Factors Affecting Conventional Pulp Moisture Determination

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INTRODUCTION

In Taiwan, the most common conventional pulp moisture determination by the pulp manufacturer is the same as those generally used in the organic chemistry laboratory and are described in readily available laboratory manuals. Oven drying is most convenient carried out in an electrically heated oven maintain at 100-105°C. However, several questions concerning coventional pulp moisture testing procedures are raised. Problems should be clarified were:

1. What is the best way to determine per cent moisture-free pulp at the production end of a machine?
2. What is the effect of higher temperature on moisture testing within the oven drying?
3. What is the effect of relative humidity on moisture testing within the oven drying?
4. In testing an oven repeatedly on the same sample of pulp, does the pulp always have the same moisture-free value each time it is dried, or can it actually have changing final weight?
5. Determing moisture-free pulp in a shipment is often a problem for both the buyer and the seller. How closely can independent laboratories check each other when analyzing identical pulp samples?
6. Can we derive a mathematical equation describing the accurate drying time for the pulp moisture determination?

Since these problems have been shown by the pulp manufacturer, the author used the conventional moisture determination methods to find the solution.

THEORETICAL CONSIDERATIONS

Pulps are hygroscopic and normally retain several per cent of water in equilibrium with the ordinary atmosphere. The problem of drying involves removal of free water and hygroscopically bound water without undesirable alteration of the substance under examination.

The method of oven drying at approximately 105°C is generally accepted as a standard procedure because of its simplicity and general applicability. Completely dry pulp can not be obtained even at 105°C unless the air in the oven has been dried. The relative humidity of the usual laboratory air is reduced to about 1% when the air is heated to 105°C(1), owing to the high saturation vapour pressure at this temperature, the residual water vapor must still be in equilibrium with a significant quantity of water in the pulp. For cellulose fibers, the residual moisture may amount to about 0.2-0.5%. Because of the low residual moisture in pulp, we usually ignore it.

For evaporation to occur from a wet surface into a stream of air, there must be a driving force, the force is the gradient of vapor concentration Co-C, where Co is the concentration of vapor mass per unit volume at the surface, and C is the concentration of vapor mass in the hor hot air stream. (2)

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The rate of evaporation W is given by
$W = KA\,(C_0 - C)$
K----mass transfer coefficient
A----area of the wet surface
Since, when a surface is wet, the hot air in contact with the surface is saturated, the rate of evaporation can be expressed as:

$$W = \frac{KAMw}{RT}(Po-P)$$

Mw----Molecular weight of the vapor
R------Gas constant
T------Temperature (in degrees absolute) of the surface
Po-----Saturated vapor pressure at temperature T
P------Vapor pressure in the air stream

Hence, evaporation will occur as long as the vapor pressure in the air stream is less than the saturated vapor pressure at the surface temperature.

The evaporation of water from an exposed wet sheet is increased by raising the temperature of the surface (because this increases the saturated vapor pressure at the surface) and by lowing the vapor pressure in the air immediately above the surface. The latter is most readily achieved by increasing the temperature of the flow of air across the surface for a laboratory oven drying method.

For oven drying, the hot air flowing through the flat pulp surface (Fig. 1).

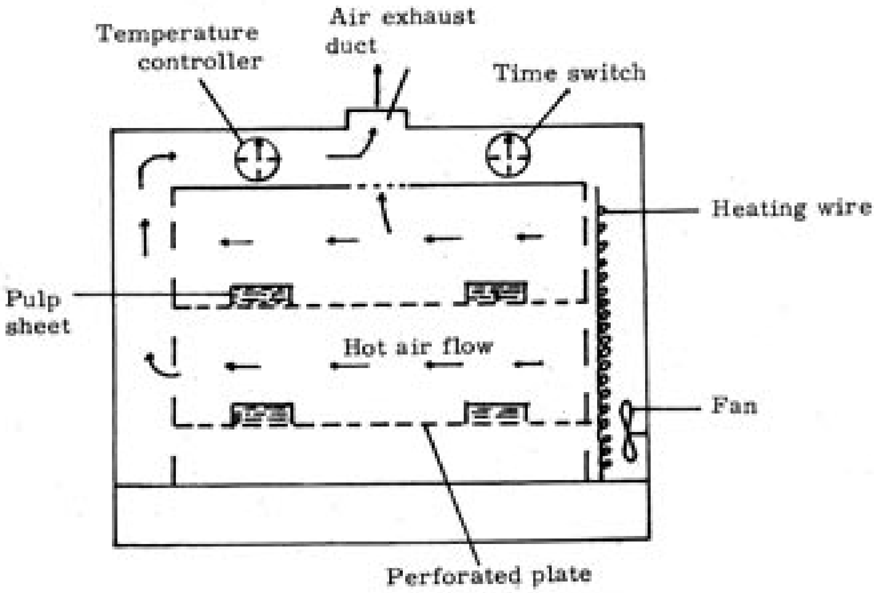

Fig. 1 Typical modern electrical oven (with fan).

Suppose that the pulp surface is cooler than the hot air, so that the heat is being transffered from the air to the pulp. Then the rate of heat flow across the solid-air interface would be expected to depend on the area of the interface and temperature drop between air and pulp.
Hence we write (3)

$Q=hA\Delta T$

Q-----Heat flow into the pulp (BTU/Hr)

A-----Exposed surface area of pulp

ΔT----Temperature difference between the solid-air interface

h------heat-transfer coefficient

Consider the hot air flowing through a rectangular pulp, whose surface temperature is everywhere maintained at To. Suppose that the hot air approaches the surface with a uniform temperature Ta, which is different from To. Then we may define a mean heat-transfer coefficient for the entire surface of the rectangular pulp by the relation

$Q=h_m \cdot 2\,(wl+lh+hw)\cdot(Ta-To)$

Where h_m =mean heat-transfer coefficient

$A=2(wl+lh+hw)$ h=Thickness of pulp sheet

w=Width of pulp sheet

l =Length of pulp sheet

A local heat flow into the pulp can also be defined:

$dQ=h_{loc}\cdot dA\cdot(Ta-To)$

where h_{loc} =local heat-transfer coefficient

This equation is more informative than h_m because it shows how the heat flux is distributed over the surface, however, h_m is more easily measured for experimenters.

For the heat transfer between the interface of hot air — pulp, the heat given up by the hot air in heating from Ta to To must equal the heat gained by the water evaporated in the pulp.

Hence we have

$dq=(Wa-W_{H_2O})\cdot Cc\cdot dT+W_{H_2O}\cdot 1\cdot dT$

Wa----Air-dry weight of pulp

W_{H_2O} -----Moisture in pulp

Cc-----Specific heat of pulp

$\frac{dq}{dt}=h_{loc}\cdot A\cdot \Delta T$

q-------Heat quantity, BTU

t-------Drying time

$\Delta T=Ta-T$

T-----Instantaneous temperature of pulp surface at time t

$dq=h_{loc}\cdot A\cdot \Delta T\cdot dt$

$$\frac{dq}{h_{loc}\cdot A\cdot \Delta T}=\frac{dq}{h_{loc}\cdot A\cdot(Ta-T)}=t$$

Integrating.

$$\int\frac{dq}{h_{loc}\cdot A\cdot(Ta-T)}=\int dt=t \text{-------------}(1)$$

Now $dq=(Wa-W_{H_2O})\,Cc\cdot dT+W_{H_2O}\cdot dT$

Substituting into equation (1)

$$\int\frac{(Wa-W_{H_2O})\cdot Cc\cdot dT+W_{H_2O}\cdot dT}{h_{loc}\cdot A\cdot(Ta-T)}=\frac{(Wo\cdot Cc+W_{H_2O})}{h_{loc}\cdot A}\int\frac{dT}{Ta-T}=t$$

(Where $Wo=Wa-W_{H_2O}$)

Let $\frac{WoCc+W_{H_2O}}{h_{loc}\cdot A}=H$

Rearranging above equation, then we have

$$H\int_{80}^{100}\frac{dT}{Ta-T}=H\left[-\ln(Ta-T)\right]_{80}^{100}=t \text{------------}(2)$$

Where 30=Initial pulp surface temperature
100=Water in pulp evaporating at 100°C

Drying time under constant drying conditions, i.e., the same hot air temperature, humidity and air velocity might be predicted by equation (2). Because the pulp sheet is both porous and hygroscopic, only the unbound water can form the funicular and pendular states. When the unbound water has been removed, considerable bound water is left. This is then removed by progressive vaporization below the surface of the solid, which is accompanied by diffusion of water vapor through the pulp sheet.

EXPERIMENTAL

Four different pulp sheets, one softwood bleached kraft pulp and 3 unbleached kraft pulps were selected for pulp moisture determination. Cut each pulp sheet into several small strips, for the unbleached kraft samples (Basis weight 60g/m²) were 2.5 by 12 cm, and for the bleached kraft pulp samples (Basis weight 1245 g/m²) were 8.5 by10 cm. All pulp samples were drying in the oven (with fan) and weighing immediately in a nearby electronic direct reading analytical balance (accuracy ±1 mg). Drying was at 105±2°C

The bundled sheet used in this study was made by cutting the unbleached pulp sheet into 4 strips (2.5 by 12 cm), and rolling each one tight before taking out from the oven.

RESULTS AND DISCUSSION

1. Effect of repeated drying:

It was interesting to determine whether or not a pulp sheet will return to the same moisture-free and humidified weights upon repeated drying and humidifying. To make this determination, 3 samples of unbleached kraft pulp strips were dried individually and humidifying 2 times. The results are shown in Fig. 2 for these samples. The first drying for each sample resulted in a higher moisture-free weight than subsequent drying. This higher first weight was observed in all 3 samples. Obviously, the moisture content of pulp sheet depends on whether the pulp has been moved from an atmoshere of higher or lower humidity, or in other words, whether equilibrium is reached by adsorption or desorption of moisture. This phenomenon is known as hysterisis which was usually found for cellulose fibers and wood. It would seem that some volume of bound water removed in the first drying is not captured in the dry pulp fiber upon humidification.

Samples were exposed to moist air of 65-73% relative humidity. This first humidified weight of each sample is the original pulp weight.

2. Effect of convection on drying rate:

To evaluate the effect of an oven fan (convection) on the drying rate of open sheet pulp, Taiwan red pine unbleached kraft pulp was dried, first with the fan on and then with the oven fan off. Results are shown in Fig. 3. as drying time versus bone dry pulp weight. With fan on, an evident increase in drying rate is found, proved by the shorter drying time to reach a given per cent dryness. On the contrary, with the fan off the decrease in drying rate is due to the lack of moisture removal from the oven air. Therefore, the oven humidity is raised and the drying rate decreased.

3. Effect of humidity on drying tate:

In determing the effect of oven humidity on drying rate, two cases were selected.

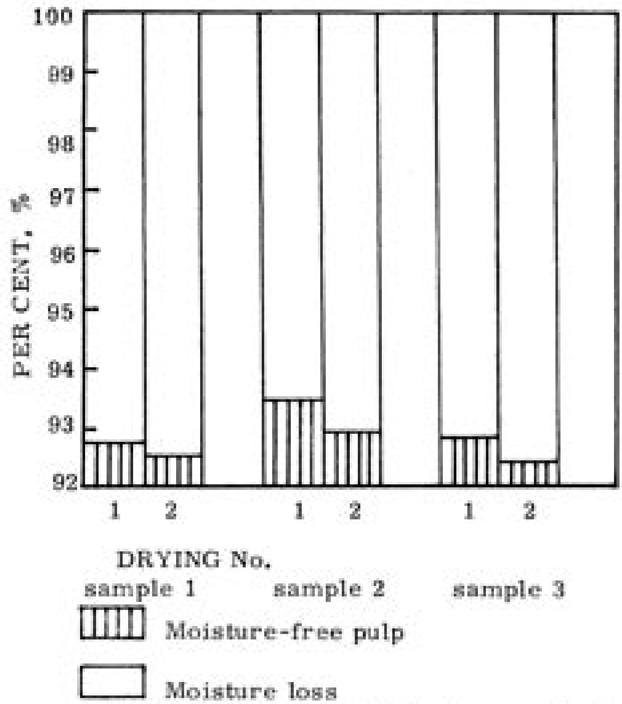

Fig. 2 Effect of repeated drying on pulp sheet moisture determination

One, a dried atmosphere (105°C), the other, a saturated atmosphere resulting from placing a tray of water at the bottom of oven. Results are shown in Figure 4. The moisture content of the oven under normal operating conditions (105°C) is quite low. The saturated atmosphere, greatly reduced the drying rate by reducing the difference in water concentration between the sheet surface and the moist oven air.

4. Effect of bundling on moisture pickup:

To find the difference in moisture pick-up between a bundled and an open sheet while the pulp samples were weighing in an electronic direct reading analytical balance. Six open sheets and 6 bundles were dried to about 100% moisture-free. Then they were individually exposed to moist air of 73% relative humidity and wetting curves were obtained, 6 typical curves were shown in Figure 5.

The bundled pulp sheet exposes 3.14cm² to the moist air while the open sheet exposes about 60cm². This difference is seen in the amount of moisture absorbed by each, as indicated in Fig. 5.

It is evident that bundling of the pulp sheet will result in far greater accuracy in determing moisture-free weight where the pulp sample is exposed to air before weighing.

5. Drying time under variable drying conditions:

Under certain specific conditions, equation (2) might be used for calculating the

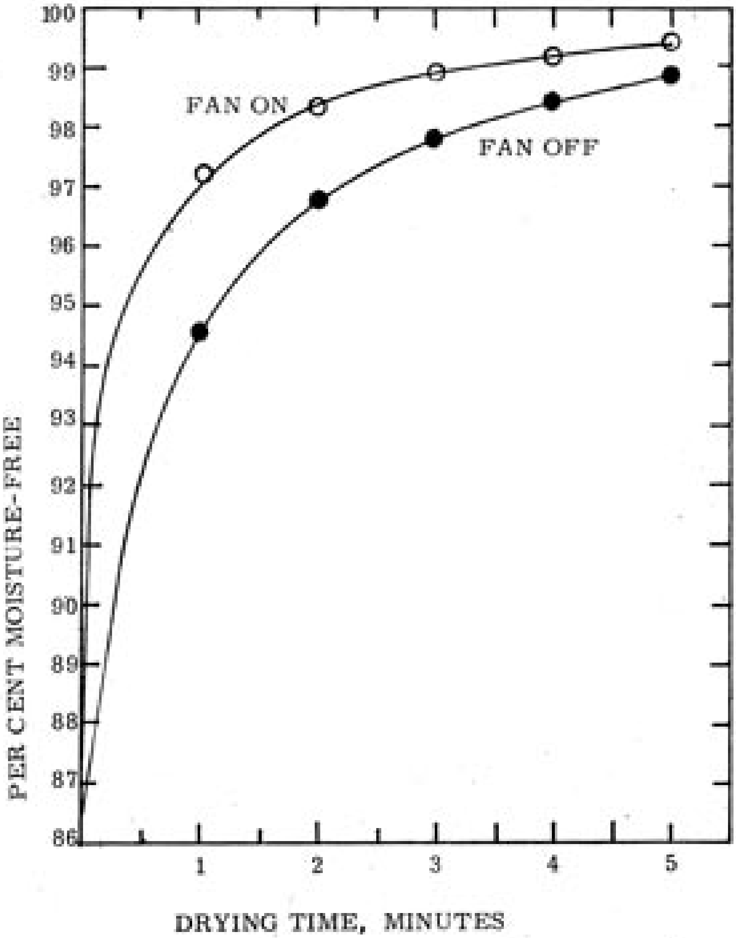

Fig. 3 Effect of convection on drying rate

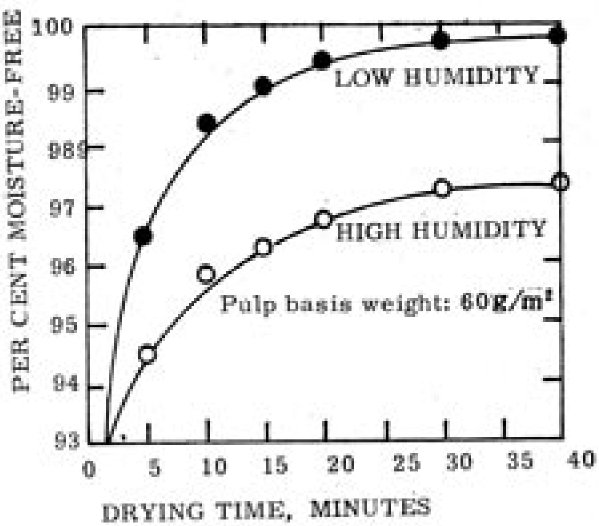

Fig. 4 Effect of humidity on drying rate

approximate drying time in an oven when the temperature of the hot air are varying. It is generally necessary that the solid be porous and that the drying fall in the first falling-rate period. (4)

To accelerate the drying rate and save the drying time, drying-rate curve for variable drying conditions were shown in Fig.6. At higher oven temperature, an evident increase in drying rate is found, evidenced by the shorter drying time to require to reach a given per cent dryness. Theoretically, can we find the most exact drying time for the moisture-free pulp using the equation we derived?

For the oven drying (with fan), assuming W_0, W_{H_2O}, h_{100}, Cc and A are known, then we rewrite equation (2) as follows:

$$\frac{(W_0 - W_{H_2O})Cc + W_{H_2O}}{Hh_{100} \quad A} \left[-\ln(Ta-T) \right]_{30}^{100}$$

$$= H\left[-\ln(Ta-T) \right]_{30}^{100} = t$$

Let $Ta = 105^{\circ}C$, $125^{\circ}C$ respectively. Substituting into above equation, then we have

(i) For $Ta = 105^{\circ}C$

$$H\left[-\ln(Ta-T) \right]_{30}^{100} = -H\left[\ln(105-100) - \ln(105-30) \right]$$
$$= -H\left[1.61 - 4.31 \right] = 2.7H$$

(ii) $Ta = 125^{\circ}C$

$$H\left[-\ln(Ta-T) \right]_{30}^{100} = -H\left[\ln(125-100) - \ln(125-30) \right]$$
$$= -H(3.21 - 4.55) = 1.34\ H$$

In both cases, the time obtained at higher oven temperature were considerably shorter than that obtained at lower oven temperature, and which seemed corresponding to the experimental results we did (Fig. 6). However, further study on this mathematical modal equation (2) we derived is needed.

CONCLUSIONS

1. Due to the hysterisis phenomenon of cellulose fiber, same moisture-free pulp can not be obtained by testing in oven repeatedly. However, much less difference among them.
2. With oven fan on, better hot air convection resulted in increasing the moisture removal, the shorter drying time for pulp moisture determination is desired.
3. Upon determing the moisture-free pulp weight, other wetted materials in the same oven will greatly reduce the drying rate of pulp samples.
4. Bundling of the pulp sheet before weighing will result in far greater accuracy in determing moisture-free weight.
5. Equation (2) we derived in this study seems to be a good indication of the approximate drying time for variable drying conditions.

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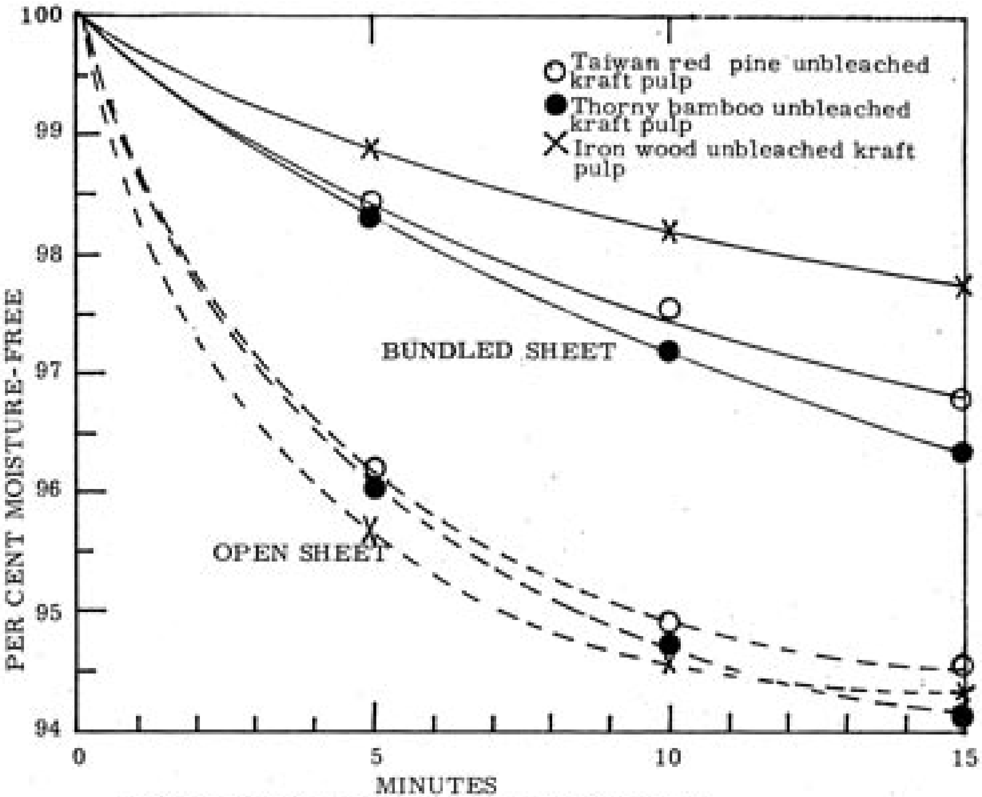

WEIGHING ROOM RELATIVE HUMIDITY: 73%

Fig. 5 Moisture absorption curves

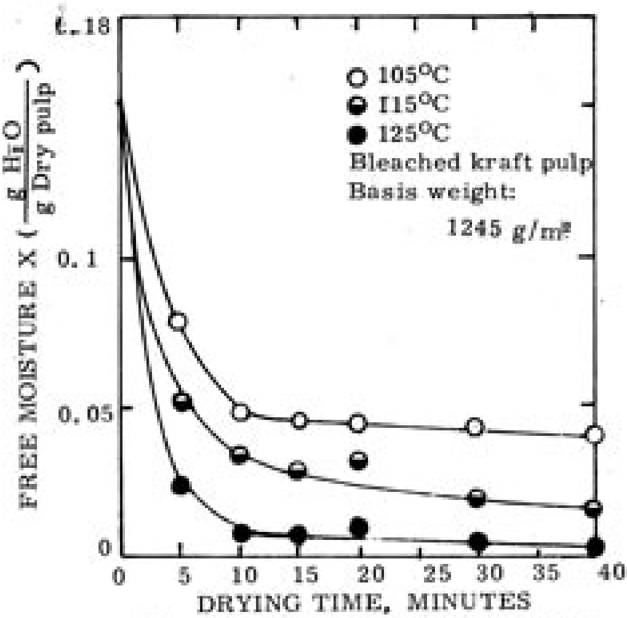

Fig. 6 Dring-rate curve for variable drying conditions

ABSTRACT

A theoretical modal analysis of moisture-free pulp drying time under variable drying conditions was evaluated and defined, produced results which seem in good agreement with available observational data of oven (with fan) drying in general. The effect of various relative humidity and drying rate (with fan on or off) on moisture testing within the oven drying were presented. The bundling of the pulp sheet or not while weighing and an evaluation of the accuracy of both moisture determination methods were presented too.

影響測定紙漿含水量因素之研究

中文摘要

一般而論，利用本報告所導出之數學模式預測在烘箱中紙漿乾燥至絕乾重所需時間與試驗結果近似一致。

烘箱內之濕度及乾燥速率（有無氣流循環）會影響紙漿乾燥所需時間之長短。

在高濕度（73％）室內稱量甫自烘箱取出之乾漿深受紙漿暴露在含濕大氣面積之影響。設法減少稱量時乾漿之面積，將可提高測定值之精確度。