1. We begin by identifying the conditions of the two streams on the psychrometric chart as follows. For the first stream, the point on the psychrometric chart is obtained by following the constant enthalpy line of 175 kJ/kg till we intersect the relative humidity curve of 15 %. For the second stream, the point on the psychrometric chart is obtained by following the constant wet bulb temperature of 25 °C till we intersect the humidity ratio line corresponding to 0.016 kg water / kg dry air.

We then join the two points on the psychrometric chart by a straight line. The length of this line was measured and found to be 5.5 cm. We then mark out “[2/(2 + 3)](5.5) cm” (= 2.2 cm) from the point corresponding to the first stream on the line joining the two points, and this point represents the conditions of the mixture of the two streams.

The properties of the mixture were determined from the psychrometric chart to be:

\[ T_{db} = 59 °C, \quad T_{wb} = 35.8 °C, \quad W = 0.029 \text{ kg water / kg dry air} \]
\[ RH = 23 \%, \quad H = 135 \text{ kJ/kg}, \quad V' = 0.98 \text{ m}^3/\text{kg dry air} \]

2. We first identify the conditions of the air on the psychrometric chart by following the constant enthalpy line of 190 kJ/kg till we intersect the line corresponding to a specific volume of 1.07 m³/kg dry air. In order to determine the dew point temperature of this air, we move horizontally from this point to the left till we intersect the 100 % relative humidity line (this corresponds to the dew-point temperature) and we find that the dew-point is 36.5 °C.

3. We perform the following energy balance to determine the enthalpy of the heated air (\( H_2 \)):

\[ m_a (H_1) + 1,250 = m_a (H_2) \]

where \( m_a = 60 \text{ kg/hr} \), and \( H_1 = 55 \text{ kJ/kg dry air} \)

Converting to SI units, we get: \( m_a = 1/60 \text{ kg/s} \), and \( H_1 = 55,000 \text{ J/kg dry air} \)

This yields, \( H_2 = 130 \text{ kJ/kg dry air} \)

We identify the conditions of the inlet air on the psychrometric chart by following the constant enthalpy line of 55 kJ/kg till we intersect the relative humidity line of 20 %. We then follow the constant humidity ratio line from this point and move to the right till we intersect the constant enthalpy line of 130 kJ/kg dry air. This represents the conditions of the heated air. The humidity ratio of air at this point is 0.007 kg water vapor / kg dry air (= \( W_2 \)).

We then perform the following mass balance for water to determine the humidity ratio of the air exiting the spray dryer (= \( W_3 \)):

\[ m_p (0.95) + m_a (W_2) = m_s (W_3) \]

In the above equation \( m_p = 15 \times 10^{-3}/60 \text{ kg/s} = 0.00025 \text{ kg/s} \) and \( m_s = 1/60 \text{ kg/s} \)

Solving, we get: \( W_3 = 0.021 \text{ kg water vapor / kg dry air} \)

Thus, to identify the conditions of the exit air, we follow the constant enthalpy line from the conditions of the heated air till we intersect the constant humidity ratio of 0.021. At this point we find that the specific volume is 1.01 m³/kg dry air and that the relative humidity is 10 %. 
4. a. We begin by drawing a horizontal line from the 20 °C point on the 100 % RH curve and intersecting it with the vertical line corresponding to a dry bulb temperature of 30 °C. This represents the conditions of the air at 3 kg/s. We then follow the constant enthalpy line of 123 kJ/kg till we intersect the horizontal line corresponding to a humidity ratio of 0.011 kg water vapor per kg dry air. This represents the conditions of the air at 12 kg/s. We join the above two points by a straight line. The length of the line happens to be 9.5 cm.

We mark off \( \frac{3}{3+12} \{9.5 \} \) cm from the second point (air at 12 kg/s) and this point represents the conditions of the mixture of the two streams of air. This point is 1.9 cm from the point that represents the conditions of air at 12 kg/s. The properties of the mixture at this point (Point A) are:

- Dry bulb temperature = 78 °C
- Wet bulb temperature = 32.5 °C
- Enthalpy = 113 kJ/kg
- Relative humidity = 4.5 %
- Humidity ratio = 0.012 kg water vapor / kg dry air
- Specific volume = 1.02 m\(^3\) / kg dry air

b. From this point, we follow the constant enthalpy line till we intersect a relative humidity line of 40 %. This represents the conditions of the exit air (after drying the product) -- Point B on the chart. The humidity ratio at this point happens to be 0.025 kg water vapor per kg dry air, the specific volume 0.94 m\(^3\) per kg dry air, and the enthalpy at this point happens to be 113 kJ/kg dry air. From this point, we go horizontally till we intersect a relative humidity line of 10 %. This is point C on the chart. The enthalpy of the mixture at this point happens to be 145 kJ/kg dry air.

Amount of water removed from product = \( \frac{\dot{V}}{V_B} (W_B - W_A) = (2/1.02) (0.025 - 0.012) \)
= 0.0255 kg/s

Thus, in 30 minutes, amount of water removed = 0.0255 (30) (60) = 45.9 kg

Initially, the product had 350 kg water and 150 kg solids. Finally, the product has (350 - 45.9) kg water, i.e., 304.1 kg water and 150 kg solids.

Thus final moisture content = 304.1/(304.1 + 150) = 0.67 = 67 %

c. Energy supplied by heater = \( \frac{\dot{V}}{V_B} (H_C - H_B) = (2/0.94) (145 - 112) (10^{-3}) = 70.2 \) kW

5. a. We begin by horizontal line from the 25 °C point on the wet bulb saturation temperature curve till we intersect the constant enthalpy line of 90 kJ/kg (this is point ‘A’ on the chart). Since this air is heated till the dry bulb temperature is 85 °C, we move horizontally from point ‘A’ till we intersect the dry bulb temperature of 85 °C (this is point ‘B’ on the chart). The enthalpy at point ‘B’ turns out to be 141 kJ/kg.

The wattage of the heater required to take air from point ‘A’ to point ‘B’ is given by:
\[ Q = \dot{m} (H_B - H_A) = 80 (142 - 90) = 4080 \text{ kJ/hr} = 1.16 \text{ kW} \]

b. To determine the exit conditions of the air (after drying), we follow a constant enthalpy line from point ‘B’ till we intersect the 70% relative humidity line. From the chart, we see that the moisture contents of the air at points ‘B’ and ‘C’ are:

- \( W_B = 0.02 \text{ kg water / kg dry air} \)
- \( W_C = 0.0405 \text{ kg water / kg dry air} \)

Thus, amount of water removed from product = \( \dot{m} (W_C - W_B) = 80 (0.0405 - 0.02) \)

\[ = 1.64 \text{ kg/hr} \]

Since 1.64 kg of moisture is removed from milk every hour, and milk contains 90% moisture, the mass flow rate of milk = \( \frac{1.64}{0.9} = 1.82 \text{ kg/hr} \)

6. We begin by identifying the conditions of ambient air by intersecting the dry bulb temperature line of 25°C with a relative humidity line of 50%. This is point ‘A’ on the psychrometric chart. From this point, we draw a horizontal line and intersect it with the vertical line corresponding to a dry bulb temperature of 90°C (point ‘B’ on chart). The humidity ratio at point ‘A’ and ‘B’ is 0.01 kg water / kg dry air (= \( W_B \)).

In order to identify the condition of the exit air, we perform a water balance as follows (with the assumption that no moisture leaves with the dried milk powder):

\[ 0.9 (2) + 85 (W_B) = 85 (W_C) \]

Substituting \( W_B = 0.01 \), we get \( W_C = 0.031 \text{ kg water / kg dry air} \)

From point ‘B’, we follow a constant enthalpy line till we intersect a horizontal line corresponding to a humidity ratio of 0.031. This represents the conditions of the exit air (point ‘C’ on the chart). We note that the relative humidity at point ‘C’ is 65%.

7. We begin by identifying the state of the two streams of air on the low temperature range psychrometric chart. The point of intersection of the vertical line corresponding to a dry bulb temperature of 30°C and the curved line corresponding to a relative humidity of 50% yields the conditions of the air of the first stream (point ‘A’ on the chart). The point of intersection of the vertical line corresponding to a dry bulb temperature of 45°C and the inclined line corresponding to a wet bulb temperature of 20°C yields the conditions of the air of the second stream (point ‘B’ on the chart).

We then join the points ‘A’ and ‘B’ by a straight line. The length of this line turns out to be 6.6 cm. The conditions of the mixture of the two streams of air (point ‘C’) are obtained by dividing line AB in the inverse ratio of the mass flow rates of the two streams of air. Accordingly, distance \( AC = \left[ \frac{3}{3 + 2} \right] \times 5.5 = 3.3 \text{ cm} \)

Or, distance \( BC = \left[ \frac{2}{2 + 3} \right] \times 5.5 = 2.2 \text{ cm} \)

Thus, we can locate point ‘C’ on the chart. We then look at the constant relative humidity lines (curved lines) and note that the relative humidity at point ‘C’ is ~ 18%. 
8. We begin by identifying the conditions of ambient air on the psychrometric chart (point ‘A’) as the point of intersection of the vertical line corresponding to a dry bulb temperature of 25 °C and the curved line corresponding to a relative humidity of 50%. The condition of the heated air is obtained by moving horizontally from point ‘A’ till we intersect the vertical line corresponding to a dry bulb temperature of 70 °C (point ‘B’). The condition of the exit air is obtained by following a constant enthalpy line from point ‘B’ till we intersect the horizontal line corresponding to a dew point temperature of 25 °C (point ‘C’).

a. Energy input to ambient air by heater = \((H_B - H_A) \frac{\dot{V}_{air}}{V_A} = (98 - 51) (2)/(0.86) = 109.3 \text{ kW}\)

Cost of operating heater for 2 hrs = \((109.3)(0.05)(2) = $ 10.93\)

b. Amount of moisture lost by product = amount of moisture gained by air

\[ = \frac{\dot{V}}{V_A} (W_C - W_B) = (2/0.86) (20 - 10) = 23.3 \text{ g/s} \]

Thus, in 2 hrs, moisture lost by product = 23.3*3600*2 = 167760 g = 167.8 kg

Thus, final mass of product = (250 - 167.8) = 82.2 kg

Total moisture in product before drying = 0.75(250) = 187.5 kg
Total solids in product before drying = 0.25(250) = 62.5 kg

Total moisture in product after drying = 187.5 - 167.8 = 19.7 kg
Total solids in product after drying = 62.5 kg

Thus, moisture content of final product = \([19.9/(19.7 + 62.5)]*100 = 24\%\)

9. We begin by identifying the conditions of the first stream on the psychrometric chart (point ‘1’) as follows. From the 25 °C point on the 100% RH line, we move horizontally till we intersect the RH = 50% curved line. We then identify the conditions of the second stream (point ‘2’) on the chart as follows. We draw a vertical line from the x-axis corresponding to a dry bulb temperature of 60 °C and intersect it with the horizontal line from the right side y-axis corresponding to humidity ratio of 0.008 kg water / kg dry air.

The mass flow rate of the first stream of air = \(0.4/V_1' = 0.4/0.91 = 0.44 \text{ kg/s}\)

The mass flow rate of the second stream of air = \(0.9/V_1' = 0.9/0.96 = 0.94 \text{ kg/s}\)

The conditions of the mixture of the above two streams is determined as follows:

We draw a straight line between points ‘1’ and ‘2’. The length of this line is 3.4 cm. We divide this line in the inverse ratio of the mass flow rates to obtain the conditions of the mixture (point ‘A’ on the chart). Thus, point ‘A’ is located \([0.44/(0.44 + 0.94)]\{3.4 \text{ cm}\} = 1.1 \text{ cm from point ‘2’}.\)

The enthalpy at point ‘A’ turns out to be 85 kJ/kg dry air and the humidity ratio at point ‘A’
turns out to be 0.012 kg water / kg dry air. Also, the mass flow rate of the mixture is 0.44 + 0.94 = 1.38 kg/s.

We denote the conditions of the heated air by point ‘B’ on the chart and the conditions of the exit air from the dryer as point ‘C’ on the chart.

Performing an energy balance between points ‘A’ and ‘B’, we get:

\[ 1.38 \times (85000) + 65000 = 1.38 \times H_b \]

Solving, we get: \( H_b = 132101 \text{ J/kg} = 132.1 \text{ kJ/kg} \)

Thus, we identify point ‘B’ on the chart by going horizontally from point ‘A’ till we intersect the line corresponding to an enthalpy of 132.1 kJ/kg.

We then identify point ‘C’ on the chart by following a constant enthalpy line of 132.1 kJ/kg from point ‘B’ till we intersect the vertical line corresponding to a dry bulb temperature of 45 °C. We note that the humidity ratio at point ‘C’ is 0.034 kg water / kg dry air.

We then perform a water balance during the drying process as follows:

\[ 1.38 \times 0.012 + \text{mass of water from product per second} = 1.38 \times 0.034 \]

Thus, mass of water from product per second = 0.03036 kg/s

Thus, in 30 mins, amount of water removed from product = 0.03036*30*60 kg = 54.7 kg

Thus, moisture content of final product = \(((0.85)(100) - 54.7)/(100 - 54.7)\) = 0.67

Thus, moisture content = 67%

10. a. We begin by looking at the high temperature psychrometrics chart. Here, we identify the conditions of the exit air by drawing a horizontal line from 35 °C on the curved wet bulb temperature line and intersecting it with the 50% RH line. This is point ‘C’ on the chart. We note that at this point, \( H_e = 145 \text{ kJ/kg} \) and \( W_e = 0.037 \text{ kg water / kg dry air} \).

From ‘C’, we follow the constant enthalpy line till we intersect the curved line corresponding to a RH of 1%. This represents the condition of the hot air entering the spray dryer and is denoted by point ‘B’ on the chart. We note that at this point, \( W_b = 0.095 \text{ kg water / kg dry air} \).

To identify point ‘A’ on the chart, we would need to draw a horizontal line from point ‘B’ and intersect this line with a vertical line corresponding to a dry bulb temperature of 15 °C. Since this point cannot be located on the high temperature chart, we use the low temperature chart and intersect a horizontal line corresponding to a moisture content of 0.0095 kg water / kg dry air with a vertical line corresponding to a dry bulb temperature of 15 °C. This is point ‘A’ on the chart. We note that at this point, \( H_a = 39 \text{ kJ/kg} \) and \( W_a = 0.0095 \text{ kg water / kg dry air} \).

b. The mass flow rate of air = (Vol. flow rate of air at point ‘A’)/(sp. volume at point ‘A’)

\[ = 0.2/0.83 = 0.24 \text{ kg/s} = m_a \]
Performing an energy balance between points ‘A’ and ‘B’, we get:
0.24 (39000) + Q = 0.24 (145000)
Solving, we get: Q = 25440 W = 25.44 kW

c. We then perform a water balance during the drying process as follows:
\[(m_a) (W_b) + (\text{mass flow rate of milk}) (\text{m.c. of milk}) = (m_a) (W_b)\]
Thus, \[0.24 (0.0095) + m_{\text{milk}} (0.9) = 0.24 (0.037)\]
Solving, we get: \[m_{\text{milk}} = 0.007 \text{ kg/s}\]