

# Preliminary study on the utilization of geothermal energy for drying of agricultural product

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## Abstract

Indonesia is highly rich in natural resources. Volcanoes are spread over the Sumatra, Java, Bali and Nusa Tenggara islands in connection with a Mediterranean circumferential. The rest are volcanoes in Sulawesi, the Maluku archipelago and Northern Papua in connection with a Pacific circumferential. Volcanic activities create a potential source of geothermal energy. One of the famous geothermal energy centres in Indonesia is the Dieng plateau. It is also well known for tobacco and mushroom plantations. However, due to the heavy rainfall and drying problems the quality of the tobacco produced here is somehow still below the international standard. Therefore, a research into the utilization of geothermal energy for tobacco drying becomes very important. The research into the drying of tobacco leaves was conducted using an indirect heating system. The heat source for the dryer was geothermal steam. A certain amount of sliced tobacco leaves was placed into a tray dryer. Then the steam was kept flowing at a selected velocity. The moisture loss of the tobacco leaves was indicated by direct balancing of the sample and was then recorded at five-minute intervals. The experiment was stopped after one hour since the steam started to leak into the system. Using the moisture loss and time data, a drying rate curve was obtained. The effects of the steam flow rates and the sliced tobacco leaves layer thickness on the drying performance were investigated in this research. Experimental works showed that the increase of steam flow rate can enhance the drying performance, while increasing the layer thickness reduced the drying performance. However the high sulphur content in the steam caused rusting of the tray material and an unpleasant odour was produced.

*Keywords: geothermal energy, drying, tobacco, sulphur.*

## 1 Introduction

Indonesia is very rich in volcanoes, which are spread out over the Sumatra, Jawa, Bali and the Nusa Tenggara islands in connection with Mediterranean circumferential and Sulawesi, Maluku archipelago and Northern Papua in the connection with Pacific circumferential. The volcanic activities create a potential source of geothermal energy. Data collected by Pertamina (Indonesian State owned Oil and Gas Company) in 1998 indicated that the geothermal energy potential of the Indonesian resources was about 20.000 MW spread out over almost all its territory (Devisi Panas Bumi, Pertamina, Juni 1999). Twelve geothermal energy fields were explored upto the year 1998, four fields were commercialized by Pertamina, while the rest were exploited in joint venture between Pertamina and other private companies. The total production was 2,690,997,219 KWh. One of the famous geothermal energy areas in Indonesia is the Dieng plateau. Dieng has 27 geothermal fields and 12 wells, which have the potential of producing electrical power of more than 1,400 MW (Devisi Panas Bumi, Pertamina, June 1999).

The Dieng plateau is also well known for tobacco and mushroom growing. When the tobacco leaves have reached the desired yellow colour and are thoroughly wilted,

the leaves must be dried. However, due to the heavy rainfall and drying problems the quality of the tobacco produced in Indonesia is still below international standard. Therefore, a research into the utilization of geothermal energy for tobacco drying is very important.

## 2 Review of drying technology

Drying is very important to the conservation of agro-products in the food industry. For tobacco drying is critical because tobacco is sensitive to temperature changes. Impatience to capture a good colour often results in a tendency to increase the temperature too rapidly, and thereby cause a browning or barn scald. On the other hand if the temperature is increased too slowly, sponging may occur. Thus close control of airflow and temperature is mandatory during leaf drying to prevent undesirable colour in the cured leaf. To prevent sponging, the leaf needs to be dried as rapidly as possible, but at a rate so high as to cause scalding. For tobacco leaves (which are hygroscopic), the moisture held within them is usually bound moisture, such as moisture trapped in closed capillaries, the water component of juices or water held by surface forces, as well as unbound water held within the material by the surface tension of the water itself (Howe, 1980). There are two main drying rate regimes for agricultural products, namely the constant drying rate period and the falling drying rate period.

### 2.1 Constant drying rate period

During the constant drying period, drying takes place from the saturated surface of the material by diffusion of the water vapour through a stationary air film into the air stream and is simply the evaporation of moisture from the free water surface. The rate of moisture removal during this period is mainly dependent on the surrounding conditions and only slightly affected by the nature of the materials. The end of the constant drying rate period is marked by a decrease in the rate of moisture migration from within the material below that which is sufficient to replenish the moisture being evaporated from the surface. At this stage, which defines the critical moisture content, the ambient conditions cease to play much role in the rate of drying.

Ambient factors, namely the vapour pressure difference between the drying air and the wet surface, the surface area of the product exposed to the drying air, the mass transfer coefficient and the drying air velocity, are related to the drying rate according to the following formula (Hall, 1980):

$$\frac{dW}{dt} = \frac{K_m A_s}{R_o T} (P_v - P_{va}) = K_f A_s \frac{(T_a - T_s)}{\lambda_{vap}} \quad (1)$$

where the thermal conductance of the air film,  $K_f$  and mass transfer coefficient,  $K_m$  are a function of the air velocity.  $W$  is the mass of moisture (kg) transferred into drying medium. While,  $(P_v - P_{va})$  is the vapour pressure difference between air at the condition studied and at its respective saturated condition (atm)  $T$ , whereas  $T_a$  and  $T_s$  are the equilibrium temperature of drying medium (air) and the drying material (solid) at the operating condition studied, temperature of drying medium (air) and temperature of the solid surface at the condition studied respectively ( $^{\circ}\text{K}$ ).  $\lambda_{vap}$  is heat of vaporisation of the moisture, (kcal/kg moisture).  $R_o$  and  $A_s$  are the ideal gas constant (kcal atm/mol  $^{\circ}\text{K}$ ) and effective surface area (m). The above equation also

suggests that the rate of drying is independent of the geometrical shape of the surface of the material.

## 2.2 Falling drying rate period

In the falling drying rate period the material surface is no longer capable of supplying sufficient moisture to saturate the air in contact with it (Hall, 1980). This drying rate regime is dependent essentially on the rate of diffusion of moisture from within the material to the surface and also on moisture removal from the surface. It is subdivided usually into two stages, namely the first falling drying rate period which involves the unsaturated surface drying and the second falling drying rate period where the rate of moisture diffusion to the surface is slow and is the determining factor (Hall, 1980).

## 2.3 Drying time

The time of drying is the summation of the time needed in the constant drying rate period ( $t_{cr}$ ) and falling rate period ( $t_{fr}$ ). This may be represented by the equation:

$$\text{Constant rate period, } t_{cr} = \frac{(M_{db0} - M_{dbc})}{R_{cr}} \quad (2)$$

or  $M_{db} = M_{db0} - R_{cr}t$ ;  $M_{db} \geq M_{dbc}$ ;  $t \leq t_c$ , where  $R_{cr}$  is the constant drying rate, (kg water/kg dry solid/s).  $M_{db0}$ ,  $M_{db}$  and  $M_{dbc}$  are the initial moisture content, moisture content at corresponding time and critical moisture of the material in dry basis (kg water/kg dry solid), respectively.

$$M_{db} = \frac{W_o - W_d}{W_d} \quad (3)$$

where  $W_o$  is initial weight of the drying material, while  $W_d$  is the weight of dry material.

$$\text{Falling rate period, } t_{fr} = \frac{(M_{dbc} - M_{dbeq})}{R_{fr}} \ln \left[ \frac{(M_{dbc} - M_{dbeq})}{M_{db} - M_{dbeq}} \right] \quad (4)$$

where  $R_{fr}$  is the falling drying rate, (kg water/kg dry solid/s),  $M_{dbeq}$  is the moisture content of the material at equilibrium with the moisture content of the drying air used in the experiment, (kg water/kg dry solid). Therefore, it is obtained that  $t = t_{cr} + t_{fr}$

## 3 Methodology

### 3.1 Material

The sliced tobacco leaves were used here as the material to be dried. The initial moisture content of the tobacco leaves was a 75% wet basis, but the equilibrium moisture content of the tobacco leaves was close to zero. The steam used here was saturated geothermal steam generated in a geothermal steam generator system at a pressure of 1 atmosphere.

### 3.2 Experimental apparatus

A cabinet-type dryer similar to the tobacco-barn dryer was chosen for the farmer option. The size of the dryer was designed to be 1.2 m x 1.2 m x 2.4 m with the front-loading of 10 rectangular trays. Each tray can handle up to approximately 10 kg of product. The housing of the dryer was made of concrete block with corrugated galvanized iron sheet roofing. The heat from the steam generated by geothermal energy was supplied to the dryer by a multitubes located at the bottom of the dryer. The steam from the steam generator flew through the multitube bundle, which was 0.15 m in diameter and 8 m in length. There were three openings at the bottom of the dryer to provide the ventilation for the dryer. To increase the rate of ventilation by natural draft, a rectangular chimney made of galvanized iron sheet was installed at the top of the dryer. Figure 1 illustrates the tray dryer used for tobacco leaves drying.

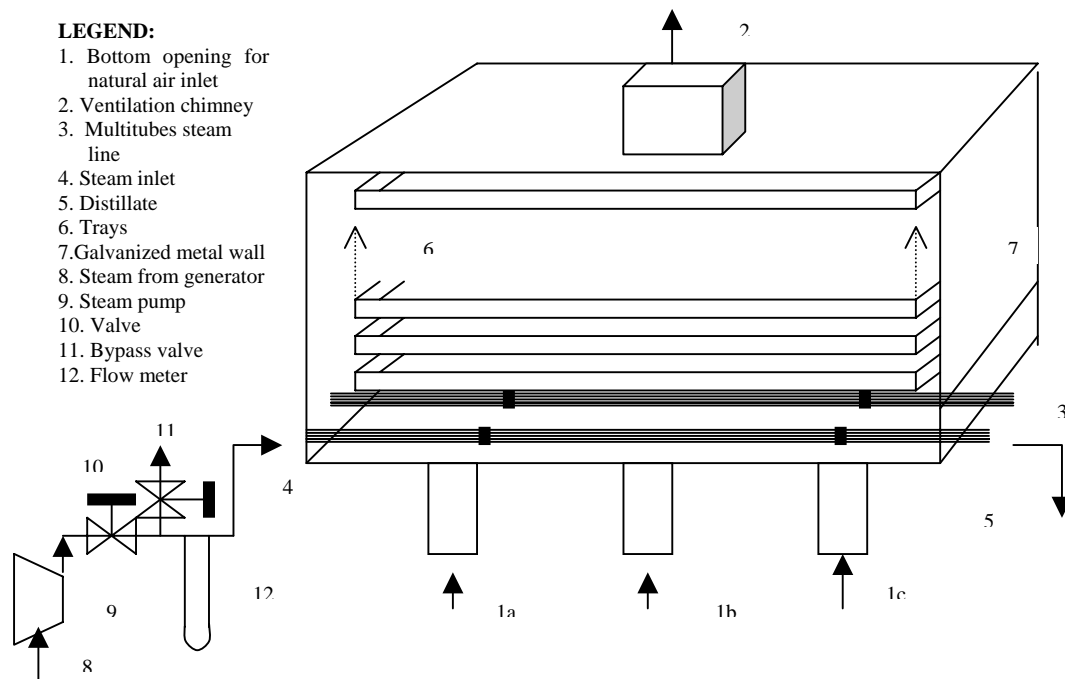


Figure 1: Experimental rig used for drying of tobacco leaves.

### 3.3 Experimental procedure

A pre-determined quantity of sliced tobacco leaves was placed into a tray dryer. Then the steam was admitted at a selected velocity. The moisture loss of the tobacco leaves was indicated by direct balancing of the sample and was then recorded at five-minute intervals. The experiment was stopped after two hours since the steam started to leak into the system. The drying rate curve was obtained using the moisture loss and time data from the test. The effects of steam flow rates and the layer thickness of the sliced tobacco leaves on the drying performance were investigated in this research.

## 4 Results and discussion

### 4.1 Effect of the steam velocity to the tobacco leaves drying rate

Increasing the flow rate of the heating medium (Chandran, et al., 1990; Thomas and Varma, 1992; and Chen, et al., 2001) significantly increases the drying rate in the constant rate period by. This is due to decrease in gas film resistance surrounding the

particle. However, this effect will be significant when the external diffusion controls the rate of drying.

The influence of steam flow rate on the falling rate period is small, however, since the gas film resistance plays a minor role (Kannan, et al., 1995). The steam velocity in this experiment plays a role in supplying the heat. Figure 2 shows the drying process conducted for a 9 cm thickness of the tobacco layer. It is clear that the higher steam velocity gave the higher drying rate. This phenomenon is indicated by the time needed to achieve the desired value of final moisture content being shorter for higher steam velocity, and vice versa. When the steam velocity is high, the flow pattern inside the tube tends to follow the plug flow pattern. The high turbulence of the steam flow increases both the contact between the steam and the tubes wall and the convective heat transfer from the condensed steam to the tube surface (Kern, 1950; Perry and Chilton, 1973). Finally, the conductive heat transfer from the tube surface to the tobacco leaves layer is also increased. Then the drying rate of the tobacco leaves is higher because there is more heat available in the drying system. It is also reasonable, that the increase during falling rate period is due to the tobacco leaves attaining a higher temperature, which increases intraparticle moisture diffusion to the surface. An unpleasant odour was produced, however, when high velocity steam was admitted into the system. This is because the high sulphur content of the steam causes rusting of the tubes and trays.

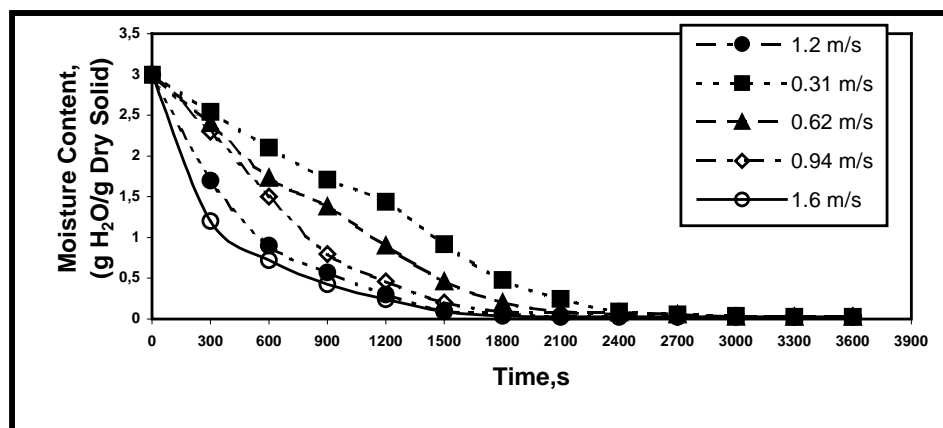


Figure 2: Effect of the steam velocity on drying rate of tobacco leaves.

#### 4.2 Effect of layer thickness on the drying rate of tobacco leaves

Figure 3 shows the effect of layer thickness of the tobacco leaves on the drying rates at a steam velocity of 0.62 m/s. The layer thickness of the sliced tobacco leaves influences the efficiency of the heat transfer from the tubes surface to the layer of sliced tobacco leaves.

Since the conductivity of the sliced leaves is very low, the conductive heat transfer in the layer is very slow. Therefore, increasing the layer thickness lowers the drying rate. Once the layer thickness exceeds 12 cm, no significant change in drying rate is observed.

This result agrees well with the theory proposed by Temple (2000) that the air inside the lower part of the tray dryer is exhausted at saturation. For the thick layers, there is thus no saturation at all after a few seconds; partially dried material in the upper layer will be in contact with the saturated air moving up from the lower layer. This partially dried material will be re-wetted and the air moving away from

saturation. If the air is not at saturation, then the equilibrium relative humidity of the material will limit the degree of saturation of the exhaust air.

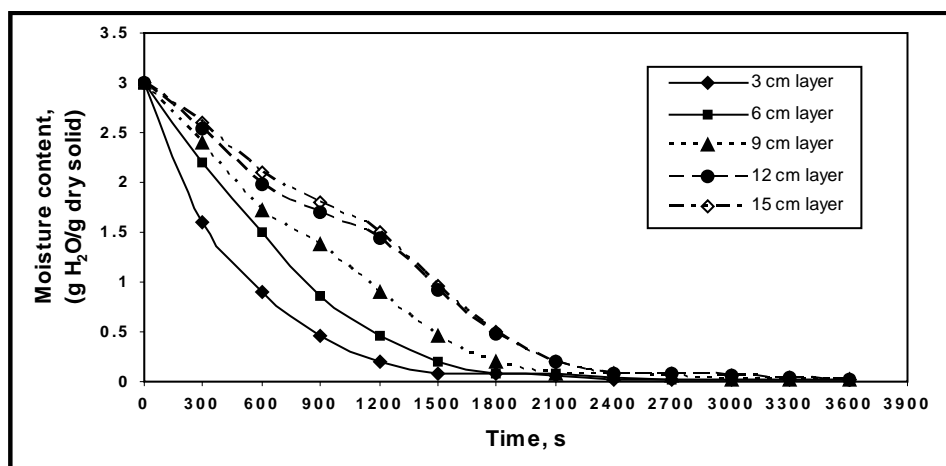


Figure 3: Effect of layer thickness on the drying rate of tobacco leaves.

## 5 Conclusions

From the experimental results and theoretical analysis, it can be concluded that increasing steam velocity may enhance the drying performance, while increasing the layer thickness reduces drying performance. It was moreover observed that the high sulphur content in the steam caused rusting of the tray material and produced unpleasant odour.

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## 6 References

- Chandran, A.N., Rao, S.S. and Varma, Y.B.G. (1990). Fluidised bed drying of solids. *AIChE Journal*, Vol. 36 (1), pp. 29-38.
- Chen, Z., Agarwal, P.K. and Agnew, J.B. (2001). Steam drying of coal Part 2: Modelling the operation of a fluidised bed drying unit. *Fuel*, 80, pp. 209-223.
- Devisi Panas Bumi. (1999). Company Monthly Report. Pertamina.
- Hall, C.W. (1980). *Drying and storage of agricultural products*. Avi, Westport.
- Howe, E.D. (1980). Principles of Drying and Evaporating. *Sunworld*, 4 (96), pp.182-186.
- Kern, D.Q. (1950). *Process Heat Transfer*. McGraw-Hill Book Company Inc., New York.
- Kannan, C.S., Thomas, P.P. and Varma, Y.B.G. (1995). Drying of solids in fluidised bed. *Ind.Eng.Chem.*, 34, pp. 3068-3077.
- Perry, R.H. and Chilton, C.H. (1973). *Perry's Chemical Engineers Handbook*. McGraw-Hill Kogakusha, Tokyo.

Temple, S.J. (2000). *Control of Fluidised Bed Tea Drying*. PhD Thesis, Wageningen University, Wageningen.

Thomas, P.P. and Varma, Y.B.G. (1992). Fluidised bed drying of granular food materials. *Powder Technology*, 69, pp. 213-222.