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# COPRA AND FISH DRYING USING LOW-TEMPERATURE GEOTHERMAL ENERGY

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## ABSTRACT

This report highlight the indirect air dryer, which utilized low-temperature geothermal energy as heat source. Detailed theoretical formulas and principles of many different drying schemes are not covered nor discussed, but rather take only the commonly used equations and parameters applicable to the assessment and design of drying plant for copra and fish products. The material describes the procedures and results of experiments made on copra and fish, the calculation of mass and energy balance on dryer, process flow sheets, the determination of constant drying rate curves and the selection/sizing of ancillary equipments for the dryer i.e. fans, blowers and heating element. Finally, the report provides a practical dryer design example for reference and guide in its concept and development.

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## 1. INTRODUCTION

The general idea of utilization of geothermal energy for non-electrical application in the Philippines was conceived as early as the stages of geothermal electric power development started 20 years ago. The existence of small research activities on possible non-electrical uses of geothermal energy was focused mainly on salt making and grain drying in the Bicol region which come years later or at the same time COMVOL (Commission on Volcanology) inaugurated a 2.5 kW test facility on electric power generation in barrio Cale, Tiwi, Albay in 1969. (Tolentino et al., 1986). The site is located in the Bicol peninsula approximately 300 km south of Metro Manila with neighboring provinces of Camarines Sur and Sorsogon.

In January 1979, when the first geothermal power plant in Tiwi was inaugurated and commissioned for operation, study and research on the different aspect of other uses of the excess steam and hot water was continuously undertaken. The implementation was carried out by experts from the following government agencies-COMVOL, the Philippine Navy, and the National Science Development Board.(Goodman and Love, 1980).

The past activities on non-electrical application of geothermal energy in the early years was very limited and it mainly constitute the studies of drying of copra and palay aside from salt making by means of geothermal steam. The trend of development was low as it is affected by, the geothermal field resource characteristic, the technical knowledge on hand, the source of budget allocation, and the government national objectives.

In 1970 the government national program was focused to rural electrification and the industrialization of the urban areas as such the non-electrical and industrial application of geothermal energy was considered then a low priority as compared to all other government national task. In effect all areas in the country with potential low temperature geothermal resources are undeveloped. While it is true that achievement in the national energy and electrification program was not quantifiable, the economic situation in contrast in some areas of the country remain unstable. Considered among the most economically depressed in the country is the Bicol region. To uplift the standard of living conditions from the area the government various agencies initiated food and energy programs. The Bicol River Basin Development Program (BRBDP) of the province of Albay and the government owned PNOC-Energy Development Corporation are some of the entities that are now implementing the goal in the Bicol region.

The PNOC-EDC and the UNDP assisted project PHI/85/003 entitled "Development of Geothermal Energy for Power and Non-Electrical Uses" that commenced in 1986 was a country wide development programme mainly focused on the utilization of geothermal energy for direct agro-industrial applications. The provinces of Albay and Sorsogon where to of the many beneficiaries of this undertakings. Today feasibility studies are going on for Manito lowland, Albay which PNOC-EDC plans to develop into a geothermal based agro-industrial estate. The studies are now making significant progress and this report on drying process of fish and copra by means of geothermal hot water is mere part of the many research, studies and training that are in progress in and out of the country. Fig.1, is the agro-industrial complex process flow chart showing the scope of this work.

## 2. COPRA AND FISH DRYING PRACTICE IN THE PHILIPPINES.

### 2.1. Copra Drying Practice

Dried copra production in the country does not vary from one region to another. In most cases, copra drying process in the rural areas is done in the same manner as the old practice fifty years ago. A break through to quality and economic copra drying production methods is very limited. In many provinces all over the country, copra is sold to the market in poor quality condition. Usually percentage of spoilage is high because required moisture content and the water activity in the product after drying completion is above the desired requirement. Fig.2, shows the growth of molds and bacteria with respect to percent water activity in the product/food. Undried copra is easy target of insects and bacteria which result to foul smell, decay and deterioration. Double handling of copra product is rampant since partially dried copra is again repeatedly dried in the dryer or in the sun for 1 or more days prior to delivery to oil milling plants.

The process of drying copra start from husk removal of coconut fruit using a wedged or pointed steel round/flat bars approximately 40 to 60 mm in size and 700 mm in length installed and fixed slightly perpendicular to the level ground. Manual splitting of coconut shell follows, and the drying process usually is accomplished by;

Sun Drying - where split coconut are placed on concrete floors or racks with coconut halves are laid or turned facing the sun. This practice is seasonal in nature as it depends on the availability of sunshine for long period of time. Good quality of copra is produced if sunlight is always present for many days.

Kiln Drying or Tapahan - this is an artificial process of copra drying where split coconuts are smoke dried on an open fire on a grate or tray. The coconut meat in this system can be dried in the shell and/or removed from the shell and dried separately. Fig.3, are types of drying kiln used in few provinces in the Philippines. This scheme produced variable quality of copra as heat in the kiln could not easily controlled. Uneven drying is almost present and one serious effect is case hardening. It occurs whenever copra is dried abruptly, by having too hot heat source and irregular loading in the dryer as free hot air circulation cannot reached the upper layer of copra which may not dry at all. Another effect of this drying practice are, color and taste are impaired resulting to poor quality of oil by-products.

A good quality of dried copra according to FAO, studies should be brittle and break easily. The moisture content must be within 5-7%. Burning test is one way of checking the quality of product since it was found out that, if copra burns readily, the moisture content is less than 7%, if the flame splutters it is 7-10% and if copra burns with difficulty it is above 10%.(Grimwood, 1975).

Large copra producers usually employed number of men to undertake the closer supervision of the drying operation which last to 2-4 days before the coconut meat is separated from the shell. Separation of coconut meat is done within the drying process and final drying occurs on the third and fourth day of the drying period. The drying kiln is constructed approximately 1.5 m x 2.5 m x 2 m in depth, degree of variations in size of desired drying structure is affected by potential production of coconut farms. The source of heat in line with this basic drying practice are wood, coconut shell, sugar cane fibers, saw dust and other equivalent local heating materials. The last phase prior to domestic marketing of copra product is reconditioning by means of sun drying or by placing back the coconut meat to the dryer in another day.

Improvements of copra dryers have been made to attain good quality of copra products in the country way back the pre war years. One is shown in Fig.4, it was developed by New College of the Phil. in 1930. It was claimed that the dryer produces good quality of copra. However this type of dryer are not common in the rural areas of the country and copra planters still stick to the tapahan ways of coconut meat drying process.

### 2.2. The Fish Drying Practice

There are at least three types of fish drying process noted in some part of the country, one is sun drying,second is the process of drying fresh or salted fish in a barn similar to copra, and the last one is the use of electricity to generate heat utilizing electric bulbs installed in a tray drying cabinets with air circulation induced by motorized blowers. This third process is good because sanitation is maintained. However the operation imposes and consumed considerable amount of electric energy, such that this is not commercially implemented. Quality of dried fish product sold in the local market in the country is within the average with regards to sanitary requirement practice. Usually fish product dried in the sun are placed on 1 $m^2$ split bamboo trays elevated from the ground 1 m or higher. The final product is clean and free from foreign matter, but the common problem is product storage life. Spoilage is high as dried fish is similarly attack by molds and bacteria easily.

In view of facts that were presented, the necessity of product processing improvement should be made to attain the most economically convenient, products drying process operation and system of product preservation with maximum use of existing energy resources in the country.

## 3. HISTORICAL BACKGROUND

The beginning of drying process using low-temperature geothermal energy as source of heat cannot be precisely established, due to limited literatures on hand, but the historical development of hot air drying process can be given due consideration to bring into perspective the previous accomplishment of some people and institutions who pioneered and made important contributions to the drying technology. According to Brundrett (1987)., it is the scientists at the Academio del Cimento in Florence in the fifteenth century who quantified the amount of moisture in the air, followed in eighteenth century by de Saussure of Switzerland who determined the humidity in a reproducible way and Dalton of England, who develop the laws of partial pressures, which up to present provide the necessary scientific concept on heating theories. On the same period Van Arsdel and Copley (1963), sight the work of Prescott and Proctor (1937)., who record the first artificial drying of food and its progress from different countries all over the globe. A brief reference from same literature can be presented as follows;

| | |
|---|---|
| 1780 | British patent on dried vegetables by J. Graefer |
| 1840 | British patent 1780, vegetables drying by Edwards, Allen et al. (1943). |
| 1871 | German pea sausage by Erbswurst<br>German dried potatoes, Prescott (1919).<br>Onion dehydration by W. A. Beck, Anon (1959). |
| 1890 | Oregon drying tunnel invented by Allen, Cruess (1938). |
| 1914-1940 | Germans further advancement in food dehydration, Prescott (1919). |
| 1915-1940 | U.S. various patent on food preservation, etc. |

However there are many more outstanding achievement that follows, the work of Mujumdar (1980)., present a perspective of current research and development on drying technology from different countries. Fig.5, is an advancement and trend of drying of fish developed by Dr. Passey, C.in which the conventional dryer was fitted with energy saving device called PCHP. The dryer is reported to operate in any weather condition.

As might have been noted the art of drying could not be put into chronological order and according to Brundrett (1987)., its origin is unknown. Other countries have their own particular contributions to this old trade because it is said that drying processes have been handed down to us from one generation to another and still widely adopted to the present on small scale basis. It can be found out that in some instance, the new development to this day modern drying system are referred to our old practices. Today consumers find varieties of dried food elsewhere in the market as the demand grows for natural food and longer storage life.

## 4. DRYING THEORY

"The term drying is difficult to define within rigid limits. From the industrial standpoint it is understood to represent the removal of a liquid usually, but not always water from solid by thermal means. It can also mean the removal of water or other volatile liquid from another liquid or gas, or the removal of water from a suspension or solution of a solid" (Gardner, 1971). The definition generally holds to all drying processes and to differentiate the drying operation involved in this paper we have to consider the type of dryer and the drying system. Thus, the drying process carried out by removing water on a batch, cabin tray dryer or its equivalent by means of circulating or passing air through the solid product to carry away the water vapor will provide a limitation to the wide and complex subject of drying.

The scheme of drying process can be clearly formulated to the description discussed by Hall (1979)., as the removal of moisture from a substance involving the simultaneous transfer of heat to the substance and moisture from the substance known as unit operation. The heat for evaporation of the moisture in the material is transferred by conduction, convection, radiation and internal heating. The vapor mass is transferred by diffusion or capillary flow to the surface from which the vapor is carried by a gas. As a result, the biological and chemical activity of the product is decreased.

The main purpose of drying are;

1. To preserve the product for future use.
2. To reduce bulk and weight.
3. To condition raw materials for further processing.
4. To recover liquid by-products from solids i.e. oils of fish and copra, etc.
5. Obtain convenience in transporting, handling, and marketing of product.

Dryden (1975)., discussed that the product or materials drying rate is dependent on;

External factors; the drying air temperature, humidity, velocity and turbulence, the material surface area and thickness.

Internal influences; the nature of the material affects the migration of moisture to the surface by diffusion, capillary flow and flow due to pressure gradients caused by gravity, or internal vaporization.

Considering the external factors and other observation described, lets take into account the following experiment conducted on copra and the capelin fish to cover some aspects of the drying principles and characteristic of the raw materials during the drying period. As the fundamental course of action in practical drying applications suggests that an experiments should be made to acknowledged and record the factors affecting the minimum drying periods of the product to be dried, obtain the economics of drying process that will be considered and the maximum use of energy.

## 5. DESCRIPTION OF WORK

This section provide the detailed work carried out to embraced and understand the science of drying technology. Experiments where undertaken with the following aims;

1. To know the constant drying rate of copra and the capelin fish.
2. To know the mass and energy balance of the dryer.
3. Observed the influence of the external factors which affect the minimum drying rate of the product.
4. Gather product drying data for basic copra dryer design calculation.
5. Observed the maximum use of low thermal energy in the drying process.
6. Compare test results with other previous data.

### 5.1. The Pilot Test Dryer

Drying test of copra and capelin was carried out in a cabinet type tray dryer. This is shown in Fig.6. The dryer heat source is geothermal hot water feed through a fin type radiator heater(1), then an electric motor(2), drives a blower(3), which provide air flow to the dryer(4), air dampers(5) control the air recirculation to the dryer. The hot water inlet temperature is maintained by automatic temperature controller(6), installed 100 mm from pressure indicator(7), placed 560 mm above the top of heating element. Volumetric flow reading of the thermal water is taken from a high temperature water meter(8) fitted along the pipe line 560 mm before the temperature indicator(9) and the heater. The drying cabinet,is made of 16 mm thick marine plywood 440 mm x 545 mm x 2040 mm in size, at the top of the dryer is an air duct made of G.I. sheet used to take discharged air to the atmosphere and/or diverted back again to the blower inlet and then to the dryer. Inside the dryer are fin cells where 420 mm x 410 mm trays are placed on top of each other with approximate 40 mm clearance between trays in the cells where drying takes place.

### 5.2. The Thermal Heat Source

The low temperature geothermal heat source used in the drying experiment was supplied by district heating of Reykjavik where the thermal hot water is low on solids or other minerals. The temperature of geothermal water was accessible to 67°C enough to provide 56°C in the pilot test dryer.

### 5.3. Copra Drying Test

The scarcity of coconuts affected the various planned test to the raw material. The experiment have to be done with limited test samples so it is necessary to divide the raw materials into different size. The available coconut product was made into four test samples cut into 60 mm x 60 mm, 40 mm x 40 mm, 30 mm x 30 mm and the excess classified into various sizes/ nil. The estimated total weight of raw material is 1191.26 g.

The respective weights of test samples, initial moisture content and water activity were measured prior to the start of the test. The dryer was set to the maximum drying temperature it can attained with available inlet hot water source of 65°C. The thermal water flowrate was 270 kg/hr. Drying evaluation of copra was made with air recirculation on the dryer and air velocity was maintained at 3 m/sec.

On the first day of the experiment the loss of weight of copra was monitored every 30 min. intervals, to observe the maximum rate of water loss in the raw materials. The succeeding days the loss of weight was monitored on hourly or daily basis with corresponding moisture content and water activity analyzed in the laboratory. Copra drying process flow sheet is shown in Fig.7, with monitored air drying conditions at various test location in the drying system.

### 5.4. Capelin Fish Drying Test

A 7.03 kg of wet capelin fish was used in the test. Samples where made with three types of loads on the drying tray. The first test sample consist of two trays marked 1A and 1B fish load is arranged with spacing in the tray, second samples is marked 2A and 2B with tray totally filled. The last specimen was loaded twice as the load of sample 2. Similar procedure in the copra experiment was carried out in gathering the data, except that the temperature of hot water entering the heater was reduced to 47.5°C and the air velocity was maintained at 1.5 m/sec while drying temperature is 22.5°C. Fig.8, is the capelin fish drying process flow sheet showing the different conditions of drying air stream.

### 5.5. Method Of Data Calculation

To start with experiment data determination of the two products each samples is analyzed in the laboratory to take into account the percent initial moisture content. Below is the results of the analysis;

| Description of product | % initial moisture content |
|---|---|
| Coconut meat | 38% |
| Capelin fish | 81.8% |

From the data above we can determine the initial percent of dry matter of product given as;

$$\% \text{ Dry Matter} = 100\% - \text{Moisture Content } (\%H_2O) \qquad (5\text{-}1)$$

Then the equivalent initial weight of dry matter in a given sample is;

$$\text{WT. Dry Matter} = \% \text{ Dry Matter} * \text{WT.of Prod.}/100 \qquad (5\text{-}2)$$

The succeeding percent of dry matter is calculated for every change in time interval as follows;

$$\% \text{ Dry Matter} = \text{WT. Dry matter} / (\text{WT. of product} - \text{Loss WT.}) * 100\% \quad (5\text{-}3)$$

To determine the percent of water in the product or moisture content we use the relation;

$$\% \text{ Moisture Content } (\% H_2O) = 100 - \% \text{ Dry Matter} \quad (5\text{-}4)$$

Taking the ratio of % moisture content with % dry matter we find the free moisture content of the product given by;

$$\text{Free Moisture Content: } X = \% H_2O / \% \text{ Dry Matter} \quad (5\text{-}5)$$

Note however that the average values of free moisture content X is used against the drying rate R in plotting the constant rate curve, because the value of drying rate R is acquired over the average period of time during the stages of drying process. The equation for the drying rate R was adopted from the literature of Geankoplis,(1983). The mathematical relation is given by;

$$R = - Ls/A * dX/dt \quad (5\text{-}6)$$

where the rate of change of free moisture dX/dt can be taken to be equal to $\Delta X/\Delta T$ in the experiment expressed as;

$$dX/dt = \Delta X/\Delta T \quad (5\text{-}7)$$

Therefore the equation can be re-written as;

$$R = - Ls/A * \Delta X/\Delta T \quad (5\text{-}8)$$

which Ls is the weight of dry product, A is the exposed surface area for drying and $\Delta X/\Delta T$ is difference of free moisture content for every given change in time. Values of exposed surface A was approximately measured as the product is irregular in shapes. The unit area of test sample of copra was calculated by taking the average surface that can be obtain if the sample is laid in the paper and surface drawn respectively. The resulting unit areas are found in table of Ls/A ratio of copra. Meanwhile the unit area of capelin fish test specimen was measured by planimeter instrument. Table 1, are results of calculated unit areas with used equation as;

A = Unit Area of prod./Unit WT. of Prod. * WT. of Prod. (5-9)

Tables 2-3 provide the Ls/A ratio of different test samples of copra and capelin fish while, Tables 4-7 and Tables 8-12 are the gathered drying test result of product. The possible errors in area/weight calculation does not change the results as the rate of drying is usually used for comparing the different sizes of copra and effect of load in capelin drying. Note that the same method was utilized to obtain the area/weight ratio in all instances.

## 6. The Drying Rates Of Product

The rate of drying characteristic of product is one of the many important factors that provide a criteria in the selection and aspects in the choice of design and method of operation of drying plants. Early experiments of food preservation and drying of raw materials pave the way to the phenomena and classification of drying time into constant-rate and falling-rate drying periods.

### 6.1. Constant-Rate Drying Period

This is the time of drying of wet product where the removal of moisture to the surface of the product remain constant for considerable span of time until all the water present in the surface are evaporated. As exposed surface becomes relatively dry the surface temperature of the product undergoing the process of drying will approximately approach the condition of drying air wet bulb and dry bulb temperatures. From Geankoplis (1983), Fig.9, is a drying-rate curve for constant drying conditions. The point where the free moisture Xc and drying-rate R meet at C, is the limit of constant rate period and generally called as critical moisture content of product. According to Dryden (1975), that if the required final moisture content is above this critical moisture content the whole drying process will occur at constant rate after heating up period and while if the initial moisture content is below the critical value the whole process will be in the falling-rate zone.

### 6.2. Falling-Rate Period

As the drying process go beyond the critical moisture content and the surface of product is almost dry the resisting film of surface water vapor in the skin pores of the product breaks or diffuses out in the interior surface or tissues of the product and out to the skin film. When the interior surface of the product tend to rise towards the air drying temperature the water inside the tissue are activated and moves from one place to another and escape to the surface skin and vaporize to the drying air. A falling-rate zone is also shown in Fig.9, by line CD and DE. The process of drying may have only a falling-rate zone because in some few cases the initial moisture content of product is beyond the critical value and the constant drying rate of product is not present at all. However this two zones is usually observed to be present in all products that passes the process of drying. Gardner (1971), discussed that the falling-rate curves themselves may be concave, convex or may approximate to straight line, as they are inflected when a change of a physical form occurs like, shrinking, cracking and/or a skinform on the surface of partly dried material.

### 6.3. Copra And Capelin Fish Drying Curve Analysis

Fig.10 and Fig.11, shows the drying rate curve for constant drying condition of copra and capelin. The calculated values of drying-rate R and average free moisture content X of the various test specimen were respectively plotted. Following closely all the appearance and the trend of curves and try to relate one to the other we find difficulty in comparing the drying rate characteristic of two product. To figure out and explore the difference of the two drying rates we have to apply the law of average. The procedure is to draw a common curve that will represent all test samples. The dotted dash curve drawn graphically in chart represent the average values of drying rate R and free moisture content X. In this regard we can draw a more definite observation on its features. Using the configuration, it is simple to predict the stages of water and moisture movement of the product and the process of evaporation that occur within the body of copra and wet capelin fish. The approach to the analysis disclosed the break points of the constant drying rate curve that can be found in Fig.10 and Fig.11. Each transition or deflection of line in the curve can be evaluated in detail which the effect of external factors during the time of drying can be visualized. In both cases the constant drying rate is almost nonexistent.

## 7. Mass And Energy Balance on Dryer

Normally the mathematical evaluation of mass and energy balance of any process is made possible by figuring out the flow stream of the system under consideration. On this premise we can take the principle of conservation of matter and energy. This applies to all mass or matter, chemical elements and other properties that remain unchanged during the period or stages of drying. The calculation account any addition or reduction on the property of materials or the matter that causes the changed. Unfortunately it was assumed in this presentation that the kinetic and potential energy, chemical reaction and blower work is negligible as it is found out in actual drying plant operation. A schematic diagram of test dryer is shown for analysis. Refer the terms in section 13.

### 7.1. Heat and mass balance on heaters and dryers

#### 7.1.1. The Water Mass Balance On Air Heater

Taking point TP1 to TP2 we have the relation as,

$$Ma_1 * X_1 + Ma_5 * X_5 = Ma_2 * X_2 \qquad (7\text{-}1)$$

$$Ma^1 + Ma_5 = Ma_2 \qquad (7\text{-}2)$$

and from point TP2 and TP3 the equation is,

$$Ma_2 = Ma_3 \qquad (7\text{-}3)$$

$$X_2 = X_3 \qquad (7\text{-}4)$$

since we do not add water in the heater. Refer to Mollier.

#### 7.1.2. Water Mass Balance On Dryer

From point TP3 to TP4 the equation is,

$$Ma_3 * X_3 + Mp_1 = Ma_4 * X_4 + Mp_2 \qquad (7\text{-}5)$$

$$Ma * (X_4 - X_3) = \Delta Mp \qquad (7\text{-}6)$$

$$Ma_3 = Ma_4 \qquad (7\text{-}7)$$

and TP4 to TP5 gives, $$X_4 = X_5 \qquad (7\text{-}8)$$

### 7.1.3. Energy Balance On Air Heater

From point TP2 to TP3 the relation is,

$$Ma_2 * I_2 + Qw = Ma_3 * I_3 \qquad (7-9)$$

$$Qw = Ma_2 * (I_3 - I_2) \qquad (7-10)$$

Where Qw is also equal to,

$$Qw = Mw * C_{pw} * (Tin - To) \qquad (7-11)$$

### 7.1.4. Energy Balance On The Dryer

Taking point TP3 to TP4 and TP5 the equation is,

$$I_3 = I_4 = I_5 \qquad (7-12)$$

Since drying is theoretically an adiabatic process we can write that the enthalpies are equal, as we do not take into account heat losses from the surroundings.

### 7.1.5. Heat Supplied To The Air

Heat supplied by hot thermal $H_2O$ = Heat absorbed by air that enters the dryer.
Then we have the equation,

$$Mw * C_{pw} * (Tin - To) = Qair \qquad (7-13)$$

### 7.1.6. Mass Flowrate Of Air Required

The equations is taken as,

$$Ma = Qw/ C_{pa}*(Ta_0 - Tain) \qquad (7-14)$$

$$Ma = Qw/ (I_3 - I_2) \qquad (7-15)$$

### 7.1.7. Mass Flowrate Of Water Required

The equation showing the mass flow of water is,

$$Mw = Qw/ C_{pw}*(Tin - To) \qquad (7-16)$$

### 7.2. Mass And Energy Balance On Commercial Fish Dryer

To acquaint with drying practices and apply the principle of mass and energy balance, it was decided to take actual measurements of one commercial fish dryer in operation in Reykjavik. The dryer was newly constructed and momentarily operated manually, that is temperature and air mixing are manually done. Fig.12, and the Mollier diagram on appendix 2, provide the results of those measurements. The data where taken on hot and dry day, where condition of fresh air outside is hotter and dry than the recirculated air in the dryer. It can be seen on Mollier diagram the irregularity in the dryer operation, it was figure out that a favorable result can be achieved, if the dryer was run or operated without air circulation. In this particular case, it stresses the importance of regular monitoring and checking of drying parameters as drying without circulation on this example could give same effect for about 80% of hot water, if the operator left out the circulation process. In appendix 1, the calculation of mass of air and dryer heat requirement are illustrated and Fig.12 further shows the summarized results. The pressure drop is very low as the dryer was only 1/3 filled during the time of drying variables data gathering.

## 8. DESIGN OF INDIRECT AIR DRYER

Designing a dryer is a tedious tasks for a particular material as there are limited literatures and information on product characteristic to be used as basis for direct determination of drying variables. This factor was discussed by Gupta, R. as one of the main problems in dryer design, (Mujumdar, 1980). A usual design method and practice is to obtain and gather design data for a product by experiment in a test dryer or adopt parameters of existing similar dryer in operation. Evaluation of drying test data will clarify and provide the effect of external factors to the drying characteristic of product where a realistic design procedures can be achieved. This concept was practically applied in the basic design example of copra dryer.

### 8.1. Copra Dryer Basic Design Calculation

The drying data assumed in the calculation was adopted and fixed after the result of copra drying experiment, gathered data for consideration are shown in Tables 4-7. Other figures are based on Iceland drying experience and the use of information from Grimwood, (1975)., on FAO studies on copra processing in the developing countries.

| Design Consideration | Figures | Remarks |
|---|---|---|
| Dia. of coconut, Dc | 140 mm | - |
| Air velocity, Vm on filled drying box | 3.0 m/sec | Based on test & experience |
| Air velocity, $V_0$ of empty drying box | 1.0 m/sec | -do- |
| Pressure drop, P | 70.0 mm $H_2O$ | Adopted from exist. dryer |
| Inlet thermal $H_2O$ | 90°C | Figure out in experiment |
| Outlet thermal $H_2O$ | 55°C | |
| Wt./coconut, $W_1$ | 0.7 kg/pc. | -do- |
| Dryer temperature | 65°C | FAO, data |
| Outside air temp. | 26°C | Based Phil. condition |
| Dryer input, $D_in$ | 1.0 ton/batch | |

The design criteria for the size of dryer was based on three steps, 1, to loosen coconut meat from shell 2 and 3, for process drying. The convenient size and type of dryer was taken on batch system of processing where 1.0 ton/batch of product for drying was considered its production output. The dryer have three columns or unit dryers, column or unit 1, takes the loosening process of coconut meat, column 2 and 3, for steps 2 and 3, for drying process respectively. The scheme needs a day for loosening and 2 days for drying, this set-up gives a continuity in work, as one batch of dry copra can be taken for packaging process each day, another batch can be prepared for loosening and consequently one batch can be move for final drying each day of work operation.

The dryer is also expected to handle fish drying process, however the dryer was designed with higher drying temperature and greater air quantities than the fish drying requirement.
It was then our feeling that we could use the same system by reducing the drying parameters and adopt trays in each column or unit dryer. An explanation on use of trays in first step of fish drying is found in section 11.2.

In addition to the design criteria the unit volume of coconut was figure out, that each coconut will take up a maximum space as if, it is a box with sides of length Dc as shown, that is built on the assumption that we have a sphere.

The basic mathematical calculation is presented as follows;

$$\text{Qty. of coconut for drying} = Din/\ W_1 = 1428.57 \text{ say } 1430 \text{ pcs} \quad (8\text{-}1)$$

$$\text{Unit vol. needed for 1 coconut} = Dc^3 = 2.744 * 10^{-3} m^3/pc \quad (8\text{-}2)$$

$$\text{Total volume of coconut} = Dc^3 * 1430 = 3.924\ m^3 \quad (8\text{-}3)$$

The dryer boxes design volume is provided with 30% to 60% space allowance to accommodate possible pressure build-up within the drying boxes. Use say 30% then;

$$\text{Dryer load design vol. } Vd = 1.3 * 3.924 \text{ m}^3 \qquad (8-4)$$
$$= 5.1 \text{ m}^3$$

A drying unit is designed with three drying boxes that are placed on top of each box. Diagrammatic scheme of the dryer is shown in Fig.13.

$$\text{Unit vol. of drying box} = Vd/\ 3 \qquad (8-5)$$
$$= 1.7 \text{ m}^3$$

Sizing and design of drying box should be based on the commercial construction material that are locally available in the market to achieve the minimum cost of construction.

In this particular scheme of dryer, 1220 mm x 2440 mm x 19 mm marine plywood was figure out to suit the requirement of the drying box, since it is estimated that least material excess will be discarded.

$$\text{Size of design box} = 1.22 \text{ m} * 1.22 \text{ m} * 1.22 \text{ m} \qquad (8-6)$$
$$= 1.82 \text{ m}^3 > 1.7 \text{ m}^3$$

$$\text{Sectional area of box, } A_1 = 1.22 \text{ m} * 1.22 \text{ m} \qquad (8-7)$$
$$= 1.49 \text{ m}^2$$

Considering the velocity of air, $V_0$ of 1.0 m/sec it is assumed that the air speed can deliver the desired velocity of 3.0 m/sec in the filled drying boxes, thus;

$$\text{Vol. of air in box, } Va_1 = V_0 * A_1 \qquad (8-8)$$
$$= 1.49 \text{ m}^3/\text{sec}$$

$$\text{Required vol. of air, } Vt = 3 * Va_1 \qquad (8-9)$$
$$= 3 * 1.49 \text{ m}^3/\text{sec}$$
$$= 4.47 \text{ m}^3/\text{sec} * 3600 \text{ sec/hr}$$
$$= 16092 \text{ m}^3/\text{hr}$$

Required mass of air, Ma = Vt * air density (8-10)

$= 4.47\ m^3/sec * 0.963\ kg/sec$

$= 15496.6$ kg air/hr

Refer to appendix 4 for value of air density used.

From Tables 4-7 we take the average percent loss of copra as equal to mass of water that are evaporated into the air in the first three hours of drying, and use the factor to get the maximum amount of water that will evaporate when drying 1.0 ton of copra, then we take;

Ave. % loss of weight, Lw = 20% (8-11)

Mass of $H_2O$ to be evaporated in first 3 hours of drying in the first unit dryer will be;

$Mw = D_in * Lw$ (8-12)

$= 1000\ kg * 0.20/3hr$

$= 66.7$ kg/hr

Maximum heat required to evaporate the total mass of water in 1.0 ton of product in the dryer is;

$Qe = Q_1 + Q_2 + Q_3$ (8-13)

Where; First unit $Q_1 = Mw * \Delta hfg$ (8-14)

$= 66.7\ kg/hr\ (2618.3 - 272.06)$

$= 156491.54$ kJ/hr

Δθζη ιτ μαυεξυ θεαυ οζ χαποσιφαυιοξ αυ 65τΓ

Ζοσ υθε τεγοξδ δσϑεσ υθε πεσγεξυ μοττ ψατ υαλεξ αυ ζιστυ ειηθυ θοφστ οζ υθε τεγοξδ δαϑ ατ, δσϑιξη ψιμμ ξου υαλε 24 θοφστ πεσ δαϑ τιξγε μοαδιξη αξδ φξμοαδιξη οζ πσοδφγυ ιτ φξδεσυαλεξ δφσιξη υθε ψθομε δαϑτ οζ δσϑιξη οπεσαυιοξ.

Αχε. ÷ μοττ οζ ψυ. = 0.6÷

Νατт ος ψαυεσ υο βε εχαποσαυεδ ζοσ υθε τεγοξδ δσθεσ ιξ τεγοξδ δαθ ος δσθιξη ιτε

$$N\psi_1 = 1000\ \lambda\eta \times 0.006/3\theta\sigma \qquad (8\text{-}15)$$
$$= 2.0\ \lambda\eta/\theta\sigma$$

Τθεξ ζοσ Τεγοξδ δσθεσ, $P_2 = N\psi_1 \times \Delta hfg$ at 65°C (8-16)

$$= 2.0 * 2346.2$$
$$= 4692.4\ kJ/kg$$

The third dryer which simultaneously operate with second unit was figure out to take a minimum amount of water that can be evaporated from the product since $Q_3$ takes the final drying process therefore, $Q_3$ capacity to evaporate $H_2O$ is > than $Q_2$ then we can assume;

$$Q_3 = Q_2 = 4692.4\ kJ/kg \qquad (8\text{-}17)$$

The total heat required to remove $H_2O$ in 1.0 ton of coconut is;

$$Qe = (156491.54 + 4692.4 + 4692.4)\ kJ/hr \qquad (8\text{-}18)$$
$$= 165876.34\ kJ/hr$$
$$= 165876.34\ kJ/hr * 2.78 * 10^{-}_{4}\ kW/hr$$
$$= 59.67\ kW$$

The heat loss to surrounding Qs is given by heat transfer equation;

$$Qs = A * U * TD \qquad (8\text{-}19)$$

To calculate this equation we have to determine the overall heat conductance U and the type of flow of air if laminar or turbulent since this variables correlate the rate of heat transmission to inside and outside surface walls of the dryer, the empirical relations of formulas were adopted from literatures of Holman, (1981). and Geankoplis, (1983)., are as follows;

$$U = 1/(1/h_1 + k/x + 1/h_0) \qquad (8\text{-}20)$$

Where film coefficient h is calculated to determine the appropriate values of $h_1$ and the equations are;

Nusselt number, $Nud = h * d/k = 0.023\ Red^{0.8}\ Pr^{n}$ (8-21)

The value of n is = 0.4 for heating
= 0.3 for cooling

Reynolds number, $Red = p * Um * d/u$ (8-22)

The properties of air at atmospheric pressure is then determine at drying temperature of 65°C + 273°C = 338°K from Appendix 6 by interpolation then we have ;

Air viscosity, $u = 2.02 * 10^{-5}$ kg/m sec
Prandtl number, $Pr = 0.7$

The air density p was calculated from;

$$p = P/R * T \qquad (8\text{-}23)$$

Where; Atmospheric pressure, $P = 1.0132 * 10^{5}$ kg $m^{2}$/sec
and Gas constant, R = 287 J/kg°K

$$p = 1 * 1.0132 * 10^{5}/287 * 338$$
$$= 1.04 \text{ kg/m}^{3}$$

Velocity of air, Um = 3.0 m/sec
Heat coefficient of air, K = 1 kJ/kg°C

The physical factor d is equal to hydraulic dia. $D_H = 4A/P_{er}$. for fluid or the air not flowing in a circular section. Refer to (Hollman, 1981).

Substituting gathered values from equation (8-22);

$$Red = 1.04 * 3 * 1.22/2.02 * 10^{-5}$$
$$= 1.88 * 10^{5}$$

Red is > 2100, the flow of air is turbulent

And from equation (8-21) we have;

$$Nud = 0.023 * (1.88*10^5)^{0.8} * 0.7^{0.4}$$
$$= 0.023 * 16570 * 0.867$$
$$= 287.32$$

Since Nusselt number is also = h d/k, the heat transfer coefficient h can be written as;

$$h_1 = 287.32 * d/k \qquad (8-24)$$

Where, $d = D_H = 4 * 1.22 * 1.22/4 * 1.22$
$k = 0.029$ from Appendix 6 by interpolation

Therefore, $h_1 = 287.32 * 0.029/1.22$
$= 6.8\ W/m^2 \cdot C$

Referring the figure from convection heat transfer coefficients Appendix 7 we can approximately assume the values of;

Free convection, $h_0 = 4.5\ W/m^2 \cdot C$

And $k_1$ the thermal conductivities of material can be assumed as equal to value of pine wood = 0.151 $W/m^2 \cdot C$ and x is the thickness of plywood used in walls of dryer.

Solving for ratio of, $k_1/x = 0.151/0.019$
$= 7.95\ W/m^2 \cdot C$

Finally overall thermal conductance from equation (8-20) is;

$$U = 1/(1/6.8 + 1/7.95 + 1/4.5)$$
$$= 2.02\ W/m^2 \cdot C$$

From the foregoing result and using equation (8-19), the heat loss to the surrounding Qs, if total surface area, A = 72.994 $m^2$ and TD is the differential value of dryer and the outside air temperatures we have;

$$TD = 65°C - 26°C = 39°C \qquad (8\text{-}25)$$

Substituting values;

$$Qs = 72.994\ m^2 * 2.02\ W/m^2°C * 39°C$$
$$= 5750.50\ W$$
$$= 5.75\ kW$$

The heat loss to the exhaust air, Qex is expressed by;

Qex = Ma * (Enthalpy of exhaust air taken at inlet moisture content - Enthalpy of inlet air at dryer) (8-26)

It can also be equal to, Qex = Ma * Cp( Tin - To) with Cp taken at inlet conditions. However this value is often observed as very minimal in actual drying plant practice such that we can assume the value equal to zero.

The total heat required by the dryer is;

$$Qd = Qs + Qe + Qex \qquad (8\text{-}27)$$
$$= 5.75 + 59.67 + 0$$
$$= 65.42\ kW$$
$$= 235512.0\ kJ/hr$$

Then mass flowrate of thermal water is;

$$Mw = Qd/Cpw * (Ti - To) \qquad (8\text{-}28)$$
$$= 235512.0\ kJ/hr/4.18\ kJ/kg°C\ (90°C\text{-}55°C)$$
$$= 0.447\ kg/s \text{ say } 0.45\ kg/sec$$

Refer to Appendix 3, 4 and 5 for mass of air required, Mollier diagram and mass/energy balance of dryer.

## 9. SELECTION AND SIZING OF HEATING ELEMENT

One key factor that contribute and usually have the major influence in the economics of drying industry is the right choice of heating element. The heater should have the capability to supply and transfer the optimum requirement of heat the dryer needs. It is physically built with numbers of tubular rows where hot thermal fluid passes and heat are transferred by conduction to metal fins and carried by flowing air into drying chamber. An essential part of correct selection and sizing should be based on the realistic definition of operating conditions and product output requirement. From the basic mathematical calculation in section 8.0 and the test results of drying experiment we can developed the operating conditions as basis for detailed engineering works. Pre-determined operating conditions of heater are usually supplied to equipment vendors and manufacturers in a data sheet or specifications form for quotations, as heaters design and thermal coefficients differ from one manufacturer to the other, as the conditions of dryer is not standard. Air heater procurement then is made on this calculated data which practically do not cover dryer conditions. The basic design calculation then is manufacturers or heater equipment suppliers tool to undertake the final phase of heater conceptual development for a particular dryer. The specifications usually contains all information sufficient enough for the manufacturers to carried out the job. In case of copra design example we can provide this specification;

| | |
|---|---|
| Heat supplied to dryer | = 51.0 kW |
| Mass flowrate of hot $H_2O$ | = 0.35 kg/sec |
| Inlet thermal $H_2O$ temp. | = 90°C |
| Outlet thermal $H_2O$ temp. | = 55°C |
| Drying temperature | = 65°C |
| Surrounding air temp. | = 26°C |
| Total volume of air | = 15496.6 kg.air/hr |
| Vel. air to heater | = 2.5 m/sec |

Other items like chemical analysis of thermal $H_2O$,humidity of air in the heater and moisture content of surrounding air should be supplied to the manufacturer as this aids in the evaluation of properties of material to be used in the heater construction. Once detailed engineering works are completed and approved for construction drawing are in the hands of manufacturers fabrication floor line the owner should look into the phases of work to insure that the equipment is accomplished in accordance with pre-determined standard.

Final acceptance of works from heater manufacturer should be made after required testing to the heater is accomplished. Usually a pressure test load or hydrostatic test is applied to the heating element to check for leaks and strength of construction material used. Generally a warranty clause should be secured by the owner to protect its worthiness and quality for specified period of time.

## 10. SELECTION AND SIZING OF FANS AND BLOWERS

In contrast with heating element procurement for dryer, fans and blowers primarily requires power, temperatures and volume of water/air for sizing and further design consideration. Usually we can find wide range of fans and blowers that are free fabricated and ready to use in the local market. Several manufacturer catalogs are available to refer our calculated data which provide guide in proper choice of fans, blowers and its driving mechanism. Fig.14 is sample of manufacturer guide for selecting the right equipment. Following the guide we can plot our calculated data on the chart and arrived with tabulated fans characteristic as follows;

Basic Design Data
Volume of air = 16092 $m^3hr$
Pressure drop = 70 mm $H_2O$

Fans Manufacturer Data
Fan shaft rating = 4.45 kW say 5kW
Efficiency rating = 70%
Sound level(noise)= 83 dB
Motor power = 5 kW * 1.2 factor
= 6 kW

Although we have now this parameters we do not know the type of fans that will deliver the most desirable performance to the drying system. Practically a basic knowledge of fans and blower classification and operation is also necessary in drying practice. Matley, et al (1979)., present a tabulated types of fans that are typically used in industrial application. This is shown Table 13, from where we can find the types of fans commonly used in process heating. It is classified as follows;

Tube-Axial Fans - Designed for a wide range of volumes at medium pressures, these consists primarily of a propeller enclosed in a cylinder that collects and directs air flow.

Vane-Axial Fans - These are characterized by air guide vanes on the discharged side, which differentiates it from tube-axial type. This type can develop pressures up to 20 in. of water; modified, they can go even higher. Usually these fans are nonoverloading. The units are available with adjustable fan blade pitch which provides performance variation.

Radial-Blade Type - This fan performs well in many applications, ranging from pneumatic conveying to exhausting process air or gas in high resistance . Its main features is that this fan can achieve high static pressure with relatively low capacity and can develop high pressures at high speeds.

Backward-Curved and Backward-Inclined Types - These fans operate at medium speed, have broad pressures-volumes capabilities, and can develop less velocity head than forward-curved units of the same size. The fan is easy to control as small variations in system volume results in small variation of pressures.

Airfoil Centrifugal Fans - Airfoil fan also generally quieter and do not pulsate within their operating range, because the air is able to flow through the wheels with turbulence.

Generally it is necessary also to know the essential rules of fan laws as it is sometimes necessary to vary the working parameters of one fan to another to improve its working characteristic to suit the system. In some cases fans are affected by elevations above sea level or the air temperature, or both parameters vary, it is advisable to apply pressures correction curves factor which should be provided or supplied by fan manufacturer.

The selection and sizing of this equipment will not be useful if we don't have to indicate or ascertain the allowable safety factor given to driving mechanism. Practically the range added to theoretical or calculated motor horsepower is between 10% up to 20%. Likewise if we are given the value of fan or blower absorbed shaft power the scheme is to apply the plus factor to the fan motor rating. In this regard we are protecting the fan not to be overloaded. The equations for calculating air and motor horsepower is;

Air horsepower = (144 * 0.0361)Qh/33,000 in Eng. unit (10-1)

Where; $Q$ = inlet vol. cu.ft./min
$h$ = static pressure rise, inches of $H_2O$

For air motor rating given in kilowatts we have this relation;

Motor horsepower, H.P. = kW * 1.34 (10-2)
Motor efficiency = Output horsepower/Input horsepower (10-3)

All other accessories required in the selection of fans and blowers for installation are usually included if the equipment are purchased in package i.e., shaft key, coupling safety devices etc.

With the foregoing points enumerated we have at least a base on how to consider and evaluate a given equipment for drying process. However when problem occur in the selection of fans and it is beyond the standard range of application it is suggested and advisable to consult fans and blowers manufacturer for proper recommendation.

## 11. RESULT AND DISCUSSION

The studies on copra and capelin fish gave considerable features for reference even though the tests were made on limited basis. It was felt that many significant drying variables can be derived and explored, that will help draw ideas on how to carry on the present drying project in the proposed agro-industrial complex in the country. The following points of interest are;

### 11.1. Effect Of Product Size In Drying Load

Fig.10 and Fig.15, are the drying characteristic of copra both curves present the degree and trend of drying rate of small particle against the big samples. In the first three hours of drying process the small size has already a separate path and show fast drying rate. It is observed further that the bigger sample has long span of constant rate drying line while the small specimen has long falling rate period of drying. The works of Ede and Hales, (1948).

Fig.16 similarly confirms the influence of material size on the course of drying. It is evident then that a correlation can be made with different sizes and volume of specific product to be dried with drying temperature. A pre-determined drying condition of product with respect to its volume and size could give quantitative economic results.

### 11.2. Effect Of Product Loading

Another factor that affect the course of drying is the system of loading. This effect was observed by Van Arsdel,(1951)., Fig.17, his study was made on tray loading on drying of potato half-dice. In the same manner Fig.18, has similar path in capelin test. The fish trays with spacing have fast rate of drying compared to trays completely filled and fully loaded. It was however noted, as drying process had passed the critical moisture content at point B, the drying rates of all the capelin fish samples began to close to each other, in which case fish are often dried in two stages, 1, with spacing and 2, fully loaded. This illustrate that the factor influence the early stages of drying process, where it will cause damage if the product has longer period of drying. In case of fish, the effect will be on the taste since it is possible that mould and bacteria may cause damage to the product since air in fully loaded tray will have longer time to penetrate the inner most section of the product. In this case loading arrangement should be given considerable attention to maximize the benefits that can be achieve to the drying process.

### 11.3. Significance Of Constant-Rate Drying Period

Again in Fig.10 and Fig.11, defines the period of constant-rate drying of copra and capelin, where breaks in the curve identify the transition of each drying process. The first break in copra sample was approximately located within the range of 0.43 moisture content and the other is 0.35 at pointmarked B. Falling rate period appears for every identified break points. This stage of curve is the specific drying characteristic of product at particular drying condition. It had been determined from many studies of drying process that the application of external factors of drying is very significant. It suggest that high air velocity and temperature may be employed during constant-rate drying period as the product surface in the process of drying almost remain close to the air wet bulb temperature, in contrast with falling-rate period this drying variables should be reduce to prevent overheating the product. In short the drying curve is very useful in visualizing the operational requirement, control, design scheme and choice of dryer for various product for drying.

### 11.4. Effect Of Recirculation On Condition Of Air

In actual operation of drying plants, it is seldom that air used in the dryer is discharged to the atmosphere. Usually air leaving the dryer is circulated back over the moist product continuously and only small percentage of fresh air are allowed to mix to the drying air in circulation. This make-up air takes care of losses in the dryer due to leaks and the air that leaves the dryer exit.

During the course of drying the air temperature rapidly falls because of fast evaporation of water to the incoming air stream and humidity of air increases, as the process goes on continuously the system will come to the point of equilibrium and the drying condition of air in the dryer is approximately maintained.
This theory of air mixing is complemented with saving practice in the supplied heat to the heating element. Unfortunately this should be properly balanced, since high proportion of air recirculation reduces the drying potential of the air that results to lower drying rate of product. It is then advisable to have the right percent ratio of make-up air with the amount of recirculating air inside the dryer.

In some few cases no air recirculation is applied as observed in one commercial fish drying plant in north of Iceland Fig.19 and 20. This drying plant is designed for final stage of drying process where it takes advantage of maximum potential of drying condition of the air. In this sense the operating condition of dryer is also affected by the properties of air introduced to the drying chamber.

### 11.5. Copra Drying Temperature

The result of experiment of copra drying confirms the studies made by FAO, in developing countries with regards to indirect drying practice (Grimwood, 1975). Fig.15 and Fig.21, shows the similarity in the rate of moisture content removal with respect to drying time. The test produces the right quality of copra as the sample burns continuously when subjected to fire. Meaning the moisture content of copra attained is within 5%-7%. The approximate ideal temperature then for copra drying process is 90°C down to 50°C inside the drying chamber since it is found out in the previous study of FAO, that high temperature of 100°C will damage the texture endosperm (coconut meat) and causes browning which result to discolored oil.

## 11.6. Thermal Water Supply To Dryer

The geothermal water found in Reykjavik contain negligible solids or impurities and are directly use as heat source. This system while very economical will not work in the Philippines as thermal water mostly found in the area have lots of minerals and solids. It is then required that a well designed steam-water heat exchange equipment should be used. Lund, (1987)., discussed that problems on corrosion and scaling that attack heat exchange equipment are confined to higher temperature,and proper choice of material and engineering design is a primary way to solve it. The proposed agro-industrial complex then is a positive prospect as it takes a cascading system of heat utilization.

## 11.7. The Designed Copra Dryer

In addition to the discussion in section 8.1 the dryer design was developed and patterned to existing commercial drying plant in operation in Iceland. It was evaluated that its features is simple and flexibility to accommodate other drying process of similar products is practically attainable. This type of dryer can also be used as fish dryer as mentioned earlier by having trays placed into the drying boxes and air temperature reduced to fish drying condition. The dryer can be constructed 0.60 m below ground to have loading and unloading of product to the drying chamber easy as drying boxes can be designed with steel wheels and lifting of drying boxes can be made possible by lifting gantry installed in the plant area, as means of loading and unloading of products to commercial dryer are accomplished by manually operated mobile lifting jacks. This type of dryer can be constructed from small to large commercial size dryer which can accommodate any range of production output requirement. It is projected to work economically as its development and operating costs is minimal compared to other industrial projects.

## 12. CONCLUSION

It therefore appears that indirect air drying process using low-temperature geothermal energy is viable and has positive features in drying of copra, fish and other similar products as the dryer can operate at varying range of drying conditions. However the economics of drying does not depend only on the type of dryer and the temperature it can take, it has also to consider the product drying characteristic in the first place as this variable dictates the operational requirement of the equipment. Finally the stage of experimentation and data gathering is a requirement in successful design and development of dryers since thermal properties of product is quite limited.

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**NOMENCLATURE**

$A$ = Exposed area of product ($m^2$)

$A_1$ = Sectional area ($m^2$)

Cp = Coconut production (ton/ha)

$C_{pa}$ = Specific heat of air (kJ/kg°C

= 1.0 kJ/kg°C

$C_{pw}$ = Specific heat of thermal (kJ/kg°C)

= 4.18 kJ/kg°C

dB = decibels

$D_H$ = Hydraulic diameter (m)

Dc = Diameter of coconut (mm)

Din = Dryer input (kg)

h = Film coefficients (W/$m^2$°C)

$h_1$ = Free convection heat transfer coefficients (W/$m^2$°C)

$h_0$ = forced convection heat transfer coefficients (W/$m^2$°C)

hfg = Latent heat of vaporization (kJ/kg)

$I_2$ = Enthalpy of air (kJ/kg.dry air)

$k_1$ = Thermal conductivity (W/m°C)

Ls = Weight of dry product (kg)

Ma = Mass flowrate of dry air (kg.air/hr)

$Mp_1$ = Mass of product input (kg)

$Mp_2$ = Mass of product output (kg)

Mw = Mass flowrate of thermal water (kg/hr)

Nud = Nusselt number (dimensionless)

p = Air density (kg/$m^3$)

P = Atmospheric pressure (kg.$m^2$/sec)

= $1.0132 \times 10^5$ kg.$m^2$/sec

P = pressure drop (mm $H_2O$)

Qd = Heat required in the dryer (kJ/sec)

Qe = Total heat evaporated (kJ/sec)

Qs = Heat loss to surrounding (kJ/sec)

$Q_1$ = Heat evaporated - 1st dryer (kJ/sec)

$Q_2$ = Heat evaporated - 2nd dryer (kJ/sec)

$Q_3$ = Heat evaporated - 3rd dryer (kJ/sec)

Qex = Heat loss to exhaust air (kJ/sec)

Q,air = Heat absorb by flowing air (kJ/sec)

Qw = Heat given off by thermal water (kJ/sec)

R = Drying rate (kg.$H_2O$/hr.$m_2$)

R = Gas constant (J/kg$^K$)

= 287 J/kg°K

Red = Reynolds number (dimensionless)

Tin = Inlet temperature (°C)

To = Outlet temperature (°C)

$Ta_0$ = Outlet temperature of air (°C)

Tain = Inlet temperature of air (°C)

Tw.b. = Wet bulb temperature (°C)

Td.b. = Dry bulb temperature (°C)

TD = Temperature differential (°C)

T = Time difference in the drying period ($^h$r)

u = Air viscosity (kg/m.sec)

U = Overall thermal conductance (W/$m^2$°C)

Um = design velocity of air (m/sec)

$Va_1$ = Volumetric flow of air ($M^3$/sec)

Vm = Velocity of air at filled drying boxes (m/sec)

$V_0$ = Velocity of air at empty drying box (m/sec)

Vd = Dryer load design volume ($m^3$)

Vt = Total volume of air ($m^3$/hr)

WT = Weight of product (kg)

x = Wall thickness (mm)

X = Free moisture content (kg.$H_2O$/kg.dry Prod.)

X = Free moisture content change (kg.$H_2O$/kg.dry Prod.)

%D.M. = Percent dry matter

%$H_2O$ = Percent moisture content of product

**REFERENCES**

Aertermica Nicotra spa:20151 Milano, "Manufacturer Catalog On Centrifugal Fans."

Badger, W. L., McCabe, W. L. (1936): A book on Elements Of Chemical Engineering, pp. 280-285.

Brundrett, G. W. (1987): A Handbook Of Dehumidification Technology, Butterworths, London, pp. 6-12, 113-140.

Boxer, G. (1979): A book on Applications Of Engineering Thermodynamics, pp. 142-153.

Dossat, R. J. (1981): A book on Principles Of Refrigeration, John Willy and Sons, New York, U.S.A., pp.25-56.

Dryden, I. G. C. (1975): A book on The Efficient Use Of Energy, IPC Science and Technology Press, Surrey, England, pp. 165-175.

Furnas, C. C., et al (1942): A book titled Rogers Manual Of Industrial Chemistry, D. Van Nostrand Co. Inc., U.S.A. pp.56-62.

Gardner, W. A. (1971): A book on Industrial Drying, pp. 2-79.

Geankoplis, C. J. (1983): A book on Transport Processes And Unit Operations, Allyn and Bacon Inc., Massachusetts, U.S.A., pp. 524-535.

Goodman, L. J., Love, R. N. (1980): A book on Geothermal Energy Projects Planning and Management, Pergamon Press Inc., U.S.A., pp. 168-222.

Grimwood, B. E., (1975): A book of FAO studies on Coconut Palm Products Their Processing In The Developing Countries, pp. 24-114.

Hall, W. C., (1979): A book on Dictionary Of Drying, Marcel and Dekker Inc., New York and Basel.

Hollman, J.P., (1981): A book on Heat Transfer, MacGraw-Hill Inc., U.S.A., pp. 1-259.

Karel, M., Fennema, O. R., Lund, D. B. (1975): A book on Principles Of Food Science Part 2, Marcel and Dekker Inc., Newyork and Basel, pp. 309-335.

Keey, R. B. (1972): A book on Drying Principles And Practice, Pergamon Press Ltd., Oxford, England, pp. 3-13.

Lund, J. W. (1987): A Lecture notes on Industrial Applications Of

Energy, UNU Geothermal Training Programme, Reykjavik, Iceland, pp. 122-130.

Matley, J. et al (1979): A book on Chemical Engineering- Fluid Movers, pp. 92-106.

Mujumdar, A. S. (1980): A book on Drying 80 Vol. 1, Hemisphere Publishing Co., Washington, U.S.A., pp. 308-319.

Tolentino, B. S. (1986): A report on Lectures On Geothermal Energy in the Philippines, UNU Geothermal Training Programme, Reykjavik, Iceland, pp. 61-101.

Van Arsdel, W. B., Copley, M. J. (1963): A book on Food Dehydration Principles Vol.1, The AVI Publishing Co. Inc., Westport, Connecticut, U.S.A.

**APPENDIX 1**

**Commercial Fish Dryer Mass Of Air And Heat Requirement Calculation**

| Measured Drying Variables | | Mollier Diagram Values (Refer to appendix 2) Enthalpy (kJ/kg), Moist.Content (kg/kg) |
|---|---|---|
| Incoming fresh air, | Tdb - 21.5°C, Twb - 10°C | $I_1 = 28.5$ , $X_1 = 0.0029$ |
| Air entering heater, | Tdb - 19.3°C, Twb - 12.4°C | $I_2 = 34.0$ , $X_2 = 0.006$ |
| Air inside dryer, | Tdb - 26°C, Twb - 15°C | $I_3 = 41.0$ , $X_3 = 0.006$ |
| Recirculated air, | Tdb - 17°C, Twb - 15°C | $I_4 = 41.0$ , $X_4 = 0.0098$ |

Mass flow rate of thermal water = 0.88 kg/sec
Temperature of inlet thermal $H_2O$ = 78°C
Temperature of $H_2O$ leaving heater = 25.3°C
Pressure drop = 2.0 mm of $H_2O$

Using the equations of mass and energy balance we can find the following drying variables;

Heat required by dryer, $Qw = Mw * C_{pw} * (Tin - To)$ (1)
$= 0.88 * 4.18(78°C - 25.3°C)$
$= 193.85$ kJ/sec

Mass flow of air to heater, $Ma_2 = Qw/(I_3 - I_2)$ (2)

$= 193.85/(41 - 34)$

$= 27.7$ kg.of air/sec

Mass of air into dryer, $Ma_3 = Ma_2 = 27.7$ kg. of dry air/sec

Air mixed-up ratio is taken from this equations;

$$Ma_1 * X_1 + Ma_4 * X_4 = Ma_2 * X_2 \quad (3)$$

$$Ma_1 + Ma_4 = Ma_2 \quad (4)$$

$$Ma_4 = Ma_2 - Ma_1 \quad (5)$$

Substituting equation (16-5) into equation (16-3) we can have;

$$Ma_1 * X_1 + (Ma_2 - Ma_1) * X_4 = Ma_2 * X_2 \quad (6)$$

then grouping similar terms the equations is reduced to,

$$Ma_1 * (X_1 - X_4) = Ma_2 * (X_2 - X_4) \quad (7)$$

The air mixed-up ratio is expressed as,

$$Ma_1/Ma_2 = (X_2 - X_4)/(X_1 - X_4) \quad (8)$$

Solving for the ratio with figures from Mollier diagram, appendix 16.2 equation (16-8) gives;

$$Ma_1/Ma_2 = (0.006 - 0.0098)/(0.0029 - 0.0098) \quad (9)$$

$$= 0.55 \text{ or } 55\%$$

Therefore;

Mass of make-up air, $Ma_1 = 0.55 * Ma_2$ (10)

$= 0.55 * 27.7$ kg.dry air/sec

$= 15.24$ kg.air/sec

Mass of recirculated air, $Ma_4 = Ma_2 - Ma_1$ (11)

$= 27.7 - 15.24$

$= 12.46$ kg.air/sec

**APPENDIX 1**

**Commercial Fish Dryer Mass Of Air And Heat Requirement Calculation**

| **Measured Drying Variables** | | **Mollier Diagram Values** (Refer to appendix 2) Enthalpy (kJ/kg), Moist.Content (kg/kg) |
|---|---|---|
| Incoming fresh air, | Tdb - 21.5°C, Twb - 10°C | $I_1 = 28.5$ , $X_1 = 0.0029$ |
| Air entering heater, | Tdb - 19.3°C, Twb - 12.4°C | $I_2 = 34.0$ , $X_2 = 0.006$ |
| Air inside dryer, | Tdb - 26°C, Twb - 15°C | $I_3 = 41.0$ , $X_3 = 0.006$ |
| Recirculated air, | Tdb - 17°C, Twb - 15°C | $I_4 = 41.0$ , $X_4 = 0.0098$ |

Mass flow rate of thermal water = 0.88 kg/sec
Temperature of inlet thermal $H_2O$ = 78°C
Temperature of $H_2O$ leaving heater = 25.3°C
Pressure drop = 2.0 mm of $H_2O$

Using the equations of mass and energy balance we can find the following drying variables;

Heat required by dryer, $Qw = Mw * C_{pw} * (Tin - To)$ (1)
$= 0.88 * 4.18(78°C - 25.3°C)$
$= 193.85$ kJ/sec

Mass flow of air to heater, $Ma_2 = Qw/(I_3 - I_2)$ (2)

$= 193.85/(41 - 34)$

$= 27.7$ kg.of air/sec

Mass of air into dryer, $Ma_3 = Ma_2 = 27.7$ kg. of dry air/sec

Air mixed-up ratio is taken from this equations;

$$Ma_1 * X_1 + Ma_4 * X_4 = Ma_2 * X_2 \quad (3)$$

$$Ma_1 + Ma_4 = Ma_2 \quad (4)$$

$$Ma_4 = Ma_2 - Ma_1 \quad (5)$$

Substituting equation (16-5) into equation (16-3) we can have;

$$Ma_1 * X_1 + (Ma_2 - Ma_1) * X_4 = Ma_2 * X_2 \quad (6)$$

then grouping similar terms the equations is reduced to,

$$Ma_1 * (X_1 - X_4) = Ma_2 * (X_2 - X_4) \quad (7)$$

The air mixed-up ratio is expressed as,

$$Ma_1/Ma_2 = (X_2 - X_4)/(X_1 - X_4) \quad (8)$$

Solving for the ratio with figures from Mollier diagram, appendix 16.2 equation (16-8) gives;

$$Ma_1/Ma_2 = (0.006 - 0.0098)/(0.0029 - 0.0098) \quad (9)$$

$$= 0.55 \text{ or } 55\%$$

Therefore;

Mass of make-up air, $Ma_1 = 0.55 * Ma_2$ (10)

$= 0.55 * 27.7$ kg.dry air/sec

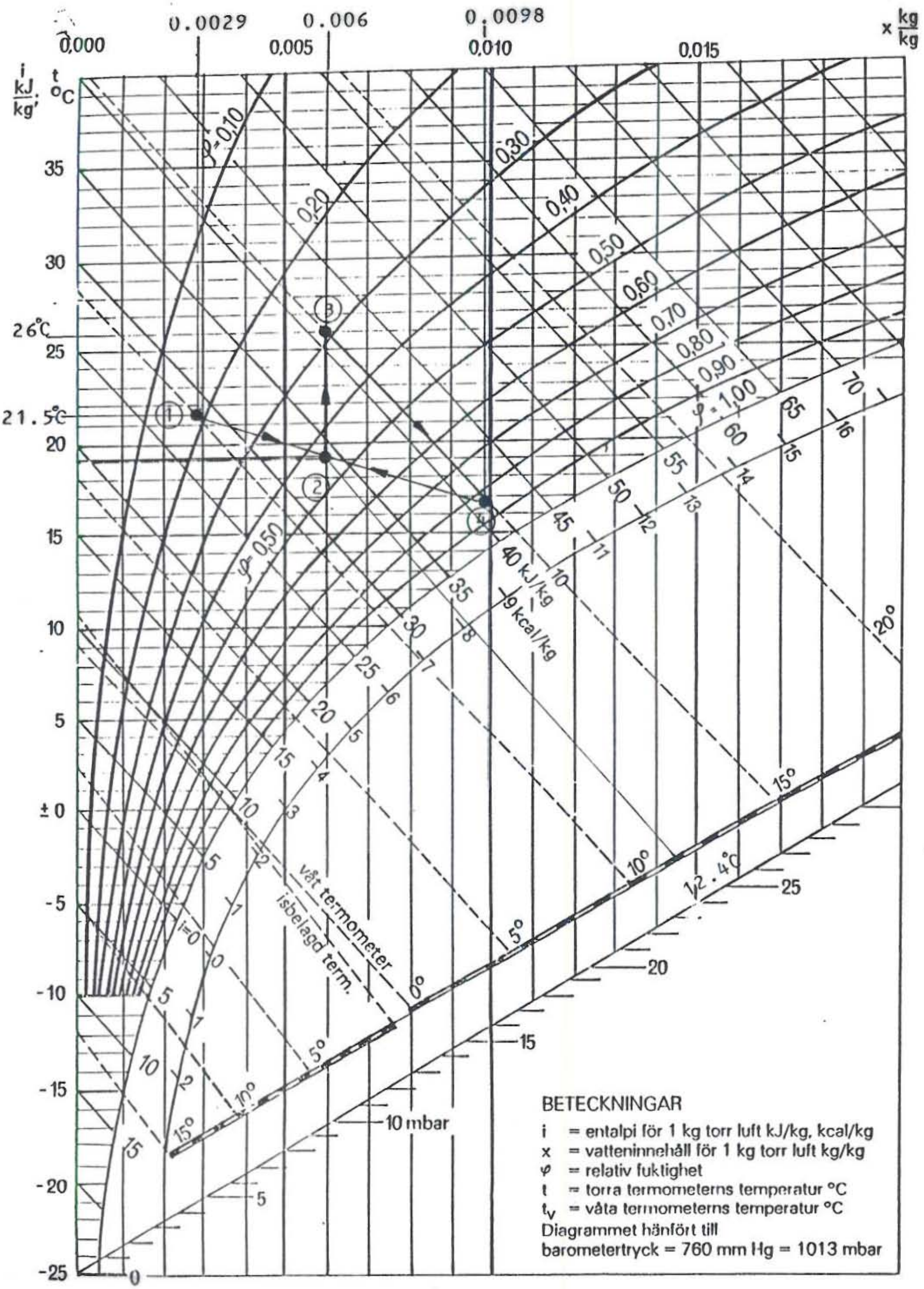
$= 15.24$ kg.air/sec

Mass of recirculated air, $Ma_4 = Ma_2 - Ma_1$ (11)

$= 27.7 - 15.24$

$= 12.46$ kg.air/sec

## APPENDIX 2




**Mollier diagram of commercial fish dryer**

**APPENDIX 3**

**Designed Copra Dryer Mass Of Air Calculation**

Referring to section 8, equation (8-10), the mass of dry air required is equal to,

$$Ma = 15496.6 \text{ kg.dry air/hr or} \quad (1)$$
$$= 4.3 \text{ kg.dry air/sec}$$

and the calculated total mass of $H_2O$ evaporated from 1.0 ton of coconut is; Refer to equations, (8-12), (8-15) and (8-17).

$$Mwt = Mw + M_1 + M_2 \quad (2)$$
$$= 66.7 + 2.0 + 2.0$$
$$= 70.7 \text{ kg.}H_2O\text{/hr}$$

Taking the change in moisture content X, we can equate the ratio of total mass of $H_2O$, (Mwt) over the mass of dry air, (Ma) expressed as;

$$Mwt/Ma = X = 70.7/15496.6 \quad (3)$$
$$= 0.0046 \text{ kg.}H_2O\text{/kg.dry air}$$

From the designed dryer temperature of 65°C and incoming fresh air of 26°C, we can assume theoretically the percent relative humidity of existing dryer now in operation in Iceland, since no fixed data are available on hand with regards to prevailing atmospheric condition in the Phil..
Thus we have this air properties for consideration;

Inlet fresh air to dryer, Tdb - 26°C and RH - 90%
Air inside the dryer, Tdb - 65°C and RH - 40%

Using the mollier diagram on appendix 4 and plotting the data we can find other drying parameters and figures of designed copra dryer;

| Condition of air | Enthalpy (kJ/kg) | Moisture content (kg/kg) |
| --- | --- | --- |
| Inlet fresh air, $Ma_1$ | $I_1 = 77.0$ | $X_1 = 0.019$ |
| Air entering heater, $Ma_2$ | $I_2 = 235.0$ | $X_2 = 0.068$ |
| Air inside the dryer, $Ma_3$ | $I_3 = 245.0$ | $X_3 = 0.068$ |
| Recirculated air, $Ma_4$ | $I_4 = 245.0$ | $X_4 = 0.068 + X$ $= 0.0726$ |

Calculating for air mixed-up ratio we have this relation as;

$$Ma_1 * X_1 + Ma_4 * X_4 = Ma_2 * X_2 \quad (4)$$

$$Ma_1 + Ma_4 = Ma_2 \quad (5)$$

$$Ma_4 = Ma_2 - Ma_1 \quad (6)$$

Substituting equation (16-17) into equation (16-15) we can have;

$$Ma_1 * X_1 + (Ma_2 - Ma_1) * X_4 = Ma_2 * X_2 \quad (7)$$

then grouping similar terms the equation is;

$$Ma_1 * (X_1 - X_4) = Ma_2 * (X_1 - X_4) \quad (8)$$

Air make-up ratio is;

$$Ma_1/Ma_2 = (X_2 - X_4)/(X_1 - X_4) \quad (9)$$

$$= (0.068 - 0.0726)/(0.019 - 0.0726)$$

$$= 0.086 \text{ or } 8.6\%$$

where mass flowrate of dry air, $Ma = Ma_2 = Ma_3 = 4.3$ kg/sec

Therefore we have;

Mass of make-up air, $Ma_1 = 0.086 * Ma_2$ (10)

$= 0.086 * 4.3$

$= 0.37$ kg.air/sec

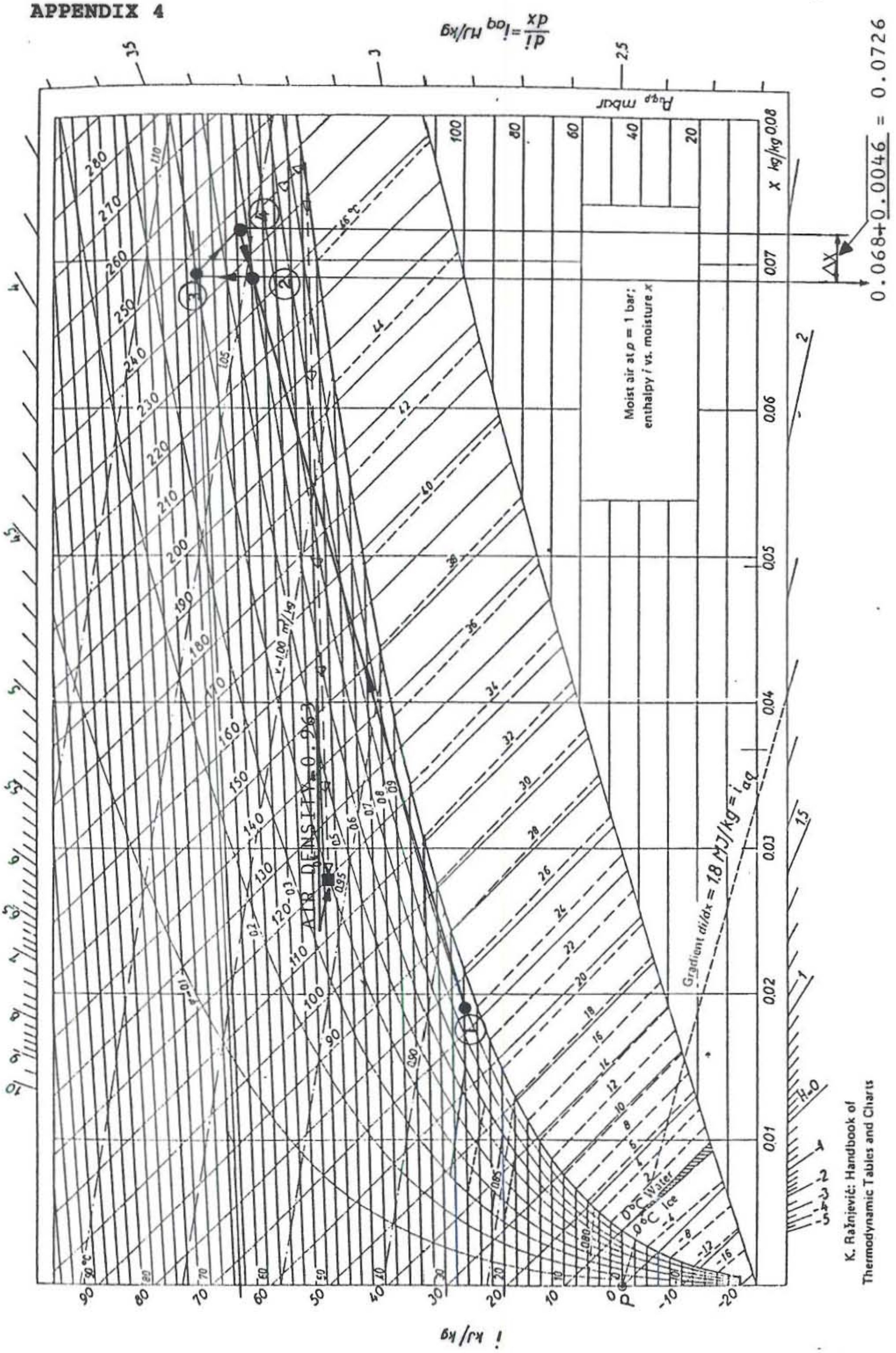
Mass of recirculated air, $Ma_4 = Ma_2 - Ma_1$ (11)

$= 4.3 - 0.37$

$= 3.93$ kg.dry air/sec

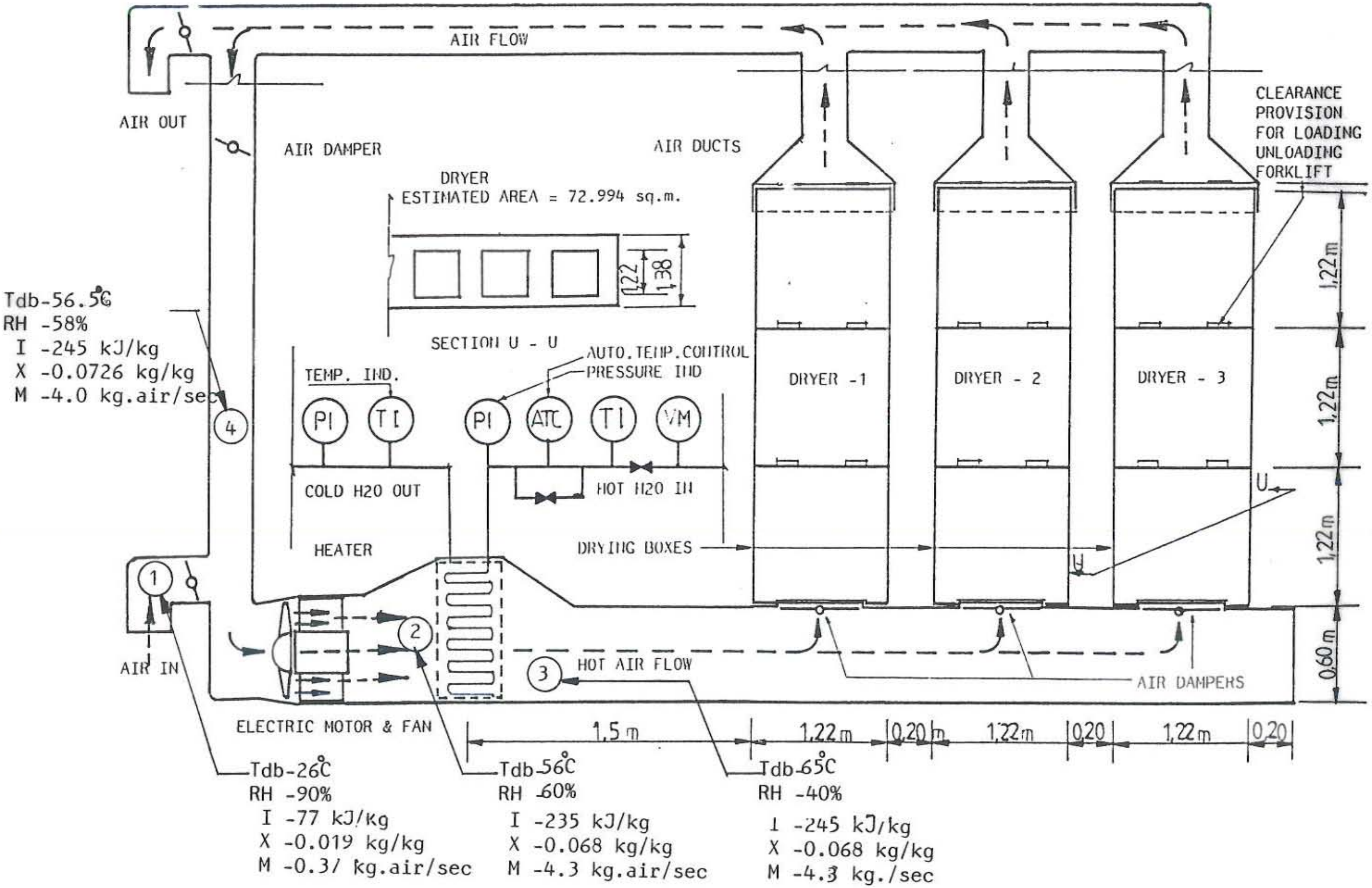
say 4.0 kg.dry air/sec

APPENDIX 4




Mollier diagram of designed copra dryer

APPENDIX 5




Mass/energy balance of designed copra dryer

**APPENDIX 6**

# Properties of air at atmospheric condition

The values of $\mu$, $k$, $c_p$, and Pr are not strongly pressure-dependent and may be used over a fairly wide range of pressures.

| $T$, K | $\rho$ kg/m$^3$ | $c_p$, kJ/kg·°C | $\mu$, kg/m·s × $10^5$ | $\nu$, m$^2$/s × $10^6$ | $k$, W/m·°C | $\alpha$, m$^2$/s × $10^4$ | Pr |
|---|---|---|---|---|---|---|---|
| 100 | 3.6010 | 1.0266 | 0.6924 | 1.923 | 0.009246 | 0.02501 | 0.770 |
| 150 | 2.3675 | 1.0099 | 1.0283 | 4.343 | 0.013735 | 0.05745 | 0.753 |
| 200 | 1.7684 | 1.0061 | 1.3289 | 7.490 | 0.01809 | 0.10165 | 0.739 |
| 250 | 1.4128 | 1.0053 | 1.5990 | 11.31 | 0.02227 | 0.15675 | 0.722 |
| 300 | 1.1774 | 1.0057 | 1.8462 | 15.69 | 0.02624 | 0.22160 | 0.708 |
| 350 | 0.9980 | 1.0090 | 2.075 | 20.76 | 0.03003 | 0.2983 | 0.697 |
| 400 | 0.8826 | 1.0140 | 2.286 | 25.90 | 0.03365 | 0.3760 | 0.689 |
| 450 | 0.7833 | 1.0207 | 2.484 | 31.71 | 0.03707 | 0.4222 | 0.683 |
| 500 | 0.7048 | 1.0295 | 2.671 | 37.90 | 0.04038 | 0.5564 | 0.680 |
| 550 | 0.6423 | 1.0392 | 2.848 | 44.34 | 0.04360 | 0.6532 | 0.680 |
| 600 | 0.5879 | 1.0551 | 3.018 | 51.34 | 0.04659 | 0.7512 | 0.680 |
| 650 | 0.5430 | 1.0635 | 3.177 | 58.51 | 0.04953 | 0.8578 | 0.682 |
| 700 | 0.5030 | 1.0752 | 3.332 | 66.25 | 0.05230 | 0.9672 | 0.684 |
| 750 | 0.4709 | 1.0856 | 3.481 | 73.91 | 0.05509 | 1.0774 | 0.686 |
| 800 | 0.4405 | 1.0978 | 3.625 | 82.29 | 0.05779 | 1.1951 | 0.689 |
| 850 | 0.4149 | 1.1095 | 3.765 | 90.75 | 0.06028 | 1.3097 | 0.692 |
| 900 | 0.3925 | 1.1212 | 3.899 | 99.3 | 0.06279 | 1.4271 | 0.696 |
| 950 | 0.3716 | 1.1321 | 4.023 | 108.2 | 0.06525 | 1.5510 | 0.699 |
| 1000 | 0.3524 | 1.1417 | 4.152 | 117.8 | 0.06752 | 1.6779 | 0.702 |
| 1100 | 0.3204 | 1.160 | 4.44 | 138.6 | 0.0732 | 1.969 | 0.704 |
| 1200 | 0.2947 | 1.179 | 4.69 | 159.1 | 0.0782 | 2.251 | 0.707 |
| 1300 | 0.2707 | 1.197 | 4.93 | 182.1 | 0.0837 | 2.583 | 0.705 |
| 1400 | 0.2515 | 1.214 | 5.17 | 205.5 | 0.0891 | 2.920 | 0.705 |
| 1500 | 0.2355 | 1.230 | 5.40 | 229.1 | 0.0946 | 3.262 | 0.705 |
| 1600 | 0.2211 | 1.248 | 5.63 | 254.5 | 0.100 | 3.609 | 0.705 |
| 1700 | 0.2082 | 1.267 | 5.85 | 280.5 | 0.105 | 3.977 | 0.705 |
| 1800 | 0.1970 | 1.287 | 6.07 | 308.1 | 0.111 | 4.379 | 0.704 |
| 1900 | 0.1858 | 1.309 | 6.29 | 338.5 | 0.117 | 4.811 | 0.704 |
| 2000 | 0.1762 | 1.338 | 6.50 | 369.0 | 0.124 | 5.260 | 0.702 |
| 2100 | 0.1682 | 1.372 | 6.72 | 399.6 | 0.131 | 5.715 | 0.700 |
| 2200 | 0.1602 | 1.419 | 6.93 | 432.6 | 0.139 | 6.120 | 0.707 |
| 2300 | 0.1538 | 1.482 | 7.14 | 464.0 | 0.149 | 6.540 | 0.710 |
| 2400 | 0.1458 | 1.574 | 7.35 | 504.0 | 0.161 | 7.020 | 0.718 |
| 2500 | 0.1394 | 1.688 | 7.57 | 543.5 | 0.175 | 7.441 | 0.730 |

† From *Natl. Bur. Stand. (U.S.) Circ.* 564, 1955.

## APPENDIX 7

# Convection heat transfer coefficients

| | *h* | |
|---|---|---|
| *Mode* | W/m²·°C | Btu/h·ft²·°F |
| Free convection, $\Delta T = 30°C$ | | |
| Vertical plate 0.3 m [1 ft] high in air | 4.5 | 0.79 |
| Horizontal cylinder, 5-cm diameter, in air | 6.5 | 1.14 |
| Horizontal cylinder, 2-cm diameter, in water | 890 | 157 |
| Forced convection | | |
| Airflow at 2 m/s over 0.2-m square plate | 12 | 2.1 |
| Airflow at 35 m/s over 0.75-m square plate | 75 | 13.2 |
| Air at 2 atm flowing in 2.5-cm-diameter tube at 10 m/s | 65 | 11.4 |
| Water at 0.5 kg/s flowing in 2.5-cm-diameter tube | 3500 | 616 |
| Airflow *across* 5-cm-diameter cylinder with velocity of 50 m/s | 180 | 32 |
| Boiling water | | |
| In a pool or container | 2500–35,000 | 440–6200 |
| Flowing in a tube | 5000–100,000 | 880–17,600 |
| Condensation of water vapor, 1 atm | | |
| Vertical surfaces | 4000–11,300 | 700–2000 |
| Outside horizontal tubes | 9500–25,000 | 1700–4400 |

APPENDIX 8

**Water activity v.s. moisture content curve of copra test sample**

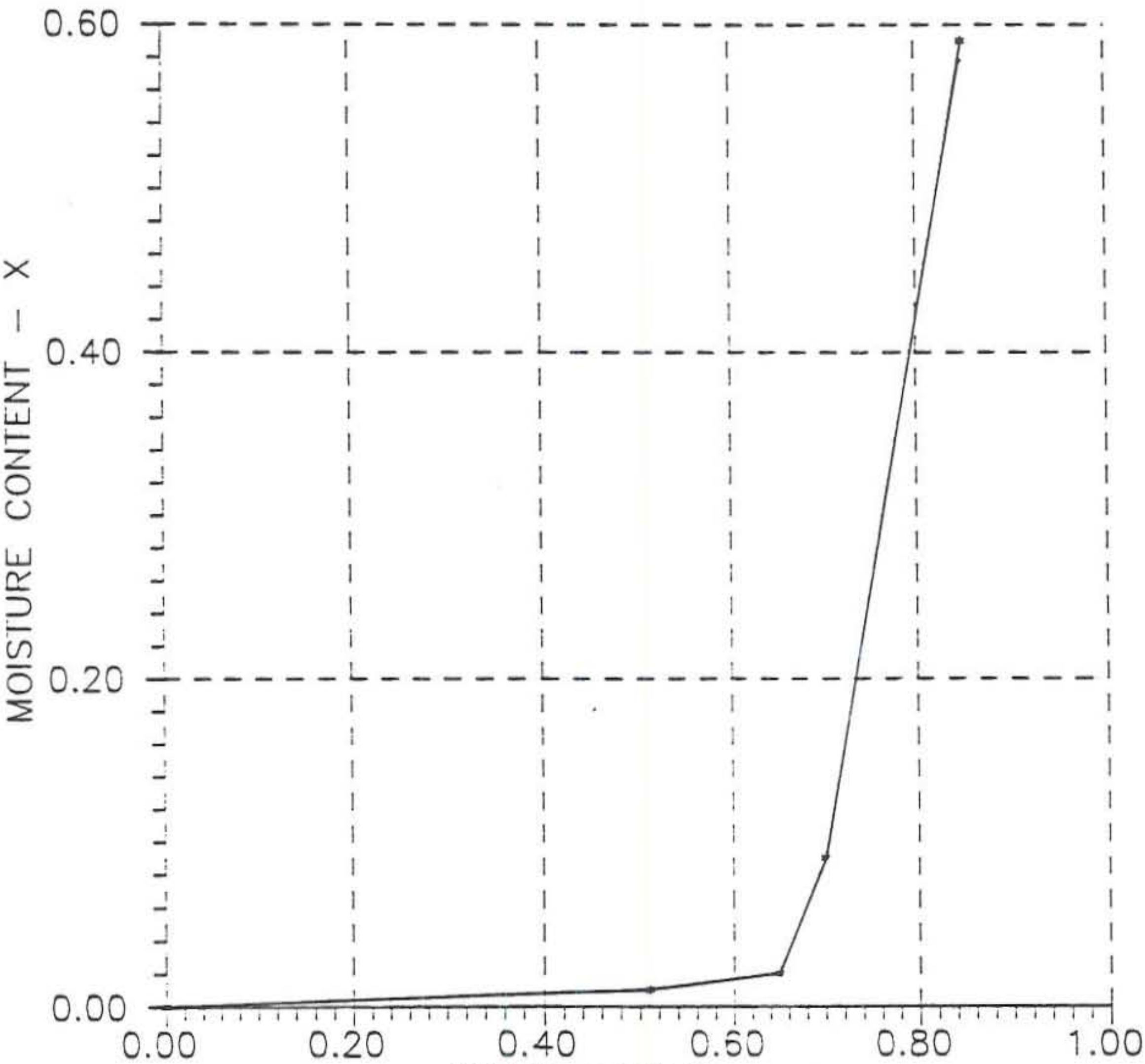


**Table 1 - Surface area of capeline fish**

1.0 Planimeter constant = 0.0091 sq.m/ unit reading

| 2.0 Fish sample | Reading | Constant | Surface Area |
|---|---|---|---|
| 1 | 0.243 unit | 0.0091 | 0.0022 sq.m |
| 2 | 0.244 unit | 0.0091 | 0.0022 sq.m |
| 3 | 0.223 unit | 0.0091 | 0.0020 sq.m |
| 4 | 0.274 unit | 0.0091 | 0.0025 sq.m |
| 5 | 0.264 unit | 0.0091 | 0.0024 sq.m |
| 6 | 0.222 unit | 0.0091 | 0.0020 sq.m |
| 7 | 0.255 unit | 0.0091 | 0.0023 sq.m |
| 8 | 0.182 unit | 0.0091 | 0.0016 sq.m |
| 9 | 0.212 unit | 0.0091 | 0.0019 sq.m |
| 10 | 0.190 unit | 0.0091 | 0.0017 sq.m |

Average estimated sides surface area ----------- 0.0021 sq.m

| Top surface area of fish | | |
|---|---|---|
| 1 | 5 mm + 10 mm x 140 mm/ 2 | 0.0011 sq.m |
| 2 | 4 mm + 8 mm x 162 mm/ 2 | 0.0010 sq.m |
| 3 | 3 mm + 9 mm x 155 mm/ 2 | 0.0009 sq.m |
| 4 | 4 mm + 10 mm x 180 mm/ 2 | 0.0013 sq.m |
| 5 | 3 mm + 10 mm x 170 mm/ 2 | 0.0011 sq.m |
| 6 | 2 mm + 7 mm x 152 mm/ 2 | 0.0007 sq.m |
| 7 | 2 mm + 8 mm x 159 mm/ 2 | 0.0008 sq.m |
| 8 | 2 mm + 6 mm x 135 mm/ 2 | 0.0005 sq.m |
| 9 | 3 mm + 6 mm x 145 mm/ 2 | 0.0006 sq.m |
| 10 | 3 mm + 5 mm x 145 mm/ 2 | 0.0006 sq.m |

Average top surface area of fish -------------- 0.0009 sq.m

Total average surface area = 0.0021 + 0.0009 --- 0.0030 sq.m

**Table 2 - Capeline Ls/A ratio**

TEST SAMPLE Ls/A RATIO

1.0 Tray with spacing 1A

Ls = 0.14196 kg dry product

Unit wt. of fish = 0.00622 kg

A = 0.003 sq.m x 0.14196 kg/ 0.00622 kg = 0.068 sq.m

Ls/A = 0.14196 kg/ 0.068 sq.m ------------ 2.09 kg/ sq.m

Tray with spacing 1B

Ls = 0.13104 kg dry product

A = 0.003 sq.m x 0.13104 kg/ 0.00622 kg = 0.063 sq.m

Ls/A = 0.13104 kg/ 0.063 sq.m ------------ 2.08 kg/ sq.m

2.0 Tray without spacing 2A

Ls = 0.2548 kg dry product

A = 0.003 sq.m x 0.2548 kg/ 0.00622kg = 0.122 sq.m

Ls/A = 0.2548 kg/ 0.122 sq.m ------------ 2.09 kg/ sq.m

Tray without spacing 2B

Ls = 0.26754 kg dry product

A = 0.003 sq.m x 0.26754 kg/ 0.00622 = 0.128 sq.m

Ls/A = 0.26754 kg/ 0.128 sq.m ------------ 2.09 kg/ sq.m

3.0 Tray 2 x load mark 3

Ls = 0.48412 kg dry product

A = 0.003 sq.m x 0.48412 kg/ 0.00622 kg = 0.232 sq.m

Ls/A = 0.48412 kg/ 0.232 sq.m ------------2.09 kg/ sq.m

**Table 3 - Copra Ls/A ratio**

TEST SAMPLE Ls/A RATIO

1.0 60 mm x 60 mm copra

Ls = 0.1895 kg dry product
Unit wt. of copra = 0.0416 kg
A = 0.00987 sq.m x 0.1895 kg/ 0.0416 kg = 0.045 sq.m
Ls/ A = 0.1895 kg / 0.045 sq.m ------------ 4.21 kg./sq.m

2.0 40 mm x 40 mm copra

Ls = 0.1154 kg dry product
Unit wt. of copra = 0.0172 kg
A = 0.0042 sq.m x 0.1154 kg/ 0.0172 kg = 0.0282 sq.m
Ls/ A = 0.1154 kg/ 0.0282 sq.m ----------- 4.09 kg/ sq.m

3.0 30 mm x 30 mm copra

Ls = 0.092 kg dry product
Unit wt. of copra = 0.014 kg
A = 0.00364 sq.m x 0.092 kg/ 0.014 kg = 0.0239 sq.m
Ls/ A = 0.092 kg/ 0.0239 sq.m ------------ 3.85 kg/ sq.m

4.0 Various sizes (NIL)

Ls = 0.354 kg dry product
Unit wt. of copra = 0.0065 kg
A = 0.0018 sq.m x 0.354 kg/ 0.0065 kg = 0.1035 sq.m
Ls/ A = 0.354 kg/ 0.1035 sq.m -------------3.42 kg/ sg.m

Table 4 - 60 mm x 60 mm copra drying test data

| DAY | TIME | WT. | LOSS WT. | % I.WT. | % D.M. | % $H_2O$ | $\Delta T$ | $\Delta X$ | $\Delta X/\Delta T$ | LS/A | R | X | AVE.X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17:8:87 12:30:PM | 0.00 | 300.860 | 0.000 | 100.000 | 63.000 | 37.000 | | | | | | 0.590 | |
| | | | | | | | 0.500 | 0.120 | 0.240 | 4.210 | 1.010 | | 0.525 |
| | 0.500 | 280.400 | 20.400 | 93.200 | 68.000 | 32.000 | | | | | | 0.470 | |
| | | | | | | | 0.500 | 0.040 | 0.080 | 4.210 | 0.340 | | 0.450 |
| | 1.000 | 269.900 | 30.900 | 89.700 | 70.000 | 30.000 | | | | | | 0.430 | |
| | | | | | | | 0.750 | 0.060 | 0.080 | 4.210 | 0.340 | | 0.400 |
| | 1.750 | 258.600 | 42.200 | 86.000 | 73.000 | 27.000 | | | | | | 0.370 | |
| | | | | | | | 0.750 | 0.050 | 0.070 | 4.210 | 0.300 | | 0.340 |
| | 2.500 | 250.860 | 50.000 | 83.400 | 76.000 | 24.000 | | | | | | 0.320 | |
| | | | | | | | 0.500 | 0.020 | 0.040 | 4.210 | 0.170 | | 0.310 |
| | 3.000 | 245.000 | 55.800 | 81.400 | 77.000 | 23.000 | | | | | | 0.300 | |
| | | | | | | | 0.500 | 0.020 | 0.040 | 4.210 | 0.040 | | 0.290 |
| | 3.500 | 242.900 | 57.800 | 80.800 | 78.000 | 22.000 | | | | | | 0.280 | |
| | | | | | | | 16.500 | 0.189 | 0.010 | 4.210 | 0.020 | | 0.190 |
| 18:8:87 8:30AM | 20.000 | 206.700 | 94.100 | 68.700 | 91.700 | 8.300 | | | | | | 0.091 | |
| | | | | | | | 0.500 | 0.002 | 0.004 | 4.210 | 0.020 | | 0.090 |
| | 20.500 | 206.300 | 94.500 | 68.600 | 91.800 | 8.200 | | | | | | 0.089 | |
| | | | | | | | 0.500 | 0.002 | 0.004 | 4.210 | 0.020 | | 0.089 |
| | 21.000 | 205.800 | 95.000 | 68.400 | 92.000 | 8.000 | | | | | | 0.087 | |
| | | | | | | | 0.500 | 0.002 | 0.004 | 4.210 | 0.010 | | 0.085 |
| | 21.500 | 205.400 | 95.400 | 68.300 | 92.200 | 7.700 | | | | | | 0.085 | |
| | | | | | | | 1.000 | 0.003 | 0.003 | 4.210 | 0.010 | | 0.084 |
| | 22.500 | 205.000 | 95.800 | 68.200 | 92.400 | 7.600 | | | | | | 0.082 | |
| | | | | | | | 1.000 | 0.003 | 0.003 | 4.210 | 0.010 | | 0.081 |
| | 23.500 | 204.500 | 96.300 | 68.000 | 92.700 | 7.300 | | | | | | 0.079 | |
| | | | | | | | 2.000 | 0.005 | 0.003 | 4.210 | 0.010 | | 0.077 |
| | 25.500 | 203.500 | 97.300 | 67.600 | 93.100 | 6.900 | | | | | | 0.074 | |
| | | | | | | | 2.000 | 0.006 | 0.003 | 4.210 | 0.010 | | 0.071 |
| | 27.500 | 202.400 | 98.400 | 67.300 | 93.600 | 6.400 | | | | | | 0.068 | |
| | | | | | | | 16.000 | 0.044 | 0.003 | 4.210 | 0.010 | | 0.046 |
| 19:8:87 8:00AM | 43.500 | 194.000 | 106.800 | 64.500 | 97.700 | 2.300 | | | | | | 0.024 | |
| | | | | | | | 2.000 | 0.006 | 0.003 | 4.210 | 0.010 | | 0.021 |
| | 45.500 | 193.060 | 107.800 | 64.200 | 98.200 | 1.800 | | | | | | 0.018 | |
| | | | | | | | 4.000 | 0.004 | 0.001 | 4.210 | 0.004 | | 0.016 |
| | 49.500 | 192.100 | 108.700 | 63.900 | 98.600 | 1.400 | | | | | | 0.014 | |
| | | | | | | | 18.000 | 0.014 | 0.001 | 4.210 | 0.004 | | 0.007 |
| 20:8:87 8:00AM | 67.500 | 188.400 | 112.400 | 62.900 | 100.000 | 0.000 | | | | | | 0.000 | |

Table 5 - 40 mm x 40 mm copra drying test data

| DAY | TIME | WT. | LOSS WT | % I.WT. | % D.M. | % H2O | ΔT | ΔX | ΔX/ΔT | LS/A | R | X | AVE.X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17:8:87 12:30:PM | 0.000 | 183.100 | 0.000 | 100.000 | 63.000 | 37.000 | | | | | | 0.590 | |
| | | | | | | | 0.500 | 0.120 | 0.240 | 4.090 | 0.980 | | 0.530 |
| | 0.500 | 169.200 | 13.900 | 92.400 | 68.200 | 31.800 | | | | | | 0.470 | |
| | | | | | | | 0.500 | 0.060 | 0.120 | 4.090 | 0.490 | | 0.440 |
| | 1.000 | 163.000 | 20.100 | 89.000 | 70.800 | 29.200 | | | | | | 0.410 | |
| | | | | | | | 0.750 | 0.060 | 0.080 | 4.090 | 0.330 | | 0.380 |
| | 1.750 | 155.600 | 27.500 | 85.000 | 74.100 | 25.900 | | | | | | 0.350 | |
| | | | | | | | 0.750 | 0.050 | 0.070 | 4.090 | 0.290 | | 0.330 |
| | 2.500 | 150.700 | 32.400 | 82.300 | 76.500 | 23.500 | | | | | | 0.300 | |
| | | | | | | | 0.500 | 0.020 | 0.040 | 4.090 | 0.160 | | 0.290 |
| | 3.000 | 147.600 | 35.500 | 80.600 | 78.200 | 21.800 | | | | | | 0.280 | |
| | | | | | | | 0.500 | 0.020 | 0.040 | 4.090 | 0.160 | | 0.270 |
| | 3.500 | 145.400 | 37.700 | 79.400 | 79.300 | 20.700 | | | | | | 0.260 | |
| | | | | | | | 16.500 | 0.185 | 0.010 | 4.090 | 0.040 | | 0.170 |
| 18:8:87 8:30AM | 20.000 | 123.600 | 59.500 | 67.500 | 93.000 | 7.000 | | | | | | 0.075 | |
| | | | | | | | 0.500 | 0.005 | 0.010 | 4.090 | 0.040 | | 0.072 |
| | 20.500 | 123.300 | 59.800 | 67.300 | 93.500 | 6.500 | | | | | | 0.070 | |
| | | | | | | | 0.500 | 0.003 | 0.006 | 4.090 | 0.020 | | 0.058 |
| | 21.000 | 123.100 | 60.000 | 67.200 | 93.700 | 6.300 | | | | | | 0.067 | |
| | | | | | | | 0.500 | 0.003 | 0.006 | 4.090 | 0.020 | | 0.066 |
| | 21.500 | 122.900 | 60.200 | 67.100 | 93.800 | 6.200 | | | | | | 0.064 | |
| | | | | | | | 1.000 | 0.002 | 0.002 | 4.090 | 0.008 | | 0.063 |
| | 22.500 | 122.500 | 60.600 | 66.900 | 94.200 | 5.800 | | | | | | 0.062 | |
| | | | | | | | 1.000 | 0.002 | 0.002 | 4.090 | 0.008 | | 0.061 |
| | 23.500 | 122.300 | 60.800 | 66.800 | 94.300 | 5.700 | | | | | | 0.060 | |
| | | | | | | | 2.000 | 0.004 | 0.002 | 4.090 | 0.008 | | 0.058 |
| | 25.500 | 121.800 | 61.300 | 66.500 | 94.700 | 5.300 | | | | | | 0.056 | |
| | | | | | | | 2.000 | 0.003 | 0.002 | 4.090 | 0.008 | | 0.055 |
| | 27.500 | 121.000 | 62.100 | 66.100 | 95.000 | 5.000 | | | | | | 0.053 | |
| | | | | | | | 16.000 | 0.004 | 0.002 | 4.090 | 0.008 | | 0.032 |
| 19:8:87 8:00AM | 43.500 | 116.700 | 66.400 | 63.700 | 99.900 | 1.000 | | | | | | 0.010 | |
| | | | | | | | 2.000 | 0.004 | 0.002 | 4.090 | 0.008 | | 0.008 |
| | 45.500 | 116.100 | 67.000 | 63.400 | 99.940 | 0.060 | | | | | | 0.006 | |
| | | | | | | | 4.000 | 0.004 | 0.001 | 4.090 | 0.004 | | 0.004 |
| | 49.500 | 115.600 | 67.500 | 63.100 | 99.980 | 0.020 | | | | | | 0.002 | |
| | | | | | | | 18.000 | 0.002 | 0.000 | 4.090 | 0.000 | | 0.001 |
| 20:8:87 | 67.500 | 113.700 | 69.400 | 62.100 | 100.000 | 0.000 | | | | | | 0.000 | |

Table 6 - 30 mm x 30 mm copra drying test data

| DAY | TIME | WT. | LOSS WT | % I.WT. | % D.M. | % H2O | ΔT | ΔX | ΔX/ΔT | LS/A | R | X | AVE.X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17:8:87 12:30PM | 0.000 | 145.700 | 0.000 | 100.000 | 63.000 | 37.000 | | | | | | 0.590 | |
| | | | | | | | 0.500 | 0.130 | 0.260 | 3.850 | 1.001 | | 0.520 |
| | 0.500 | 134.000 | 11.700 | 92.000 | 68.500 | 31.500 | | | | | | 0.490 | |
| | | | | | | | 0.500 | 0.050 | 0.100 | 3.850 | 0.380 | | 0.440 |
| | 1.000 | 129.300 | 16.400 | 89.000 | 70.900 | 29.100 | | | | | | 0.410 | |
| | | | | | | | 0.750 | 0.060 | 0.080 | 3.850 | 0.310 | | 0.380 |
| | 1.750 | 123.900 | 21.800 | 85.000 | 74.100 | 25.900 | | | | | | 0.350 | |
| | | | | | | | 0.750 | 0.040 | 0.050 | 3.850 | 0.190 | | 0.330 |
| | 2.500 | 120.200 | 25.500 | 82.300 | 76.300 | 23.700 | | | | | | 0.310 | |
| | | | | | | | 0.500 | 0.020 | 0.040 | 3.850 | 0.150 | | 0.300 |
| | 3.000 | 118.200 | 27.500 | 81.100 | 77.600 | 22.400 | | | | | | 0.290 | |
| | | | | | | | 0.500 | 0.020 | 0.040 | 3.850 | 0.150 | | 0.280 |
| | 3.500 | 116.200 | 29.500 | 79.800 | 79.000 | 21.000 | | | | | | 0.270 | |
| | | | | | | | 16.500 | 0.174 | 0.010 | 3.850 | 0.040 | | 0.180 |
| 18:8:87 8:30AM | 20.000 | 101.100 | 44.600 | 69.400 | 91.000 | 9.000 | | | | | | 0.096 | |
| | | | | | | | 0.500 | 0.006 | 0.010 | 3.850 | 0.040 | | 0.093 |
| | 20.500 | 99.800 | 45.900 | 68.500 | 92.000 | 8.000 | | | | | | 0.090 | |
| | | | | | | | 0.500 | 0.006 | 0.010 | 3.850 | 0.040 | | 0.087 |
| | 21.000 | 99.600 | 46.100 | 68.400 | 92.200 | 7.800 | | | | | | 0.084 | |
| | | | | | | | 0.500 | 0.001 | 0.002 | 3.850 | 0.008 | | 0.084 |
| | 21.500 | 99.400 | 46.300 | 68.200 | 92.300 | 7.700 | | | | | | 0.083 | |
| | | | | | | | 1.000 | 0.002 | 0.002 | 3.850 | 0.008 | | 0.082 |
| | 22.500 | 99.200 | 46.500 | 68.100 | 92.500 | 7.500 | | | | | | 0.081 | |
| | | | | | | | 1.000 | 0.002 | 0.002 | 3.850 | 0.008 | | 0.080 |
| | 23.500 | 98.900 | 46.800 | 67.900 | 92.800 | 7.200 | | | | | | 0.079 | |
| | | | | | | | 2.000 | 0.004 | 0.002 | 3.850 | 0.008 | | 0.077 |
| | 25.500 | 98.700 | 47.000 | 67.700 | 93.000 | 7.000 | | | | | | 0.075 | |
| | | | | | | | 2.000 | 0.005 | 0.002 | 3.850 | 0.008 | | 0.073 |
| | 27.500 | 98.000 | 47.700 | 67.300 | 93.700 | 6.300 | | | | | | 0.070 | |
| | | | | | | | 16.000 | 0.039 | 0.002 | 3.850 | 0.008 | | 0.050 |
| 19:8:87 8:00AM | 43.500 | 94.600 | 51.100 | 64.900 | 97.000 | 3.000 | | | | | | 0.031 | |
| | | | | | | | 2.000 | 0.003 | 0.002 | 3.850 | 0.008 | | 0.030 |
| | 45.500 | 94.300 | 51.400 | 64.700 | 97.300 | 2.700 | | | | | | 0.028 | |
| | | | | | | | 4.000 | 0.006 | 0.002 | 3.850 | 0.004 | | 0.025 |
| | 49.500 | 93.800 | 51.900 | 64.400 | 97.800 | 2.200 | | | | | | 0.022 | |
| | | | | | | | 18.000 | 0.017 | 0.001 | 3.850 | 0.000 | | 0.014 |
| 20:8:87 | 67.500 | 92.200 | 53.500 | 63.300 | 99.500 | 0.500 | | | | | | 0.005 | |

## Table 7 - Various size copra drying test data

| DAY | TIME | WT. | LOSS WT. | % I.WT. | % D.M. | % H2O | ΔT | ΔX | ΔX/ΔT | LS/A | R | X | AVE.X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17:8:87 12:30PM | 0.000 | 561.600 | 0.000 | 100.000 | 63.000 | 37.000 | | | | | | 0.590 | |
| | | | | | | | 0.500 | 0.164 | 0.330 | 3.420 | 1.130 | | 0.510 |
| | 0.500 | 503.800 | 57.800 | 89.700 | 70.200 | 29.900 | | | | | | 0.426 | |
| | | | | | | | 0.500 | 0.056 | 0.112 | 3.420 | 0.380 | | 0.400 |
| | 1.000 | 484.500 | 77.100 | 86.300 | 73.000 | 27.000 | | | | | | 0.370 | |
| | | | | | | | 0.750 | 0.056 | 0.075 | 3.420 | 0.260 | | 0.340 |
| | 1.750 | 484.800 | 96.800 | 82.800 | 76.100 | 23.900 | | | | | | 0.314 | |
| | | | | | | | 0.750 | 0.042 | 0.060 | 3.420 | 0.180 | | 0.290 |
| | 2.500 | 450.400 | 111.200 | 80.200 | 78.600 | 21.400 | | | | | | 0.272 | |
| | | | | | | | 0.500 | 0.030 | 0.060 | 3.420 | 0.180 | | 0.250 |
| | 3.200 | 439.100 | 122.500 | 78.200 | 80.500 | 19.500 | | | | | | 0.242 | |
| | | | | | | | 0.500 | 0.019 | 0.040 | 3.420 | 0.140 | | 0.230 |
| | 3.500 | 432.500 | 129.100 | 77.000 | 81.800 | 18.200 | | | | | | 0.233 | |
| | | | | | | | 16.500 | 0.162 | 0.010 | 3.420 | 0.030 | | 0.140 |
| 18:8:87 8:30AM | 20.000 | 375.100 | 186.500 | 66.800 | 94.300 | 5.700 | | | | | | 0.060 | |
| | | | | | | | 0.500 | 0.003 | 0.006 | 3.420 | 0.020 | | 0.059 |
| | 20.500 | 374.000 | 187.600 | 66.600 | 94.600 | 5.400 | | | | | | 0.057 | |
| | | | | | | | 0.500 | 0.002 | 0.004 | 3.420 | 0.010 | | 0.056 |
| | 21.000 | 373.300 | 188.300 | 66.500 | 94.800 | 5.200 | | | | | | 0.055 | |
| | | | | | | | 0.500 | 0.002 | 0.004 | 3.420 | 0.010 | | 0.054 |
| | 21.500 | 372.800 | 188.800 | 66.400 | 95.000 | 5.000 | | | | | | 0.053 | |
| | | | | | | | 1.000 | 0.003 | 0.004 | 3.420 | 0.010 | | 0.051 |
| | 22.500 | 371.000 | 190.600 | 66.000 | 95.300 | 4.700 | | | | | | 0.049 | |
| | | | | | | | 1.000 | 0.003 | 0.003 | 3.420 | 0.010 | | 0.048 |
| | 23.500 | 369.800 | 191.800 | 65.800 | 95.600 | 4.400 | | | | | | 0.046 | |
| | | | | | | | 2.000 | 0.005 | 0.002 | 3.420 | 0.007 | | 0.044 |
| | 25.500 | 367.500 | 196.300 | 65.600 | 96.300 | 3.700 | | | | | | 0.041 | |
| | | | | | | | 2.000 | 0.003 | 0.002 | 3.420 | 0.007 | | 0.039 |
| | 27.500 | 365.600 | 196.000 | 65.100 | 96.800 | 3.200 | | | | | | 0.038 | |
| | | | | | | | 16.000 | 0.038 | 0.002 | 3.420 | 0.007 | | 0.090 |
| 19:8:87 8:00AM | 43.500 | 347.600 | 214.000 | 61.900 | 100.000 | 0.000 | | | | | | 0.000 | |
| | | | | | | | 2.000 | 0.000 | 0.000 | 3.420 | 0.000 | | 0.000 |
| | 45.500 | 340.200 | 221.400 | 60.600 | 0.000 | 0.000 | | | | | | 0.000 | |
| | | | | | | | 4.000 | 0.000 | 0.000 | 3.420 | 0.000 | | 0.000 |
| | 49.500 | 339.000 | 222.600 | 60.400 | 0.000 | 0.000 | | | | | | 0.000 | |
| | | | | | | | 18.000 | 0.000 | 0.000 | 3.420 | 0.000 | | |
| 20:8:87 | 67.500 | 335.000 | 226.600 | 59.600 | 0.000 | 0.000 | | | | | | 0.000 | |

**Table 8 - Capeline fish drying test data, 1A**

SAMPLE-1A

| DAY | TIME | WT. | LOSS WT. | % I.WT. | % D.M. | % H20 | T | X | X/ T | LS/A | R | X | AVE.X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20:8:87 | 0.000 | 780.000 | 0.000 | 100.000 | 18.200 | 81.800 | | | | | | 4.490 | |
| 10:00AM | | | | | | | 1.000 | 0.770 | 0.770 | 2.090 | 1.610 | | 4.100 |
| | 1.000 | 670.000 | 110.000 | 86.000 | 21.200 | 78.800 | | | | | | 3.720 | |
| | | | | | | | 1.000 | 0.350 | 0.350 | 2.090 | 0.730 | | 3.500 |
| | 2.000 | 620.000 | 160.000 | 79.500 | 22.900 | 77.100 | | | | | | 3.370 | |
| | | | | | | | 2.000 | 0.350 | 0.180 | 2.090 | 0.380 | | 3.200 |
| | 4.000 | 570.000 | 210.000 | 73.000 | 24.900 | 75.100 | | | | | | 3.020 | |
| | | | | | | | 2.000 | 0.360 | 0.180 | 2.090 | 0.380 | | 2.840 |
| | 6.000 | 520.000 | 260.000 | 66.700 | 27.300 | 72.700 | | | | | | 2.660 | |
| | | | | | | | 16.000 | 1.060 | 0.070 | 2.090 | 0.150 | | 2.130 |
| 21:8:87 | 22.000 | 370.000 | 410.000 | 47.400 | 38.400 | 61.600 | | | | | | 1.600 | |
| 8:00AM | | | | | | | 5.000 | 0.140 | 0.020 | 2.090 | 0.040 | | 1.530 |
| 1:00PM | 27.000 | 350.000 | 430.000 | 44.900 | 40.600 | 59.400 | | | | | | 1.460 | |
| | | | | | | | 68.000 | 0.910 | 0.010 | 2.090 | 0.020 | | 1.010 |
| 24:8:87 | 95.000 | 220.000 | 560.000 | 28.200 | 64.500 | 35.500 | | | | | | 0.550 | |
| 9:00AM | | | | | | | 47.000 | 0.070 | 0.001 | 2.090 | 0.002 | | 0.520 |
| 26:8:87 | 142.000 | 210.000 | 570.000 | 26.900 | 67.600 | 32.400 | | | | | | 0.480 | |
| 8:00AM | | | | | | | | | | | | | |

Table 9 - Capeline fish drying test data, 1B

SAMPLE-1B

| DAY | TIME | WT. | LOSS WT. | % I.WT. | % D.M. | % H2O | T | X | X/ T | LS/A | R | X | AVE.X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20:8:87 10:00AM | 0.000 | 720.000 | 0.000 | 100.000 | 18.200 | 81.800 | | | | | | 4.490 | |
| | | | | | | | 1.000 | 0.690 | 0.690 | 2.080 | 1.440 | | 4.150 |
| | 1.000 | 630.000 | 90.000 | 87.500 | 20.800 | 79.200 | | | | | | 3.810 | |
| | | | | | | | 1.000 | 0.460 | 0.460 | 2.080 | 0.960 | | 3.580 |
| | 2.000 | 570.000 | 150.000 | 79.200 | 23.000 | 77.000 | | | | | | 3.350 | |
| | | | | | | | 2.000 | 0.380 | 0.190 | 2.080 | 0.400 | | 3.160 |
| | 4.000 | 520.000 | 200.000 | 72.200 | 25.200 | 74.800 | | | | | | 2.970 | |
| | | | | | | | 2.000 | 0.370 | 0.190 | 2.080 | 0.380 | | 2.800 |
| | 6.000 | 470.000 | 250.000 | 65.300 | 27.900 | 72.100 | | | | | | 2.600 | |
| | | | | | | | 16.000 | 1.080 | 0.070 | 2.080 | 0.150 | | 2.060 |
| 21:8:87 8:00AM | 22.000 | 330.000 | 390.000 | 45.800 | 39.700 | 60.300 | | | | | | 1.520 | |
| | | | | | | | 5.000 | 0.160 | 0.030 | 2.080 | 0.060 | | 1.440 |
| 1:00PM | 27.000 | 310.000 | 410.000 | 43.100 | 42.300 | 57.700 | | | | | | 1.360 | |
| | | | | | | | 68.000 | 0.830 | 0.010 | 2.080 | 0.020 | | 0.940 |
| 24:8:87 8:00AM | 95.000 | 200.000 | 520.000 | 27.800 | 65.500 | 34.500 | | | | | | 0.530 | |
| | | | | | | | 47.000 | 0.000 | 0.000 | 2.080 | 0.000 | | 0.530 |
| 26:8:87 8:00AM | 142.000 | 200.000 | 520.000 | 27.800 | 65.500 | 34.500 | | | | | | 0.530 | |

**Table 10 - Capeline fish drying test data, 2A**

SAMPLE-2A

| DAY | TIME | WT. | LOSS WT. | % I.WT. | % D.M. | % H20 | T | X | X/ T | LS/A | R | X | AVE.X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20:8:87 | 0.000 | 1400.000 | 0.000 | 0.000 | 18.200 | 81.800 | | | | | | 4.490 | |
| 10:00AM | | | | | | | 1.000 | 0.540 | 0.540 | 2.090 | 1.130 | | 4.220 |
| | 1.000 | 1260.000 | 140.000 | 90.000 | 20.200 | 79.800 | | | | | | 3.950 | |
| | | | | | | | 1.000 | 0.360 | 0.360 | 2.090 | 0.750 | | 3.770 |
| | 2.000 | 1170.000 | 230.000 | 83.600 | 21.800 | 78.200 | | | | | | 3.590 | |
| | | | | | | | 2.000 | 0.470 | 0.240 | 2.090 | 0.490 | | 3.400 |
| | 4.000 | 1050.000 | 350.000 | 75.000 | 24.300 | 75.700 | | | | | | 3.120 | |
| | | | | | | | 2.000 | 0.320 | 0.160 | 2.090 | 0.330 | | 3.000 |
| | 6.000 | 970.000 | 430.000 | 69.300 | 26.300 | 73.700 | | | | | | 2.800 | |
| | | | | | | | 16.000 | 1.050 | 0.070 | 2.090 | 0.150 | | 2.300 |
| 21:8:87 | 22.000 | 700.000 | 700.000 | 50.000 | 36.400 | 63.600 | | | | | | 1.750 | |
| 8:00AM | | | | | | | 5.000 | 0.200 | 0.030 | 2.090 | 0.060 | | 1.650 |
| 1:00PM | 27.000 | 650.000 | 750.000 | 46.400 | 39.200 | 60.800 | | | | | | 1.550 | |
| | | | | | | | 68.000 | 0.900 | 0.010 | 2.090 | 0.020 | | 1.100 |
| 24:8:87 | 95.000 | 420.000 | 980.000 | 30.000 | 60.700 | 39.300 | | | | | | 0.650 | |
| 8:00AM | | | | | | | 47.000 | 0.080 | 0.002 | 2.090 | 0.004 | | 0.610 |
| 26:8:87 | 142.000 | 400.000 | 1000.000 | 28.600 | 63.700 | 36.300 | | | | | | 0.570 | |

Table 11 - Capeline fish drying test data, 2b

SAMPLE-2B

| DAY | TIME | WT. | LOSS WT | % I.WT. | % D.M. | % H2O | T | X | X/ T | LS/A | R | X | AVE.X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20:8:87 | 0.000 | 1470.000 | 0.000 | 100.000 | 18.200 | 81.800 | | | | | | 4.490 | |
| 10:00AM | | | | | | | 1.000 | 0.490 | 0.490 | 2.090 | 1.020 | | 4.240 |
| | 1.000 | 1340.000 | 130.000 | 91.200 | 20.000 | 80.000 | | | | | | 4.000 | |
| | | | | | | | 1.000 | 0.370 | 0.370 | 2.090 | 0.770 | | 3.820 |
| | 2.000 | 1240.000 | 230.000 | 84.400 | 21.600 | 78.400 | | | | | | 3.630 | |
| | | | | | | | 2.000 | 0.450 | 0.225 | 2.090 | 0.470 | | 3.410 |
| | 4.000 | 1120.000 | 350.000 | 76.200 | 23.900 | 76.100 | | | | | | 3.180 | |
| | | | | | | | 2.000 | 0.290 | 0.145 | 2.090 | 0.300 | | 3.040 |
| | 6.000 | 1040.000 | 430.000 | 70.700 | 25.700 | 74.300 | | | | | | 2.890 | |
| | | | | | | | 16.000 | 1.010 | 0.067 | 2.090 | 0.140 | | 2.400 |
| 21:8:87 | 22.000 | 770.000 | 700.000 | 52.400 | 34.700 | 65.300 | | | | | | 1.880 | |
| 8:00AM | | | | | | | 5.000 | 0.260 | 0.043 | 2.090 | 0.090 | | 1.750 |
| 1:00PM | 27.000 | 700.000 | 770.000 | 47.600 | 38.200 | 61.800 | | | | | | 1.620 | |
| | | | | | | | 68.000 | 0.940 | 0.014 | 2.090 | 0.030 | | 1.150 |
| 24:8:87 | 95.000 | 450.000 | 1020.000 | 30.600 | 59.400 | 40.600 | | | | | | 0.680 | |
| 9:00AM | | | | | | | 47.000 | 0.070 | 0.002 | 2.090 | 0.004 | | 0.645 |
| 26:8:87 | 142.000 | 430.000 | 1040.000 | 29.200 | 62.200 | 37.800 | | | | | | 0.610 | |
| 8:00AM | | | | | | | | | | | | | |

Table 12 - Capeline fish drying test data, 3

SAMPLE-3

| DAY | TIME | WT. | LOSS WT | % I.WT. | % D.M. | % H2O | T | X | X/ T | LS/A | R | X | AVE.X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20:8:87 | 0.000 | 2660.000 | 0.000 | 100.000 | 18.200 | 81.800 | | | | | | 4.490 | |
| 10:00AM | | | | | | | 1.000 | 0.410 | 0.410 | 2.090 | 0.860 | | 4.300 |
| | 1.000 | 2460.000 | 200.000 | 92.500 | 19.700 | 80.300 | | | | | | 4.080 | |
| | | | | | | | 1.000 | 0.340 | 0.340 | 2.090 | 0.710 | | 3.900 |
| | 2.000 | 2290.000 | 370.000 | 86.100 | 21.100 | 78.900 | | | | | | 3.740 | |
| | | | | | | | 2.000 | 0.450 | 0.225 | 2.090 | 0.470 | | 3.500 |
| | 4.000 | 2080.000 | 580.000 | 78.200 | 23.300 | 76.700 | | | | | | 3.290 | |
| | | | | | | | 2.000 | 0.390 | 0.195 | 2.090 | 0.410 | | 3.100 |
| | 6.000 | 1890.000 | 770.000 | 71.100 | 25.600 | 74.400 | | | | | | 2.900 | |
| | | | | | | | 16.000 | 1.180 | 0.080 | 2.090 | 0.170 | | 2.300 |
| 21:8:87 | 22.000 | 1320.000 | 1340.000 | 50.400 | 36.700 | 63.300 | | | | | | 1.720 | |
| 8:00AM | | | | | | | 5.000 | 0.200 | 0.030 | 2.090 | 0.060 | | 1.600 |
| 1:00PM | 27.000 | 1220.000 | 1440.000 | 45.900 | 39.700 | 60.300 | | | | | | 1.520 | |
| | | | | | | | 68.000 | 0.910 | 0.010 | 2.090 | 0.020 | | 1.100 |
| 24:8:87 | 95.000 | 780.000 | 1880.000 | 29.300 | 62.100 | 37.900 | | | | | | 0.610 | |
| 9:00AM | | | | | | | 47.000 | 0.060 | 0.001 | 2.090 | 0.002 | | 0.600 |
| 26:8:87 | 142.000 | 750.000 | 1910.000 | 28.200 | 64.500 | 35.500 | | | | | | 0.550 | |
| 8:00AM | | | | | | | | | | | | | |

**Table 13 - Typical types of fan. Matley et al, 1979.**

**Typical Industrial Applications for the Various Types of Fans**

| Application | Type of Fan | | | | | |
|---|---|---|---|---|---|---|
| | Tube-Axial | Vane-Axial | Radial | Forward-Curved | Backward-Inclined | Airfoil |
| Conveying systems | | | X | | X | |
| Supplying air for oil and gas burners or combustion furnaces | X | X | X | X | X | X |
| Boosting gas pressures | | | X | | X | X |
| Ventilating process plants | X | X | | | X | X |
| Boilers, forced-draft | | X | | | X | X |
| Boilers, induced-draft | | | X | X | | |
| Kiln exhaust | | | X | X | | |
| Kiln supply | | X | | | X | X |
| Cooling towers | X | | | | | |
| Dust collectors and electrostatic precipitators | | | X | X | | |
| Process drying | X | X | X | | X | X |
| Reactor off-gases or stack emissions | | | X | X | | |

Figure 1 - Agro-Industrial complex geothermal process

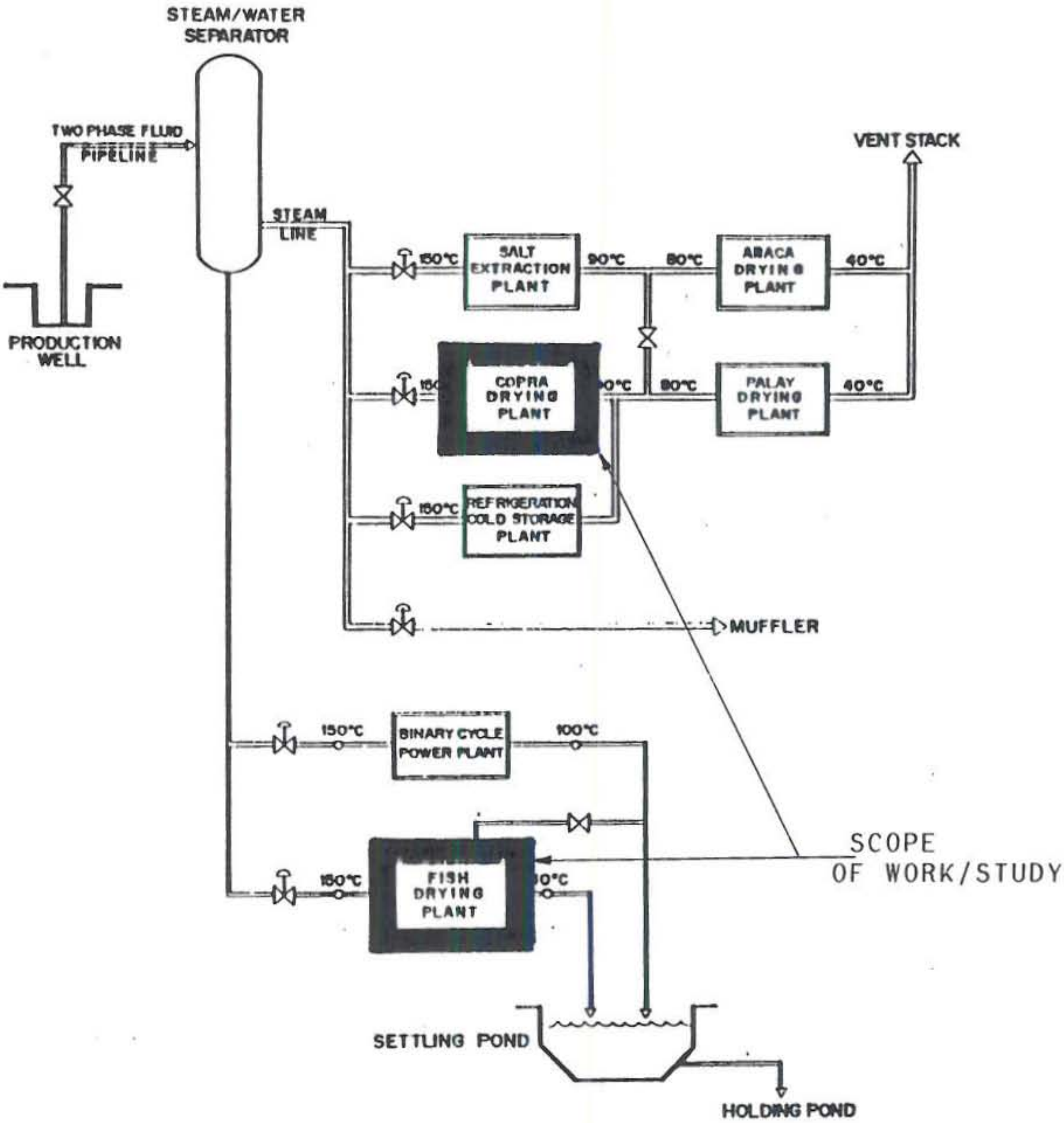


**Figure 2 - Generalized deterioration reaction in food**

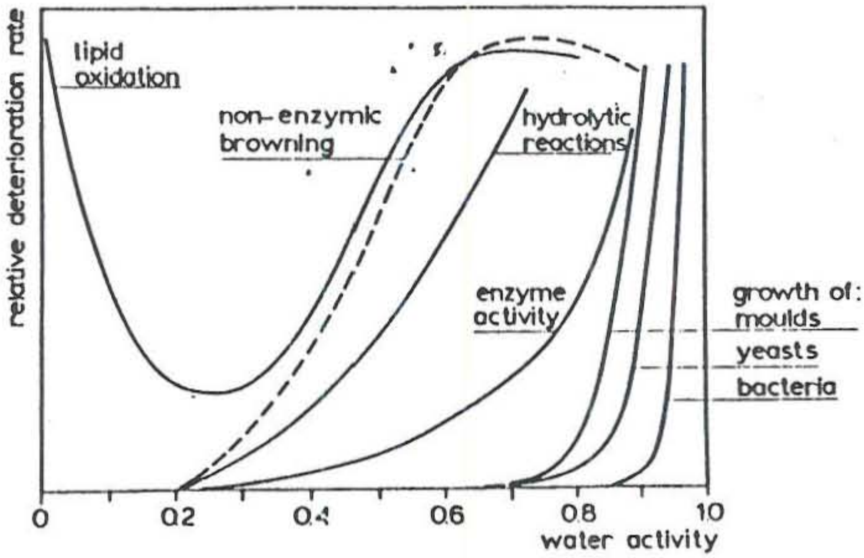



Figure 2 - Generalized deterioration reaction rates in food. Fennema, (1976) and Heiss & Eichner (1971).

Figure 3 - Types of copra drying kiln

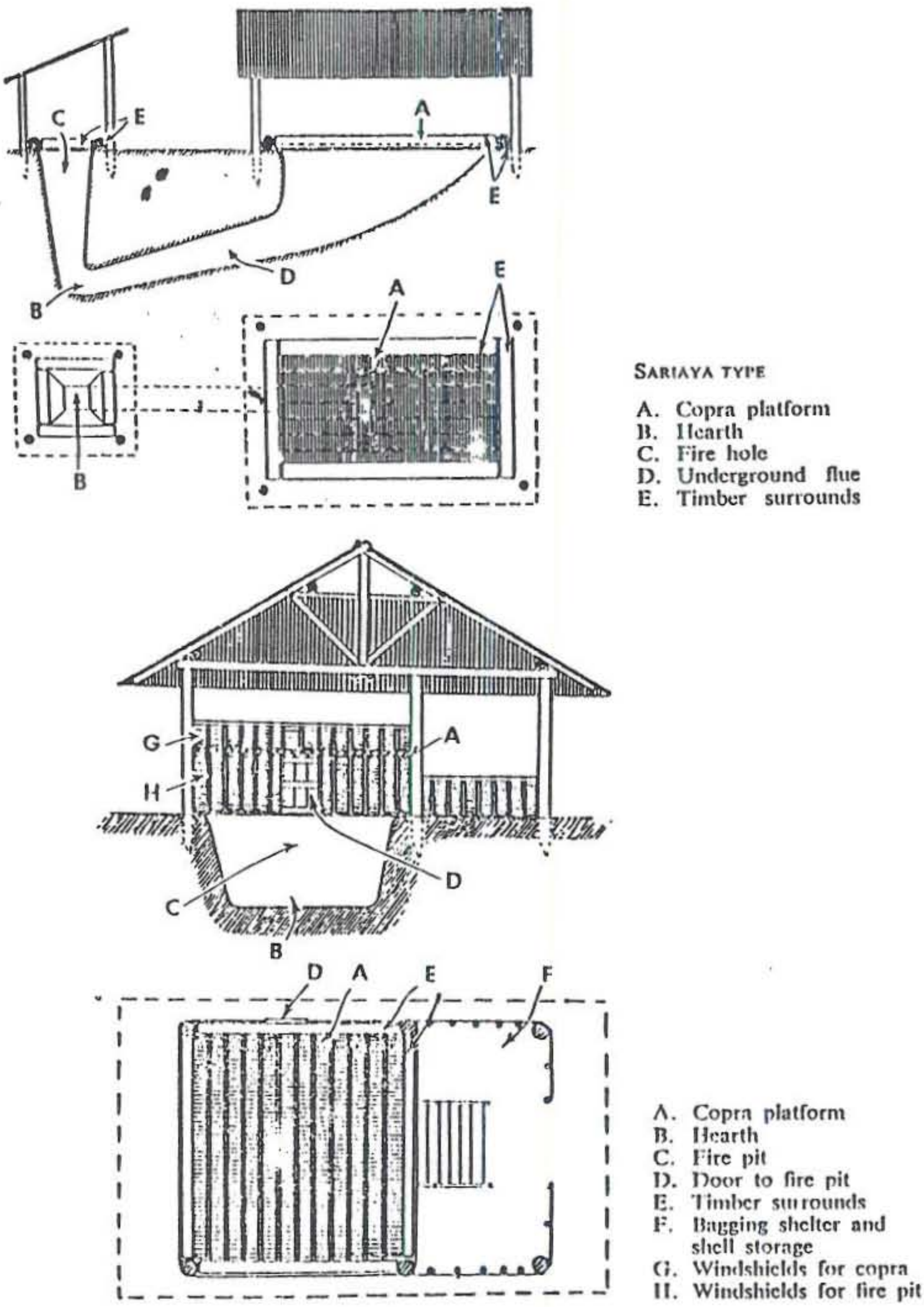



Figure 3 - Types of copra drying kiln in Luzon, Philippines.
Cooke, (1936) and Grimwood, (1975).

**Figure 4 - The New College copra drier**

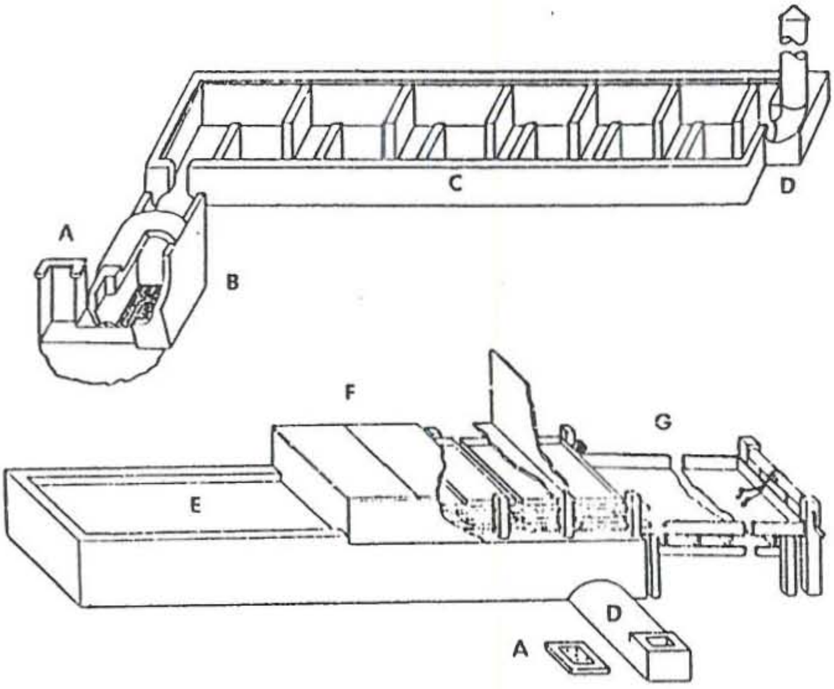



Figure 4 - The New College copra drier of the Philippines. Kalaw, (1930) and Grimwood, (1975).

Figure 5 - Conventional circulating air dryer with PCHP energy saving system

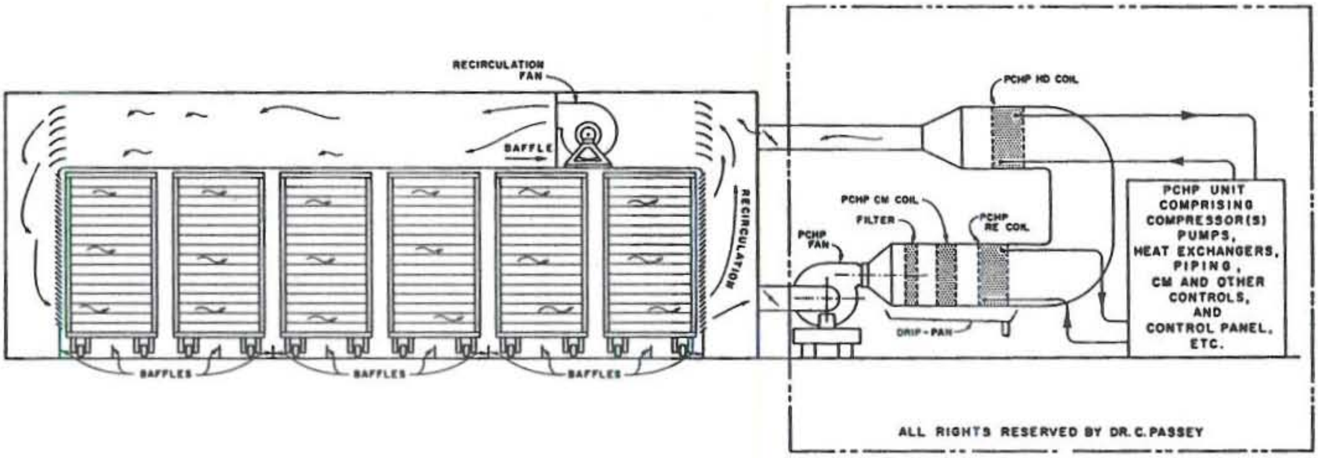



Figure 5 - Conventional circulating air dryer built with PCHP energy saving system. Mujumdar, (1980).

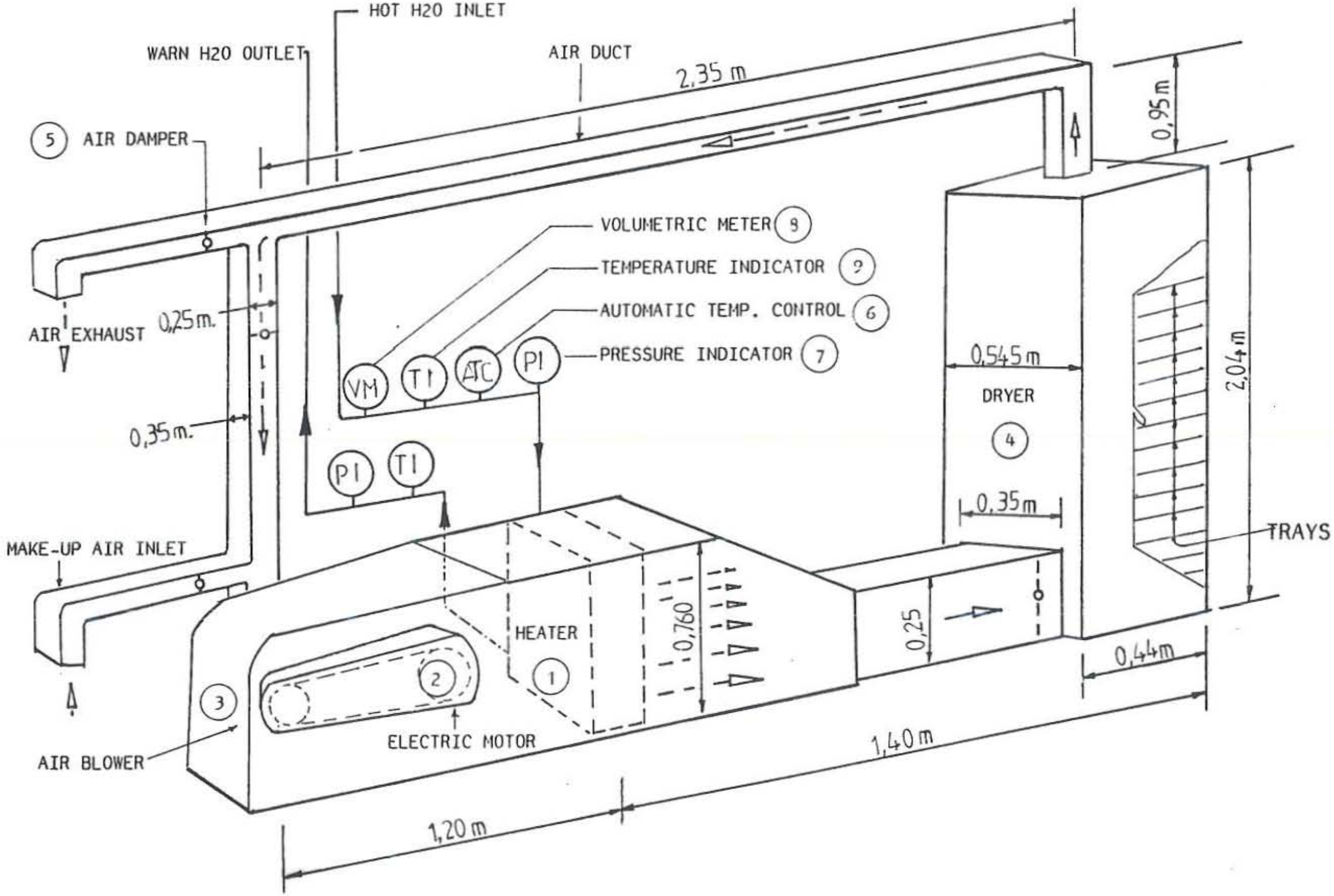



Figure 6 - Schematic diagram of pilot test dryer

Figure 7 - Drying process flowsheet of copra

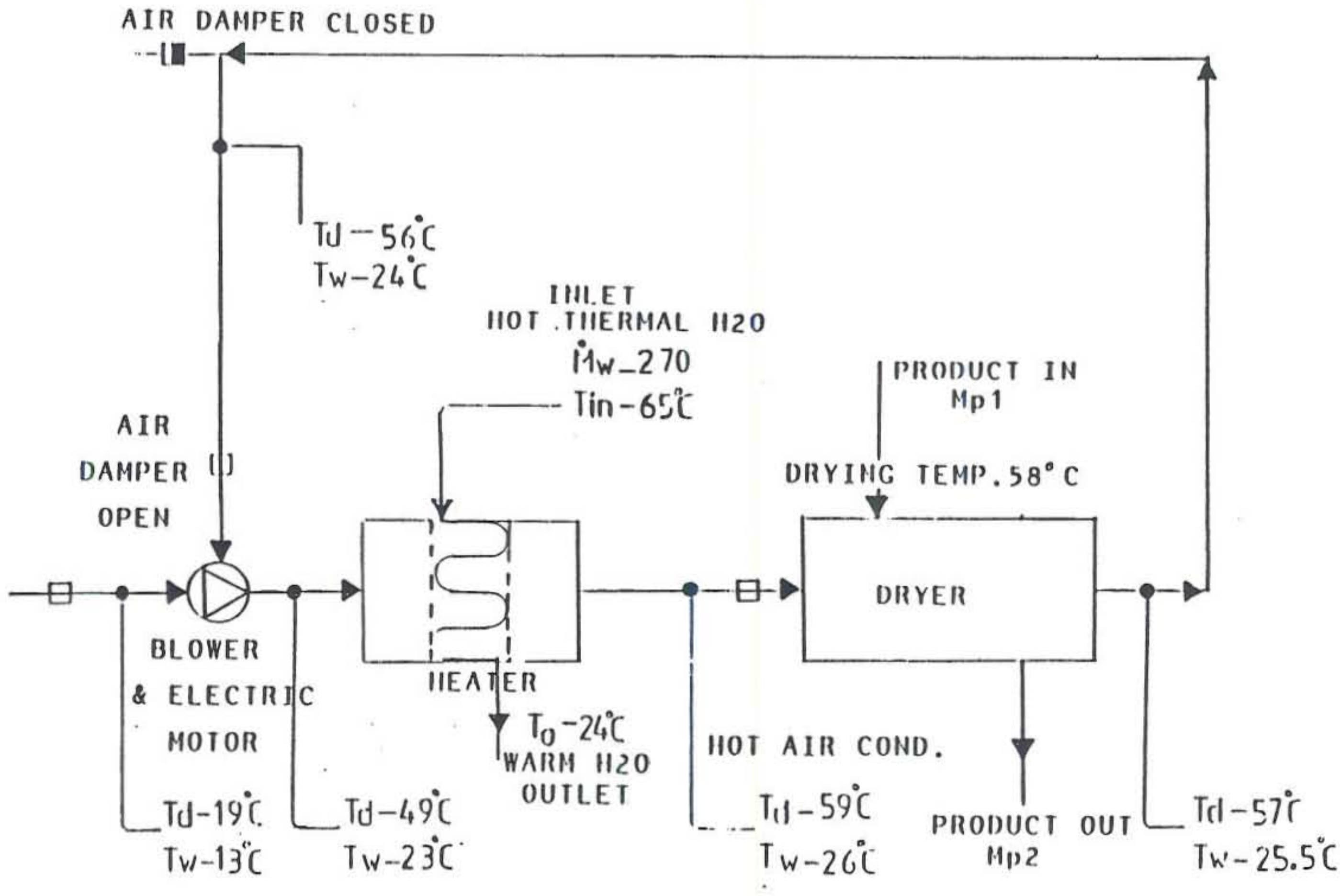


Figure 8 - Drying process flowsheet of capeline fish

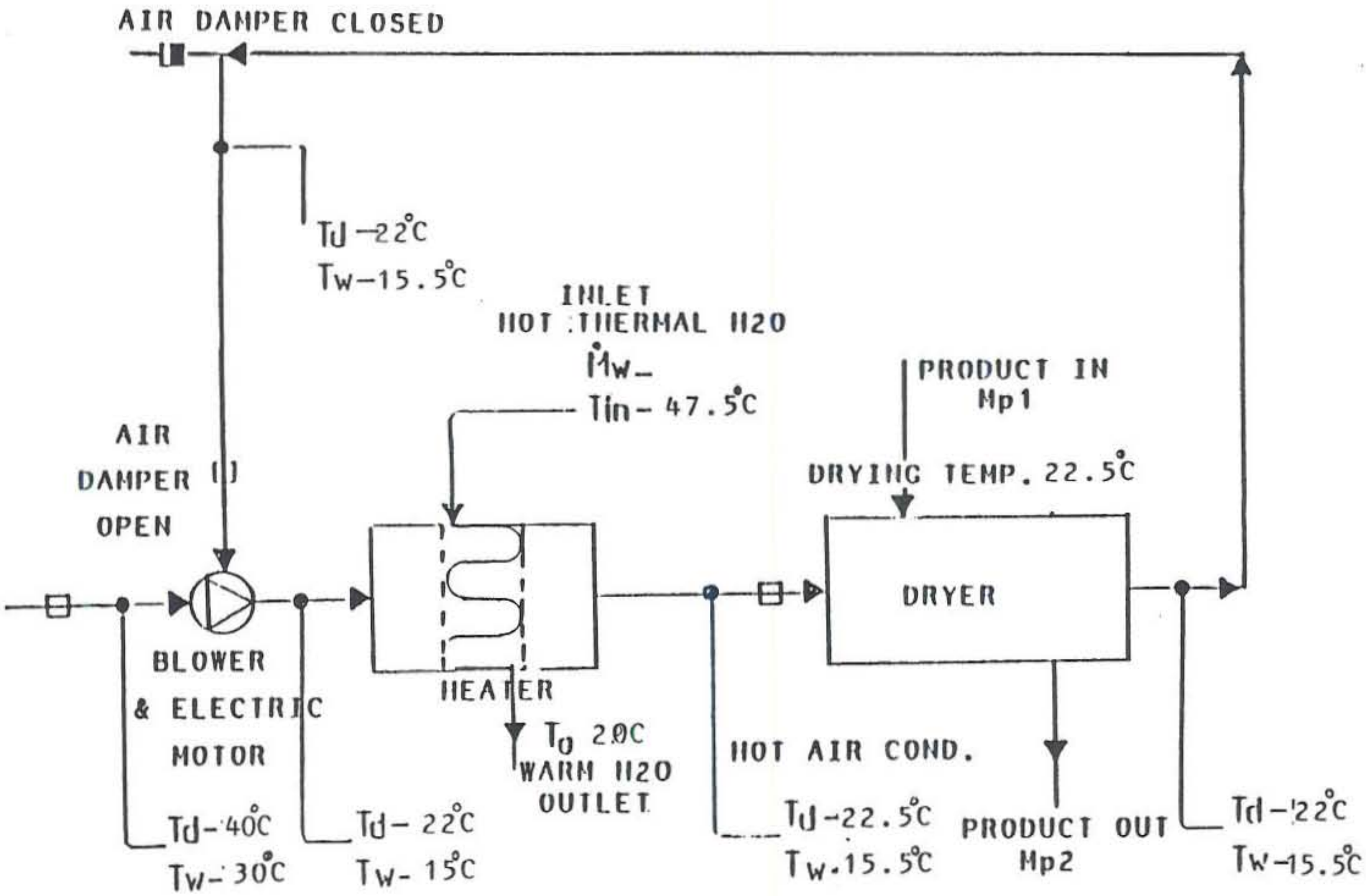


Figure 9 - Drying rate curve for constant drying

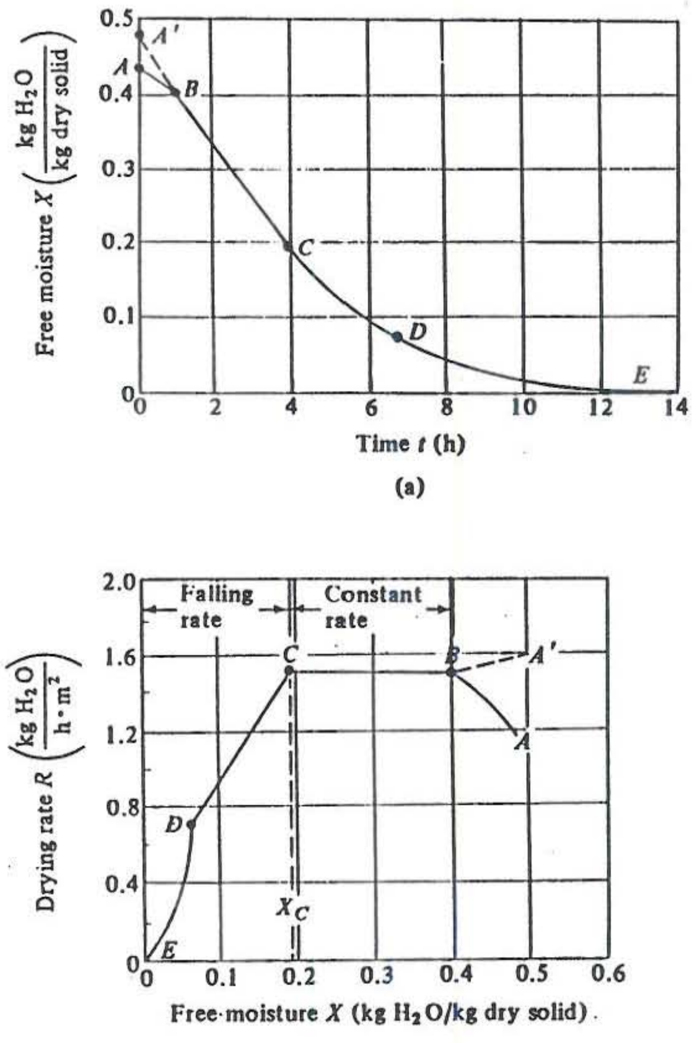



Figure 9 - Drying-rate curve for constant drying condition.
Geankoplis, (1983).

**Figure 10 - Copra drying rate curve**

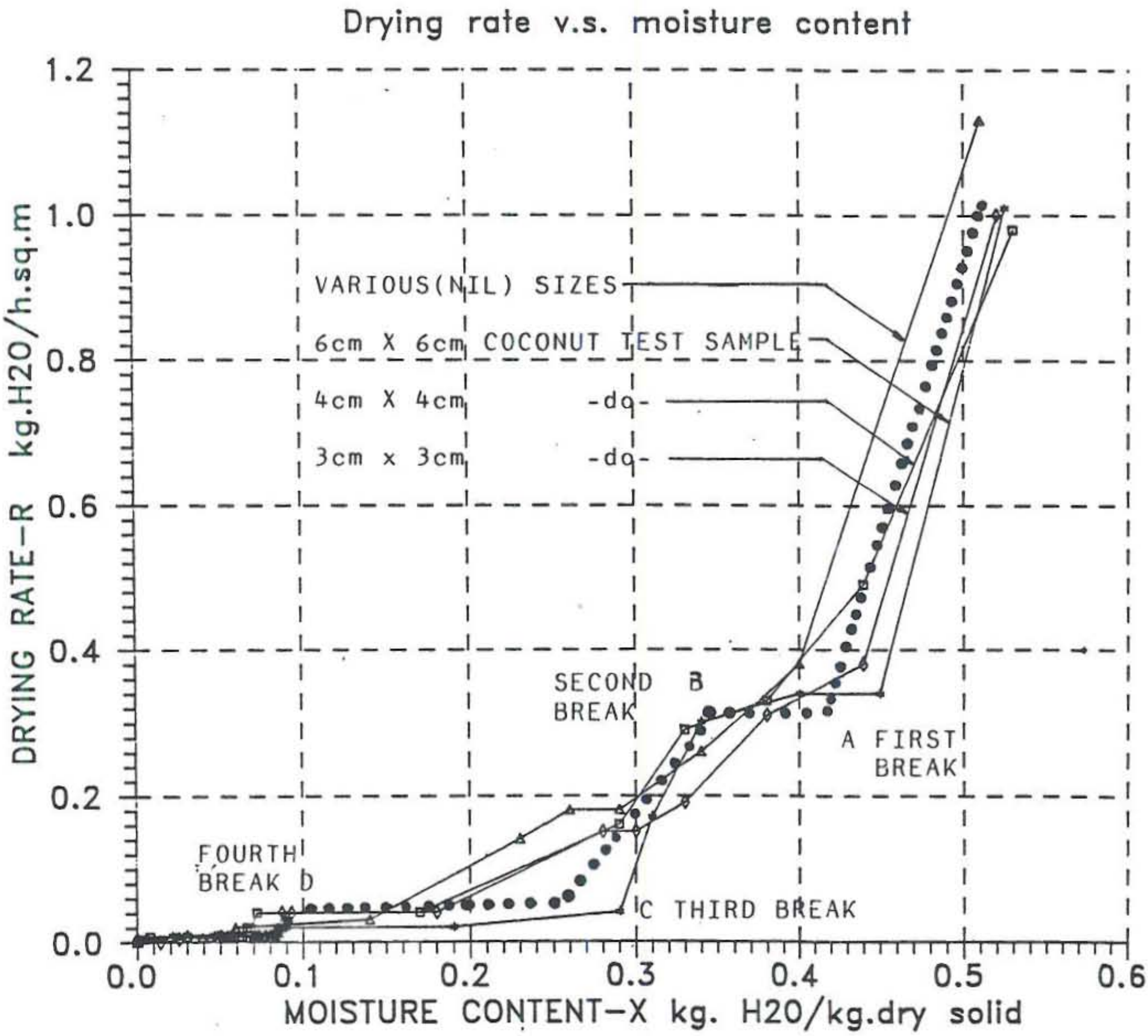


Figure 11 - Capeline fish drying rate curve

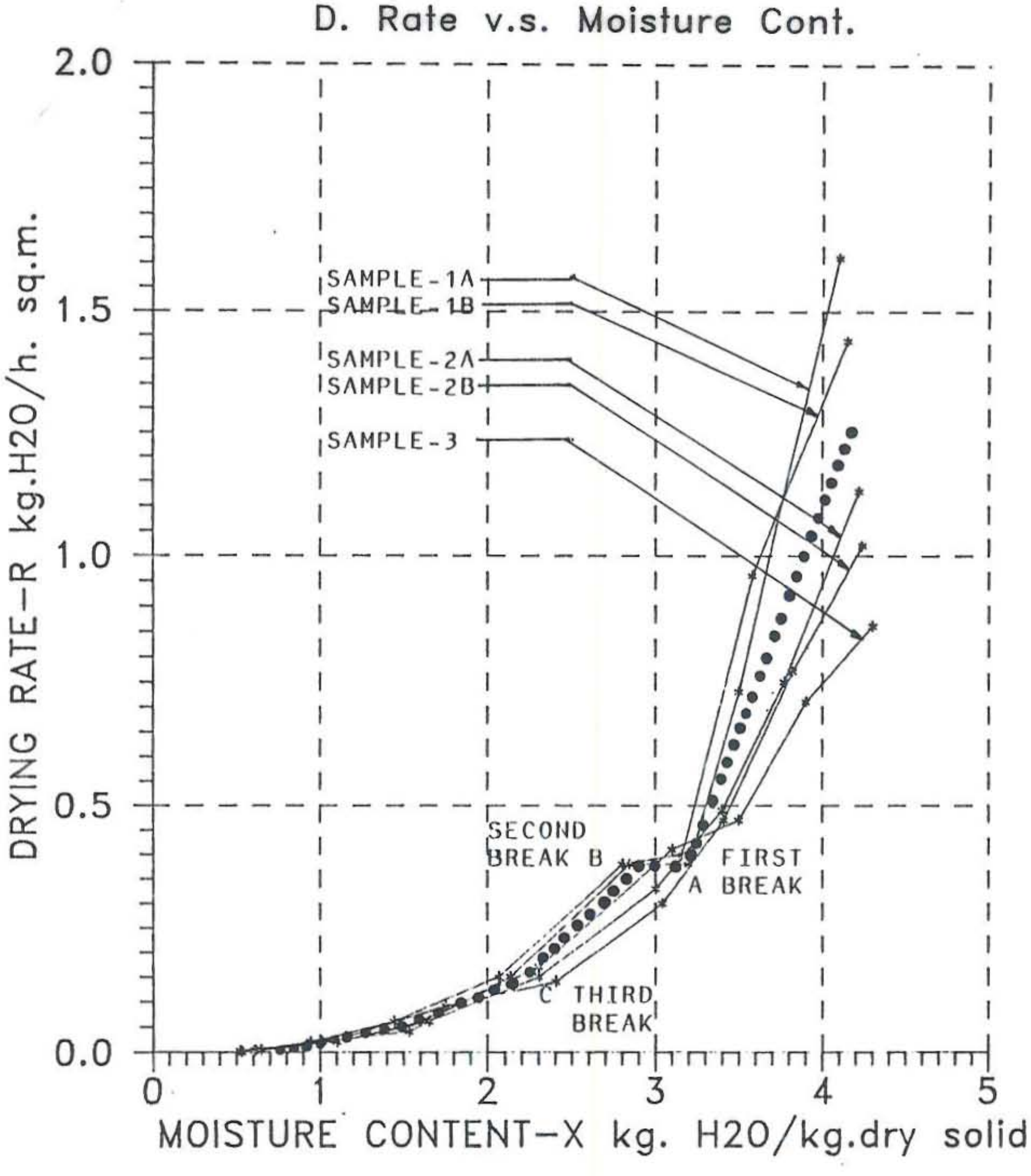
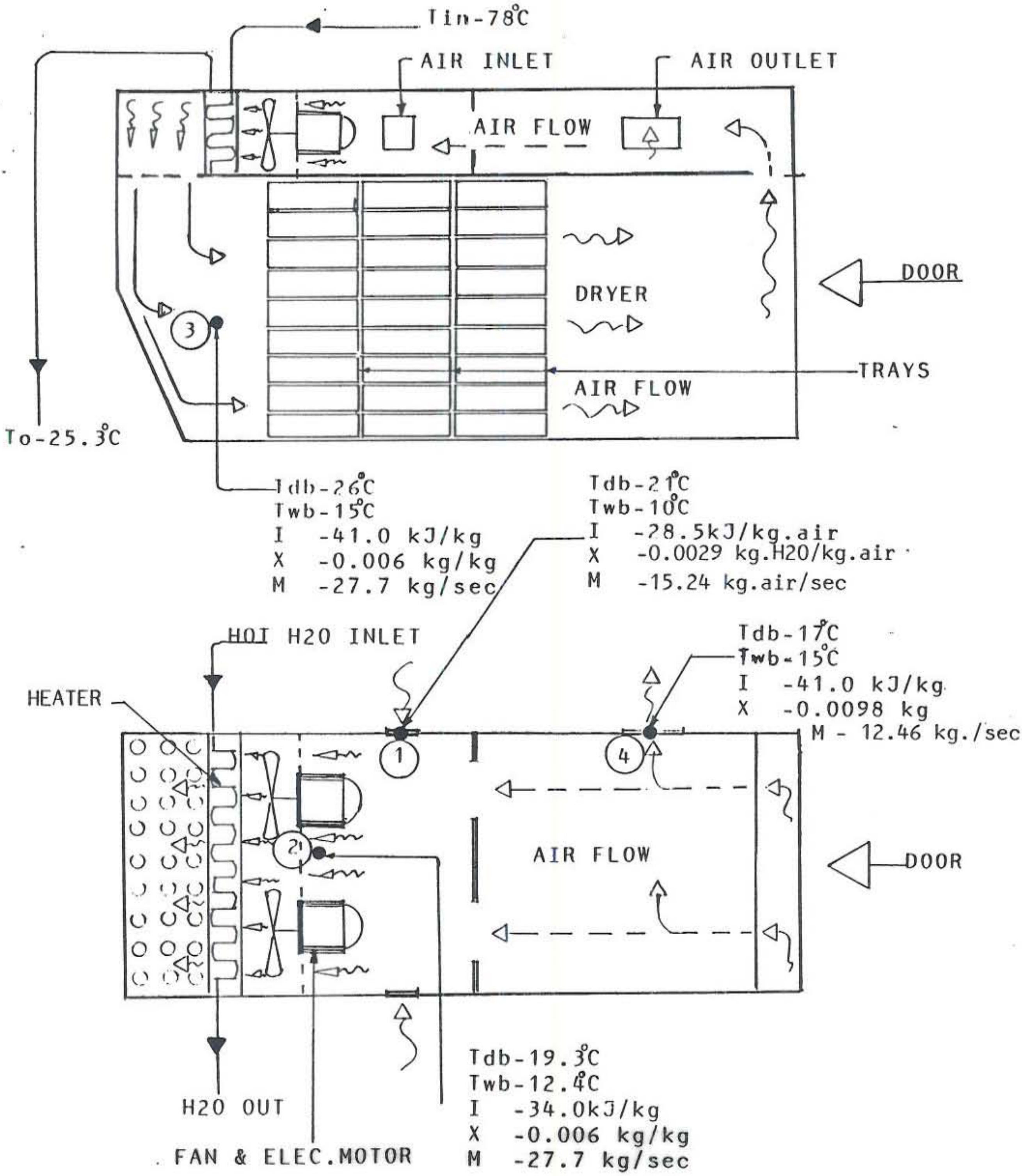


**Figure 12 - Mass/energy balance of commercial fish dryer**



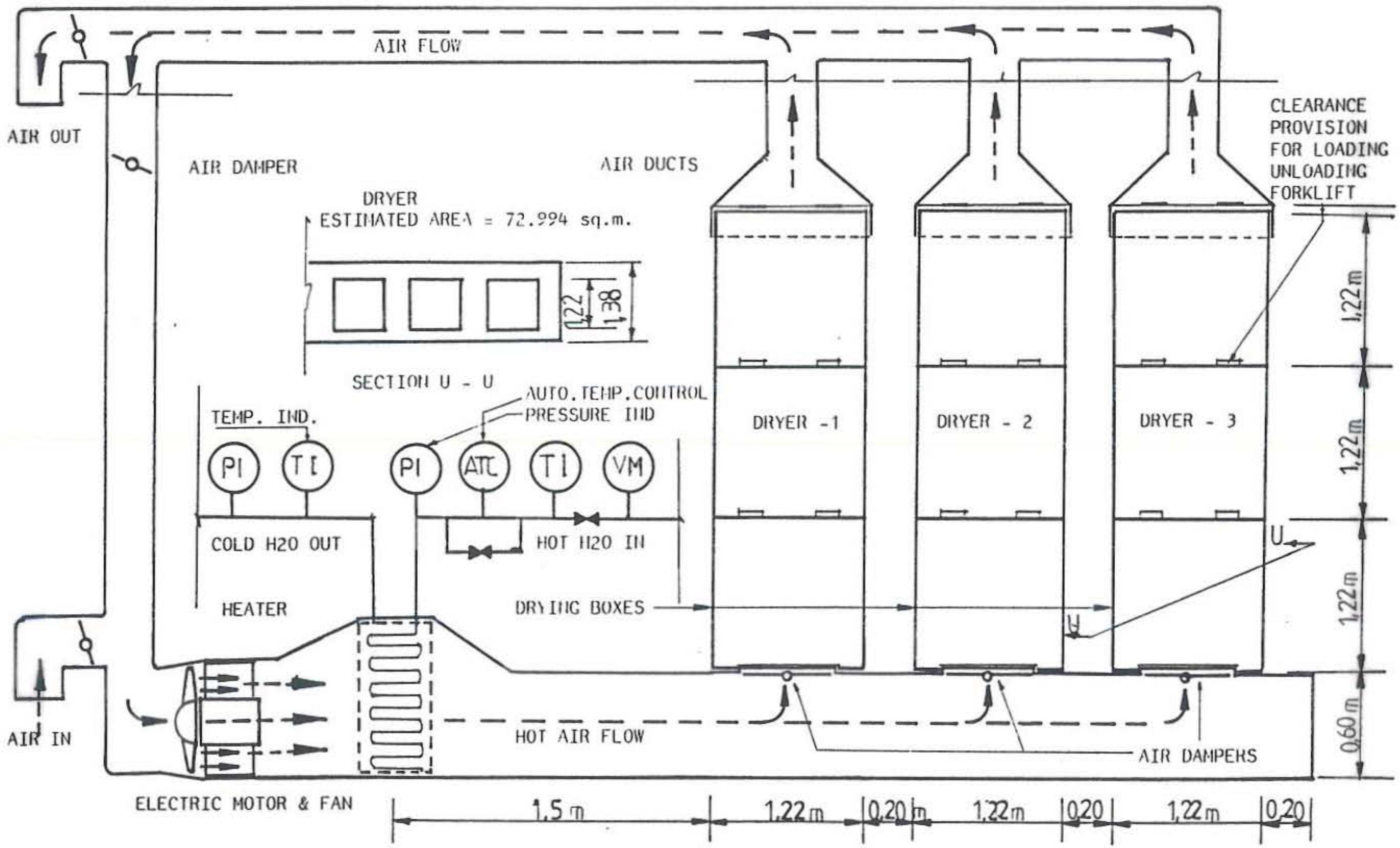



Figure 13 - Diagrammatic scheme of copra dryer design

**Figure 14 - Catalog for fan sizing and selection**

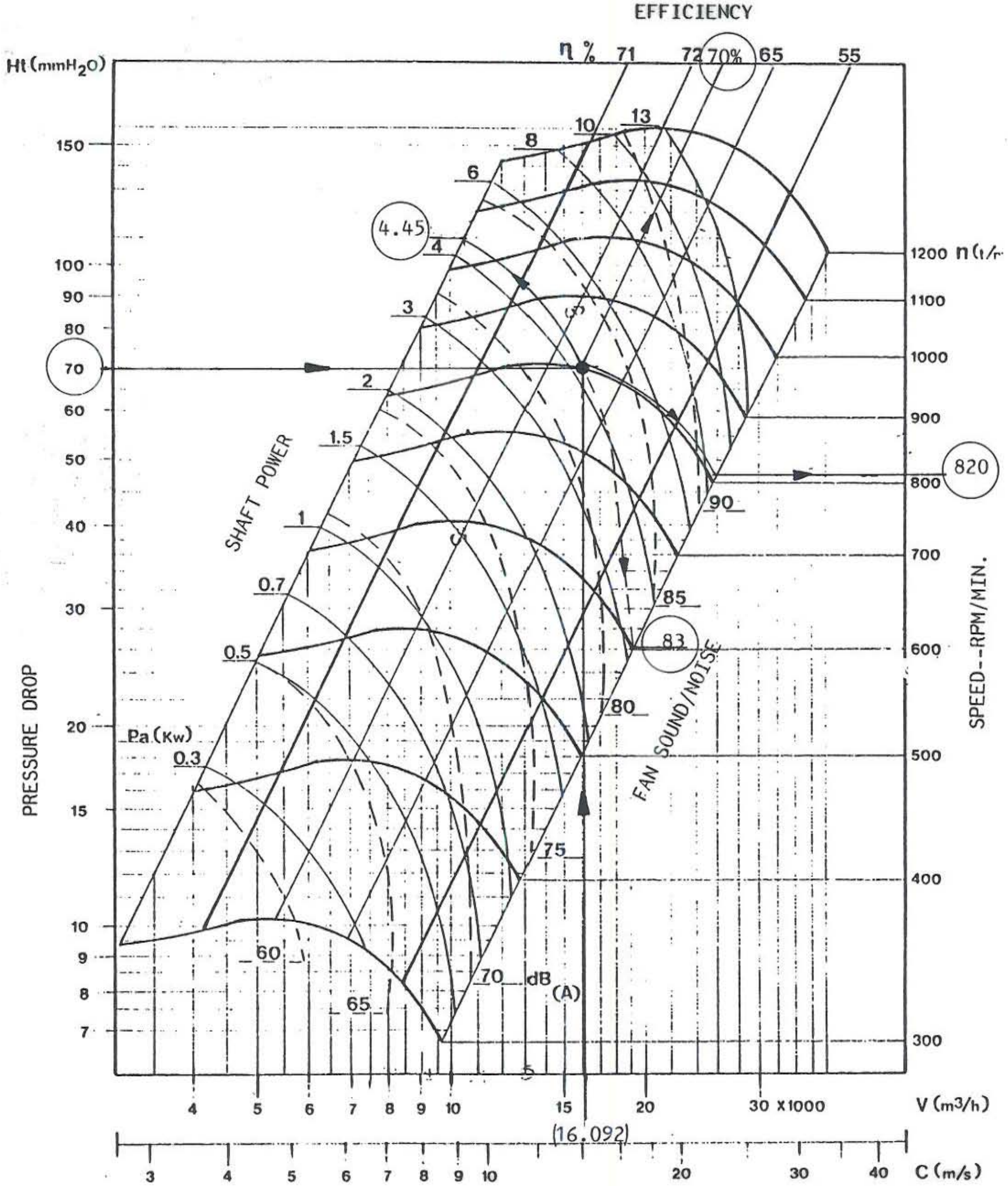



**Figure 14 - Manufacturer guide for fan sizing and selection. Aertermica Nicotra spa catalog.**

**Figure 15 - Copra moisture content curve**

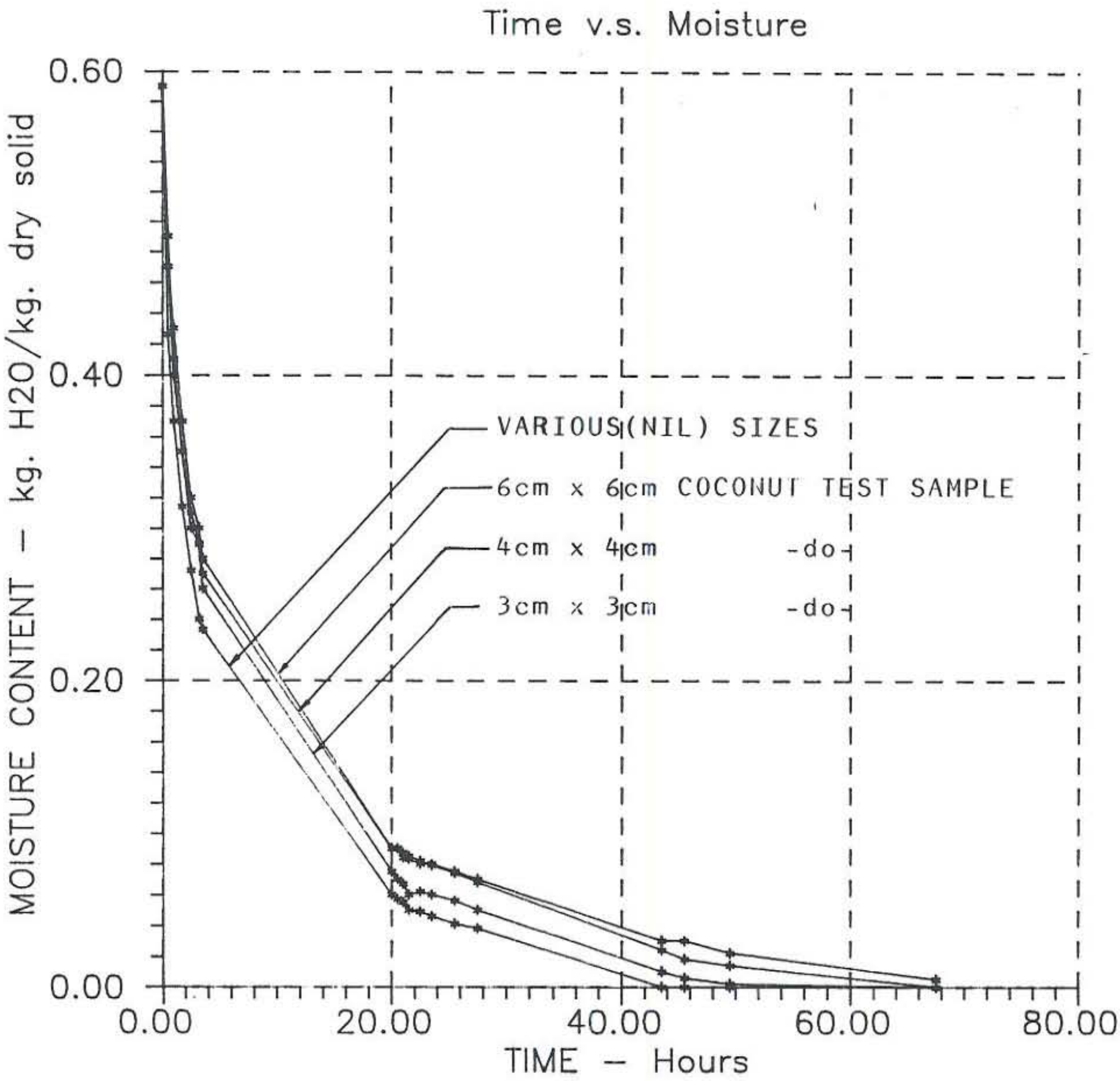


Figure 16 - Effect of size in course of drying

FACTORS INFLUENCING RATE OF DRYING

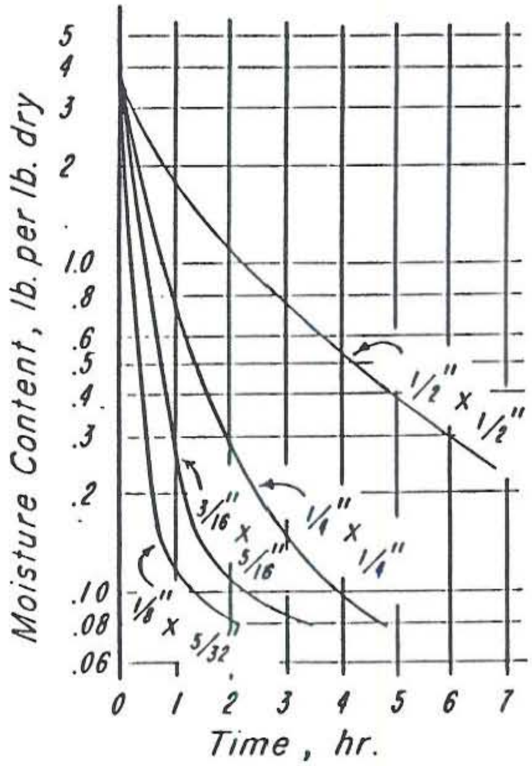



Figure 16 - Effect of size on course of drying of potato strips. Ede and Hales, (1948).

Figure 17 - Effect of loading in course of drying

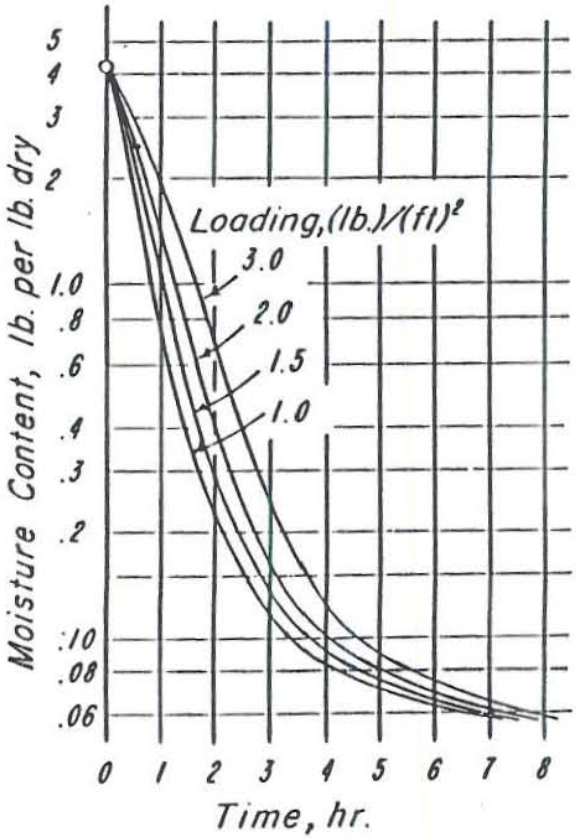



Figure 17 - Effect of tray loading on course of drying of potato half dice. Van Arsdel, (1951).

**Figure 18 - Capeline fish moisture content curve**

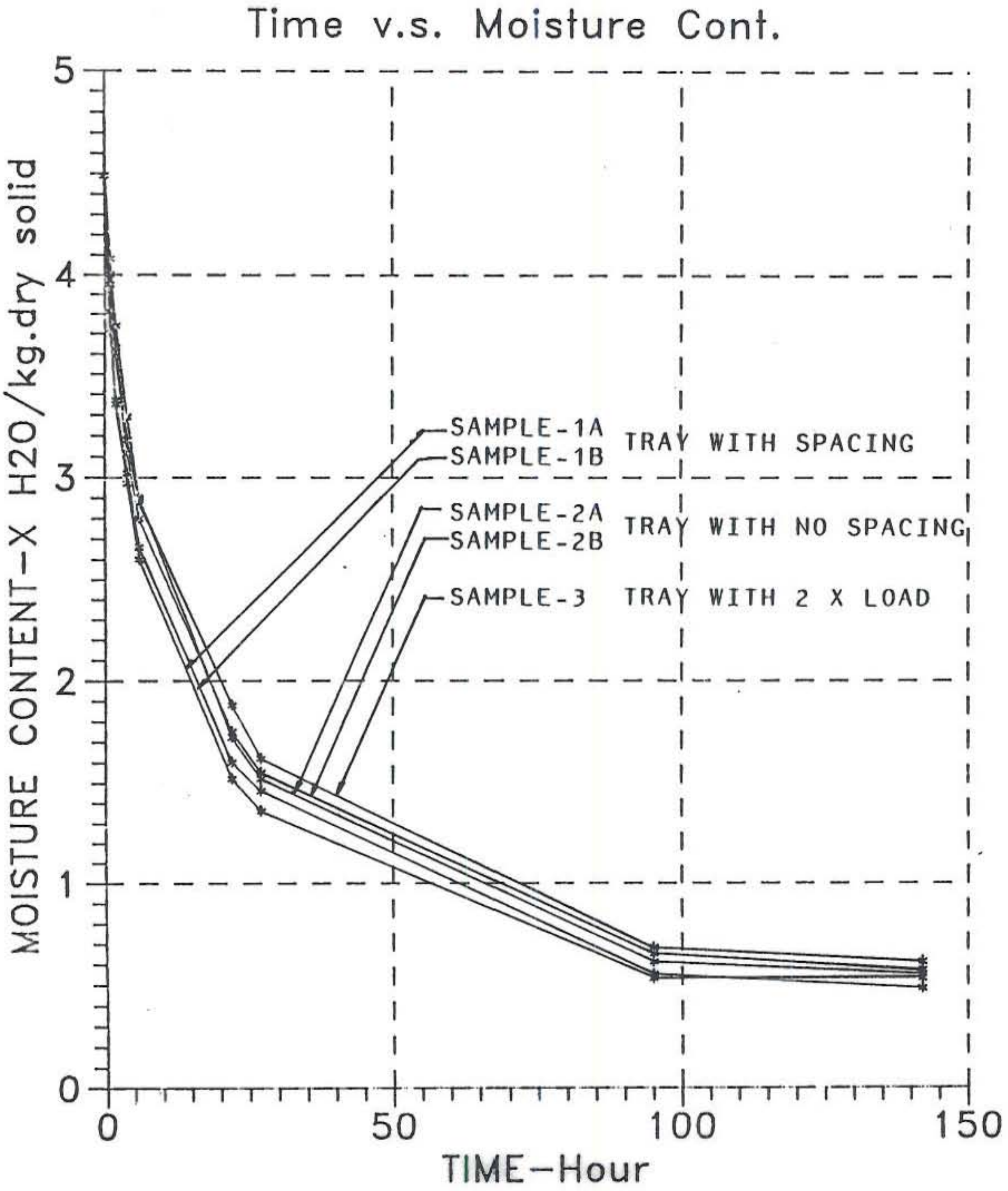


Figure 19 - Commercial fish drying plant layout

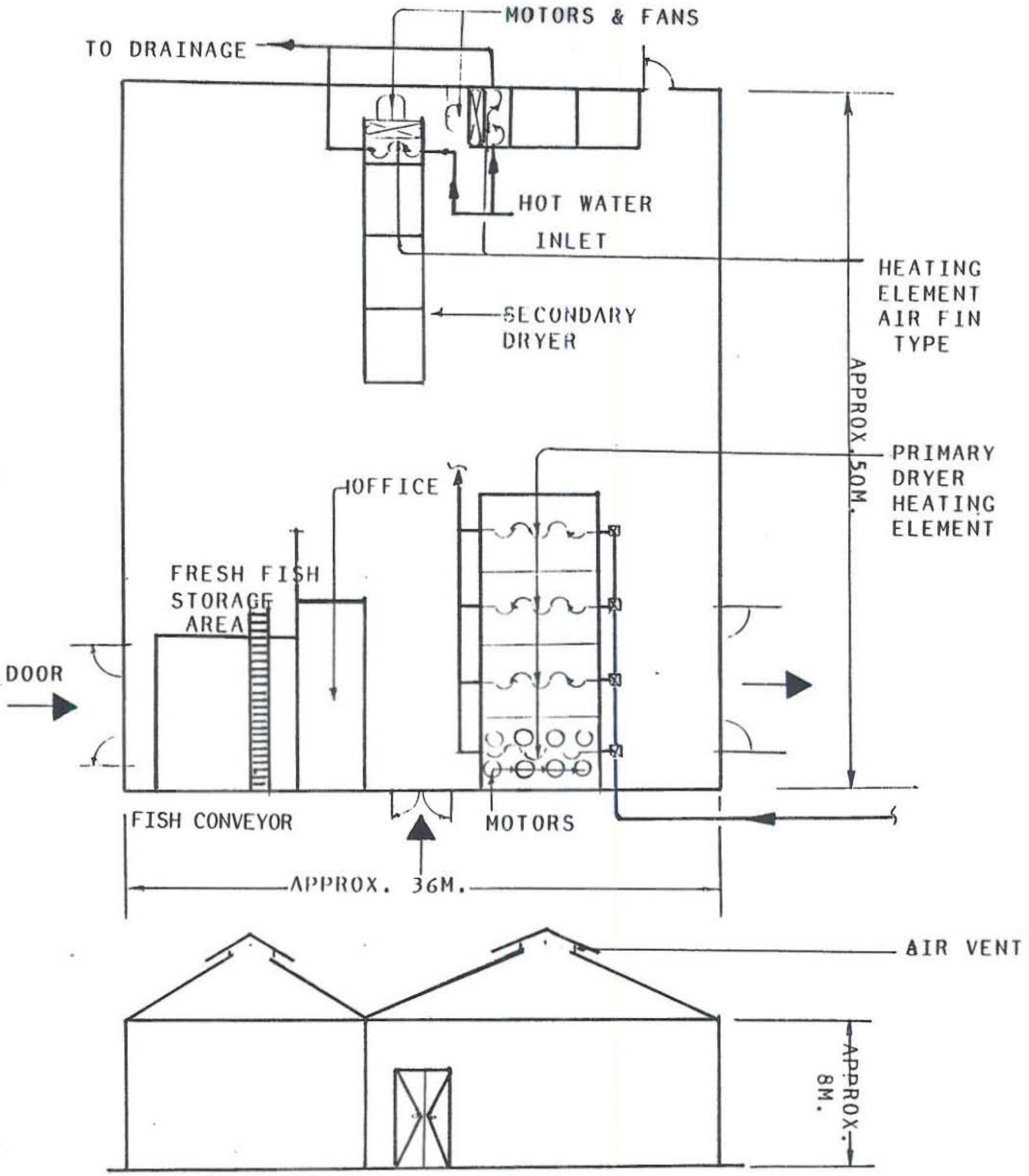
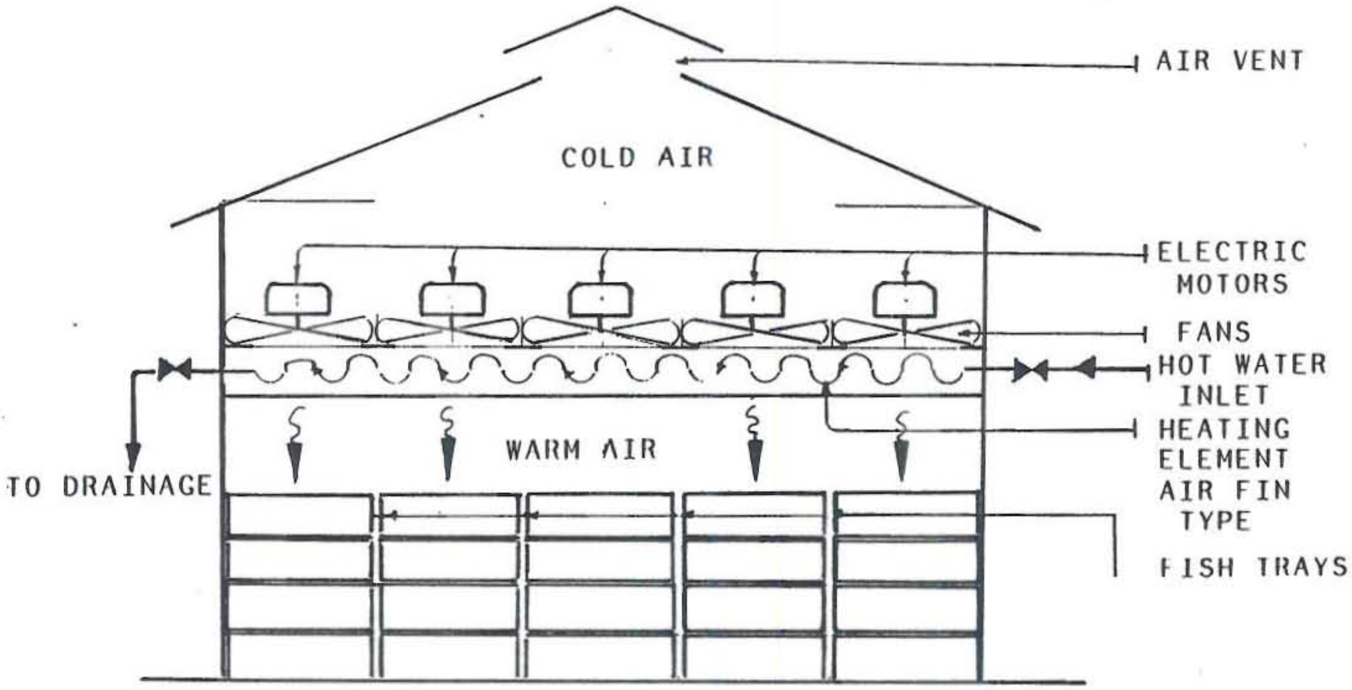
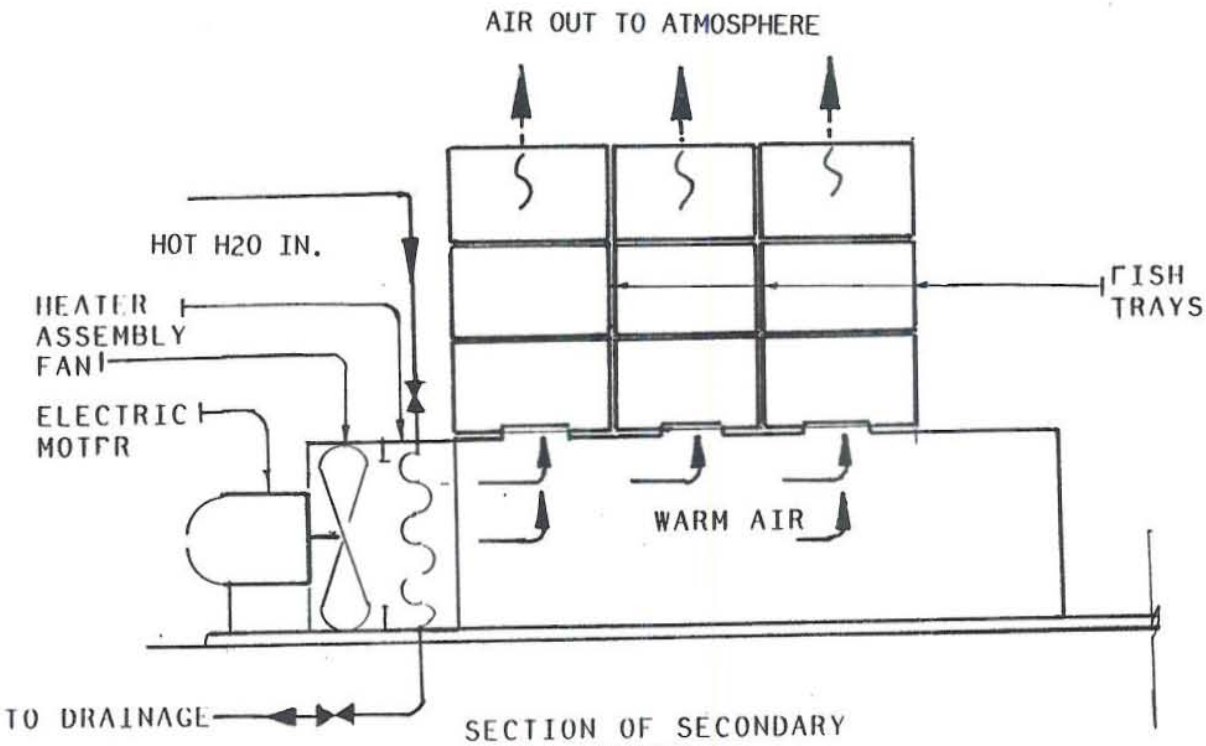



Figure 19 - Commercial fish drying plant layout. Husavik, Iceland.

**Figure 20 - Commercial fish drying plant sectional view**




SECTION OF PRIMARY DRYER




SECTION OF SECONDARY DRYER

**Figure 21 - Drying time of copra**

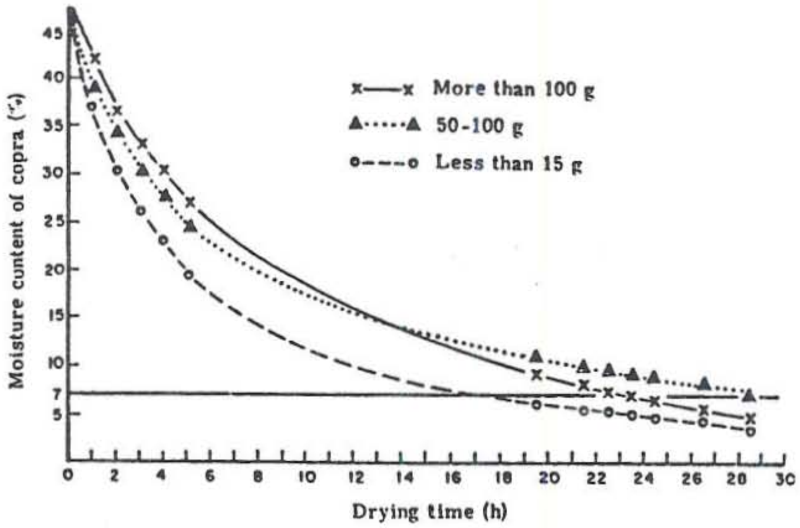



FIGURE 21. Comparative drying rates for copra pieces of different sizes.

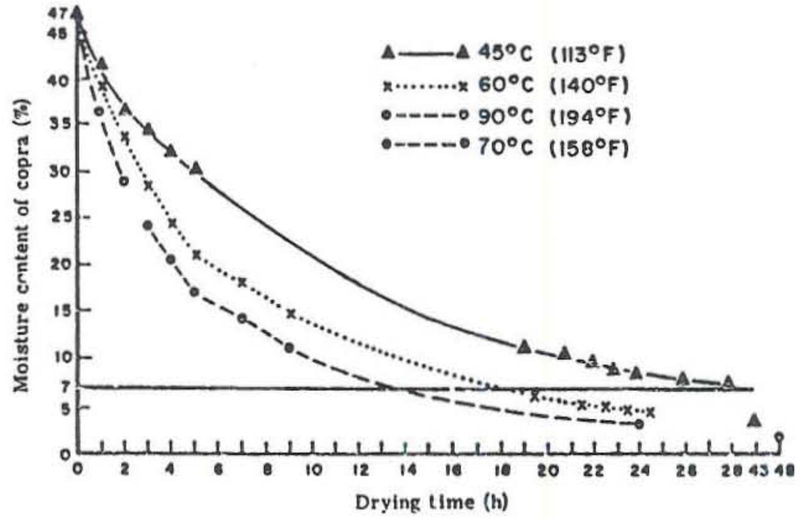



**Figure 21 - Drying time of copra at different temperatures. Grimwood, (1975).**