APPENDIX 5

TRIAL LOGSHEET

Trial No.   Dates: Venue:

		Dates		
		Day 1	Day 2	Day 3, etc
Start of drying				
End of drying				
Air flow m^3s^{-1}	High			
	Low			
	Mean			
Ambient Air Temperature °C	High			
	Low			
	Mean			
Air Temperature at Collector Outlet °C	High			
	Low			
	Mean			
Air Temperature at Drying Chamber Outlet °C	High			
	Low			
	Mean			
Ambient Air Relative Humidity %	High			
	Low			
	Mean			
Total Insolation, J m^{-2}				
Weight, or Moisture Content of Batch	Start			
	End			
Collection Efficiency %				
System Drying Efficiency %				
'Pick-Up' Efficiency %				

EVALUATION OF DRYER PERFORMANCE

It is necessary to evaluate the thermodynamic performance of a solar dryer. Examination of logged results show that the dryer dries 100kg of fresh peppers at 80% (wb) moisture to the required degree of dryness, 5% (wb) in 3 days. The dryer has a collector of effective area $15m^2$ and a fan that maintains an air flow of $0.5m^3s^{-1}$. Climatic data show a mean level of insolation of 20 MJ m^{-2} per 12 hour day. Ambient air conditions indicate a mean daily temperature of 25°C with a relative humidity of 70% and the temperature of the air entering the drying chamber has been monitored as a mean of 35°C.

What are the system drying efficiency and the pick-up efficiency of the dryer?

<u>Solution</u>

The system drying efficiency, η_d is obtained from equation 4.1 viz.

$$\eta_d = \frac{W \, \Delta H_L}{I_d \cdot A_c}$$

where W = moisture evaporated, kg

ΔH_L = latent heat of vaporization of water, 2320 kJ kg^{-1}

I_d = total daily insolation incident upon collector
= 20,000 kJ m^{-2} day $^{-1}$

A_c = area of collector, 15 m^2

W is calculated as follows:

Moisture initially present = 100 x 0.8 = 80 Kg

∴ Bone dry weight of peppers = 20 kg

Moisture present in dried peppers = $\frac{20 \times 0.05}{0.95}$ = 1.05 kg

∴ Moisture evaporated in dryer, W = 80 - 1.05
= 78.95 kg

Total insolation upon collector over 3 days = 20 x 3 = 60 MJm^{-2}

$$\therefore \eta_d = \frac{78.95 \times 2320}{15 \times 60 \times 1000} = 0.204$$

<u>System Drying Efficiency</u> = <u>20.4%</u>

The pick-up efficiency η_p is calculated from equation 4.4 viz.

$$\eta_p = \frac{W}{V . \rho . t . (h_{as} - h_i)}$$

where v = volumetric air flow rate, 0.5 m^3s^{-1}

ρ = air density = 1.28 kg m^{-3}

t = drying time = 3 days = 129,600 s

h_{as} = adiabatic saturation humidity

h_i = absolute humidity of inlet air

From the psychrometric chart, h_i at 25°C and 70% RH is 0.014 kg kg^{-1}. h_{as} is also found from the psychrometric chart by following a line of constant humidity from h_i to its intercept with the 35°C line and then along the line of constant enthalpy to its intercept with the 100% saturation curve, giving a value of 0.0186 kg kg^{-1}

$$\therefore \quad \eta_p = \frac{78.95}{0.5 \times 1.28 \times 129{,}600 . (0.0186 - 0.014)} = 0.207$$

Pick-up Efficiency = 20.7%

ESTIMATION OF NATURAL CONVECTION AIR FLOW RATES

Ambient air at a temperature of 25°C and 60% RH is heated to 40°C in a solar chimney dryer to be used to dry rice, as shown in Figure A12.1:

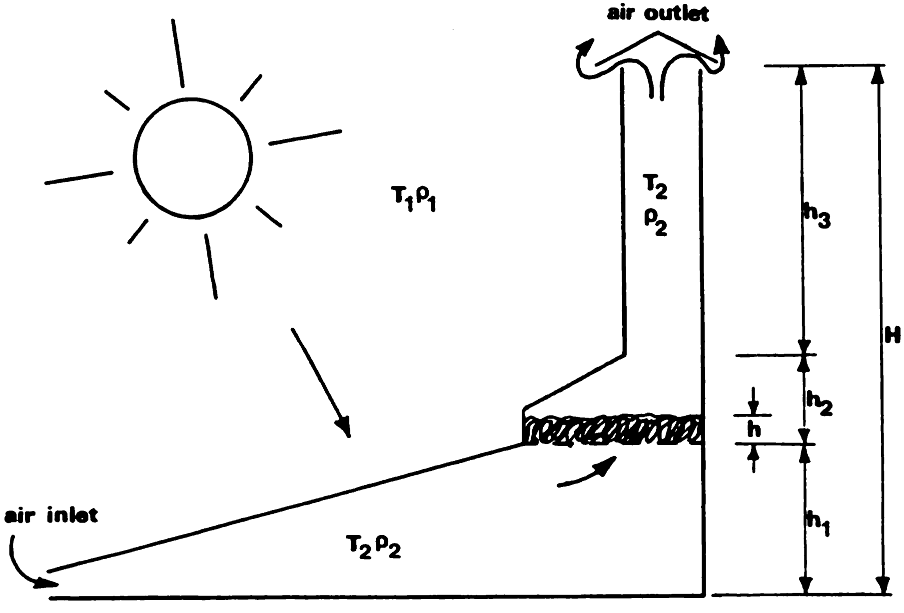

Figure A12.1

The drying chamber height is 0.6m and the height between the ground and the base of the drying chamber is 1.0 m. For an air flow of 5.5 $mm.s^{-1}$ through a 0.2 m deep rice bed, what chimney height would be necessary to achieve the required temperature rise? What would be the effect on the air flow of increasing the chimney height by one third and by decreasing it by one third? If the weather becomes cloudy reducing the dryer temperature to 30°C, what would be the resulting air flow?

Solution

Assumptions made in determining the equations relating chimney height to air flow are:

(i) at all points inside the solar dryer the air temperature and therefore the air density is uniform,

(ii) there is no leakage of air from the sides of the dryer and the warm air leaves only from the chimney outlet,

(iii) the drying of grain takes place by convection only (not by direct radiation),

(iv) the resistance to air flow through the dryer components, ie the collector, drying chamber and chimney is negligible in comparison with the resistance of the grain bed.

The resistance to air flow for grain is obtained from equation 12.1:

$$v = a(\Delta P/h_b)^b$$

where v = volumetric air flow rate per unit cross-sectional area of grain bed ($m^3\ s^{-1}\ m^{-2}$)

ΔP = pressure drop across grain bed (Pa)

h_b = grain bed thickness (m)

a, b = empirical constants

In a natural convection solar dryer, the pressure difference across the grain bed is solely due to the density difference between the hot air inside the dryer and the ambient air, ie

$$\Delta P = (\rho_1 - \rho_2)\, g.H. \qquad \text{(A12.1)}$$

where $\rho_1\ \rho_2$ = air densities at temperatures T_1 and T_2 respectively ($kg\ m^{-3}$)

g = acceleration due to gravity ($9.81\ ms^{-2}$)

H = height of hot air column (m)

Over the temperature range 25-90°C air density can be calculated from the expression:

$$\rho = 1.11363 - 0.00308T \qquad \text{(A12.2)}$$

Substituting for ρ in equation A12.1 gives:

$$\Delta\rho = 0.00308\,\Delta T.g.h. \qquad \text{(A12.3)}$$

Substituting for $\Delta\rho$ in equation A12.1:

$$v = a(0.00308\,\Delta T.g.H/h_b)^b$$

Experimental values of a and b have been reported by Vindal and Gunasekaran (1982) for natural convection of air flow through rice beds of 0.0008 and 0.87 respectively.

Hence,	v	=	$0.0008\,(0.00308.\,\Delta T.g.\ H/h_b)^{0.87}$
or	v	=	$3.81.\ 10^{-5}\,(\Delta T.H/h_b)^{0.87}$ (A12.4)

(i) Calculation of chimney height

$H_1 = 1.0$ m

$H_2 = 0.6$ m

$v = 0.0055\ ms^{-1}$

$\Delta T = 40 - 25 = 15°C$

Substituting these values into equation A12.4:

$$0.0055 = 3.81 \times 10^{-5}\,(15.H/0.2)^{0.87}$$
$$= 3.81 \times 10^{-5} \times 42.29 \times H^{0.87}$$
$$= 1.63 \times 10^{-3} \times H^{0.87}$$

From which $H = 4.05$ m

The chimney height, $H_3 = H - (H_2 + H_1)$

$= 4.05 - (0.6 + 1.0)$

$= \underline{2.45}$ m

(ii) Calculation of effect upon air flow if chimney height increased by one third

(New) $H_3 = 2.45 \times 1.33 = 3.27$ m
$\therefore\ H = 1.0 + 0.6 + 3.27 = 4.87$ m

Substituting for H in equation A12.4:

$v = 3.81 \times 10^{-5}\,(15 \times 4.87/0.2)^{0.87}$

$= 3.81 \times 10^{-5} \times 109.6$

$= \underline{0.0065\ ms^{-1}}$, <u>an increase of 18%</u>

(iii) Calculation of effect upon air flow if chimney height decreased by one third

(New) $H_3 = 2.45 \times 0.67 = 1.63$ m

$\therefore\ H = 1.0 + 0.6 + 1.63 = 3.23$ m

Substituting for H in equation A12.4:

$v = 3.81 \times 10^{-5}\,(15 \times 3.23/0.2)^{0.87}$

$= 3.81 \times 10^{-5} \times 118.7$

$= \underline{0.0045\ ms^{-1}}$, <u>a decrease of 18%</u>

(iv) Calculation of air flow through the rice bed when dryer air temperature is reduced to 30°C

$\Delta T = 30 - 25 = 5°C$

Substituting for ΔT in equation A12.4:

$$v = 3.81 \times 10^{-5} (5 \times 4.05/0.2)^{0.87}$$

$$= 3.81 \times 10^{-5} (5 \times 4.05/0.2)^{0.87}$$

$$= \underline{0.0021\ ms^{-1}}$$

<u>Note</u> In this example the chimney neither looses nor gains heat. In practice many solar dryers are constructed in a manner such that the chimney behaves as an absorber. The chimney therefore heats up and transfers this heat to the dryer exhaust air thereby increasing its temperature and the draught developed.

CALCULATION OF AIR FLOW THROUGH DRYING BEDS

A forced convection solar dryer with a separate collector and drying chamber (2 m x 2 m x 1.5 m deep) is being used to dry 3 tonnes of a cereal crop having a bulk density of 780 kg m^{-3}. It is known that the resistance to air flow per metre depth of this crop is 325 Pa. Estimate the air flow through the bed and the fan power required.

Solution

(i) Air flow estimation

Resistance to air flow for grain is obtained from equation 12.1:-

$$v = a(\Delta P/h_b)^b$$

where v = volumetric air flow per unit cross-sectional area of grain bed ($M^3 s^{-1} m^{-2}$)

ΔP = pressure drop across the grain bed (Pa)

h_b = grain bed depth (m)

a, b = empirical constants

a and b are determined as 0.0003 and 1 respectively.

$$\therefore \quad v = 0.0003\,(\Delta P/h) \qquad (A13.1)$$

Now, 3 tonnes of the crop with bulk density of 780 kg m^{-3}, would occupy a volume of 3000/780 = 3.85 m^3. The drying chamber is of cross section 2 m x 2 m.

Hence h_b = 3.85/(2 x 2) = 0.96 m

and ΔP = 325 x 0.96 = 312 Pa

Substituting for ΔP and h in equation A13.1

$$v = 0.0003\,(312/0.96) = 0.1 \text{ ms}^{-1}$$

$\therefore$ Volumetric air flow V = 0.1 x 2 x 2 = <u>0.4 $m^3 s^{-1}$</u>

(ii) Estimation of fan power

The air power (static) of a fan is obtained from the expression:

$$\text{Air power} = V \,.\, \Delta P \qquad (A13.2)$$

Substituting for V and ΔP

$$\text{Air power} = 0.4 \times 312$$

$$= \underline{125\ W}$$

Taking into consideration a mechanical efficiency of the fan of 60% the motor for the fan should be 125/0.6 = 210 W.