate and air supply rate of 11300 slpm. Assign all state numbers in sequence from the boiler input and determine their respective properties in a table. From the property table, compute heat input rate, net power generated, Rankine cycle efficiency, plant heat rate.

$$W_{pump} = \dot{m} \cdot (h_4 - h_1) = 1.5 \frac{kg}{s} (346.7 - 340..5) \frac{kJ}{kg} = 9.3 \cdot kW$$

$$W_{turbine} = \dot{m} \cdot (h_3 - h_2) = 1.5 \frac{kg}{s} (3656 - 2494) \frac{kJ}{kg} = 1743 \cdot kW$$

$$W_{net} = W_{turbine} - W_{pump} = 1743 - 9.3 = 1733.7 \cdot kW$$

$$\eta_{carnot} = 1 - \frac{T_l}{T_h} = 1 - \frac{(273.15 + 81.33°C)}{(273.15 + 600°C)} = 59.4\%$$

$$Q_{in} = \dot{m} \cdot (h_2 - h_1) = 1.5 \frac{kg}{s} (3656 - 346.7) \frac{kJ}{kg} = 4963.95 \frac{kJ}{s}$$

$$Q_{out} = \dot{m} \cdot (h_3 - h_4) = 1.5 \frac{kg}{s} (2494 - 340.5) \frac{kJ}{kg} = 3230.25 \frac{kJ}{s}$$

$$\eta_{rankine} = \frac{W_{net}}{Q_{in}} = \frac{1734}{4964} = 0.3493 = 34.93\%$$

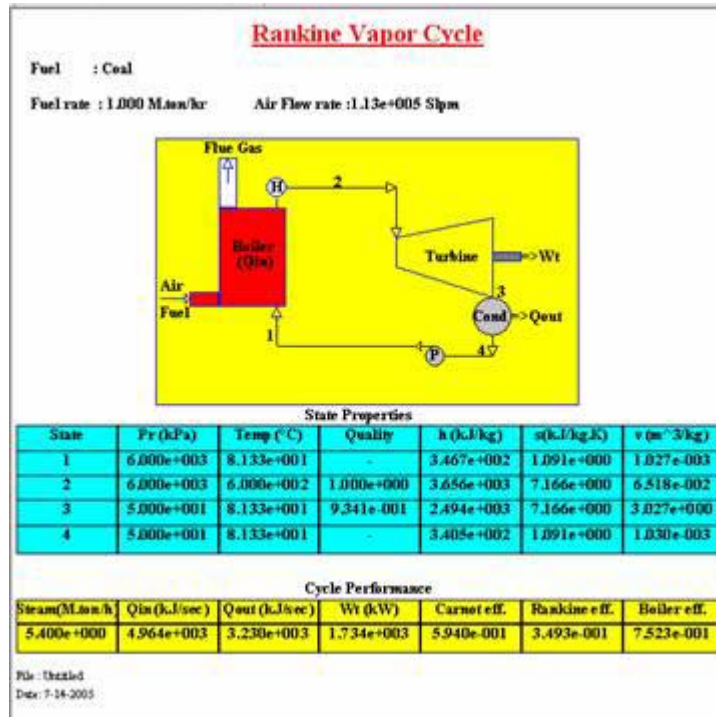$$\eta_{boiler} = \frac{Q_{in}}{Total\ Heat\ Credits} = \frac{4964}{6598} = 0.7523 = 75.23\%$$

Where: Total Heat Credit = combustion heat + air-preheat (from combustion analysis)
   Combustion heat = high calorific value*fuel feed rate
   Air-preheat = cp*(T_{air} – T_{amb})*air flow rate

$$PlantHeatRate = \frac{Total\ Combustion\ Heat}{Net\ Power\ Generated} = \frac{6598}{1734} = 3.81$$

Flow Joule Result:

Rankine Vapor Cycle

Fuel   : Coal

Fuel rate : 1.000 M.ton/hr   Air Flow rate :1.13e+005 Slpm

State Properties

State	Pr (kPa)	Temp (°C)	Quality	h (kJ/kg)	s(kJ/kg.K)	v (m^3/kg)
1	6.000e+003	8.133e+001	-	3.467e+002	1.091e+000	1.027e-003
2	6.000e+003	6.000e+002	1.000e+000	3.656e+003	7.166e+000	6.518e-002
3	5.000e+001	8.133e+001	9.341e-001	2.494e+003	7.166e+000	3.027e+000
4	5.000e+001	8.133e+001	-	3.405e+002	1.091e+000	1.030e-003

Cycle Performance

Steam(M.ton/h)	Qin (kJ/sec)	Qout (kJ/sec)	Wt (kW)	Carnot eff.	Rankine eff.	Boiler eff.
5.400e+000	4.964e+003	3.230e+003	1.734e+003	5.940e-001	3.493e-001	7.523e-001

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Exercise 2:

Modify the above model with a two-stage turbine with 10 bar intermediate pressure for reheat at 400°C and a feed water heater extraction of 500 kg/hr steam at 5 bar and determine heat input, net power generated, Rankine cycle efficiency and plant heat rate.

To do this, double click on turbine component it will display the property page for the turbine. Select 'Two-stage' radio button, the stage-2 data section is enabled for you to enter. Enter the outlet pr of stage-1 and inlet pressure of stage-2 as 10 bar. In addition, enter the inlet temperature of stage 2 after reheat as 400 °C. While condenser pressure remaining the same, enter stage-2 outlet pressure as 0.5 bar. Since isentropic expansion is checked, to set the outlet temperature of stage 1 and 2 click 'Apply' button. This will compute the temperature as 310.65 °C and 81.33 °C respectively for isentropic expansion.

Next, to add feed water heater, check the feed water heater under 'Extraction points'. This would enable the Feed water heater data section. Enter the flow rate 500 kg/hr at 5 bar bleed pressure. Since isentropic expansion has been checked, to set the bleed temperature, click the 'Apply' button. This computes the temperature as 300.73 °C. This completes the modification procedure and the new turbine property page will look like one shown in the following dialog box.
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Now, the generic model has been modified and you can browse through the property pages of the feed pump, condenser and see respective changes have occurred. However, this will not take in to effect until you click the 'OK' button as a final acceptance for the modifications. If you click the 'Cancel' button, the model goes back to its original status. The modified model is shown below. Save this file as 'rankine_mod1' for future reference or further modifications

Rankine Cycle Properties

Boiler | Turbine | Condenser | Feed Pumps | Feedwater Heater

No of Stages
- ○ Single stage
- ● Two stage (HP and IP)
- ○ Three stage (HP, IP, LP)

Extraction points
- ☑ Condenser (stage 3 outlet)
- ☑ Feedwater heater
- ☐ Process Heat   [Data]

Feedwater heater extraction
- Flow rate   500   *kg/hr
- Bleed Pr   5   Bar
- Bleed Temp   300.73   °C

Stage 1 (HP)
- Inlet Pr   60   Bar
- Inlet Temp   600   °C
- Outlet Pr   10   Bar
- Outlet Temp   310.65   °C
- ☑ Isentropic expansion

Stage 2 (IP)
- Inlet Pr   10   Bar
- Inlet Temp   400   °C
- Outlet Pr   0.5   Bar
- Outlet Temp   81.34   °C
- ☑ Isentropic expansion

Stage 3 (LP)
- Inlet Pr   0
- Inlet Temp   0
- Outlet Pr   0
- Outlet Temp   0
- ☑ Isentropic expansion

Note: Click 'Apply' in order to get the temperature for isentropic expansion.
For non-isentropic enter the temperature data.

[OK]   [Cancel]   [Apply]

One may notice several changes in both model space as well as description space after incorporating the above modifications. Now there are nine states and two additional components. It recalculated the property data for all nine states and then modified the cycle performance summary. There is a drop in total heat (Qin) suggests that one may need lesser fuel if the boiler operates at the same efficiency level. Therefore, you can edit this data under combustion analysis section. To do this, reduce the coal feed rate from 1000 kg/hr to 975 kg/hr and check the heat balance sheet. Stop editing if the boiler efficiency gets back to its original vale (75% to 76%). Note: this would also result in reduced airflow rate.

From the new state property data, you can compute different cycle performance and efficiencies as given below. It may be noted that the property data displayed in the table has been rounded off to the 4th digit. Therefore, calculated result differs slightly from the cycle performance summary.

$$Q_{in} = \dot{m} \cdot (h_2 - h_1) + \dot{m}(h_4 - h_3) = 1.5 \frac{kg}{s}[(3656 - 599.3) + (3264 - 3075)] \frac{kJ}{kg} \approx 4870 \frac{kJ}{s}$$

$$m_6 = m_1 - m_5 = 1.5 \frac{kg}{s} - \left(\frac{500}{3600}\right) \frac{kg}{s} = 1.3611 \frac{kg}{s}$$

$$Q_{out} = \dot{m}_6 \cdot (h_6 - h_7) = 1.3611 \frac{kg}{s}(2601 - 340.5)\frac{kJ}{kg} = 3076\frac{kJ}{s}$$

$$W_{turbine} = \dot{m}_1[(h_2 - h_3) + (h_4 - h_6)] - m_5(h_5 - h_6) = 1.5[(3656 - 3075) + (3264 - 2601)] - 0.139(3066 - 2601) = 1801.4\,kW$$
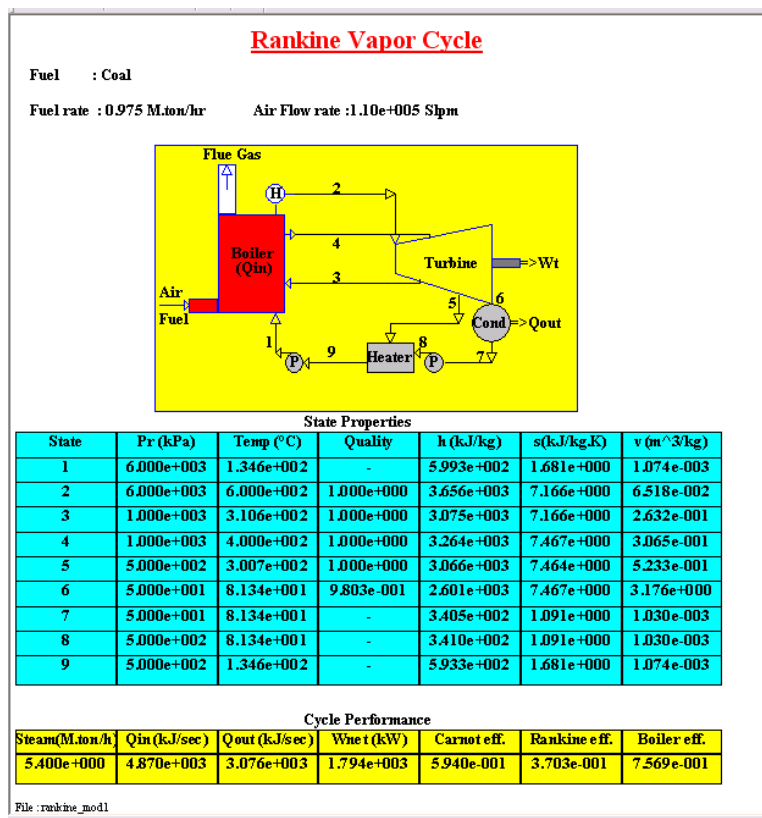
$$W_{pump} = m_7(h_8 - h_7) + m_8(h_1 - h_9) = 1.361(341. - 340.5) + 1.5(599.3 - 593.3) = 9.7\,kW$$

$$W_{net} = W_{turbine} - W_{pump} \approx 1794\,kW$$

$$\eta_{rankine} = \frac{W_{net}}{Q_{in}} = \frac{1794}{4870} = 0.368 = 36.8\%$$

$$\eta_{boiler} = \frac{Q_{in}}{Total\,Heat\,Credits} = \frac{4870}{6430} = 0.7574 = 75.7\%$$

$$PlantHeatRate = \frac{Total\,Combustion\,Heat}{Net\,Power\,Generated} = \frac{6430}{1794} = 3.59$$

Rankine Vapor Cycle

Fuel   : Coal

Fuel rate : 0.975 M.ton/hr   Air Flow rate : 1.10e+005 Slpm

State Properties

State	Pr (kPa)	Temp (°C)	Quality	h (kJ/kg)	s(kJ/kg.K)	v (m^3/kg)
1	6.000e+003	1.346e+002	-	5.993e+002	1.681e+000	1.074e-003
2	6.000e+003	6.000e+002	1.000e+000	3.656e+003	7.166e+000	6.518e-002
3	1.000e+003	3.106e+002	1.000e+000	3.075e+003	7.166e+000	2.632e-001
4	1.000e+003	4.000e+002	1.000e+000	3.264e+003	7.467e+000	3.065e-001
5	5.000e+002	3.007e+002	1.000e+000	3.066e+003	7.464e+000	5.233e-001
6	5.000e+001	8.134e+001	9.803e-001	2.601e+003	7.467e+000	3.176e+000
7	5.000e+001	8.134e+001	-	3.405e+002	1.091e+000	1.030e-003
8	5.000e+002	8.134e+001	-	3.410e+002	1.091e+000	1.030e-003
9	5.000e+002	1.346e+002	-	5.933e+002	1.681e+000	1.074e-003

Cycle Performance

Steam(M.ton/h)	Qin (kJ/sec)	Qout (kJ/sec)	Wnet (kW)	Carnot eff.	Rankine eff.	Boiler eff.
5.400e+000	4.870e+003	3.076e+003	1.794e+003	5.940e-001	3.703e-001	7.569e-001

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Practice Examples:

Use coal with following composition in all examples.
Composition : C(0.550),H(0.046),O(0.010),N2(0.010),S(0.003).M(0.045),Ash(0.336)
HCV = 5630 kcal/kg.

1. In a Rankine vapor cycle, the steam header pressure is at 6000 kPa and 600 °C temperature. The condenser pressure is maintained at 50 kPa. If steam is generated at 935 kg/hr with 76% boiler efficiency, determine the rate at which heat is added, net power generated, Rankine cycle efficiency and coal feeding rate to the boiler.

2. In a reheat Rankine vapor cycle, steam is generated at 1000 kg/hr with 6000 kPa pressure and 400 °C temperature. The exit pressure of HP turbine is 1000 kPa and steam is then reheated to 400 °C and sent to IP turbine. The condenser is set at 50 kPa. Determine the rate at which heat is added to the boiler with 76% efficiency. Also, determine the net power generated Rankine cycle efficiency and coal feeding rate to the boiler.

3. In a Rankine vapor cycle, the steam header pressure is at 6000 kPa and 600 °C temperature. The condenser pressure is maintained at 50 kPa. Steam is generated at 1000 kg/hr, with 75% boiler efficiency. An open type feed water heater uses 110 kg/hr steam at 500-kPa bleed pressure from the turbine. Determine the rate at which heat is added, net power generated Rankine cycle efficiency and coal feeding rate to the boiler.

4. In a reheat Rankine cycle with open feed water heater; steam is generated at 36000 lbm/hr (18 ton/hr) 900 psia and 600 °F temperature. The steam from HP turbine exit at 300 psia is reheated to 600 °F and sent to IP turbine. The condenser pressure is maintained at 10 psia. The feed water heater uses 3600 lbm/hr steam at 250 psia bleed pressure from the IP turbine. Determine the rate at which heat is added, net power generated, Rankine cycle efficiency and coal feeding rate to the boiler. Assume efficiency of the boiler is about 72%.

II. HVAC Cooling Cycle Modeling and Analysis

Exercise 1

The cooling cycle model consisting of conditioned space (office building), cooling coil and a circulating fan is shown below. Dehumidified air is circulated to offset the estimated sensible cooling load of 202600 BTU/hr and latent load of 41980 BTU/hr of the conditioned space. Outdoor ventilation air at 95 °F dry bulb and 75 °F wet bulb temperature enter the system @ 2000 cfm is mixed with return air and then passed through the cooling coil. The conditioned space is maintained at 75 °F dry bulb temperature with 50% relative humidity. The circuit is also consists of dampers and mixing points to control the mass flow rates. All the state numbers are assigned in sequence from outdoor air to return air. Part of the return air is bypassed the coil to maintain a constant temperature differential of 20 °F with respect to the conditioned space. Determine humid air properties of each state, Effective Sensible Heat Factor, Apparatus Dew Point, dehumidification air quantity and the grand total heat.

Given:

Room Sensible Heat (RSH) = 202600 BTU/hr
Room Latent Heat (RLH) = 41980 BTU/hr
Room Total Heat (RTH) = RSH + TLH = 244580 BTU/hr

Outside Air Sensible Heat (OASH)

$$QASH = \frac{q \cdot cp \cdot \Delta T}{v} = \frac{2000cfm \cdot 0.24 \frac{BTU}{lb \cdot °F} \cdot (95-75)°F}{13.68 \frac{ft^3}{lb}} = 42105 \frac{BTU}{hr}$$

Outside Latent Heat Load (OALH)

$$OALH = \frac{(w_{oa} - w_r)h_g \cdot q}{v} = \frac{(98.5 - 65.5)\frac{grain}{lb} \frac{lb}{7000grain} \cdot 1075 \frac{BTU}{lb} \cdot 2000 \frac{ft^3}{min}}{13.68 \frac{ft^3}{lb}} = 44454 \frac{BTU}{hr}$$

Outside Air Total Heat (OATH) = OASH + OALH = 86560 BTU/hr.

A. Effective Sensible Heat Factor:

$$ESHF = \frac{Room \, Sensible \, Heat Load \, (RSH) + cbf \cdot Outside \, Air \, Sensible \, Heat (OASH)}{Room \, Total \, Heat \, (RTH) + cbf \cdot Outside \, Air \, Total \, Heat (OATH)}$$

$$ESHF = \frac{202600 + 0.15 \times 42105}{244580 + 0.15 \times 86560} = 0.811$$

B. Apparatus Dew Point

The 'Apparatus Dew Point' is the point on the saturation line where the ESHF line from room design intersects on the psychrometric chart and found to be 51 °F

C. Dehumidification Air Quantity

The following is the dehumidified air required to offset the room sensible heat load with 20°F supply temperature differential as well as apparatus differential.

$$Q_{sup\,ply} = \frac{v \cdot ERSH}{cp \cdot (\Delta T_{sup\,ply})} = \frac{13.68 \frac{ft^3}{lb} \cdot (202600 + 0.15 \cdot 42105) \frac{BTU}{hr}}{0.24 \frac{BTU}{lb \cdot {}^\circ F} 20^\circ F} = 9923 \cdot cfm.$$

$$Q_{App} = \frac{v \cdot ERSH}{cp \cdot (T_{room} - T_{ADP})(1 - cbf)} = \frac{13.68 \cdot ft^3 \cdot lb^{-1}(202600 + 0.15 \cdot 42105)BTU \cdot hr^{-1}}{0.24 \cdot BTU \cdot lb^{-1}{}^\circ F^{-1} \cdot (75 - 51.1)^\circ F \cdot 0.85} = 9770 \cdot cfm$$

Since air quantity required to pass through the apparatus is less than room air supply required, the difference in quantity is re-circulated from the room return air.

$Q_{bypass} = Q_{supply} - Q_{app} = 9923 - 9770 = 152$ cfm

The apparatus entering temperature is calculated as follows.

$$T_3 = T_{room} + \frac{q_{vent} \cdot (T_1 - T_{room})}{Q_{Apr}} = 75 + \frac{2000 \cdot (95 - 75)}{9770} = 79.1^\circ F$$

The apparatus exit temperature is calculated based on the coil bypass factor as follows.

$$T_4 = T_{adp} + cbf(T_3 - T_{adp}) = 51.1 + 0.15(79.1 - 51.1) = 55.3^\circ F$$

D. Grand Total Heat

GTH = RTH + OATH = 331140 BTU/hr
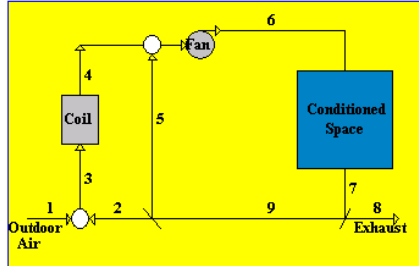
$$Capacity = \frac{GTH}{12000} \approx 28 Tons$$

Flow Joule Result

HVAC - Cooling Cycle

System Air Flow rate :9907 cfm

State Properties

State	T-dB (°F)	T-wB (°F)	RH (%)	W (gr/lb-da)	h (BTU/lb)	v (ft^3/lb)
1	9.500e+001	7.500e+001	3.856e+001	9.850e+001	3.831e+001	1.429e+001
2	7.500e+001	6.280e+001	5.000e+001	6.553e+001	2.824e+001	1.368e+001
3	7.910e+001	6.584e+001	4.795e+001	7.229e+001	3.029e+001	1.380e+001
4	5.530e+001	5.362e+001	8.939e+001	5.813e+001	2.228e+001	1.316e+001
5	7.500e+001	6.280e+001	5.000e+001	6.553e+001	2.824e+001	1.368e+001
6	5.561e+001	5.403e+001	8.825e+001	5.804e+001	2.234e+001	1.316e+001
7	7.500e+001	6.280e+001	5.000e+001	6.553e+001	2.824e+001	1.368e+001
8	7.500e+001	6.280e+001	5.000e+001	6.553e+001	2.824e+001	1.368e+001
9	7.500e+001	6.280e+001	5.000e+001	6.553e+001	2.824e+001	1.368e+001

Cycle Performance

Vent-Air (cfm)	RSH (BTU/h)	RLH (BTU/h)	cbf	ESHF	ADP (°F)	GTH (BTU/hr)
2.000e+003	2.026e+005	4.198e+004	1.500e-001	8.111e-001	5.110e+001	3.311e+005

RSH: Room Sensible Heat

Practice Examples:

Assume an apparatus coil bypass factor of 0.05 and supply air ΔT=20°F max if not given.
In each application, determine the 'Effective Sensible Heat Factor', 'Apparatus Dew Point', dehumidification air quantity, room air recirculation, apparatus entering and exit temperatures and the Grand Total Heat.
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1. **Cooling and Dehumidification**
   Application: Department store
   Summer design – 95°F db and 75°F wb
   Room design – 75°F db and 50% rh; supply ΔT=25°F
   Room Sensible Heat – 200,000 Btu/hr
   Room Latent Heat – 50,000 Btu/hr
   Ventilation – 2000 cfm; coil bypass factor 0.15

2. **Cooling and Dehumidification with high latent heat load**
   Application: Coffee shop
   Summer design – 90°F db and 73°F wb
   Room design – 75°F db and 50% rh
   Room Sensible Heat – 120,000 Btu/hr
   Room Latent Heat – 65,000 Btu/hr
   Ventilation – 2500 cfm

3. **Cooling and Dehumidification all outdoor air**
   Application: Clinic
   Summer design – 95°F db and 75°F wb
   Room design – 75°F db and 55% rh
   Room Sensible Heat – 50,000 Btu/hr
   Room Latent Heat – 11,000 Btu/hr
   Ventilation – 1600 cfm

4. **Sensible Cooling**
   Application: Storage
   Summer design – 105°F db and 70°F wb
   Room design – 75°F db and 50% rh
   Room Sensible Heat – 200,000 Btu/hr
   Room Latent Heat – none
   Ventilation – 13000 cfm

5. **Cooling with Humidification**
   Application: Textile lab
   Summer design – 95°F db and 78°F wb
   Room design – 70°F db and 70% rh
   Room Sensible Heat – 160,000 Btu/hr
   Room Latent Heat – 10000 Btu/hr
   Ventilation – 4000 cfm
   Case A: without space humidification
   Case B: With space humidification and max air flow 10000 cfm

III. HVAC Heating Cycle Modeling and Analysis

Exercise 1:

A heating cycle consisting of conditioned space (office building), heating coil and a circulating fan. Hot air is circulated to offset the estimated sensible heat loss of 101000 BTU/hr and latent heat loss of 5435 BTU/hr of the conditioned space. Outdoor ventilation air at 35 °F dry bulb with 30% relative humidity enter the system @ 2000 cfm is mixed with return air and then passed through a heating coil as well as spray for humidification. The conditioned space is maintained at 70 °F dry bulb temperature with 50% relative humidity. The circuit is also consists of dampers and mixing points to control the mass flow rates. All the state numbers are assigned in sequence from outdoor air to return air. Part of the return air is bypassed the coil to maintain a constant temperature differential of 20 °F with respect to the conditioned space. Determine humid air properties of each state, circulating air quantity, coil entering and exit temperatures of the circulating air and the grand total heat.

Given:

Room Sensible Heat (RSH) = -101000 BTU/hr
Room Latent Heat (RLH) = -5435 BTU/hr
Room Total Heat (RTH) = RSH + TLH = -106435 BTU/hr
Outside Air Sensible Heat (OASH)

$$QASH = \frac{q \cdot cp \cdot \Delta T}{v} = \frac{2000cfm \cdot 0.24 \frac{BTU}{lb \cdot °F} \cdot (35 - 70)°F}{13.52 \frac{ft^3}{lb}} = -74556 \frac{BTU}{hr}$$

Outside Latent Heat Load (OALH)

$$OALH = \frac{(w_{oa} - w_r)h_g \cdot q}{v} = \frac{(8.95 - 55.51)\frac{grain}{lb} \frac{lb}{7000grain} \cdot 1075 \frac{BTU}{lb} \cdot 2000 \frac{ft^3}{min}}{13.52 \frac{ft^3}{lb}} = -63464 \frac{BTU}{hr}$$

Outside Air Total Heat (OATH)= OASH + OALH = -138020 BTU/hr

a. Effective Sensible Heat Factor

$$ESHF = \frac{-(101000 + 0.05 \times 74556)}{-(106500 + 0.05 \times 138020)} = 0.924$$

b. Apparatus Transfer point

The 'Apparatus Transfer Point' is a hypothetical temperature point at which the heat is transferred to the air from the coil at constant rate. $T_{atp} = 100$ °F

c. Space Supply Air Quantity

$$ERSH = RSH + cbf \cdot OASH$$

$$Q_{sup\,ply} = \frac{v \cdot ERSH}{cp \cdot (\Delta T_{sup\,ply})} = \frac{13.52 \frac{ft^3}{lb} \cdot (101000 + 0.05 \cdot 74556)\frac{BTU}{hr}}{0.24 \frac{BTU}{lb \cdot °F}(20°F)} = 4916 \cdot cfm$$

$$Q_{App} = \frac{v \cdot (RSH + cbf \cdot OASH)}{cp \cdot (T_r - T_{atp})(1 - cbf)} = \frac{13.52 \frac{ft^3}{lb} \cdot (-101000 - 0.05 \cdot 74556)\frac{BTU}{hr}}{0.24 \frac{BTU}{lb \cdot °F}(70 - 100)°F \cdot (1 - 0.05)} = 3450 \cdot cfm$$

d. Recalculated Air Quantity

$$Q_{bypazs} = Q_{supply} - Q_{app} = 4916 - 3450 = 1466 \text{ cfm}$$

$$m_{bypass} = \frac{Q_{bypass}}{v} = \frac{1466 \cdot \frac{ft^3}{min}\frac{min}{60\,sec}}{13.52 \frac{ft^3}{lb}} = 1.80\frac{lb}{sec}$$

e. Humidification Rate
The humidification is carried out by means of a spray or injecting steam in to the dry air to raise its humidity ratio. The humidifier rate is the rate at which moisture is added to reach the desired humidity ratio. This is given by the following expression.

$$Humidifier\ rate = \frac{RLH + OALH}{\frac{Q_{App}}{v} \cdot hg} = \frac{(5425 + 63464)\frac{BTU}{hr}}{\frac{3277cfm}{13.52 \cdot ft^3 lb^{-1}}1075\frac{BTU}{lb}} = 0.0044\frac{lb}{lb - dair}$$
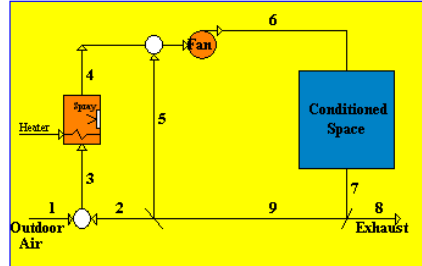
f. Grand Total Heat

$$GTH = RTH + OATH = 244455 \text{ BTU/hr}$$

Flow Joule Result:

HVAC - Heating Cycle

System Air Flow rate :4899 cfm

State Properties

State	T-dB (°F)	T-wB (°F)	RH (%)	W (gr/lb-da)	h (BTU/lb)	v (ft^3/lb)
1	3.500e+001	2.738e+001	3.000e+001	8.939e+000	9.775e+000	1.250e+001
2	7.000e+001	5.866e+001	5.000e+001	5.510e+001	2.539e+001	1.352e+001
3	4.964e+001	4.237e+001	5.341e+001	2.812e+001	1.626e+001	1.292e+001
4	9.748e+001	6.773e+001	1.967e+001	5.444e+001	3.197e+001	1.421e+001
5	7.000e+001	5.866e+001	5.000e+001	5.510e+001	2.539e+001	1.352e+001
6	8.929e+001	6.536e+001	2.566e+001	5.435e+001	2.997e+001	1.401e+001
7	7.000e+001	5.866e+001	5.000e+001	5.510e+001	2.539e+001	1.352e+001
8	7.000e+001	5.866e+001	5.000e+001	5.510e+001	2.539e+001	1.352e+001
9	7.000e+001	5.866e+001	5.000e+001	5.510e+001	2.539e+001	1.352e+001

Cycle Performance

Vent-Air (cfm)	SHL (BTU/h)	RLH (BTU/h)	cbf	ESHF	ATP (°F)	GTH (BTU/hr)
2.000e+003	1.008e+005	5.435e+003	5.000e-002	9.241e-001	1.000e+002	2.369e+005

SHL : Sensible Heat Loss

Practice Example:

Assume an apparatus coil bypass factor of 0.05 and supply air $\Delta T=20°F$ max if not given. In the following application, determine the 'Effective Sensible Heat Factor', space hot air quantity, room air recirculation, and the Grand Total Heat.

.   **1**. **Sensible Heating**:
   Application: Office
   Winter design – 35°F db and 28°F wb
   Room design – 70°F db; supply $\Delta T=20°F$
   Room Sensible Heat Loss: -100,000 Btu/hr
   Room Latent Heat Loss: -5000 Btu/hr
   Ventilation – 1000 cfm

IV. Fluid Circuit Modeling and Analysis

Exercise 1:

Build a fluid circuit consisting of following components and determine the total head with pump specification to deliver furnace oil at 20 liter/minute from a sump to a day tank vented to atmospheric pressure.

Components:
1. schedule 40 1" pipe length 50 meter – 0 elevation (ground level)
2. Globe valve 1"
3. schedule 40 1" pipe length 50 meter – 0 elevation
4. Elbow 1"
5. schedule 40 1" pipe 50 meter length to 50 meter elevation
6. U bend open to the day tank vented to atmospheric pressure.

Fluid properties:
1. Specific gravity 0.835
2. Viscosity 30 cSt at 20 °C
3. Specific heat 650 Joule/kg.K
4. Thermal conductivity 0.2 W/m.K

Circuit Builder

From the *File > New* option dialog choose 'Fluid Circuit' and click OK. This will display a 'Fluid Circuit Builder' dialog box with water as a default fluid. Follow the steps given below to create any fluid circuit and then display the circuit in the model space along with all component and system summary.

1. Select the engineering units
2. Select the fluid with inlet pressure and temperature data
3. Enter the designed flow rate for the circuit.
4. Add pipe/valve/fitting in sequence from the source to destination and build the list of components that goes in to the circuit.
5. Save the circuit as '*.ckt' file for reference
6. Analyze the circuit pressure drop and pump specifications
7. Finally, click 'OK/Draw' button to transform this circuit in to a '*.fjs' file.

Circuit Analysis:

Given:

ν = 30 cSt at 20°C (1 cSt = 10^{-2} cm^2/sec)

ρ = 835 kg/m^3

d = 26.645 mm (schedule 40)

A = 0.25πd^2 = 5.576.10^{-4}m^2

q = 20 lpm (lpm = liter/min)

$$Vel = \frac{Q}{A} = \frac{20 \cdot lpm}{5.576 \cdot 10^{-4} m^2} = 0.598 \frac{m}{\sec}$$

$$Rn = \frac{Vel * dia}{\nu} = \frac{0.598\frac{m}{\sec} \cdot 26.645 \cdot 10^{-3} m}{3 \cdot 10^{-5} \frac{m^2}{\sec}} = 530.95$$

Since Reynolds number is less than 2000, the flow is laminar and using following equation:

$$f = \frac{64}{Rn} = 0.1205$$

Pressure drop of pipe using Darcy's Equation:

$$\Delta P = f\frac{L}{D}\frac{\rho V^2}{2} = 0.1205\frac{50m}{0.0266m}\frac{835\frac{kg}{m^3} \cdot \left(0.598 \cdot \frac{m}{\sec}\right)^2}{2} = 33817 \cdot Pa \approx 0.34 \cdot Bar$$

Component wise pressure drop summary is given as follows.

```
              Fluid Pressure Drop in a Piping Circuit
                   (File Name: furnace_oil.ckt)
              ----------------------------------------
 Fluid          :Furnace oil
 Temperature    :20.00 °C
 Inlet Pressure:6.13 bar (Absolute)
 Flow rate      :20.00 lpm

 ------------------------------------------------------------------------
   Component      dia      Length       Elevatoion    K-factor   Delta P*
                  (mm)      (m)            (m)                     (bar)
 ------------------------------------------------------------------------
 1.  Pipe-Sch40  26.65   5.00e+001      0.00e+000      226.19    0.34
 2. Globe Valve  26.65   1.07e-001      0.00e+000        7.48    0.01
 3.  Pipe-Sch40  26.65   5.00e+001      0.00e+000      226.19    0.34
 4.       Elbow  26.65   1.07e-001      0.00e+000        0.66    0.00
 5.  Pipe-Sch40  26.65   5.00e+001      5.00e+001      226.19    0.34
 6.      Bend-U  26.65   1.07e-001      5.00e+001        1.10    0.00
 ------------------------------------------------------------------------
 (* pressure drop in the respective component excluding elevation)

                        Total Pressure drop in the circuit:5.12 bar
```

$$Total\ \Delta p = \left(\sum K\ factor\right) \cdot \frac{\rho \cdot V^2}{2} = 688.5 \cdot \frac{835\frac{kg}{m^3} \cdot \left(0.598 \cdot \frac{m}{\sec}\right)^2}{2} = 1.028 \cdot Bar$$
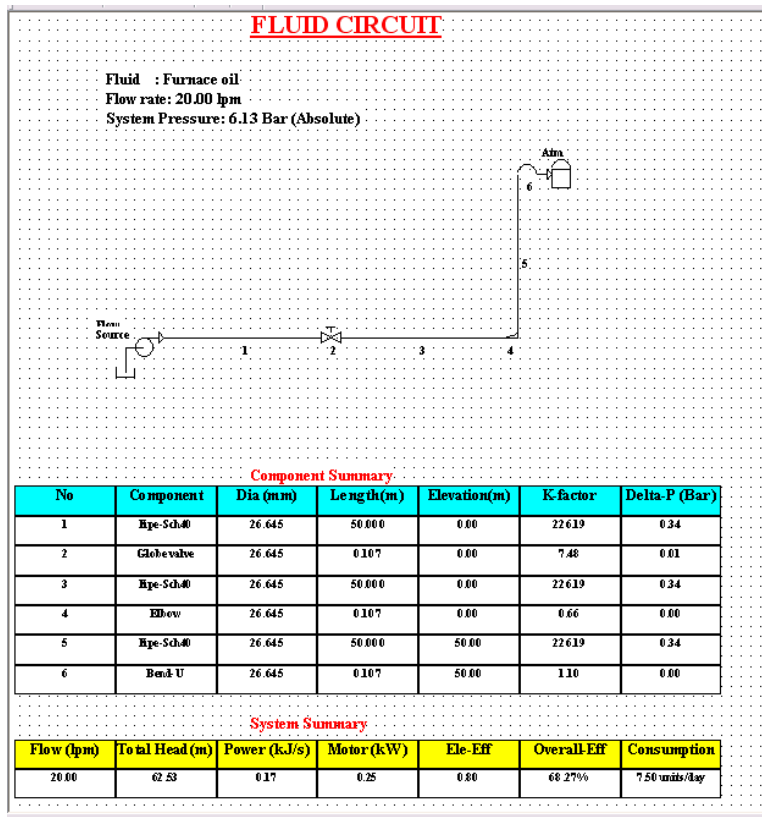
$$Pump\ head = static\ head + dynamic\ head + friction\ head = 50m + 0.001m + 12.53m = 62.53 \cdot m$$

$$Mech\ Power = \frac{(\rho \cdot g \cdot Pump\ head) \cdot Q}{60000} = \frac{835 \cdot 9.81 \cdot 62.53 \cdot 20}{60000} = 170.76 \cdot W$$

$$Motor\ Power = \frac{Power}{\eta_{pump} \cdot \eta_{motor}} = \frac{170}{0.85 \times 0.8} \approx 250W$$

$$Overall\ Efficiency = \frac{Mech\ Power}{Ele\ Power} = \frac{0.170}{250} \times 100 = 68\%$$

Flow Joule System:

FLUID CIRCUIT

Fluid   : Furnace oil
Flow rate: 20.00 lpm
System Pressure: 6.13 Bar (Absolute)

Component Summary

No	Component	Dia (mm)	Length(m)	Elevation(m)	K-factor	Delta-P (Bar)
1	Pipe-Sch40	26.645	50.000	0.00	22.619	0.34
2	Globe valve	26.645	0.107	0.00	7.48	0.01
3	Pipe-Sch40	26.645	50.000	0.00	22.619	0.34
4	Elbow	26.645	0.107	0.00	0.66	0.00
5	Pipe-Sch40	26.645	50.000	50.00	22.619	0.34
6	Bend-U	26.645	0.107	50.00	1.10	0.00

System Summary

Flow (lpm)	Total Head (m)	Power (kJ/s)	Motor (kW)	Ele-Eff	Overall-Eff	Consumption
20.00	62.53	0.17	0.25	0.80	68.27%	7.50 units/day

Practice Examples:

In the following examples assume electrical efficiency at 70% and pump efficiency at 80% unless otherwise specifically given.

1. Water at 70°F is pumped through the piping system consisting of following components. Determine the total head and pump spec if it has to deliver @ 100 gpm.
   Components:
   a. 3" schedule 40 length 30 ft – 0 elevation
   b. 3" Gate valve
   c. 3" elbow
   d. 3" schedule 40 length 100 ft to 100' elevation
   e. 3" 90° bend
   f. 3" schedule 40 length 70 ft – 100' elevation
   g. 3" 90° bend
   h. 3" schedule 40 length 300 ft – elevation 400'
   i. 3" 90° bend

2. Steam at 600 psig and 850 °F flows through a horizontal 400 ft long schedule 80 6-inch diameter steel pipe @ 90000lb/hr from the header to the turbine. Determine the pressure drop through the pipe. The circuit has following components.
   a. Globe valve (K=1.44)
   b. Two 90° bends

3. SAE 70 lube oil at 100 °F is flowing through schedule 40 -5" steel pipe. The circuit has following components. Determine the total head, pump spec to deliver oil @ 600 gpm.
   Components:
   a. Length 100' elevation 0'
   b. Gate valve
   c. Length 75' elevation 0'
   d. 90° bend
   e. Length 50' to elevation 50'
   f. Elbow
   g. Angle valve
   h. Length 75' elevation 50'
   i. Open to tank
   Properties:
   Specific gravity 0.899
   Viscosity 0.47 Pa.sec
   Specific heat: 600 Joule /kg.K
   Conductivity 0.2 W/m.K

4. Air at 65 psig and 110 °F is flowing through 75 ft of 1" schedule 40 pipe @ 100scfm. Determine the pressure drop and flow parameters.