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PEPs CHEMICAL ENGINEERING

CONFIDENTIAL

Test report:

Study on heat treatment of wood chips against harmful organisms

For the company:

Technic One

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23/09/2016

1. Introduction

The Technic One company sells a convective dryer called Dryer One. This dryer is composed of two superposed rotating discs where hot air circulates from top to bottom across them. In the framework of the international trade of wood chips, Technic One has adapted its dryer in order to be able to perform a heat treatment on wood in order to destroy harmful organisms.

This treatment is divided into two phases. The first phase consists in raising the temperature of the wood (up to 60 °C), distributed over a 10 cm layer of wood chips on the upper disc grill. This step lasts about 10 minutes. The second phase is the treatment itself which continues on the lower disc and which consists in maintaining a 30 cm bed of chips at a temperature of 60°C for 30 minutes.

Technic One asked us to perform a laboratory study to demonstrate that the core of the product correctly undergoes the heat treatment. To do this, two tests were performed to characterise each of the phases.

2. The experimental setup

PEPs has a convective dryer which is a cross-current discontinuous pilot, shown schematically in Figure 1. It allows the entry conditions of the two phases of the treatment to be generated. Forced air is applied when the dryer grid is covered with a bed of chips to obtain an air superficial velocity of the order of 0.75 m/s as during the tests performed within the Dryer One. The drying cell is a quartz tube, 160 mm in diameter and 300 mm long, equipped with a perforated grid which retains the sample while allowing the air to pass through it. In addition, a moisture probe was installed at the input of the cell to check if the conditions of temperature and moisture of the forced air were met.

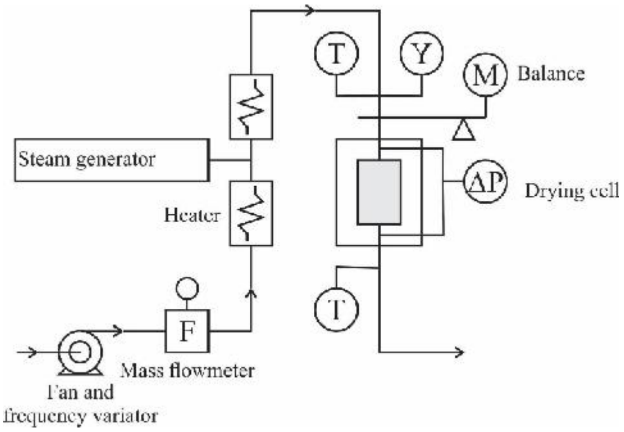

Figure 1: Pilot dryer diagram

This system allows the weight of the product to be monitored throughout the treatment operation as well as the upstream and downstream temperatures of the bed, the relative humidity of the input air and the pressure loss generated by the bed.

Lastly, a 1.5 mm thermocouple was installed at the outlet of the cell in order to be able to be inserted into the centre of a reference chip so as to monitor the evolution of the temperature in the core of the material.

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3. Theoretical aspects

Figure 2 shows, theoretically, the evolution of the drying flux (water evaporation) and the temperature of the product as a function of the moisture content on a dry basis during the convective drying of a rigid product such as wood[1]. The graph must be read from left to right given that one begins with a wet product and ends with a dry product. It is divided into 3 zones which are the different drying steps related to the intrinsic properties of the material and to its water content. Even if, in the case which we have studied, the drying phenomena were limited because of the high humidity of the air, any wet product in contact with unsaturated air will undergo drying, even partial.

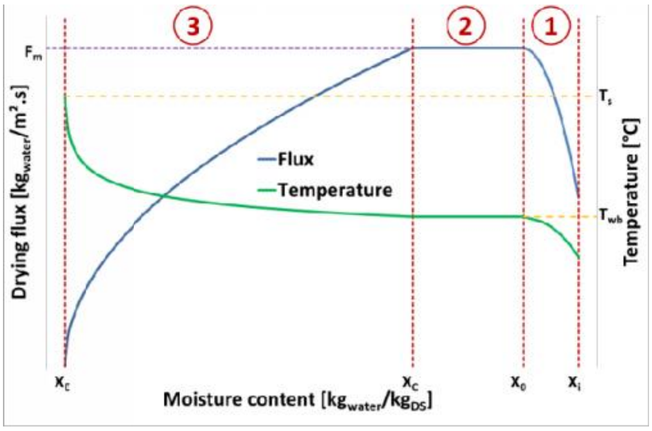

Figure 2: Theoretical drying curve

The first stage (1) is called pre-heating phase. The cold, wet product loses water and heats up to reach a surface temperature plateau which depends on the air temperature and moisture conditions. At the same time, the drying flux reaches its maximum value.

The second stage (2) continues at constant surface temperature and drying flux. It continues while the internal transport properties (permeability) allow water to migrate from the core of the product to the surface of the material. During this stage, the behaviour of the material is assimilated to a drop of water which evaporates without the presence of a solid and the drying flux and the temperature of the product, the so-called wet bulb temperature (T_{wb}) are constant. The phase is considered as isenthalpic: any heat transmitted by the air is consumed by the vaporisation of water which migrates to the surface, ignoring losses. The end of this period is characterised by the average water content, qualified as critical (X_c).

The last stage (3) appears when the external surface of the product is no longer supplied with water. Below the critical water content, the properties of the solid shall impact on the way that the drying flux decreases (permeability, tortuousness, etc.). During this stage, the heat transferred to the product is greater than the quantity required for evaporation. Consequently, the temperature of the product increases until progressively reaching the air temperature as a function of the rate at which the drying slows down. In fact the drying flux

[1] 1 A. CHARREAU, R. CAVAILLE, Sechage: I. Théorie et calculs, Techniques de l'ingénieur. [Drying: Theory and calculations, Engineering techniques]. Génie des procédés, 2 (1991) J24080. 24081-J22480. 24023.

decreases to progressively become null once thermodynamic equilibrium is reached. At equilibrium, the material attains a moisture content (X_E) which depends on the air temperature and humidity conditions.

For the heat treatment of wood chips, phase I of the treatment includes stage 1 and a part of stage 2, described above. Phase II of the treatment follows stage 2 of drying and can pass on to stage 3 depending upon the air and the water content of the wood chips.

The wet bulb temperature is an important concept in hygrometry. When a small weight of water is placed in contact with a large unsaturated air flow, its temperature evolves and tends towards a steady-state value. This pseudo-steady-state is obtained by equalising the flux of latent heat of evaporation due to the flux from the water evaporation and the heat flux into the water resulting in the difference in temperature caused by the cooling of the liquid. Table 1 shows the wet bulb temperature for different air temperature and humidity pairs in a range close to the conditions encountered in Dryer One.
It is noted that the more humid the air, the closer the wet bulb temperature is to the air temperature.

Air temperature [°C]	Air humidity [%]	Wet bulb temperature [°C]
95	15	53.6
95	20	58.6
95	25	62.7
65	55	53.0
65	60	54.7
65	65	56.2
65	70	57.7
65	75	59.0
65	80	60.3
65	85	61.6

Table 1: Several wet bulb temperatures

4. The sample

The sample studied was supplied by the Technic One company on the 15th of September 2016. It was resinous wood chips of Belgian origin equivalent to the products to treat. In fact, the sample was of the same type of wood and the chips had the same dimension as the final product.

Nevertheless, several clarifications should be made. In fact, the sample studied by PEPs is a sample which had already been treated several times by Technic One in order to test the Dryer One machine. The chips were therefore smaller than their original form as the distribution system of the Dryer One crushed the chips. In addition, PEPs prefers to specify that, the wood having undergone various heat treatments, its intrinsic properties could have changed with respect to a fresh sample. Amongst other things, the construction wood is rendered non-hygroscopic by the different heat treatments undergone.

Lastly, Technic One asked for wood to be studied, with a moisture content of 50% on a dry basis. The sample supplied having been stored outside, contained less than 20% of water, PEPs therefore re-hydrated the wood to obtain the 50% requested. To do this, a mixing barrel was used which allowed the dry wood to be put in contact with a sufficient quantity of water to obtain the desired moisture content. This mixing was performed for 48h at ambient temperature. Following the mixing, a dryness test was performed to verify the humidification process.

Figure 3 shows the chip selected as reference sample. It was chosen as it was larger than the others and therefore presented a highest limitation to the thermal diffusion. Because of this, we ensured that the other wood chips would arrive at the requested temperature of 60°C, more rapidly. In addition, this reference chip was placed at the bottom of the bed, below the other chips, so as to place it in the worst configuration possible (given the circulation of air from top to bottom).

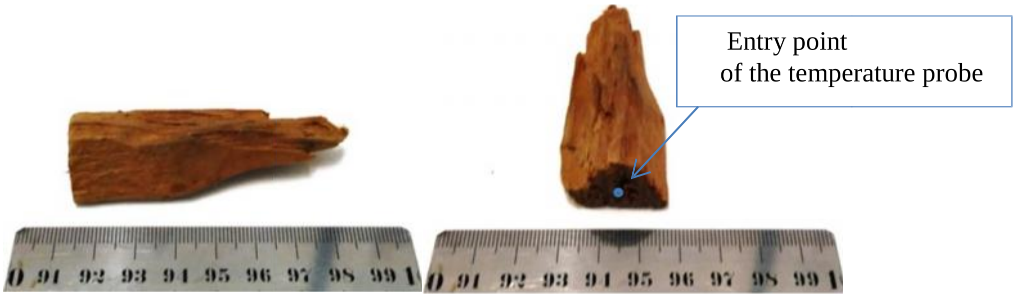

Figure 3: Reference sample

5. Study of Phase I

The study of phase I consisted in establishing that the material had reached the temperature of 60°C at the core of the product in less than 10 minutes. The air conditions were a temperature of 95°C, a humidity of 20% and an air velocity of 0.75 m/s. Figure 4 and Table 2 show, respectively, the input conditions of the experiment and the corresponding average values.

Temperature [°C]	94.9 ± 1.6
Moisture	23.4 ± 1.0
Air velocity [m/s]	0.77 ± 0.1

Table 2: Average input conditions of phase I

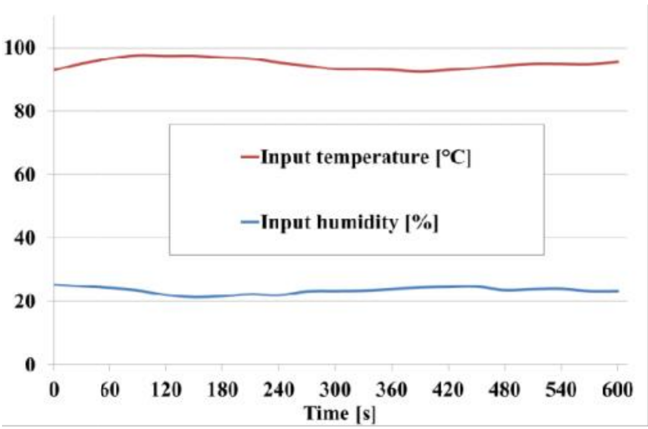

Figure 4: Air input conditions during phase I

Figure 5 shows the results taken over time during this test at different temperatures. The air temperature passes from 95°C to about 66°C at the output of the bed of chips. The order of magnitude of the process was in agreement with the tests performed by Technic One.

In addition, the core temperature of the reference chip reached a temperature of 60°C within 3 minutes which proves that phase I of the treatment was met. Nevertheless, it was noted that the core temperature stabilised at about 62°C, i.e. the wet bulb temperature under these "drying" conditions which is 61°C for the treatment average. This highlights the importance of the humidity of the treatment air because if the humidity of the air at the input to phase I is lower for chips with 50% moisture content, the temperature of the chips will stabilize at a lower temperature than the required 60°C.

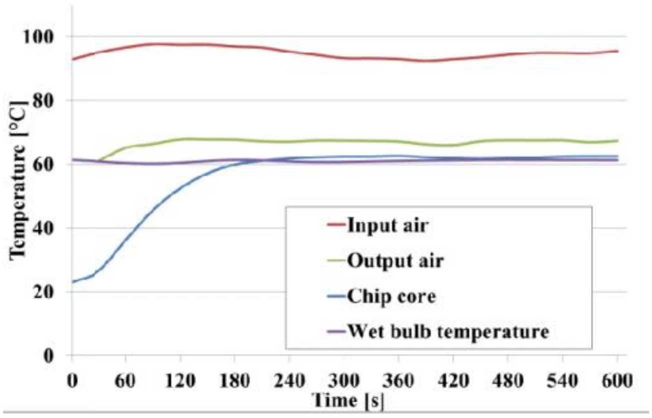

Figure 5: The different temperatures during phase I

Figure 6 shows the evolution of the weight of the sample. Given that the wood chips were at ambient temperature prior to their introduction into the dryer, the input air cools upon contact which causes water to condense in the bed of chips. This is why the weight increases at the start of the experiment. The drying process then takes over and the weight of the sample decreases.

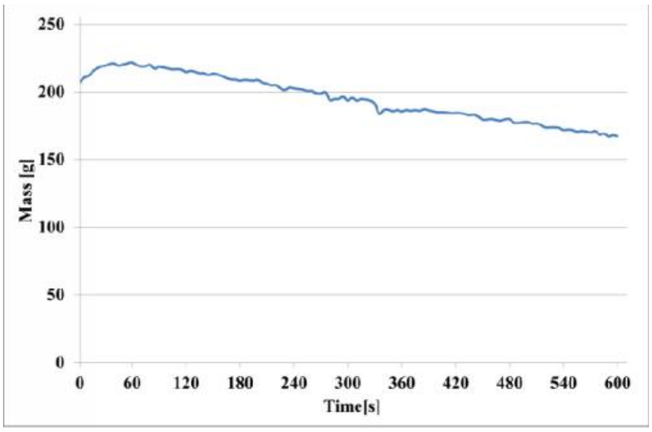

Figure 6: Evolution of the weight during phase I

6. Study of Phase II

The study of phase II consists in monitoring the temperature of the core of the reference chip in order to ensure that it remains higher than 60°C during the 30 minutes of actual treatment. The input air conditions were an average temperature of 65.1 ± 1°C and an average humidity of 65.5 ± 5.1 %. This humidity was the maximum value allowed by the controller at this temperature. In fact, the increase of the steam flow rate induced saturation of the system which was no longer stable. Figure 7 shows that under these "extreme" conditions, the automatic filling of the steam generator, which took place every 6 minutes, led to sharp drops in the humidity because of the interruption of steam generation. Nevertheless, this humidity was acceptable as, starting from the principle that the input air into phase II is the air from phase I which is only cooled, the humidity of the air goes to 60%. In the various measurements supplied by Technic One, the values of the moisture content were close to 80%. Nevertheless, a humidity of 65% is a less favourable case than 80% with respect to the time required for raising the temperature of the product and the temperature of the wet bulb thermometer, as the experiment demonstrated.

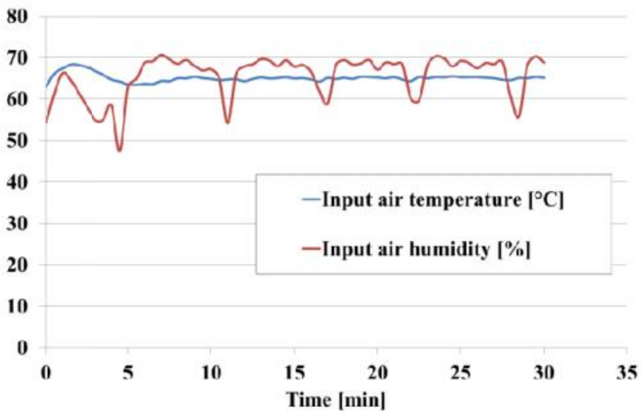

Figure 7: Air input conditions during phase II

Before performing the test, the sample had to be conditioned to be at a temperature around 62°C for simulating the output from phase I. To do this, it was placed in an oven at 62°C for 24h in a perfectly hermetically sealed container, in order to avoid drying.

Figure 8 presents the results taken over time during this test of phase II, for the different temperatures. The air temperature went from 65°C to 62°C which is on the same order of magnitude as that found by Dryer One.

The temperature of the core of the reference chip reached a steady state in 1 minute. In fact, the handling of the chips for preparing the bed and the positioning of the reference chip caused the temperature to drop to 40°C. The core temperature then remained slightly higher than the wet bulb temperature, related to the conditions of the input air. In fact, when the humidity of the input air dropped, the temperature of the output air, the temperature of the core and the wet bulb temperature also decreased. This test again highlighted the importance of the humidity of the treatment air. The higher the humidity, the more the temperature of the product will be close to that of the air. In addition, if during the treatment, the humidity drops sharply, then the heat treatment could not be guaranteed as the wood chips would remain at a lesser treatment temperature than the one required for the elimination of the harmful species. In fact, the input air conditions led to a wet bulb temperature of 56.2°C which is just required for ISPM15 treatment temperature. If the humidity of the air increases to 80%, the wet bulb temperature would be 60°C as specified in Table 1.

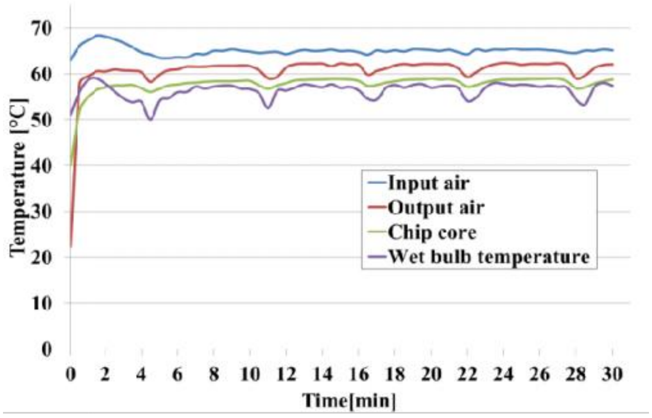

Figure 8: The different temperatures during phase II

Figure 9 shows the evolution of the weight of the chip bed during the treatment phase II. The drying was nearly stopped given the high humidity of the air as the weight remained relatively stable. The impact of the variation of the humidity of the air is once again visible as at each drop in moisture content, the drying flux intensified to come back again when the conditions became stable.

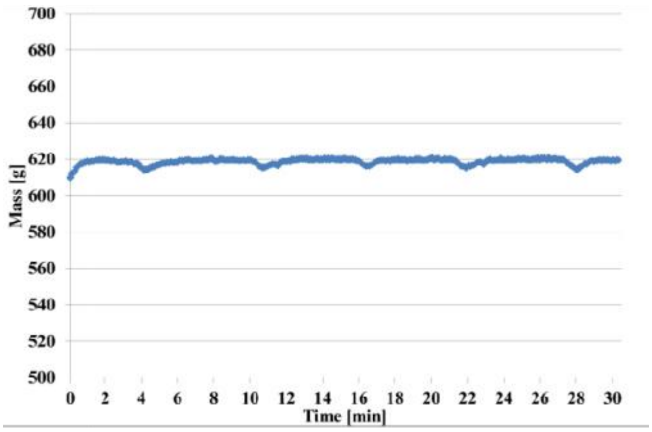

Figure 9: Evolution of the weight during phase II

7. Conclusions

The PEPs performed two studies to check if the Dryer One would allow wood chips intended for export, to be properly treated in order to eliminate any harmful species present.

Firstly, the rise in temperature of phase I was achieved in 3 minutes for the input conditions of Dryer One, i.e. A velocity of 0.7 m/s, a temperature of 95°C and a humidity of 20%. The 10 minutes which were adopted in the classic operation of Dryer One are therefore more than sufficient for this phase.

Secondly, these two experiments demonstrated the thermodynamic limitation of the heat treatment of the wood chips related to the temperature and humidity conditions of the treatment air. In fact, this pair of parameters allows the wet bulb temperature to be defined which will be the lower temperature encountered during the treatment. By monitoring these two parameters, Technic One could establish safety systems which would guarantee the effectiveness of the treatment for their customer.

Thirdly, the humidity of the air being a limiting factor for the heat treatment, Technic One could consider implementing a moisturizing system for the treatment air in order to ensure that it is set at a high level.

Fourthly, the study was performed on wood chips whose moisture content on dry basis was 50%. Technic One had already demonstrated the fact that the treatment was more complicated with a high initial moisture content, compared to dry wood. These two experiments confirm the hypothesis as the dryer the wood, the shorter the period of constant temperature and therefore the wood would heat up faster to arrive at the air temperature. For an initial moisture content of the wood of 50%, the 40 minutes of treatment was not sufficient to allow for this stage to arrive at a constant temperature.

Finally, the PEPs should recall that a single test on each phase was performed and that there was no repeat which could confirm the overall behaviour. In addition, the sample supplied having undergone several heat treatments, the PEPS cannot affirm that a fresh sample would have the same behaviour due to the possible modification of the internal structure of the wood chips.