1. It is required to design an air-cooled condenser – refrigerant will condense in the tubes at a temperature of 38°C with a film heat transfer coefficient of 525 W/m^{2}K. Incoming air at 23°C is available. It is proposed to use a face air velocity of 3.1 m/s at which velocity the convection heat transfer coefficient to the fin sheet will be 23 W/m^{2}K. It has been recommended that the unit have fin sheets of dimensions 0.85 m high by 0.42 m deep. The refrigerant carrying tubes have an inside diameter of 18mm and an outside diameter of 21.5 mm. The tubes are arranged on triangular pitch with centre to centre spacing of 53 mm. The fins are 0.4 mm thick aluminium (k = 200 W/mK) and are spaced at 6.35 mm centres. In each tube sheet there are 120 tube passes. The required heat transfer is 28.6 kW. Determine the length of the condenser, and the number of fin sheets required.

   (Note: - *c* = 1010 J/kgK for air)

2. A continuous carton freezer for beef operates at –35°C air temperature. Cartons enter at 10°C and leave at a mass average temperature of –20°C. Each day 2800 cartons, each containing 27.2kg of meat are frozen. The thermal properties of the beef are:- frozen specific heat capacity 1.9 x 10^6 J/m^{3}K, unfrozen specific heat capacity 3.6 x 10^6 J/m^{3}K, the latent heat of freezing is 207 x 10^3 J/kg, the temperature at which freezing commences –1°C.

   The freezer is totally enclosed in a large multi-storey cold store which operates at –16°C. All the walls, ceiling and floor are constructed of 150mm thick sandwich panel made of polyurethane (k = 0.026 W/mK). The dimensions of the freezer are 4m x 8m x 20m. Loading of cartons occurs for a 10 hour period every day. During this time an unprotected doorway 2m x 1m is continually open, and a velocity through it of 1.05 m/s occurs. Also during this time 2 men are present, and they use 550 W lighting.

   There are eight similar evaporators, each having a face area of 2.2m x 1.55m, and a velocity leaving the face of 3.2 m/s. the pressure drop the fans work against has been estimated at 54mm water gauge and the fan efficiency is 0.63. The fan motor efficiency has been estimated at 0.93. Each evaporator is defrosted 1 hour per week. Estimate the 24 hour mean heat load.

3. For a cool store with a heat load of 15 kW, and mean temp difference of 12.3 K, it has been proposed to use a finned air-cooled condenser. The fin sheets are 0.85 m high and 0.4 m deep. The length of the heat exchanger is 1.18m. The fins are spaced 4.5 mm apart, and are 0.5 mm thick so there are 225 fins in the length of the heat exchanger. The tubes are arranged on square pitch with 65mm pipe centres, there being (14 x 6) = 84 tubes, giving a total tube length of 99.1m. The condensation film coefficient is 450 W/m2K and the airside coefficient 18 W/m2K. the pipes are 20mm outside diameter, 17mm inside diameter, and both they and the fins are aluminium (thermal conductivity = 200 W/mK). Is there sufficient heat transfer capability?

4. Peas are frozen in fluidised bed freezers in which the surface heat transfer coefficient is typically 200 W/m^{2}K. The peas can be treated as spheres of diameter 10 mm. The peas enter the freezer at 20°C, start to freeze at about –1°C, and must reach a final centre temperature of –18°C. A residence time of 150 s and an air temperature of –36°C has been suggested. Determine whether this residence time is satisfactory. Thermal properties of peas are:- frozen thermal conductivity 1.68 W/mK, unfrozen thermal conductivity 0.49 W/mK, frozen specific heat capacity 2.1 x 10^6 J/m3K, unfrozen specific

heat capacity 3.7 x 10^6 J/m^{3}K, enthalpy change from –1°C to –20°C 238 x 10^6 J/m^3, density 1015 kg/m3.

5. Fish fillet are packed in cartons for freezing – the cartons have dimensions of 75mm x 295mm x 410mm, a wall thickness of 2.8 mm, and a wall fiberite thermal conductivity of 0.062 W/mK. When frozen the last point to freeze is not the geometric centre because the air space left in the top of the carton reduces heat transfer to that surface. The last point to freeze is 43mm up from the bottom of the carton. A rule of thumb can be applied here for uneven heat transfer:- freezing time for a 75mm carton with uneven heat transfer = freezing time for a (2 x 43) = 86mm carton with the surface heat transfer coefficient for the bottom surface = freezing time for a (2 x 32) = 64 mm thick carton with the heat transfer coefficient is difficult to estimate so the calculation will be carried out for a 86 mm thick carton with no air gap between product and surface. The fillets enter the cartons at 80°C and must be frozen to a final centre temperature of –20°C within 9 hours. Air at –38°C is to be used. Determine the air velocity required. Thermal properties of the fish are:- frozen thermal conductivity 1.59 W/mK, unfrozen thermal conductivity 0.51 W/mK, frozen specific heat capacity 2.1 x 106 J/m3K, unfrozen specific heat capacity 3.5 x 106 J/m3K, enthalpy change from –1°C to –10°C is 228 x 10^6 J/m^3, density 1022 kg/m^3.

   (Note:- in order to calculate the surface hat transfer coefficient from Pham's modification to Plank's equation it is necessary to know *E*, which itself is dependent on the surface heat transfer coefficient. Hence assume an air velocity e.g. 2-5 m/s and find an initial estimate of h_e can be calculated from the freezing time equation to see if it corresponds).

6. You are working for a company that produces pre-cooked minced beef chilli con carn. The product is vacuum sealed into plastic pouches (200µm thick) and cooked to a centre temperature of 75°C. It is then required that the product be cooled to a centre temperature of 5°C. Two cooling options are being considered, air blast chilling and immersion chilling. You are required to predict and compare the required cooling times for the two processes. The following data is available for your predictions

   The thermal properties for the minced beef are:

Unfrozen specific heat:	3.44 kJ/kgK
Unfrozen thermal conductivity:	0.68 W/mK
Density:	1050 kg/m3

   Dimensions of the packaging are 235 x 120 x 35 mm

   The immersion cooler will operate with brine at 0°C and a heat transfer coefficient to the surface of the package is estimated to be 150W/m^{2}K.

   The air blast chiller has an air flow of 3m/s over the product surface and will operate with an air temperature of 0°C.

   Compared the predicted times and discuss the advantages and disadvantages of the two cooling processes.

7. A 57 kg side of pork is being chilled to a centre temperature of 5ºC from an initial temperature of 37ºC using air at 2ºC and a velocity of 3m/s. The critical area is the deep leg position (hip bone). The measured dimensions in the 3 directions are 115 mm x 220 mm x 385 mm.

Thermal properties of pork are

Unfrozen specific heat = 2800 J/kgK
Density = 1040 kg/m^3
Unfrozen thermal conductivity = 0.48 W/mK

a) Calculate the time required for cooling.

b) Calculate the mass average temperature at the completion of cooling and the average product heat load if 30 sides are to be chilled per batch.