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DESIGN OF A DRYER AND A SWIMMING POOL USING GEOTHERMAL WATER

Rameswor Maharjan
Research Centre for Applied Science and Technology,
Tribhuvan University, Kirtipur, Kathmandu,
NEPAL

ABSTRACT

Most of the hot springs in Nepal are used only for bathing and laundry purposes, whereas there are many possibilities to utilize them in other ways. A place like the Mustang district is of vital importance from a commercial point of view, as this area is a great tourist attraction. As it is quite cold in comparison to other parts of the country, further development of this industry might benefit from the development of more facilities like swimming pools with hot water. Development of swimming pools using the geothermal water, which is available in the area, would be an attraction for tourists and a good sanitation facility for the local people. Furthermore, a large amount of fruit is grown in this area. Transporting these products to the market is a big problem, because the road is not easily accessible. In order to make the products more transportable, the fruits might be dried, with dryers using geothermal water. The main emphasis in this report has been given to designing dryers and a swimming pool using the local geothermal water.

1. INTRODUCTION

The sources of energy used in Nepal can be categorized in two groups. The first group includes the traditional sources, such as fuel wood, agricultural waste, and animal dung; and the second the commercial ones, such as petroleum, coal, and hydroelectric power. As can be seen from Figure 1, the traditional sources remain the major energy sources of Nepal, accounting for 93% of the total energy consumption of which 73% is used for fire wood. The extensive uses of fire wood causes deforestation, which results in ecological catastrophes like land slides, river flooding, irregularity in rain, and degradation of soil, etc. However, it can be seen from Figure 1 that the use of agricultural waste and animal dung are increasing intensively in comparison with commercial fuel. This degrades the health of the people, because the combustion of such fuels emits relatively high level of carbon dioxides and carbon monoxide. According to statistical data given by Pandey and Basnet (1987), 31% of respiration diseases were due to smoke pollution.

It is well known that the long-term path for the sustainable development of Nepal lies in exploiting the abundant hydropower. Experience has shown that the development of a mega hydro power project takes a long time and needs a huge investment where the country has to rely on foreign loan assistance and aids. Recently, His Majesty's Government of Nepal has given much more emphasis on the utilization of hydro-power in mini and micro scale by attracting private entities through the provision of subsidies. But the effort has a long way to go in order to be realized.

In view of the above situation, the utilization of geothermal energy can be an alternative solution in order to overcome the above mentioned problems. The main advantages of using this kind of energy are as follows:

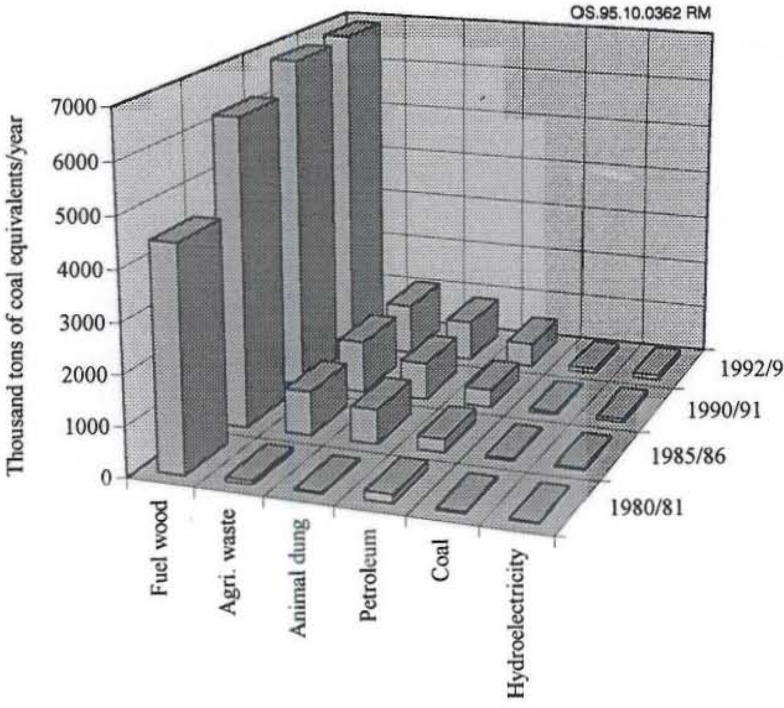

FIGURE 1: Energy consumption in Nepal (data from Water and energy commission, His Majesty's Govenment of Nepal)

- It is a renewable source of energy;
- It does not require as large investments as a mega hydro power plant;
- The electricity produced with the help of geothermal energy can in some cases cost only half of the energy produced by hydro power, which is one of the most important parameters from the consumers' point of view;
- It is a locally available resource, which is, opposite to commercial fuels, not affected by any external political and cost factors;
- It is relatively quick to build, especially with the use of pre manufactured or modular system;
- It can operate at high capacity all year round, despite drought, siltation or bad weather;
- It is an environmentally friendly technology;
- It can be used directly as a source of energy.

An overview of the available geothermal resources in Nepal is given in Table 1.

2. POSSIBILITIES OF GEOTHERMAL WATER APPLICATIONS IN NEPAL

At present, the use of geothermal water in Nepal is limited to bathing and laundering purposes. According to Ranjit (1994), the Tatopani spring of Myagdi district is extensively used for bathing because it is located along the famous Pokhara-Jomsom tracking route. Cement-mortar reservoirs have been built there to make it comfortable for bathing. The local people of this area, the guests from foreign countries and military members of the nearby barracks also use the hot water extensively for bathing and laundering. The hot spring in Jumla district is another popular place among Nepalese. The local people believe that illnesses like headache, stomach trouble and rheumatism can be treated by using this water. Many of the people from different parts of the country visit this place. The local people of Bajhang district have a great festival at their geothermal site once a year, while in Darchula a guest house and a temple have been built in the thermal spring area to attract mountaineers.

TABLE 1: Information about geothermal activity in Nepal (Ranjit, 1994)

Locality	Flow rate	Surface temperature	Geothermometer temperature (°C)			Dissolved solids
	(l/s)	(°C)	SiO_2	Chalcedony	Na/K	(mg/l)
Darchula						
Sribagar	0.85	57-73	86.2	-	-	516
Sina-Tatopani	0.76	warm	-	-	-	1000
Chamaliya	0.25	warm	37.6	-	-	1320
Bajhang-Tapoban	0.2	warm	55.1	-	-	444
Jumla						
Dhanchauri-Luma	0.6	24	106.9	-	88.2	803
Tilanadi	-	36-42	110.6	-	-	353
Jomsom	0.2-5	21	50.3	-	-	889.3
Tatopani-Mustang	1.8	71	115.4	-	-	1840.8
Sadhu Khola	1.39	69	109.8	-	115.3	954
Mayangdi	2	40	89.8	-	-	1340
Rior	1.5	33	-	54.2	52.3	788
Surai Khola	-	37	-	50.1	100.4	510
Chilime	8	55	92.1	-	-	148
Kodari	5	42	-	-	-	822

Although the use of available geothermal water is limited, if attention is given to its further development and its applications, it will certainly help to build up the economical status of local people and their welfare. The temperature of the water as mentioned is low (Ranjit, 1994), but it can be utilized for the following purposes:

- Drying of light aggregate cement slabs;
- Drying of organic materials, seaweed, grass, vegetables etc.;
- Washing and drying wool;
- Space heating and cooling (buildings and greenhouses);
- Refrigeration and heating;
- Animal husbandry;
- Soil warming;
- Swimming pool warming;
- Fermentation;
- Hatching of fish and fish farming;
- Mushroom growing.

3. FOOD DRYING

The process of drying is of considerable practical and economical importance in food as well as other industries. The drying process involves removing water or any volatile substances from solid, liquid or gas by applying thermal energy or other means. The operation time varies tremendously with the solid to be dried, from a few seconds to several days. This report is concerned only with removal of water or any volatile substances from the solid by means of thermal energy.

The development process of food drying cannot be put into chronological order. Its origin is unknown. In ancient times, people learned to dry their food in the sun or fire in order to increase storage life. The same drying process technology, which has been handed down to us from one generation to another is still being adopted by individuals as well as in small scale production in developing countries like Nepal.

The theories of drying processes have been developed after the development of a scientific concept on heating theories, gas law etc. (Brundrett, 1987). The first record of artificial drying of food and its progress from different countries all over the globe was made by Prescott and Proctor in 1937 (Soriao, 1987). However, there are many more outstanding achievements that followed. The work of Mujumdar (1980) presents a perspective of current research and development on drying technology from different countries. A conventional circulating air dryer built with an energy saving system called PCHP unit, which was developed by Dr. Passey, is one dryer worth noticing. By heat pump the energy extracted in the condensing process is used to heat up the air again before it enters the drying cabinet. This kind of dryer can be operated in any weather condition and humidity because it is a closed system in which the circulation of hot air is not from the outside.

3.1 Purpose of food drying

The removal of water or any volatile liquid from a wet solid is an integral part of food processing. Almost every food product is dried at least once at one point of its preparation for human consumption. In Figure 2 growth rates of microorganisms and rates of various chemical reactions are shown. Water activity is defined as the ratio of the partial pressure of water in a sample and vapour pressure of pure water at the same temperature.

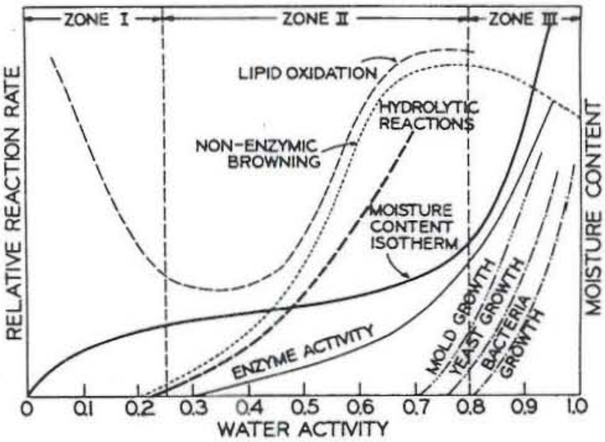

FIGURE 2: Reaction rates in food as a function of water activity (generalized behaviour at 20°C) (Fennema, 1976)

Figure 2 shows that if the solid to be dried contains a large quantity of water (zone-III), the growth of microorganisms and chemical reactions is very high. As the water is removed, the water activity gradually decreases. The total percentage of water to be removed varies from one product to another. As can be seen in the figure, when the water activity lies in the range of 0.3-0.4 the lipid oxidation is near the minimum value, and this is the optimum water content for the product. If the water content in the product is reduced below about 10 wt % by drying, the microorganisms are not active (Geankoplis, 1983). However, it is usually necessary to lower the moisture content below 5 wt % in food products to preserve flavour and nutrition. So the main purposes of drying or dehydration can be summarized as follows:

- To preserve the product for future use;
- To decrease the biological and chemical activity of the product;
- To obtain convenience in transporting, handling, and marketing of the product;
- To reduce bulk and weight;
- To prepare raw materials for further processing;
- To recover liquid by-products from solids, i.e. oils of fish etc.

3.2 Classification of dryers used in food industries

Drying, in general, means removal of relatively small amounts of water from solids. Usually the water is removed as a vapour by air. In some cases, water may be removed mechanically from solid materials by presses, centrifuging, and other methods. This is cheaper than drying by thermal means, but the product can be deformed in its physical state, so it is not always suited for further use.

Throughout the world, sun drying is a popular drying method but will not be further discussed here, because indoor drying has big advantages over sun drying. They are as follows:

- Shorter drying time than with outdoor drying;
- Drying all year round and more even export shipments;
- The product is more consistent in quality and water content,
- Flies and insects are prevented from contaminating the food product;
- Utilization of local energy sources.

There are many types of indoor dryers used in the food drying industry, each with its own speciality, but most of them can be used for drying more than one type of solid. Here dryers will be discussed which are commonly used in the food drying industry.

According to the method of heat transfer from heat source to the solid (i.e. heating of a compartment of the dryer), dryers can be classified into four different groups:

1. Conduction heating method (transfer of major quantity of heat to the solid to be dried through conduction, i.e. metal to metal);
2. Convection heating method (transfer of major quantity of heat through forced hot air flow, i.e. convection);
3. Infrared heating method (i.e. all forms of radiation heating);
4. Dielectric heating method.

Drying by conduction is different from drying by convection. In the conduction case the solid is placed in a vessel which is heated from the outside and provided with a vent through which the vapour can be removed. The vessel is frequently maintained under reduced pressure to increase the temperature driving force. In the convection case hot air is blown over or through the surface of the solid and this provides both the source of the heat and the means for removal of the vapour. The last two groups of dryer heating methods of infrared and dielectric, are beyond the scope of this report.

The two heating methods, conduction and convection, can be further divided into subgroups according to the type of drying vessel used in the process: they are tray rotating drum fluidised bed, pneumatic, spray etc. Figure 3 shows the different types of dryers adopted to operation under vacuum or with inert atmosphere. On the bases of working principle as mentioned above, Figure 3 also shows the different types of dryers which are more readily adopted in food drying process. Their detail working principles and construction as well as application in different fields can be found in different references (Karel et al., 1975; Soriao, 1987; and Keey, 1978).

3.3 Selection of a dryer

In theoretical approach, selection of dryers depends on whether the mechanism of heat transfer to the wet solid is by convection, conduction or radiation. The predominant mechanism is usually convection in

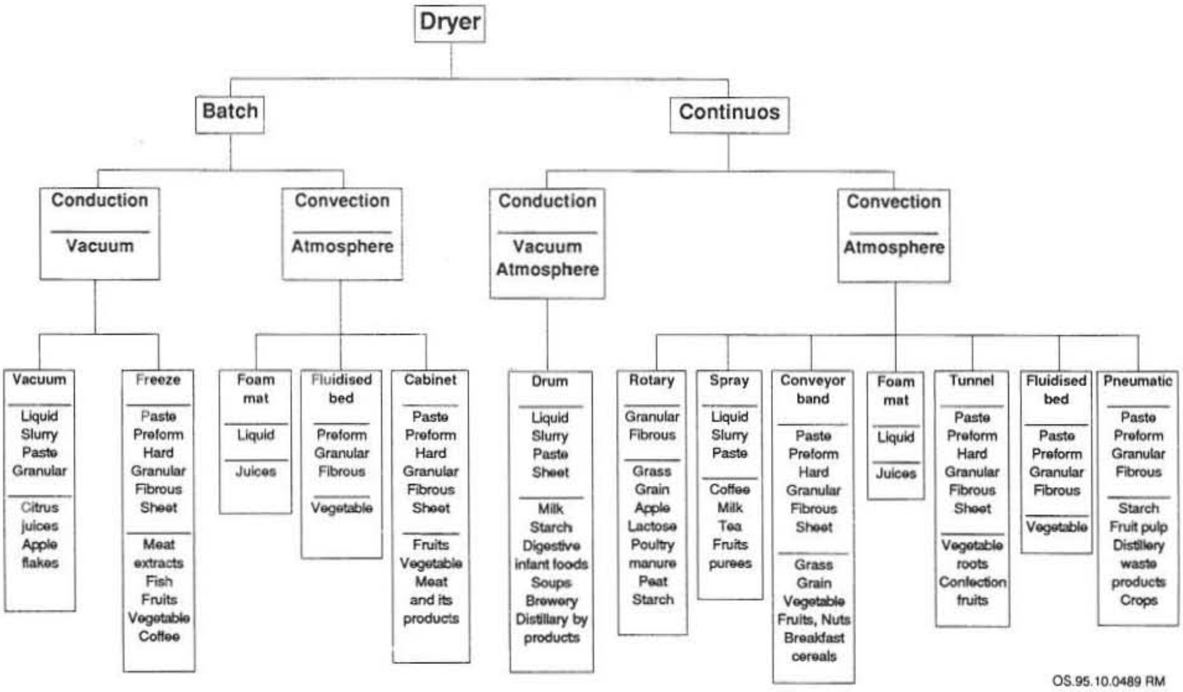

FIGURE 3: Classification of dryers based on method of operation

direct dryers, in which the solid is dried by means of a hot air stream passing over or through it, and conduction in indirect dryers in which the material is heated via a wall. There may be significant heat transfer by radiation in either case and some degree of conduction in convection dryers and vice versa. It is rare for a dryer to be operated with pure radiation alone.

If the heat transfer is accomplished at atmospheric pressure, it is called atmospheric drying and the drying is done by passing hot air. If the drying process is done below the pressure of 101 kPa but above 0.6 kPa it is called vacuum drying, in which the heat transfer is usually done by conduction method. In the same way, if the process is accomplished below 0.6 kPa pressure (the triple point of water) we have sublimation drying or freeze drying. The way of freezing is accomplished by conduction method only.

There are many types of dryers available in the market. The dryer should be chosen according to the type of material to be dried. For adaptation of technology in Nepal it is necessary to develop one which can be adopted for different working conditions, like for drying food to as many industrial materials as possible.

If the details of the above mentioned classification are analysed, we find that the tunnel and the conveyor dryers can be adopted in different food processing industries for drying varieties of foods like vegetable, fruits, nuts, grains, paper etc. Apart from that it has got high yield production capacity, and can be adopted for different types of materials and can be controlled in a simple way by the temperature of the air. Let us give this type of dryer the name continuous counter-current tray dryer which defines a working principle by its name. Its details will be discussed in later chapters.

3.4 Design of a continuous counter-current tray dryer

Figure 4 shows a schematic diagram of a continuous counter-current tray dryer in which the air for drying products is heated, using geothermal water. The air coming from the dryer is recirculated after condensing a part of the moisture content. The main advantage of recirculation of air is that the humidity and the temperature of the air can be controlled through an air condenser in which cold water is

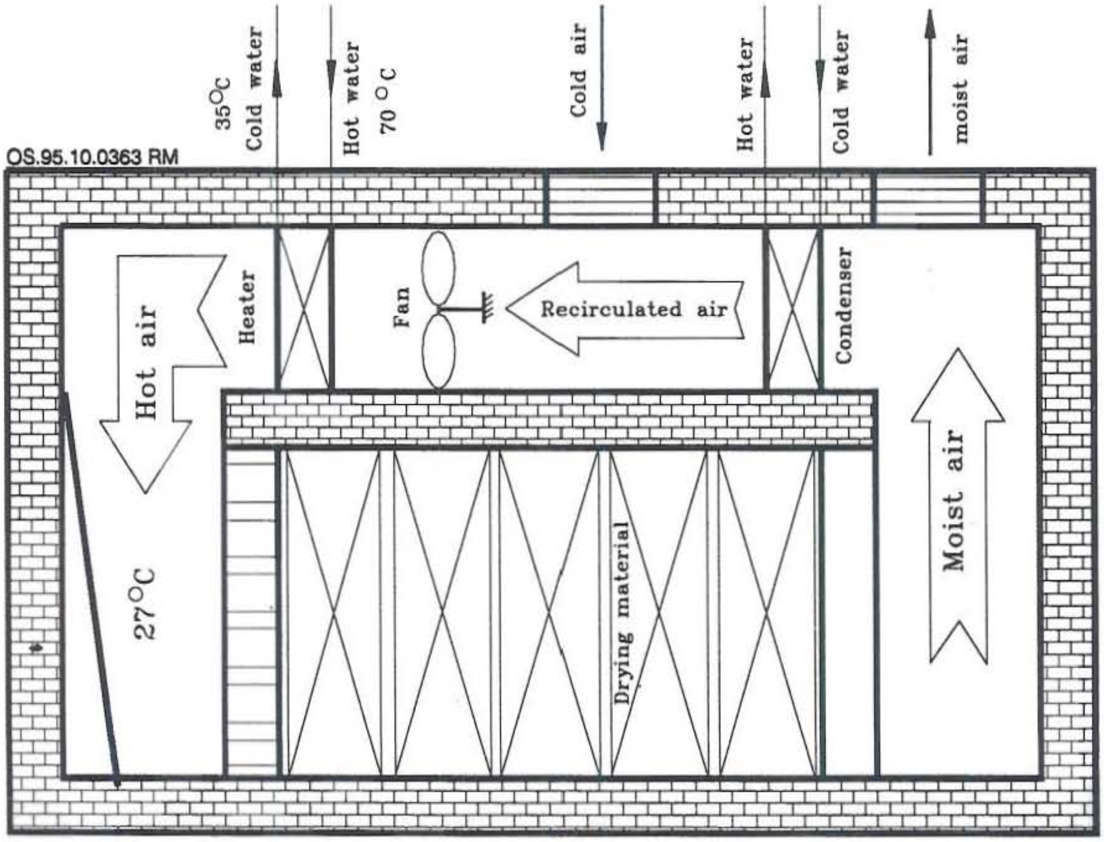

FIGURE 4: A schematic diagram of continuous counter current tray dryer

circulated. The temperature and humidity of the air can be varied by regulating the flow rate of cold water. A stream of fresh air for drying may be used if necessary by regulating the diaphragm. The air is circulated with help of a fan and blown in counter-current direction to the flow of the solid. So in this system the temperature and humidity of the drying air are independent of atmospheric conditions. The smell coming from the solid can be avoided, which could be necessary like if the dryer is installed in a city and the product to be dried is fish. The most important thing is that energy can be saved by using outlet water from condensers for preheating products or for something else.

3.5 An air circulation flow chart for continuous counter-current tray dryer

The major part of the air discharged from the dryer is recirculated, after removing the humidity contained in it, and combined with the fresh air as shown in Figure 5. The fresh air having temperature T_4 and humidity H_4 is mixed with condensed air having temperature T_5 and humidity H_5. The result is mixed air with temperature T_3 and humidity H_3. Then, the air flows into the heater where it is heated up to temperature T_2, but the humidity of the air in

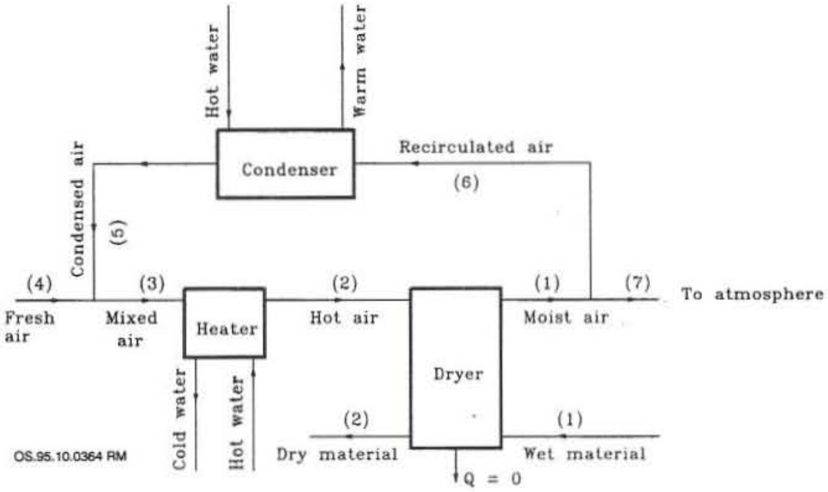

FIGURE 5: Air circulation flow chart

position 3 and 2 remains the same. The hot air coming from the heater enters the dryer and comes out from it with lower temperature T_1 and high humidity H_1. The part of discharged air from the dryer may be thrown out in the air or can all be recirculated if it is necessary. Finally the recirculated air will be passed through the condenser which condenses the moisture contained in it by lowering the temperature. The humidity and temperature of the condensed air at point 5 will be less than at point 6. The rate of condensing of humidity is regulated by changing the flow rate of cold water.

3.6 Temperature profiles for a continuous counter-current tray dryer

In a continuous counter-current tray drying process the hot air entering the dryer comes in contact with wet solid which moves in an opposite direction to the hot air. Figure 6 shows temperature profiles for hot air T_a, and the drying solid T_s. Also the humidity of the air, H, and the water content of the solid, X, at different positions in the dryer are noted in the figure. The solid is heated up to the adiabatic temperature during the preheating zone. This zone can be ignored because the drying temperature of the food product is usually very low compared to the drying temperature in other industries.

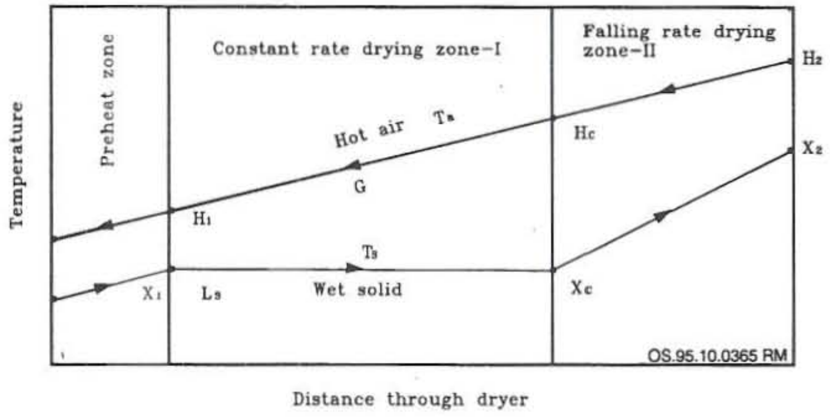

FIGURE 6: Temperature profiles for a continuous counter-current tray dryer

The free moisture, i.e. unbounded water, contained in the solid is evaporated during the constant rate drying zone-I. The content of moisture falls to the critical value, X_c, at the end of this period. The temperature of the wet solid, T_s, remains constant at the adiabatic saturation temperature, because the heat is transferred only by convection in the dryer. The rate of drying is constant but hot air temperature is changing and also the humidity.

In the falling rate drying zone-II, the temperature of the wet solid T_s does not remain constant, because the surface is no longer completely wetted. So the moisture tends to move from wet regions to dry regions. The rate of internal movement of the liquid is governed by the mechanism of liquid diffusion or capillary movement. The solid is dried to its final moisture content value X_2. The humidity of the entering hot air is H_2 and it rises up to H_c.

3.7 A mathematical model for drying cabinets

Figure 7 shows a model of drying cabinets, in which air is blown out over the surface of wet material as mentioned above. The wet solid is placed on the tray, which area is LxB. Let us divide the wet solid into unit areas equivalent to $dLxB$. A_a is the cross-section area of the duct, through which hot air is blown out to the wet solid.

By experimenting, the proportion of liquid mass and dry solid of the product can be determined. The weight of dry solid is m_s (kg_{dry}), and the ratio of liquid to dry solid is equivalent to X_i (kg_{water}/kg_{dry}). A

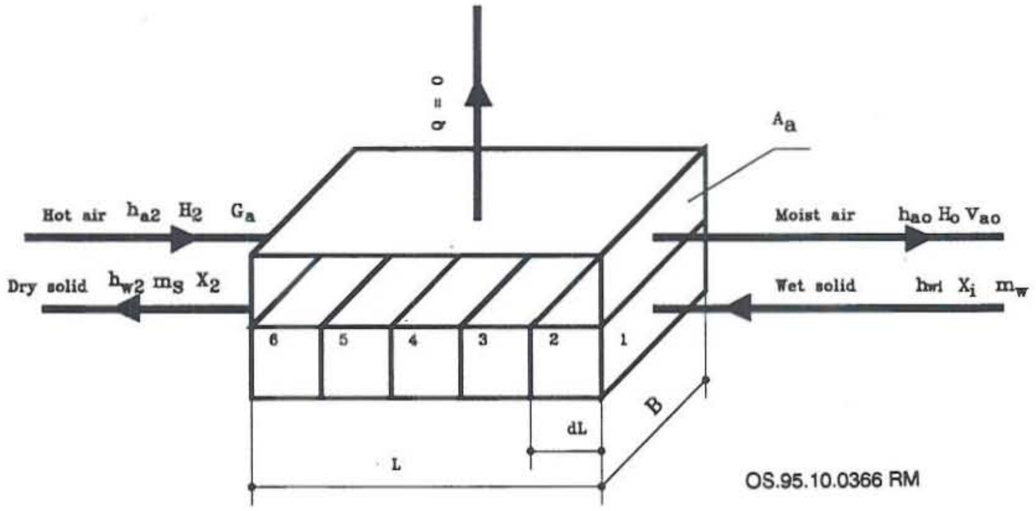

FIGURE 7: A mathematical model for drying cabinets

food technician should be able to identify how much X_i should be reduced in order to get the best quality of dry product. Let us assume that the air blowing velocity in the duct is equivalent to v_{ao} and the relative humidity of the air is ϕ_o and its outlet temperature T_{al}.

On the basis of known input parameters of air as shown in Table 2, the state of the dried material during the process of drying in each unit time can be calculated. As the hot air passes over the wet surface, the heat from hot air will be transferred into the wet surface. Due to change of temperature of solid, the state of liquid will be in equilibrium, and begin to evaporate from the surface. As a result, there will be decreased temperature of the wet solid to T_w, which is called wet bulb temperature. The wet bulb temperature is always less than air temperature and can be calculated by using the dry bulb temperature and humidity of air.

TABLE 2: Input parameters for a mathematical model of a drying cabinet

Input parameters			**Calculated values**		
Air pressure	100	kPa	Saturation pressure at air outlet	4.29	kPa
Air temperature at outlet	30	°C	Vapour partial press. in outlet air	2.574	kPa
Relative humidity of air at outlet	60	%	Air partial pressure at outlet	97.426	kPa
Air velocity at outlet	3.2	m/s	Humidity of outlet air	0.0164	kg_{water}/kg_{air}
Specific gas constant for air	0.287	$kJ/kg_{air}\,K$	Density of outlet air	1.1203	kg_{air}/m^3
Length of dryer	5	m	Mass flow rate of air	3.5851	$kg_{air}/s\,m^2$
Width of dryer	1.8	m	Cross-sect. area for the air flow	1.7010	m^2
Height of dryer	2.1	m	Total mass flow rate of air	6.0982	kg_{air}/s
Prop. of cross-sect. open for air flow	0.45		Heat transfer coefficient	79.31	$W/m^2{}^\circ C$
Number of racks	28		Number of steps	50	
Mass of dry material	400	$kg_{dr.m.}$	Drying time per step	2160	s
Water content of drying mat. at inlet	5.9	$kg_{water}/kg_{dr.m.}$			
Drying time	30	hr			
Step length for calculations	0.1	m			

Let us assume that the heat transfer from hot air to wet solid takes part only by convection, although there always occurs a small amount of heat transfer by radiation and conduction on wet solid where the solid is placed, but these are negligible (Wark, 1988). Then the rate of heat transfer can be written as follows

$$q = hA\,\Delta T \tag{1}$$

where

q = Rate of heat transfer by convection (W);
A = Exposed surface area of drying material $dLxB$ (m^2);
ΔT = Temperature difference between solid surface and hot air (°C);
h = heat transfer coefficient ($W/m^2\ ^{\circ}C$).

In order to make a good heat transfer from air to solid, it is necessary to have turbulent air flow inside the dryer. The heat transfer can be calculated by the following empirical formula which is applicable in the range of drying temperature 45-150°C, and air flow 0,7-8,14 kg/s m² (Geankoplis, 1983):

$$h = 0.0204\, G_a^{0,8} \tag{2}$$

where

G_a = Mass flow rate of air ($kg_{air}/s\ m^2$)

The mass balance equation for air and solid between cross-sections i and $i+1$.

$$m_a H_{i+1} + m_w X_i = m_a H_i + m_w X_{i+1} \tag{3}$$

where

m_w = Rate of solid flow (kg dry solid/s);
m_a = Rate of air flow (kg dry air/s);
X_i = Moisture content in the solid at cross-section i (kg H_2O/kg dry solid);
H_i = Air humidity at cross-section i ($kg_{H2O}/kg_{dry\ air}$).

As was assumed that the dryer is working in adiabatic conditions, so $Q = 0$ in kJ/s, if heat is added Q is negative. The heat balance equation for the dryer will be as follows:

$$m_a h_{a,i+1} + m_w h_{w,i} = m_a h_{a,i} + m_w h_{w,i+1} + Q \tag{4}$$

where

$h_{a,I}$ = Enthalpy of the air at cross-section i ($kJ/kg_{dry\ air}$);
$h_{w,I}$ = Enthalpy of the solid at cross-section i ($kJ/kg_{dry\ solid}$).

Let us select a reference temperature $T_0 = 0$°C for calculating the enthalpy at a given temperature, and $(T_a - T_0)$°C $= (T_a - T_0)$K. The enthalpy of air h_a at a given temperature can be calculated as follows (Wark, 1988):

$$h_a = 1.005\, T_a + H_a (2501.7 + 1.82\, T_a) \tag{5}$$

where

H_a = Humidity of air (kg_{H2O}/kg_{air});
T_a = Air temperature (dry bulb temperature) (°C).

The humidity of an air-vapour mixture is defined as kg of water vapour contained in 1 kg of dry air. The humidity so defined depends only on the partial pressure P_{vapo} of water vapour in the air and the air pressure P. Using the ratio of molecular weight of H_2O and air equivalent to 0.622; written as the following formula:

$$H_a = 0.622 \frac{P_{vapo}}{P - P_{vapo}} \tag{6}$$

water vapour partial pressure can be determined by applying relative humidity

$$\phi_o = 100 \frac{P_{vapo}}{P_{sato}} \tag{7}$$

where

P = Atmospheric pressure (kPa);
P_{vapo} = Water vapour partial pressure (kPa);
P_{sato} = Saturation pressure at given temperature T_{al} (from steam table) (kPa).

Total pressure of air is

$$P = P_{ao} + P_{vapo} \tag{8}$$

where

P_{ao} = Air partial pressure (kPa).

The mass velocity of the air can be determined by applying the formula:

$$G_a = \nu \rho \tag{9}$$

where

ν = Air velocity (m/s);
ρ = Density of air (kg/m^3);
G_a = Mass flow rate per unit area ($kg/s\ m^2$).

Finally, on the basis of calculated enthalpy of air the wet bulb temperature will be iterated by using the function $T_{wb}(h_a)$. This value will be calculated up to 0.001 accuracy. This value of T_{wb} can be found from the Mollier diagram too (Wong, 1977). The main advantage of using this function is that we will be able to know the state of the wet solid inside the drying cabinet at each step as shown in Figure 8. By means of which we can determine the duration of time required for the drying process and drying rate as shown in Figure 9.

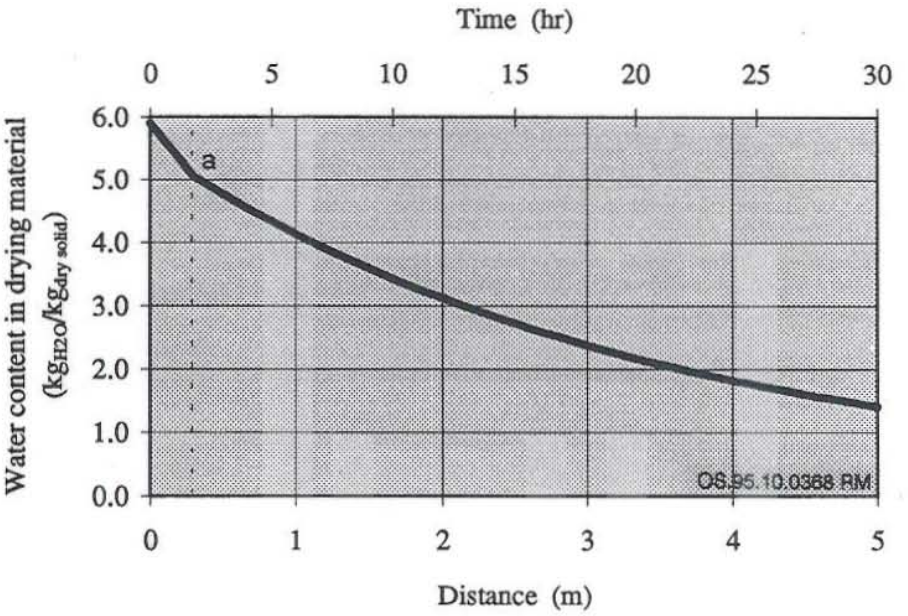

FIGURE 8: Water content in drying material

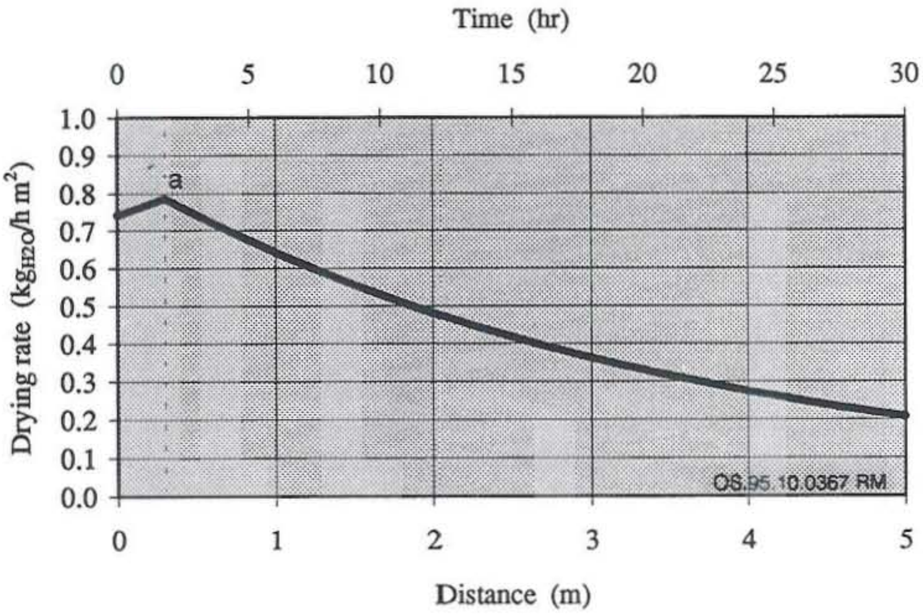

FIGURE 9: Drying rate curve for a drying cabinet

The quantity of water evaporated from position *i* to *i*-1

$$d_w = \frac{Q}{h_{fg}} \tag{10}$$

where

d_w = Quantity of water dried per step (kg_{water});
Q = Total heat transfer per step (kJ);
h_{fg} = Heat of evaporation for water (kJ/kg_{water}).

After all these calculations, all properties of air are known and state of solid when the solid reaches position 2 as shown in Figure 7. Now these values are used as input parameters for second step calculation, then by comparing the moisture content in the first and second step we come to know the quantity of water evaporated from the solid which is the main goal of all these calculations.

$$X_2 = X_o - dw \tag{11}$$

where

X_2 = Water contained in drying material in second step ($\mathrm{kg_{water}/kg_{dry}}$);
X_o = Water contained in drying material at initial state ($\mathrm{kg_{\ water}/kg_{dry}}$).

As mentioned above, the wet material contains unbounded water on the surface of the material, so the water from the wet material is evaporated as free water. According to the drying theory this means the rate of drying will be constant until there exists unbounded water. Our mathematical model gives a slightly increasing drying rate as calculated by the equation

$$R = 3.6 \frac{q}{h_{fg} dL\, B\, N} \tag{12}$$

where

R = Drying rate ($\mathrm{kg_{water}/h\ m^2}$);
q = Heat transfer rate (W);
N = Number of racks.

The duration of constant drying varies from one material to another, depending on the type of solid to be dried. Making the assumption that the drying rate always changes from constant drying rate to falling drying rate at the same water constant, X, experimental results have been used to decide when the calculations described above should be stopped.

Now the surface is no longer wetted. So the moisture tends to move from wet regions to dry. The rate of internal movement of the moisture is governed by the process of liquid diffusion or capillary movement. In practice, it is always hard to determine the way liquid flows. For simplification of calculation, we suppose that the drying rate varies linearly with the water content in this period. This is used in the mathematical model to continue the calculations in the falling drying rate period. By using this the previously calculated X value at the end of the constant drying rate period and an estimated X value at R=0, the drying rate in this period is given as follows:

$$R = a + bX \tag{13}$$

where a and b are constant values determined from experiment.

We know from the mass balance equation, that the change of mass in wet material must be equivalent to mass of water transferred into the air:

$$(X_{i-1} - X_i) m_{dry} = \frac{1}{2}(R_{i-1} + R_i) t A_a \tag{14}$$

where

$X_{i-1} - X_i$ = Change in water content in drying material (kg_{water}/kg_{dry});
m_{dry} = Mass of dry material (kg_{dry});
$(R_{i-1} - R_i)/2$ = Average rate of drying in position (i-1) to i (kg_{water}/hr m^2);
t = Time taken to move from position (i-1) to i (hr);
A = Surface area of drying material (m^2).

From Equations 12 and 13 we get the falling rate drying curve which starts from point a as shown in Figures 8 and 9. From the figures we can see how the drying rate varies along the drying cabinet. Most probably the drying process should stop when 90% water has been removed, out of the total moisture content in the wet solid. The main advantage of using mathematical models is that we get to know the state of wet solid and air blowing in it, in each step of drying.

The stepwise calculations of the drying process are shown in Tables 2 and 3; and their results are shown in Figures 8 and 9.

TABLE 3: Results from a mathematical model of a drying cabinet

Distance from drying material inlet	m	0	0.1	0.2	0.3	1	2	3	4	5
Time	hr	0	0.6	1.2	1.8	6	12	18	24	30
Air humidity	kg_{water}/kg_{air}	0.01643	0.01626	0.01609	0.01591					
Air temperature	°C	30.00	30.02	30.04	30.06					
Water content of drying material	$kg_{water}/kg_{dr.m}$	5.90	5.62	5.33	5.04	4.14	3.13	2.38	1.82	1.40
Enthalpy of the air	kJ/kg_{air}	72.16	71.7	71.3	70.9					
Temp.at the drying surf. (wet bulb)	°C	23.69	23.58	23.48	23.37					
Air-surface temperature difference	°C	6.312	6.44	6.56	6.69					
Heat transfer rate per step	W	2523	2572	2623	2675					
Heat transferred per step	kJ	5449	5556	5666	5778					
Heat of evaporation for water	kJ/kg_{water}	2430	2430	2430	2430					
Water dried per step	kg_{water}	2.242	2.286	2.331	2.377					
Water mass flow rate per step	kg_{water}/h	3.737	3.810	3.886	3.962					
Drying rate	$kg_{water}/h\ m^2$	0.7415	0.7560	0.771	0.786	0.642	0.481	0.362	0.273	0.207
Vapour partial pressure in the air	kPa	2.574	2.548	2.522	2.494					
Relative humidity of the air	%	60.00	59.32	58.64	57.93					

3.8 Heat and mass balance equations for condenser

The rate of recirculated air into condenser depends upon the rate of outflow from the dryer and the rate of discharged air into the atmosphere (see Figure 10):

$$G_6 = G_1 - G_7 \tag{15}$$

the specific enthalpy $h_{a1} = h_{a7} = h_{a6}$ (kJ/kg air). But the total heat flow at points 1, 6, and 7 will be different and can be calculated as follows:

$$q_{tot} = h_{a6} G_6 \tag{16}$$

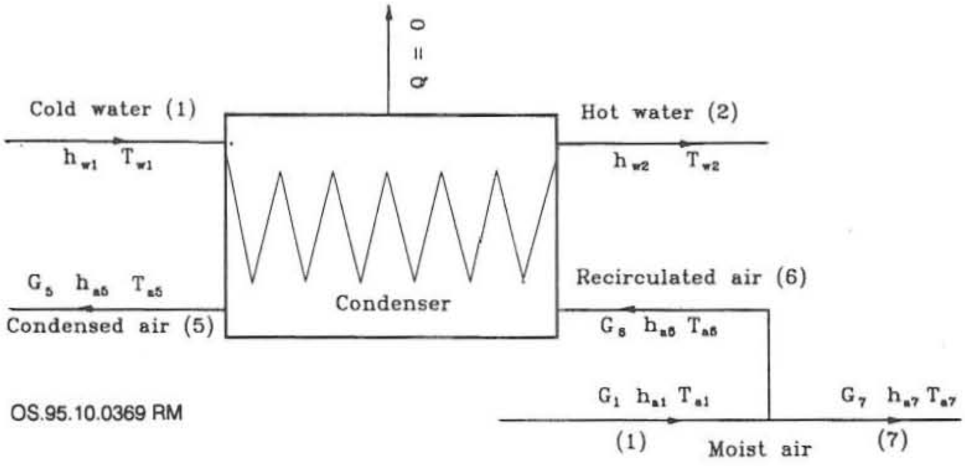

FIGURE 10: Diagram of heat and mass flow into condenser

In a similar way we have for the temperature $T_{a6} = T_{a1} = T_{a7}$ and furthermore we have for the humidity $H_6 = H_1 = H_7$. Assuming that the condenser is working under adiabatic conditions, the energy balance equation will be as follows:

$$q_a = q_w \tag{17}$$

where

q_a = Total rate of heat loss by hot air (W);
q_w = Total rate of heat gain by water (W).

$$q_a = G_6 (h_{a6} - h_{a5}) \tag{18}$$

The enthalpy of the recirculated air h_{a6} is calculated from Equation 16 and h_{a5} similar to Equation 4 for given temperature:

$$q_w = m_w (h_{w2} - h_{w1}) \tag{19}$$

where

m_w = Mass flow rate of cold water (kg/s);
h_{wi} = Enthalpy of water at given temperature (from steam table) (J/kg °C).

The design and thermal coefficients of the condensers differ from one manufacturer to another. So for procurement of the condenser the following specifications should be given to manufacturers to carry out the job:

- Flow rate of cold water, m_w;
- Rate of heat exchange, q_a, q_w;
- Outlet and inlet temperature of water, T_{w1}, T_{w2};
- Flow rate of hot air, G_6;
- Outlet and inlet temperature of hot air, T_{a5}, T_{a6}.

Heat and mass balance for the condenser can be written as Equations 3 and 4

3.9 Heat and mass balance equations for heater

The working principle of the heater is similar to the condenser, instead of cooling it heats air by transfer of heat from geothermal water as shown in Figure 11. The required temperature of the mixed air is obtained by regulating the flow rate of the hot geothermal water.

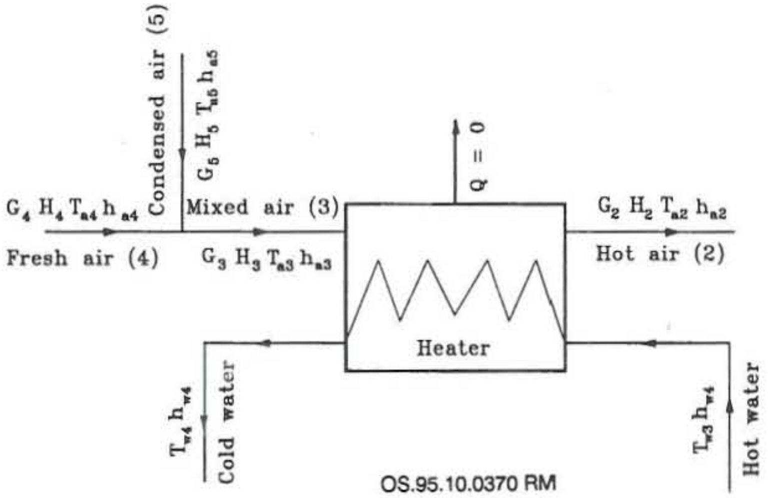

FIGURE 11: Diagram of heat mass flow into the heater

Calculation of the flow rate of air after mixing

$$G_3 = G_4 + G_5 = G_2 \tag{20}$$

The enthalpy of the air after mixing can be calculated as in Equation 5, but specific enthalpy $h_{a4} \neq h_{a5} \neq h_{a3}$ in this case. The heat flow can be calculated as in Equation 16.

The humidity of the air after mixing at point 3 is the same as the humidity at point 2, i.e. $H_3 = H_2$. It can be calculated as follows:

$$H_3 = \frac{G_3 H_4 + G_5 H_5}{G_3} \tag{21}$$

Specifications for procurement will be specified as in specification of condenser.

3.10 Size of fan

The fan is used for transfer of heat from heater to wet material. The size of blower depends upon the air quantity, air friction losses on the duct and drying cabinet, velocity and noise. The pressure drop can be calculated either by using general formula or by using friction loss graphic which is a correlation diagram in between shape and size of duct, air velocity, and flow rate. Computation of the three parameters as shown below will give the total frictional loss on lane of system.

a) Pressure drop in heater and condenser (N/m^2);
b) Pressure drop in the drying cabinet itself where wet material is placed (N/m^2);
c) Pressure drop in the air tunnel (N/m^2).

Pressure drop during the air blowing through heater and condenser will be provided by manufacturer, because it depends upon the type of product. The rest of the two pressure drops can be calculated by using a nomogram which is true for a specific rectangular shape duct made of galvanized steel, and at 20°C. As the duct is rectangular in shape, but the nomogram is based on circular cross-section, the hydraulic diameter of the duct is used, which is defined as follows (Olson, 1973):

$$d_h = \frac{2ab}{a+b} \tag{22}$$

where

d_h = Hydraulic diameter (mm);
a = Width of the duct (m);
b = Height of the duct (m).

TABLE 4: Air pressure drop in a specific rectangular shape duct

Velocity of air (m/s)	Hydraulic diameter (mm)	Pressure drop ($N/m^2/m$)	Length of duct (m)	Total pressure drop (N/m^2)
2.6	97	1.05	21	22.05
2.4	900	0.01	10	0.1
			Total	22.1

The size of the fan will be selected on the basis of total volume of air required in 30 hours, the total pressure drop on the system and permissible level of noise (see Table 4). One of the most suitable fans for the given working condition of the system, is an axial-ventilator as a large volume of air with medium pressure is needed for the given dryer.

3.11 Experimental work on apple drying

As a part of this project work an experiment on apple drying has been carried out in Icelandic Fisheries Laboratories, Reykjavík. The main objectives of the experiment were to determine the water content of an apple and the drying rate curve for an apple.

Determination of moisture content in an apple was done in the following way:

1. Three slices from three different apples are taken and placed in three different evaporating dishes;
2. Slices are cut in as small pieces as possible in order to make sure that water contained in the apple could evaporate completely;
3. The apples are weighed and put in a furnace at a temperature of 100-104°C for 3 hours;
4. The apples are taken out from the furnace and kept in a desiccator containing calcium chloride ($CaCl_2$) for 15 minutes in order to be sure that there is no more moisture in the apple;
5. Finally, the apples' dried solid is weighed again.

From the experiment it is determined that an apple contains 85,57% liquid and 14,43% dry solid. The experimental data are shown in Tables 5 and 6. Appendix I shows data from Geankoplis (1983) on various food. According to him the water content of apples is 75-85%, which is similar.

In accordance with the drying theory we have estimated that the drying rate curve should follow the dash line as shown in Figure 12, but due to lack of recorded experimental data the constant rate drying period cannot be observed in the plotted figure. So it is necessary to revise several times in order to compare with model. It is quite obvious that the estimated drying rate is higher than the values from the

TABLE 5: Determination of surface area of apple contact with hot air

Thickness of apple	Outer diameter of apple		Inner diam. of apple	Apple surface area in contact with air	
	Tray 1	Tray 2	(all apples)	Tray 1	Tray 2
(mm)	(mm)	(mm)	(mm)	(mm^2)	(mm^2)
8	62	68	13	7654	9029
8	73	75	13	10262	10776
8	67	72	13	8792	10009
8	67	73	13	8792	10262
8	67	78	13	8792	11572
8	67	74	13	8792	10517
8	75	75	13	10776	10776
8	79	69	13	11844	9269
8	54	64	13	5996	8100
8	63	72	13	7875	10009
Average area of each piece				8957	9224
No. of apple pieces in each tray				30	49
Area of apple contact with hot air				268724	451977
Tot. apple surface area in cont. with air (trays 1+ 2) (m^2)					0.72070
Size of dryer (cm^3)				LxBxH	56x56x96
Water % to be removed from apple (out of 85% liquid content)				90%	

experiment but in future it can be adjusted. The main idea of mathematical modelling is quite satisfactory to the curve plotted in Figures 12 and 13.

Drying test of an apple has been carried out in a cabinet type of dryer, in which the air is blown out at the rate of 2.2 m/s. The temperature of air has been set at 27°C. The heat was transferred to the wet material by means of the convectional method, because the hot air circulated through the wet material. The recorded ambient temperature is 20°C and humidity is 41%. The air velocity, humidity and temperature have been measured by using Testo-452 from Testoterm Ltd.

TABLE 6: Determination of water content in apple

Weight of apple before heating (Liquid + Solid) (g)	Weight of apple after heating (Solid) (g)	Total solid (%)	Total liquid (%)
11.22	1.61	14.35	85.65
12.92	1.88	14.55	85.45
5.56	0.8	14.39	85.61
	Average	14.43	85.57

Determination of the drying rate has been performed in the following way:

1. Apple slices of equal size were placed on a tray in equal distribution;
2. Apple slices were weighed and kept in drying chamber where dry air was blown out;
3. The weight of the apple was recorded every 30 minutes.

The results of the experiment are shown in Tables 7 and 8 and its data are plotted in graphic form in Figures 12 and 13.

TABLE 7: Experimental data from apple drying

Sa. No.	**Time**	**Time**	**Weight of apple and tray**		**Weight of apple Liquid + Solid**		**Air temperature**		**Relative humitity of air**		**Velocity of air**		**Remarks**
		(min.)	Tray 1 (g)	Tray 2 (g)	Tray 1 (g)	Tray 2 (g)	Inlet (°C)	Outlet (°C)	Inlet (%)	Outlet (%)	Inlet (m/s)	Outlet (m/s)	
							27.2	27.2	28.1	28.1	1,6-2,0	1,6-2,1	Inital state of dryer Switch on dryer 1 hr.before
1	9:30	0	1453.1	1732.3	482.5	993.5	29.4	25.3	34.4	37.5	2.1	0.4	
2	10:00	30	1421.1	1615.6	450.5	876.8	24.2	23.5	40.6	42.1	1.6-2.0	0-0.4	Little browning of surface
3	10:45	75	1376.6	1503	406	764.2	24.6	23	33.7	35.8	2.5	0-0.4	
4	11:15	105	1348.7	1438.5	378.1	699.7	25.3	23.7	35.3	37.3	2.1-2.5	0-0.4	Little wrinkling of surface
5	11:45	135	1320.9	1378.6	350.3	639.8	26.1	24.9	36.8	37.3	2.1-2.6	0-0.4	
6	12:15	165	1300.5	1337.1	329.9	598.3	24.4	23.4	32.3	32.6	2.4-2.8	0-0.4	
7	12:45	195	1282.2	1300.9	311.6	562.1	25.1	24.1	37.7	38.1	2.4-2.1	0-0.4	
8	13:15	225	1265.2	1267.6	294.6	528.8	24.1	23.5	33	32.8	1.8-2.2	0-0.4	
9	13:45	255	1249.4	1237.1	278.8	498.3	24.6	23.9	38.4	39.2	1.8-2.0	0-0.4	
10	14:15	285	1233.7	1205.3	263.1	466.5	24.1	23.7	30.9	41	1.8-2.0	0-0.4	Wrinkling and browning of surface
11	14:45	315	1221	1180.3	250.4	441.5	26.3	26	36.3	38.4	1.8-2.2	0-0.4	
12	15:15	345	1208.2	1155.3	237.6	416.5	26	25.6	32.4	35.1	1.8-1.2	0-0.4	
13	15:45	375	1190.5	1120.2	219.9	381.4	25.4	23.8	35.7	36.8	1.6-2.0	0-0.4	
14	16:15	405	1180.3	1100.8	209.7	362	24.9	23.1	36.5	37.5	1.4-1.8	0-0.4	Apples start to fly in air
15	16:45	435	1168.2	1077.8	197.6	339	24.5	23.3	37.2	37.6	1.6-2.0	0-0.4	
16	17:15	465	1157.2	1056.6	186.6	317.8	23.7	22.2	33.4	33.6	1.5-2.0	0-0.4	
17	17:45	495	1147.4	1038.4	176.8	299.6	26.1	25.2	30.7	33.9	1.5-2.0	0-0.4	
18	18:15	525	1139.4	1023.6	168.8	284.8	26.9	24.2	30.7	33.5	1.6-2.0	0-0.4	

TABLE 8: More experimental data from apple drying

Time (min)	**Time (h)**	**Wt. apple Liq. + sol. 100% (kg)**	**Wt. dry solid 14.43% (kg)**	**Wt. liquid H2O 85.57% (kg)**	**Free moisture - X ($kg_{H2O}/kg_{dry\ solid}$)**	**Apple surface area in contact with air - A (m^2)**	**Drying rate - R ($kg_{H2O}/h.m^2$)**
0	0	1.476	0.213	1.263	5.9296	0.7207	
30	0.5	1.3273	0.213	1.1143	5.2315	0.7207	0.4127
75	1.25	1.1702	0.213	0.9572	4.4939	0.7207	0.2906
105	1.75	1.0778	0.213	0.8648	4.0601	0.7207	0.2564
135	2.25	0.9901	0.213	0.7771	3.6484	0.7207	0.2434
165	2.75	0.9282	0.213	0.7152	3.3577	0.7207	0.1718
195	3.25	0.8737	0.213	0.6607	3.1019	0.7207	0.1512
225	3.75	0.8234	0.213	0.6104	2.8657	0.7207	0.1396
255	4.25	0.7771	0.213	0.5641	2.6484	0.7207	0.1285
285	4.75	0.7296	0.213	0.5166	2.4254	0.7207	0.1318
315	5.25	0.6919	0.213	0.4789	2.2484	0.7207	0.1046
345	5.75	0.6541	0.213	0.4411	2.0709	0.7207	0.1049
375	6.25	0.6013	0.213	0.3883	1.8230	0.7207	0.1465
405	6.75	0.5717	0.213	0.3587	1.6840	0.7207	0.0821
435	7.25	0.5366	0.213	0.3236	1.5192	0.7207	0.0974
465	7.75	0.5044	0.213	0.2914	1.3681	0.7207	0.0894
495	8.25	0.4764	0.213	0.2634	1.2366	0.7207	0.0777
525	8.75	0.4536	0.213	0.2406	1.1296	0.7207	0.0633

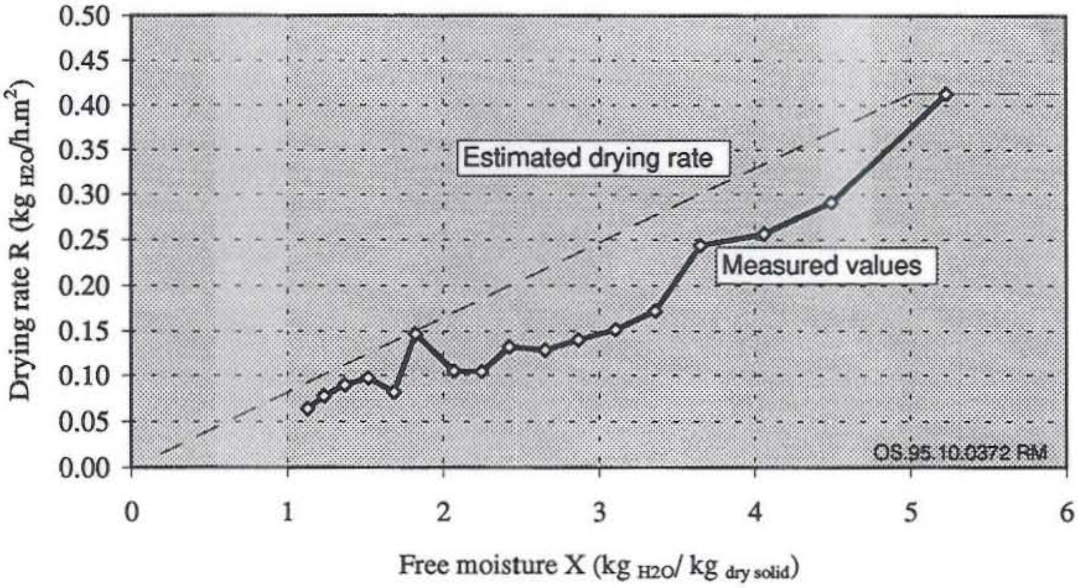

FIGURE 12: Rate of drying vs. free moisture in the apple drying experiment

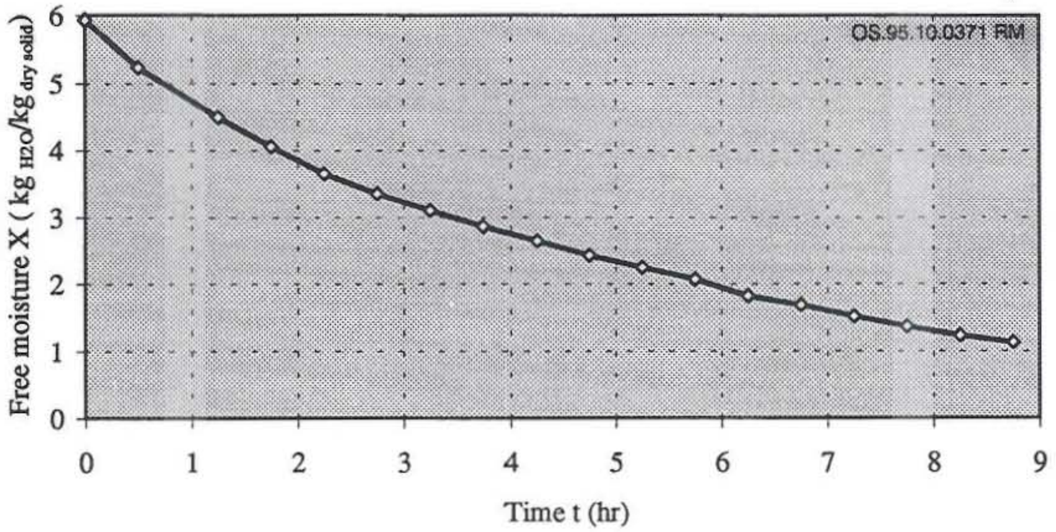

FIGURE 13: Free moisture vs. time for the apple drying experiment

4. SWIMMING POOL

Bathing and swimming have been practised by people through the ages. The earliest recorded examples can be found in the oldest religious Hindus' book like Mahabharat where it is mentioned that it is essential to take a bath before starting the day life in order to keep good health and good spirit.

Bathing and swimming has played an important part in the life of human beings. It is important, not only for pleasure, but also quite important for sanitation. Taking a bath means cleaning the body. Most people from cold regions like the Himalayas in Nepal need warm water for bathing, because the temperature in this region always remains below 5°C. Apart from that, warm water is necessary for heating houses and also for washing the clothes. Most people from these places use firewood to fulfil their needs. In order to prevent deforestation they must be provided with an alternative source of energy.

The Himalayan region is a place of tourist attraction. Most of the tourists in Nepal are from the developed countries as in Europe and United States who are used to taking their bath with hot water. So if we can provide them with warm bath water, it will be to their convenience. One example does already exist in Mustang District (Ranjit, 1994). In this part of the report we will discuss the designing aspects of public bathing system, i.e. a swimming pool using geothermal water.

4.1 Size of swimming pool

One of the basic design criteria for a public swimming pool is the size. The size indicates whom the pool is going to serve. Here we consider a swimming pool which is going to be used by three groups of people: children who are learning to swim, people who swim for their recreation, and tourists who come to Nepal to have a rest.

The space required for each individual depends upon the depth of the pool (Halldórsson, 1975). If the depth is 0.5 m, then the area of the pool for each individual should be 2 m^2, if it is deeper than 1.35 m then it should be 4.5 m^2 for each person. In the following calculations it is assumed that the maximum number of guests in the pool at the same time will be 36. Also, it is assumed that the depth of the pool will be greater than 1.35 m, so the surface area will be 162 m^2.

It seems that this size of pool also fulfils the minimum requirements of the international standards for training professional swimmers and swimming competition (Perkins, 1988). Then the pool can be sized into 25x12.6 m. The depth of the pool will be 1 m in the shallower end and 1.8 m in the deeper end of the pool. The total quantity of water inside the pool will be 440 m^3.

4.2 The working principle of the swimming pool

In Figure 14 a schematic diagram of a swimming pool is shown. It is intended to fulfill the basic requirements norms of sanitation and comfort for target guests as mentioned above. Besides this, the aim is to minimise energy consumption used for heating the water, and also the quantity of chemical dosing in it. It is strictly considered to keep the water clear, free from pathogenic bacteria, and to maintain the pool temperature at a desired setting point. These requirements can be satisfied in different ways.

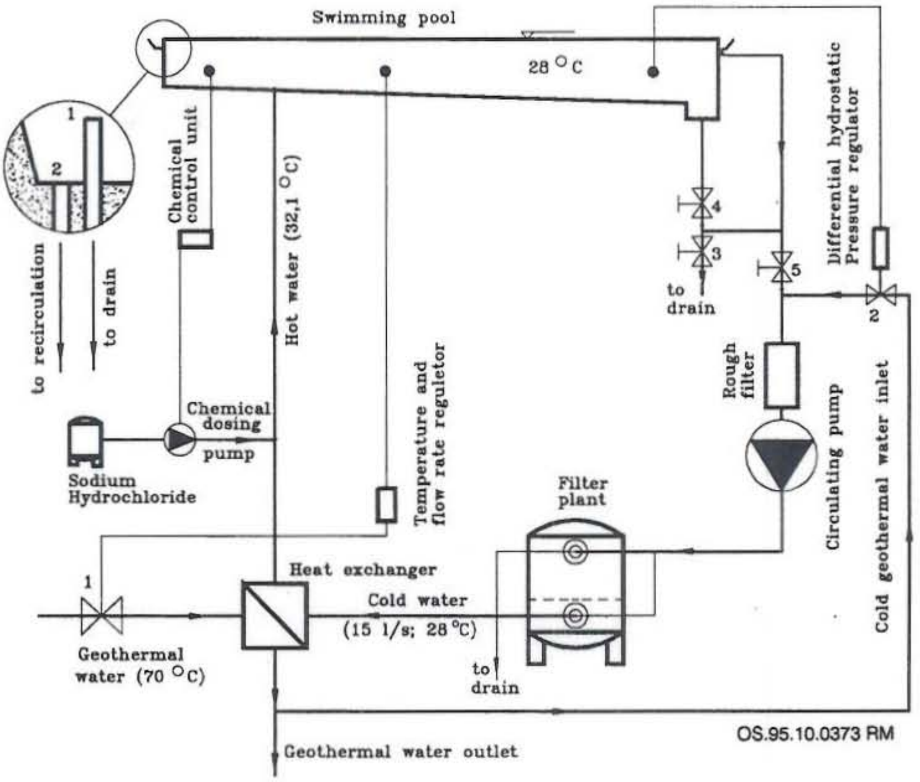

FIGURE 14: A schematic diagram of a swimming pool

The chemical feeding into the pool will be accomplished with the help of a chemical dosing pump as shown in the diagram. The quantity will be monitored by a chemical controlling unit. When the pH value of the pool water goes below the setting point, the control unit will give an electrical impulse signal to switch on the pump and inject the chemical compounds to the lane of hot water.

The installed filter plant is a simple device inside which is graded sand and gravel. The recirculated pool water which is under some pressure, is circulated through sand and gravel. The flow direction of water during filtration is from top to bottom, but while it is required to clean the sand and gravel itself the flow direction is just reversed. The outcoming water during cleaning is entirely flushed out into the drain.

A rough filter is installed before the water enters the circulating pump to remove the large impurities like sand particles, leafs etc. This will help to prolong the life of the impellers of the pump and also to keep the filter sand clean for a long time.

The conventional water temperature in swimming pools varies from one country to another. For instance, in Iceland the pool water temperature tends to be kept at 30°C, in UK 26°C etc, so there is no standard. In our case we decided to keep the water temperature at 28°C. When the temperature of the pool decreases below setting point, the temperature controlling unit will switch on a motor connected to a gate valve which opens for flow of geothermal water into the heat exchanger. Thus, the flow rate of geothermal water depends upon heat loss from the swimming pool.

The drain water coming from the surface of the pool is not completely discarded into the drain. Under normal conditions, the water flows through pipe 2, (Figure 14) and from there through a recirculation lane. If the water level goes up to pipe level 1, for example, if there are more people in the pool than expected or failure of the water level controlling unit, the overflow water will completely drain out to sewage through pipe 1. The impurities like leafs, fat, hair etc. are flushed out by opening the gate valve 3 and closing valves 5 and 4. The refilling of water into the pool can be done by the geothermal water coming from the heat exchanger. The level of the water in pool will be maintained by regulating the gate valve 2. Closing or opening the gate valves no 3 and 4 will be done manually for opening the main drain to flush out the impurities lying on the bottom of the pool. Normally the major quantity of water coming out from the bottom part is recirculated.

4.3 The piping systems in the swimming pool

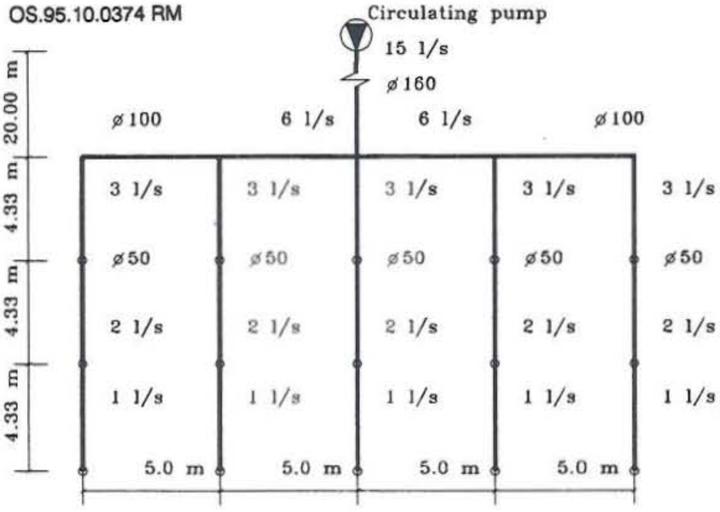

FIGURE 15: Schematic diagram of a water flow lane

In a swimming pool there are a number of pipes which penetrate the walls and floor, mostly below top water level as shown in Figure 15. If the water distribution supply is selected as one spout for 11 m^2 area, then the total number of spouts will be 15. These spouts are distributed over the bottom of the pool, because this gives equal distribution of hot water in all parts of the pool and also good cleaning of the bottom of the pool by the water flow. The pipes with a large diameter will be put in the bottom before the floor of the pool is cemented. Special care is needed around the distributors so they can be connected and packed afterwards. All pipes should be as straight as possible with minimum bends. It will minimise the leakage problems on the joints as well as the pressure drop in the system.

In case of temperature controlling system failure, water at 70°C may flow in the piping system of the pool. For this reason and also because the water is very corroding due to chloride content, the pipe material chosen is polypropane or polyethylene which can resist the given situations. The pipes are taken in three different diameters, 150 mm for the main water inlet, 100 mm for sub-distribution from the main, and 50 mm for equal distribution of water in the pool (for detailed calculation see Chapter 4.5).

The water drainage system from the pool is designed in such a way that it allows the full inflow capacity, including rain water, to be flushed out. The drainage system for cleaning the pool is designed in such a capacity that it will be able to empty the pool within five hours. The overflow water from the top of the pool is thrown out totally because it contains most of the floating impurities like body fat and hair. The outlet water from the bottom will be used either for drainage or for recirculation, depending on the requirements for renewal or refilling the pool. The cleaning of the bottom part of the pool will be carried out with the help of a special cleaning device.

4.4 Water treatment in the pool

There is no doubt that water in the pool should be clear, sparkling and free from pathogenic bacteria. As shown in Figure 14 the basic design chosen for water treatment is a system with continuous circulation with filtration and chemical treatment and water heating facilities.

The addition of chemicals to the pool water is required for various reasons, the principal one is for disinfection of the pool water and to control the pH within the range of 7.2-7.8. This is the optimum pH value for treatment of the pool water prescribed by swimming associations. The feeding of chemicals into the pool will be accomplished with help of a dosing pump, and the pH value will be controlled by a chemical controlling unit.

The recirculation water from the pool, which may contain impurities like hair, leafs, sand particles etc., should be passed through a rough filter unit before entering the main circulating pump. It will help to protect the pumping wheel and main filtering unit from its damages. These filters come with the pump as a part of it and are usually easily opened for cleaning. It has been stated (Halldórsson, 1975) that the main filtering unit size should be below 2 mm and filtering water flow rate should not exceed 75 m^3/m^2hr for a hygienic swimming pool. The turnover period of all the water from the swimming pool for purification depends upon the type of pool and the bathing conditions for the public before entering the pool. All the water from the pool should be recirculated every 2-3 hours (Perkins, 1988) by taking into consideration compulsory bathing before entering the pool and no urinating into the pool by guests.

Various types of filters for swimming pool water are available. Among them, we selected a standard sand filter manufactured by the Jacuzzi company, series SS-36, which can filter water at the rate for replacing sand and gravel 48 m^3/m^2hr. The filter tank is made of stainless steel AIS1304 with 150x110 mm opening from Jacuzzi. This model entirely satisfies requirements mentioned above. To filter the pool water at an amount of 440 m^3 in three hours, four such devices are required. Further technical information about the equipment is given in Table 9.

The quality of filtering depends on the flow rate through the sand bed. For the best filtration the water flow rate should be in the range of 41-45 m^3/m^2hr. Otherwise the flow of water could disrupt the sand bed and no filter action will be performed. For filter media, the manufacturer recommends to put two grades of media in the filter. The first one is gravel supporting base of hard round stones, 3-6 mm in diameter, with less than 2% by weight of thin, flat or elongated pieces. The second filter media is quartz, either oval shaped grains or with round edges, and the grain size should be in the range of 0.4-0.7 mm.

Sand, 175 kg, and gravel, 400 kg, is needed for one filter. The sand and gravel should be thoroughly washed before being put into the filter. It is recommended to add 0.8 kg alum per m^2 filter surface area in order to scan the dirt size up to 5-7 micron.

TABLE 9: Filter and pump performances

Tank diameter (m)	Filter area (m^2)	Pump power		Pump capacity (m^3/hr)	Filter rate (m^3/m^{2}hr)	Min. back wash rate (m^3/hr)
		(HP)	(kW)			
900	636	3	2.20	30	48	24

4.5 Selection and size of a circulating pump

The pumps chosen for the circulation of the swimming pool water are of centrifugal type with directly coupled electric motors. The head needed to lift the water to the swimming pool is not so big, but the water quantity to be circulated is very high. Furthermore to select the size of pumps it is necessary to identify the total pressure drop in the system and total flow rate of water.

The total volume of the water inside the pool is 440 m^3. The whole water from the pool has to turn over every 2-3 hours as mentioned above. To achieve this requirement the pumping rate of recirculating water should be in the range of 40-60 l/s. The number of installed filters is four, so each filter has its own circulating pump, that means each has to pump water at the rate of 10-15 l/s.

The pressure drop in the filter and heat exchanger is given by Jacuzzi and Alfa-Laval. The height of water to be lifted and the major pressure drop on lane of water during its circulation can be determined by using general formula or by using nomograms. For calculation of pressure drop in the water flow lane a friction nomogram provided by the Argu Pipe Manufacturer Company is used and gives the following:

a) Pressure drop in the heat exchanger is equal to 60 kPa;
b) Pressure drop in the sand filter is equivalent to 50 kPa;
c) The height of the pool is equivalent to 1.4 m on average, so the pressure drop will be 14 kPa;
d) Pressure drop during the water flow in the lane system depends on the number of bends, pipe diameter and length and surface roughness of the PVC-pipe, calculations are shown in Table 10.

TABLE 10: Pressure drop during water flow in the lane systems due to friction and bends (Olson, 1973)

Pressure drop in the system from pump to pool								
Max. flow rate (l/s)	**Dia. of pipe (mm**	**Pressure drop (kPa/100m)**	**Length of pipe a (m)**	**No. of bends**	**Pressure drop per bend = 1.5 diam. approx., 5 m of pipe (m)**	**Total bend equivalent in length b (m)**	**Total length a + b (m)**	**Total pressure drop (kPa)**
15	160	2.5	20.00	2	1.20	2.40	22.40	0.56
6	100	6.0	10.00	1	0.75	0.75	10.75	0.64
3	100	1.6	21.65	4	0.75	3.00	24.65	0.40
3	100	1.6	21.65	5	0.75	3.75	25.40	0.40
2	80	2.5	21.65	5	0.60	3.00	24.65	0.62
1	60	3.5	21.65	5	0.45	2.25	23.90	0.83
Pressure drop in the system from pool to pump								
15	160	0.25	39.00	4	1.20	4.80	43.80	1.10
Total pressure drop in the system of flow lane								4.55

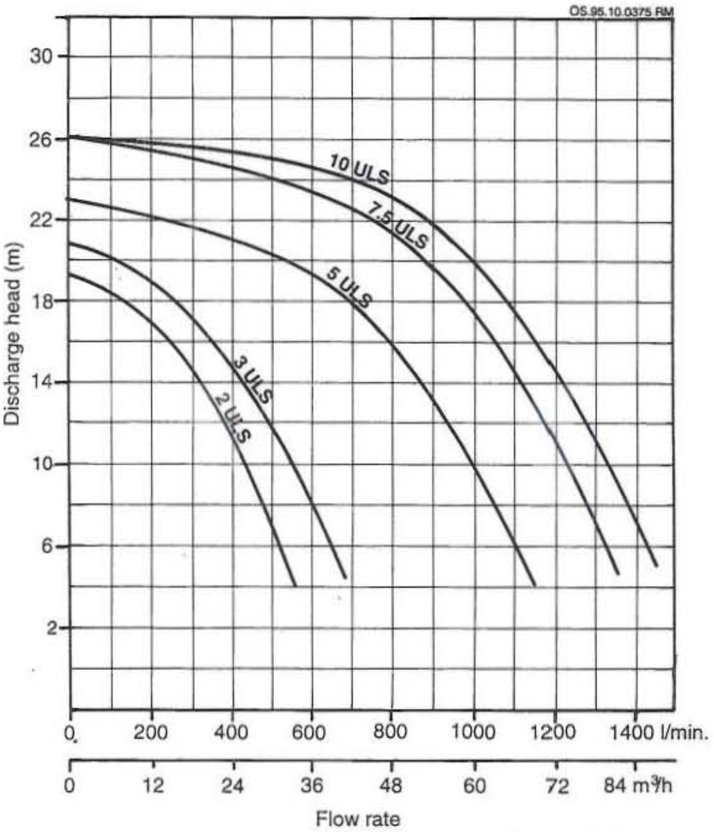

FIGURE 16: Characteristics of a Jacuzzi circulating pump for a swimming pool

Finally, we can fix the total pressure drop in the system, it is equivalent to the sum of the above mentioned pressure drop 129 kPa. The water flow rate in each pump is equal to 15 l/s (900 l/min.). The capacity of the pump fitted on the filter is only about 8 l/s (Table 9). Therefore it is necessary to install a bigger pump. We choose a Jacuzzi pump of the type ULS-5, which characteristic pumping curve is shown in Figure 16. Its pumping capacity is 61 m^3/hr and pump power is 5.52 kW (5 HP). The flow rate in the filtering unit becomes 38.8 m^3/m^{2}hr, which is still under the permissible limits for good filtration.

4.6 Energy requirement for heating the pool

Figure 17 is a simplified diagram of the swimming pool heating system. The below given data are based on assumptions which might occur in Mustang district of Nepal.

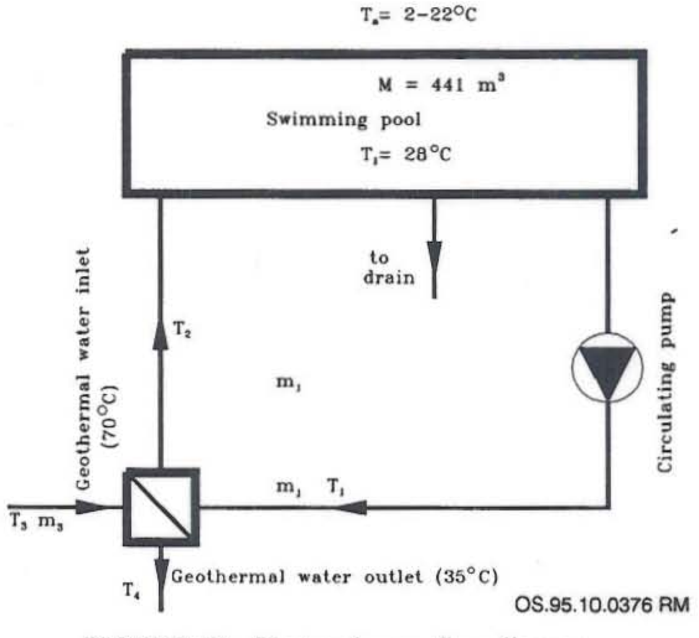

FIGURE 17: Heat and mass flow diagram for a swimming pool

The major heat losses in the swimming pool are due to convection and evaporation, which will be taken into account in further calculations. The heat loss due to radiation is taken to be the equivalent to the heat gain by means of sun, although heat gain during summer by sun radiation is great, but it is not taken into account. It is assumed that the pool is made of 180 mm thick cement concrete mortar and is insulated with 60 mm hard and moisture resistant rock-wool. Thus heat loss by means of conduction is minimum. Heat loss due to rain is also assumed to be very small. All together heat loss due to minor factors will be the estimated equivalent to 10% of total heat loss by means of evaporation and convection.

Heat loss by convection in a swimming pool is heavily dependant upon the atmospheric temperature and wind speed. Higher wind speed and low ambient air temperature will result in high heat loss. Overall heat loss by convection will be determined by using Newton's law of cooling (Holman, 1989):

$$Q_c = h_c(T_1 - T_a) \tag{23}$$

where

Q_c = Rate of heat loss by convection (W/m^2);
T_l = Temperature of pool water (°C);
T_a = Ambient temperature (°C);
h_c = Convection heat transfer coefficient (W/m^{2}°C).

The heat transfer coefficient h_c depends upon wind speed and ambient temperature. It is calculated by using the following formula by Rimsha-Doncenko (adopted from Svavarsson, 1990):

$$h_c = (K + 0.45\,v)\,4.19 \tag{24}$$

where

v = Wind speed at 2 m height from the level of the ground (m/s);
K = Empirical coefficient (W/m^2 °C).

$$K = 0.93 + 0.04\,(T_w - T_a) \tag{25}$$

Heat loss by evaporation occurs because of different partial pressure of the water steam at the surface of the pool and air over it. The evaporation takes place by loosing some energy from the surface of the water. The heat loss can be calculated by using Rinsha-Doncenko's formula

$$Q_e = (1.56\,K + 0.70\,v)\,(e_w - e_a)\,4.19 \tag{26}$$

where

Q_e = Rate of heat loss by evaporation (W/m^2);
e_w = Partial pressure of steam at surface (mbar);
e_a = Partial pressure of steam in air (mbar).

$$Q_l = Q_c + Q_e + S \tag{27}$$

where

Q_l = Total heat from the pool (W/m^2);
S = 10% of (Q_c +Q_e) for other sources of heat loss (W/m^2).

In order to maintain the required temperature of pool water, we must add the same quantity of heat as is lost. It is done by transfer of heat from geothermal water to pool water by the help of heat exchangers.

$$Q_l = Q_i \tag{28}$$

where Q_i = Required quantity of heat for pool (W/m^2).

For calculation of Q_i for heat exchanger the steady-flow energy balance on the rate basis is quite applicable (Wark, 1988).

$$Q_i = m_1 c_{p_1}(T_2 - T_1) = m_2 c_{p_2}(T_3 - T_4) \tag{29}$$

where

m_1 = Flow rate of water to be circulated (kg/s);
m_2 = Flow rate of geothermal water (kg/s);
c_{pi} = Specific heat capacity of water (J/kg °C);
T_1 = Temperature of pool water at heat exchanger inlet (°C);
T_2 = Temperature of pool water at heat exchanger outlet (°C);
T_3 = Temperature of geothermal water at heat exchanger inlet (°C);
T_4 = Temperature of geothermal water at heat exchanger outlet (°C);
Q_i = Heating requirements for the pool (W).

4.7 Selection of heat exchangers

The design of heat exchangers differs from one manufacturer to another. So for its procurement the calculated values based on the pool design as shown in Table 11, should be provided to manufacturer to carry out his job. In this report, the heat exchanger is chosen by using software programme from Alfa-Laval named CAS-200, which is used for selection of heat exchanger. As a result, we got the specification of a heat exchanger which suits the designing conditions. Its values are shown in Table 12.

TABLE 11: Energy requirement for heating the swimming pool

Input parameters	**Variable**	**Unit**	**Value**
Water temperature of the pool	T_1	°C	28
Rate of water flow into the pool (maximum)	m_1	l/s	15
Outside air temperature	T_a	°C	2-26
Geothermal water inlet temperature	T_3	°C	70
Wind speed	v	m/s	2-6
Relative humidity	H	%	60-96
Geothermal water outlet temperature	T_4	°C	35
Total area of swimming pool	A	m^2	162
Pressure drop allowed to the side of cold water flow	P_d	kPa	60
Calculated values			
Coefficient dependant on temperature difference	K	$W/m^2°C$	8.25
Heat transfer coefficient	h_c	$W/m^2°C$	19.6
Heat loss by convection	Q_c	W/m^2	509
Partial pressure of steam at water surface	e_w	mbar	37.8
Partial pressure if steam in air	e_a	mbar	7.12
Heat loss by evaporation	Q_e	W/m^2	935
Total heat loss ($Q_c + Q_e + 0.1\ (Q_c + Q_e)$)	Q_l	W/m^2	1588
Specific heat capacity of water at given temperature	c_{pi}	kJ/kg °C	4.18
Required quantity of heat for pool	Q_i	kW	257
Pool water temperat. after passing through heat exchanger	T_2	°C	32.1
Rate of geothermal water flow	m_2	kg/s	1.76

TABLE 12: Alfa-Laval plate heat exchanger specification based on CAS-200

Name	Unit	Hot side	Cold side
Model	M6-M		
Fluid		Water	Water
Density	kg/m^3	988.6	994.6
Specific heat capacity	kJ/kg K	4.17	4.18
Thermal conductivity	W/m K	0.637	0.616
Pressure drop	kPa	0.996	58.80
LMTD	°C	18.30	
OHTC clean condition	W/m^2 K	2270	
OHTC service	W/m^2 K	2089	
Heat transfer area	m^2	6.70	
Fouling resistance	m^2 K/W	0.38	
Relative direction of fluids	Counter-current		
Number of plates	No	50	
Effective plates	No	48	
Number of passes	No	1	1
Plate material/thickness	AISI316/0.50 mm		

5. CONCLUSIONS

From the above calculations the following can be concluded:

1. The artesian hot water spring available (with flowrate 1.8 l/s, surface temperature 71°C) in Mustang district could be used for a swimming pool or a drying plant.

2. The suggested dryer is a universal one, and can be adjusted for drying different raw materials.

3. The mathematical model developed in this project work for a drying cabinet could be useful for designing the dryer itself; and to predict the state of wet material and hot air during the drying process, by means of which we can identify the time required for each drying material. Of course, some series of experiments have to be carried out in order to compare the model with experimental results.

4. Both from a hygienic point of view and the size of the pool the projected swimming pool is quite satisfactory according to international standards.

5. In this report possible utilization of geothermal energy in Nepal has been studied from the technical point of view. Before implementation of real systems a more detailed study of technical solutions, as well as economical feasibility, will be necessary.

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APPENDIX I: Heat capacities of foods (average C_p at 0-100°C) (Geankoplis, 1983)

Material	**H_2O (wt %)**	**C_p (kJ/kgK)**	**Material**	**H_2O (wt %)**	**C_p (kJ/kgK)**
Lamb	70	3.18*	Apples	75-85	3.75-4.02
Macaroni	12.5-13.5	1.84-1.88	Apple sauce		4.02*
Milk, cows'			Asparagus		
a. Whole	87.5	3.85	a. Fresh	93	3.94
b. Skim	91	3.98-4.02	b. Frozen	93	2.01
Olive oil		2.01**	Bacon, lean	51	3.43
Oranges			Banana puree		3.66##
a. Fresh	87.2	3.77	Beef, lean	72	3.43
b. Frozen	87.2	1.93	Bread, white	44-45	2.72-2.85
Peas, air dried	14	1.84	Butter	15	2.30##
Peas, green			Cantaloupe	92.7	3.94
a. Fresh	74.3	3.31	Cheese, Swiss	55	2.68
b. Frozen	74.3	1.76	Corn, Sweet		
Pea soup		4.10	a. Fresh		3.32
Plums	75-78	3.52	b. Frozen		1.77
Pork			Cream, 45-60% fat	57-73	3.06-3.27
a. Fresh	60	2.85	Cucumber	97	4.10
b. Frozen	60	1.3	Eggs		
Potatoes	75	3.52	a. Fresh		3.18
Poultry			b. Frozen		1.68
a. Fresh	74	3.31	Fish, cod		
b. Frozen	74	1.55	a. Fresh	70	3.18
Sausage, franks			b. Frozen	70	1.72
a. Fresh	60	3.60	Flour	12-13.5	1.80-1.88
b. Frozen	60	2.35	Ice	100	1.958***
String beans			Ice cream		
a. Fresh	88.9	3.81	a. Fresh	58-66	3.27
b. Frozen	88.9	1.97	b. Frozen	58-66	1.88
Tomatoes	95	3.98##	Water	100	4.185**
Veal	63	3.22			

* 32.8°C ** 20°C *** -20°C # 24.4°C ## 4.4°C