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ADJUSTING OF TEMPERATURE LEVELS IN MULTI STAGE DRYING SYSTEM BY MEANS OF OUTLET AIR MEASUREMENTS

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ABSTRACT

Bio fuel plays an important role in the energy production of the forest industry. The initial moisture of the fuel typically varies between 50 - 63 w-%. A multi stage drying concept has been developed for the drying of wet bio fuel. To adjust the temperature levels in the multi stage drying system there must be a simple and fast method to define the fuel initial moisture. A method to define the initial moisture based on the measurement of the outlet air moisture was experimentally studied. Regular shaped wood particles having different moisture content were dried in a fixed bed reactor. The difference between outlet and inlet air moisture was measured. According to results, it is possible to make conclusion about the initial moisture of the material by measuring the moisture of the outlet air.

INTRODUCTION

In Finland, bio fuel represents approximately 19 % of the total primary fuel consumed in forest industry. The most common bio fuels are bark, forest residues and different kinds of waste wood. The moisture content of bio fuel typically varies between 50 and 63 w-% (water per total mass). Furthermore, the fuel can be frozen in winter. By means of fluidised bed technology, it is possible to combust bio fuel having such a high moisture content. Because of the high initial moisture, the effective heating value of the bio fuel is, however, low; this reduces the power production of the power plant. Compared to completely dry fuel, the theoretical decrease in the power production is 12 -21 % for the initial moistures 50 - 63 w-%, respectively. The variation of the initial moisture additionally makes the operation of the boiler more difficult.

To improve the effective heating value of the bio fuel the sufficient final moisture is usually 20 - 30 w-%. It is additionally important to remember that too dry fuel can cause problems for the operation of the boilers, particularly in existing boilers. For example, the combustion temperatures may rise too high.

Since the initial moisture of the fuel varies, the final moisture of the fuel depends on the initial moisture if the drying conditions are always similiar in the dryer. If the variation of the initial moisture is 50 - 63 w-%, then the moister fuel contains around 70 % more water than the drier one. The heat needed for the evaporation increases as much. The factors most affecting the initial moisture content of the bio fuel are season, weather, storage time, and the type of bio fuel (bark, forest residues et cetera). To achieve the desired final moisture, and to minimise the use of the drying energy it is necessary to adjust the drying conditions on the basis of the initial fuel moisture .

The problem is how to define the initial moisture of the fuel on-line in a simple way. The most reliable way to define the initial moisture is the drying of a few fuel samples in an oven. At least two samples are taken from the fuel flow and kept in an oven at 105 ^{o}C for at least 16 hours but not longer than 24 hours. After the drying, it can be assumed the samples are completely dry and the initial moisture (water per total mass) can be defined as follows:

$$u_o = \frac{m_1 - m_2}{m_1} \cdot 100 \qquad (1)$$

where m_1 is the mass of the sample before drying and m_2 after drying.

Although the method is reliable it is time consuming for the demand of the adjusting and it must be carried out by humans, which is not desirable.

This paper presents a method that approximately determines the initial moisture of the fuel. The determination is based on measurement of the outlet air moisture. The reliability of the method has been experimentally studied on a laboratory scale.

A multi stage drying concept has been researched at the author's laboratory. The adjustment of the temperature levels in the multi stage drying system will be based on this method.

MULTI STAGE DRYING SYSTEM

A multi stage drying system consists of several drying stages between which the same air flow is heated. Figure 1 illustrates in Mollier diagram the change in air moisture in multi stage drying having three drying stages compared to one stage drying. The change of air moisture is the same in both cases but the maximum air temperatures are lower in multi stage drying than in one stage drying. Because of the lower drying temperatures, it is possible to utilise lower temperature energy sources in the heating of drying air than in one stage drying.

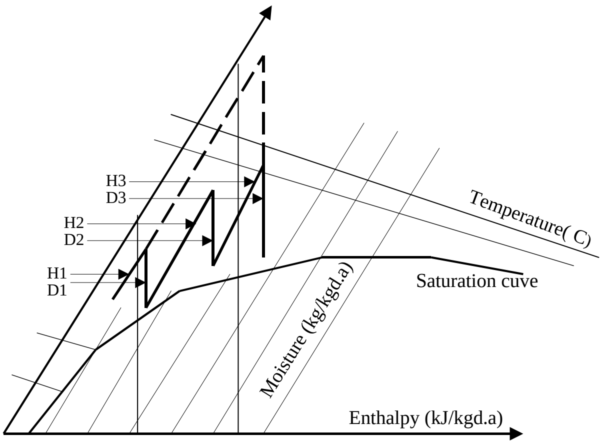

Figure 1- The comparison of multi stage drying to one stage drying. D = drying period , H = heating period. The broken line describes one stage drying.

Energy sources that are the most potential for the multi stage drying in a pulp and paper mill are secondary heat flows, back pressure steam, and extraction steam. Secondary heat flows are typically hot waters in the temperature range 50 - 90 ^{o}C. The pressure of the back pressure steam is usually 3 - 4 bar and the pressure of the extraction steam 10 - 12 bar.

Back pressure and extraction steam represent more valuable energy than secondary heat flows. By letting them expand in a turbine, it is possible to get mechanical work out of the steam process. One can say the price of the steam is higher than that of the secondary heat. Since the temperatures of the secondary heat flows are relatively low, the investment costs of the dryer become considerable if only secondary heat is utilised in drying. To minimise both running and investment costs of the dryer, it is necessary in most cases to utilise both back pressure and extraction steam. To eliminate the emissions possibly released in drying, the air from the last drying stage is led to a combustion chamber. Figure 2 shows a flow sheet of the multi stage drying process where three different energy sources are utilised.

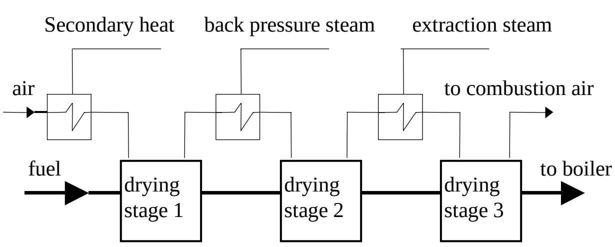

Figure 2 - Multistage drying system

Figure 3 illustrates a probable dryer construction suitable for multi stage drying. The dryer consists of several conveyors through which the drying air is blown. The fuel moves on the conveyor at the same velocity as the conveyor. As the dry mass flow of the fuel must be constant the conveyors have the same velocity in each drying stage. The air velocity is so low that the fuel particles do not fluidise in the bed. There is mixing in the bed when the particles drop from the upper conveyor to the lower conveyor. When the particles move on the conveyor, the drying is analogous to fixed bed drying. Although the number of drying stages and conveyors is three in Figure 3, there can be more stages in the dryer.

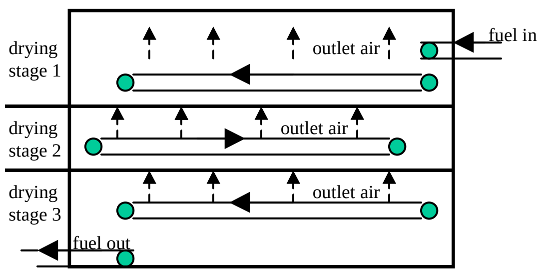

Figure 3 - A multi stage dryer having three drying stages

DRYING MECHANISM IN A FIXED BED

Drying of solid particles is usually divided into three successive periods: a short initial heating period, a constant drying rate period and a falling drying rate period /1/. If all particles in the fixed bed are in the period of constant drying rate, the outlet air moisture and temperature remain constant. The falling drying rate period first begins in the bottom part of the bed. Since the falling drying rate period has begun, the evaporation rate of the bed constantly decreases. Consequently, the outlet air moisture decreases and the outlet air temperature increases.

The main parameters affecting the evaporation rate and the duration of the constant drying rate period in a fixed bed drying are air velocity, inlet air temperature, inlet air moisture, particle size distribution, bed height, and the initial moisture of the material. The drier the material is, the faster the evaporation rate, and outlet air moisture should decrease. If parameters other than the initial moisture of the material, do not change, one can ask whether it might be possible to draw conclusion about the initial moisture of the drying material by measuring the change of the outlet air moisture or temperature.

The effect of the initial moisture of the material on the change of the outlet air moisture was experimentally studied. Regular shaped wood particles of spruce were dried in a fixed bed. The only parameter changed was the initial moisture of the particles. The most interesting question concerning the results is how soon and how distinctly the outlet air moistures differ from each other depending on the initial moisture of the particles.

How valid, then, is the assumption that all other parameters having influence on the evaporation rate do not change in a real dryer. If the dryer is similar to that in Figure 3, it can be assumed that the parameters remain constant in the first drying stage are particle size distribution, air velocity and inlet air temperature. The parameters that can vary are bed height and inlet air moisture. It is impossible to feed fuel into the dryer in such a way the bed height would always be the same . Because of the variation in the bed height the evaporation surface changes. The inlet air moisture depends on the outdoor moisture.

The bed height and inlet air moistures were changed in the tests. The effect of the changes on the outlet air moisture was also experimentally studied.

TEST RIG

The flow sheet of the test rig with measurement points is presented in figure 3. The drying reactor consisted of a glass tube and an aluminium shutter grate, through which the drying air was led into the glass tube. The inner diameter of the glass tube was 100 mm, height 400 mm, and wall thickness 5 mm. The diameter of the shutter grate holes were 1,5 mm.

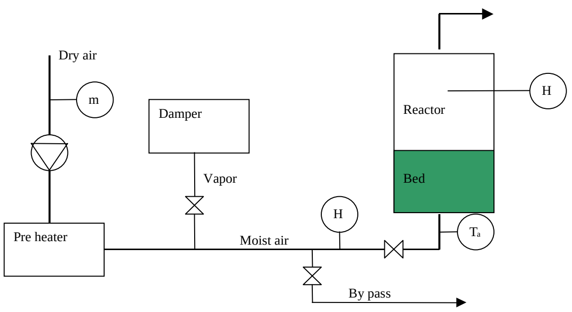

Figure 2 - Flow sheet of the test rig with measurement points. H humidity, T_a air temperature, m mass flow control.

The air temperature before the bed was measured using a thermocouple. The inlet and outlet air moistures ($g/kg_{d.a}$) were measured using humidity transmitters. The air mass flow was adjusted to a desired one using a mass flow control unit.

RESULTS AND DISCUSSION

All test particles were ideal particles of the same size and shape in each measurement. The dimensions of the particles were as follows : length 20 mm, breadth 20 mm and thickness 5 mm. The inlet air temperature was 70 ^{o}C, and air velocity per free sectional area of the shutter grate 0,6 m/s in each test.

The effect of the particles' initial moisture on the change of the outlet air moisture ($g/kg_{d.a}$) was tested by using four different initial moistures. To achieve different initial moistures, the particles were kept in water for unequal periods. The precise moisture of the sample was defined using equation (1) by drying the sample at 105 ^{o}C for at least sixteen hours after the test. The number of particles in each sample was one hundred, which approximately corresponds a bed height of 60 mm in a test reactor. Because of wetting, the initial moisture of the particles didn't wary a great deal in one sample. Each test for one initial moisture of the sample was carried out three times. The maximum moisture variation between the samples with identical initial moisture was 4 $g/kg_{d.m.}$ The given initial moisture is the mean value of the moistures the samples had. The inlet air moisture was 0 $g/kg_{d.a}$.

Figure 4 shows how the outlet air moistures change during the first ten minutes, when the initial moistures of the samples are the same. Figure 5 shows how the outlet air moistures change during the first ten minutes, when the initial moistures of the samples are different.

The effect of the frozen particles on outlet air moisture was tested by freezing two samples (both included 100 particles) before they were put into the reactor. The moistures of the samples were 62,1 w-% and 62,7 w-%. The mean value of the outlet air moistures is plotted in Figure 5.

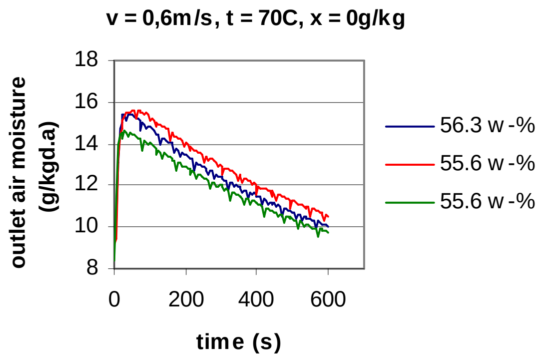

Figure 4 - The change in the outlet air moisture when the samples have the same initial moisture.

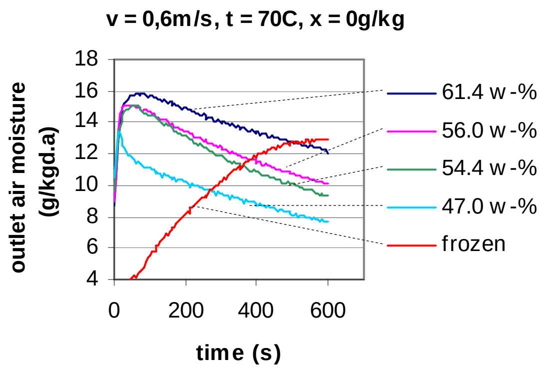

Figure 5 - The change in outlet air moisture when the samples have different initial moistures and the sample is frozen.

The effect of the bed height was examined by increasing and decreasing the evaporation surface by ten percent (110 and 90 particles). The initial moisture contents of the samples were 54,1 w-% and 55,1 w-% for 110 particles and 90 particles, respectively. Each test for both bed heights was carried out twice. Figure 6 shows how the outlet air moistures change during the first ten minutes compared to samples involving 100 particles.

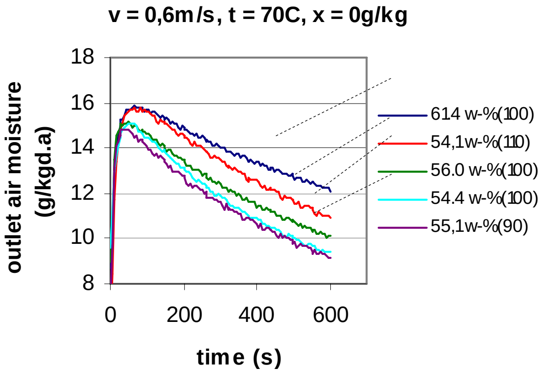

Figure 6 - The change in outlet air moisture when the evaporation surface increases and decreases by 10 %. The number after the moisture content refers to the number of particles in a sample.

The effect of the moist inlet air was examined by moisturising the air before the reactor. The inlet air moistures were 7,5 ± 0,5 g/kg$_{d.a}$ and 16 ± 0,4 g/kg$_{d.a}$. The average initial moistures of the samples were 52,8 w-% and 63,2 w-%. Each test was repeated twice. Figure 7 shows how the moisture difference between outlet and inlet air changes during the first 15 minutes. The results of the tests with dry air are also plotted in Figure 7.

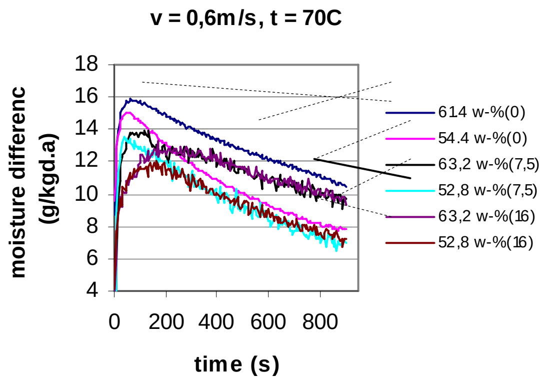

Figure 7 - The change of the moisture difference between outlet and inlet when the inlet air is moist. The value after the moisture of the sample refers to the inlet air moisture (g/kg$_{d.a}$).

One can see in Fig. 5 that the change of the outlet air moisture clearly depends on the initial moisture of the sample. Even a relatively small moisture difference between samples (56 w-% and 54,4 w-%) can be observed. Because of melting, the outlet air moisture behaves in an entirely different manner to the other moisture curves, when the particles are frozen.

When the evaporation surface increases, the moisture of the sample seems to be higher than it actually is (see Fig. 6). The decrease of the evaporation surface respectively means the initial moisture would be lower than it is. Although the conclusion about the initial moisture of the material is wrong, the conclusion concerning the adjustment is correct. There is more water to evaporate when the evaporation surface increases and, conversely, less water when it decreases.

With moist inlet air, the initial moisture of the sample still have influence on the change in outlet air moisture. The change of the moisture difference depends on the inlet air moisture at the beginning of the drying (around 200 - 250 seconds). The drier the air is, the higher is the moisture difference between outlet and inlet air. An interesting observation is that, after 200 - 250 seconds, the inlet air moisture has no noticeable influence on the change in moisture difference when the samples have the same moisture. The moisture differences seem to decrease, surprisingly well, in the same way. If this is true we can ignore the effect of the inlet air moisture.

ADJUSTMENT OF TEMPERATURE LEVELS IN MULTI STASGE DRYING

As there is no multi stage dryer in function, only the principle of the adjustment of the temperature levels is presented here.

Two important goals of the multi stage drying are:

- Drying is as energy effective as possible.
- The final moisture of the fuel varies as little as possible.

The dimensioning of the dryer is based on a particular initial and final moisture of the fuel. The design value for the initial moisture can for example be the fuel's highest moisture content or the most common moisture content. In real life, the initial moisture of the fuel varies. The most energy effective way to take into account the variation of the moisture is the adjustment of the temperature levels in the dryer. The higher the drying temperature is, the more valuable energy is used in the heating of the drying air. As the secondary heat is the most economical energy source, it is always utilised in the first drying stage. The other drying temperatures depend on the initial moisture of the fuel; the lower the initial moisture, the lower the drying temperatures that can be used.

Before we can adjust the drying temperatures in the multi stage drying, one must know:

- The maximum variation of the initial moisture of the fuel
- Drying rates in each drying stage as a function of the inlet air temperatures
- The curves describing the change in outlet air moisture or temperature for the different initial moistures of the fuel

The adjustment of the dryer is based on the constant measurement of the outlet air in the first drying stage (inlet air temperature is always the same into the first drying stage).To determine the change in outlet air moisture or temperature, there must be a moisture or temperature measurement in the first drying stage. If the dryer is similar to that in Fig. 3, the measurement system can consist of several fixed measurement points that are placed at the specific distance from each other. The measured change of the outlet air moisture is compared to the curves describing how the outlet moisture changes, when the fuel has a particular initial moisture. For example, if the measured outlet moisture seems to change in a similar way to the outlet moisture corresponding to the fuel moisture 60 w-%, one can conclude the fuel moisture must be close to this value. In practice, the determination must be based on several successive measurements.

Since the conclusion about the fuel moisture has been made, one must choose the air temperature combination in order to achieve the desired final moisture. The temperature combinations have been calculated in advance.

Table 1 illustrates four different possible temperature combinations for the dryer . It is assumed that there are three drying stages and the available air temperatures are 70 °C, 120 °C, and 160 °C approximately corresponding to the heat sources secondary heat, back pressure steam and extraction steam, respectively. The changes of the fuel moistures in table 1 are not based real calculations.

Table 1 - An example of different air temperature combination for the multi stage dryer. The changes of the fuel moistures in table are not based on any real calculations.

initial fuel moisture w-%	drying stage 1	drying stage 2	drying stage 3	final fuel moisture w-%
43 - 50	70 °C	70 °C	70 °C	25 - 30
50 - 56	70 °C	70 °C	120 °C	25 -29
56 - 60	70 °C	120 °C	120 °C	23 - 27
60 -	70 °C	120 °C	160 °C	25 - 30

CONCLUSIONS

The effect of initial moisture of the sample on the outlet air moisture has been experimentally studied in a fixed bed by using dry and moist inlet air. According to results, it is possible to make conclusion about the initial moisture of the sample by measuring the outlet air moisture. An interesting observation is that the inlet air moisture does not seem to have any noticeable effect on the determination of the sample's initial moisture. Although the inlet moistures are different, the moisture differences between outlet and inlet air change almost in the same way three to four minutes after the beginning of the drying.

The adjustment of the temperature levels in the multi stage drying system is based on the outlet air measurements. The adjustment is a good example of a fuzzy control. One does not know precisely the initial moisture of the fuel. It is, however, possible to approximately estimate what kind of fuel there is in the dryer by means of the outlet air measurements. Since the initial condition of the fuel has been determined, it is simple to choose the best temperature combination to drive the dryer. The most important advantages of this method are that it is fast enough for the demand of the adjustment, it is relatively simple to carry out, and it is automatic. Both the determination of the fuel's initial moisture and the selection of the best temperature combination can be carried out by computer.

To determine how well the method would work in reality it is necessary to conduct further tests for real bio fuel on a larger scale. Results on a laboratory scale are promising.

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