CONFIDENTIAL

Test Report:

Use of the Dryer One process for the heat treatment of harmful organisms in wood chips

Norm ISPM15 – 2000/29/CE

Novembre 2016

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1 Presentation of the Dryer One drying machine

The Dryer One drying machine is composed of 2 drying discs on which the product is distributed in 2 regular layers. These 2 discs rotate in opposite directions around an extraction chimney and have hot air blown on them from top to bottom.

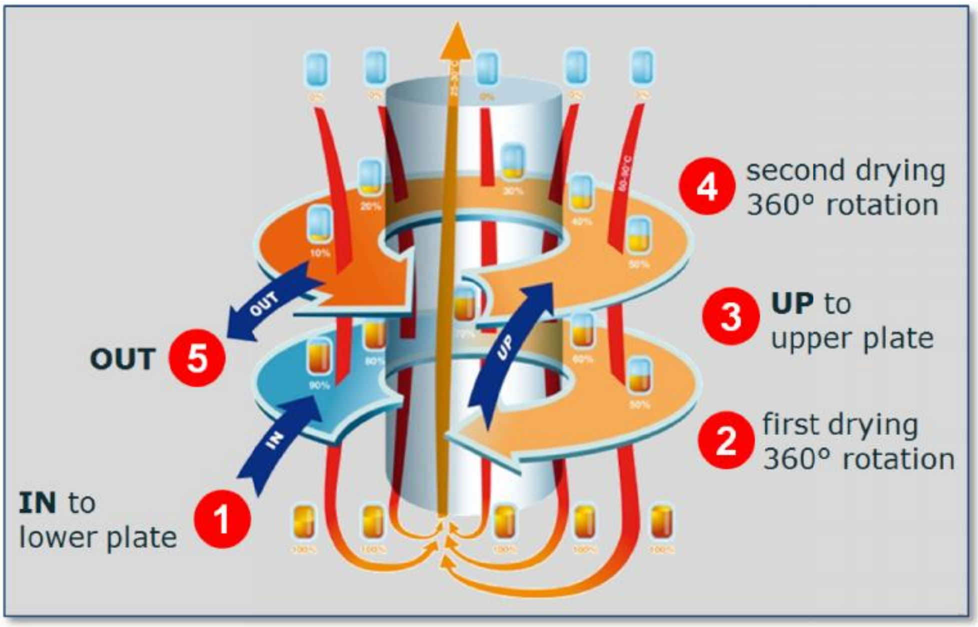

Figure 1: Operation of the Dryer One drying machine.

The product is introduced onto the lower disc (Figure 1, step 1) and turns through 360° in one direction (Figure 1, step 2). It is then transferred onto the upper disc (Figure 1, step 3) where it turns through 360° in the opposite direction (Figure 1, step 4) before leaving the drying machine (Figure 1, step 5).

The 2 superposed discs turn in opposite directions and the product encounters air which is hotter and hotter and dries throughout the process, thus limiting any thermal shock.

This patented technology of the discs turning in opposite directions, contributes to a better distribution of heat and to higher efficiency than other hot air drying techniques.

Figure 2 shows a model of 320m² mounted at Kaiserbaracke for drying wooden sawdust.

Figure 2: Dryer One drying machine for drying wooden sawdust.

2 Modifications of the process for heat treatment

Following the specific request from an American Company, we have adapted the Dryer One process in order to perform the heat treatment of wood chips as per the European directive 2009/29/EC and the International standard ISPM15.

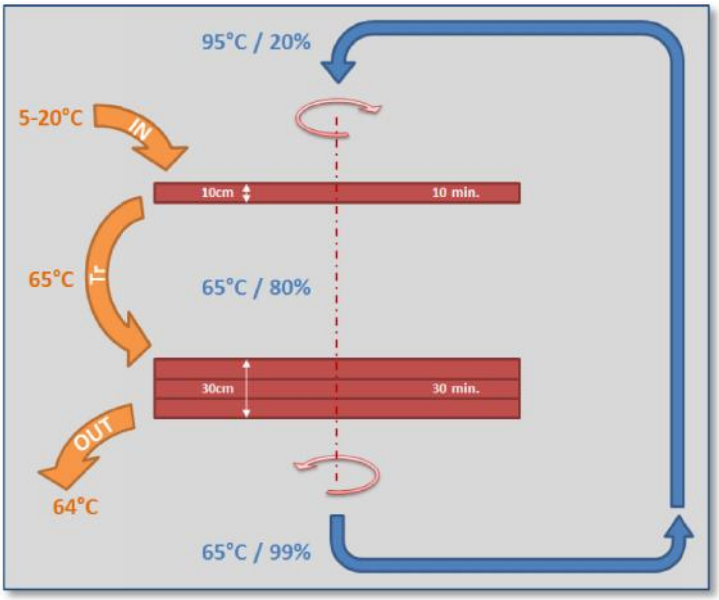

Figure 3: Modifications for heat treatment.

The product is first introduced on the upper disc (heating disc) in a 10 cm layer. It then turns through 360° in 10 minutes.

During these 10 minutes, the produce is crossed by 95°C hot air coming from the heating batteries in order to rapidly raise the temperature of the product before the actual heat treatment.

The product is then transferred to the lower disc (treatment disc). It is distributed in a 30 cm layer and turns through 360° in 30 minutes.

During this treatment period, the product is crossed by air at about 65°C having already crossed the upper disc. It is thus maintained at a temperature greater than 56°C for a minimum of 30 minutes.

In order to minimise the drying of the product and thus to optimise the transfer of heat to the core of the wood, the air circulates in a closed circuit, thus maximising the moisture content.

3 Characteristics of the treated product

Figure 4: Treated product.

This process having been developed following a specific request, the tests which will be discussed in the continuation of the document shall be based on the treatment of wood chips with the following characteristics:

- Type: Yellow pine
- Dimensions: About 60 x 25 x 6 mm
- Moisture content: About 50% (on wet basis)
- Storage temperature: Between 5 and 25°C

4 Feasibility study

A first test was performed using a drying tower adapted for the circulation of air in a closed circuit (Figures 5 and 6).

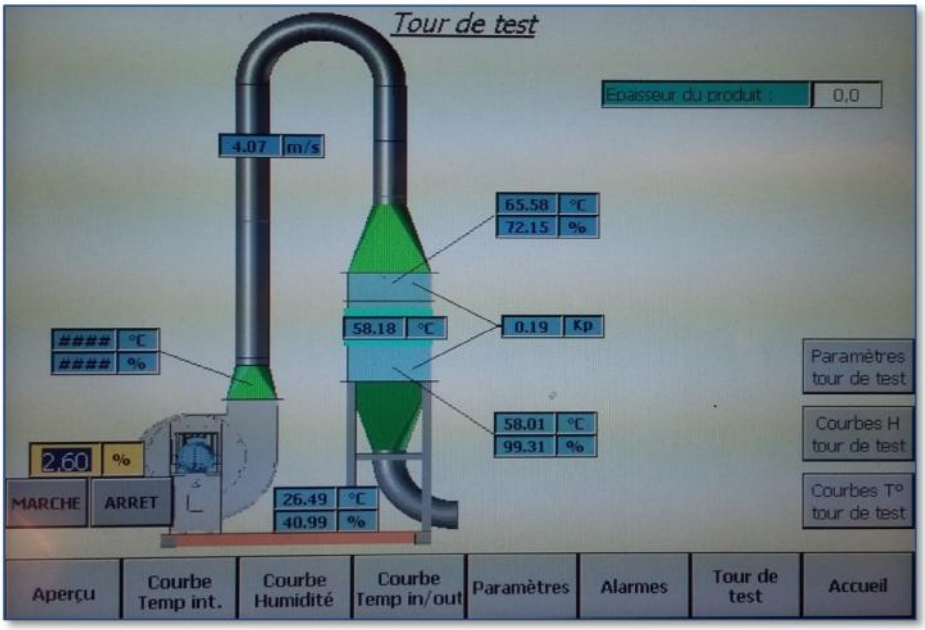

Figure 5: Control screen of the drying tower.

Figure 6: Adaptation for the recirculation of air in a closed circuit.

4.1 Heating disc

Initially, the upper disc (heating disc) was simulated as shown in figure 7.

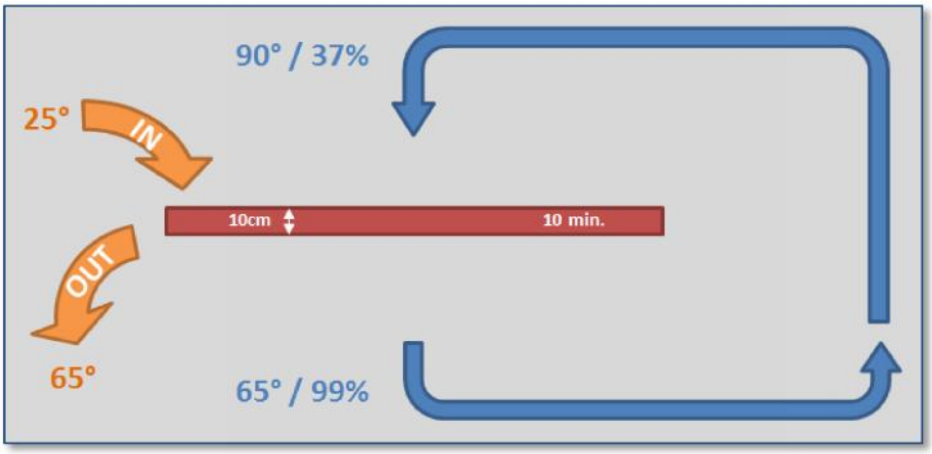

Figure 7: Simulation of the heating disc in the drying tower.

A temperature probe was inserted into a wood chip situated at the bottom of the 10 cm bed in order to measure the temperature at the core of the least favourable chips (in red in figure 8).

It can be seen in figure 8 (in green) that the poor reactivity of the heating system of the tower (see figure 6) results in an input temperature which drops down to less than 80°C.

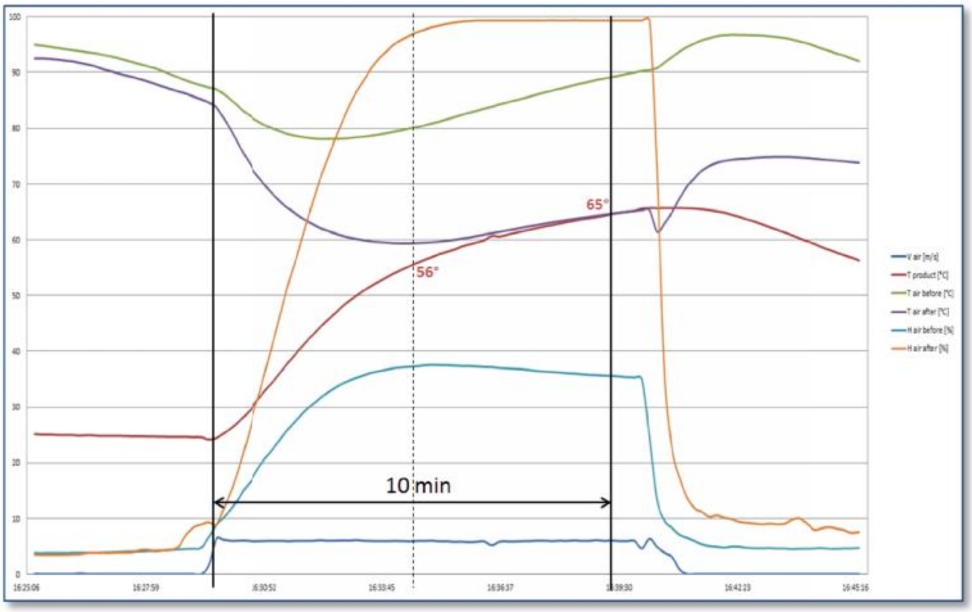

Figure 8: Results of the heating test.

Despite this, the 10 minutes provided are largely sufficient for bringing the product to temperature.

4.2 Treatment disc

Secondly, the lower disc (treatment disc) has been simulated in the same way in the drying tower (see figure 9).

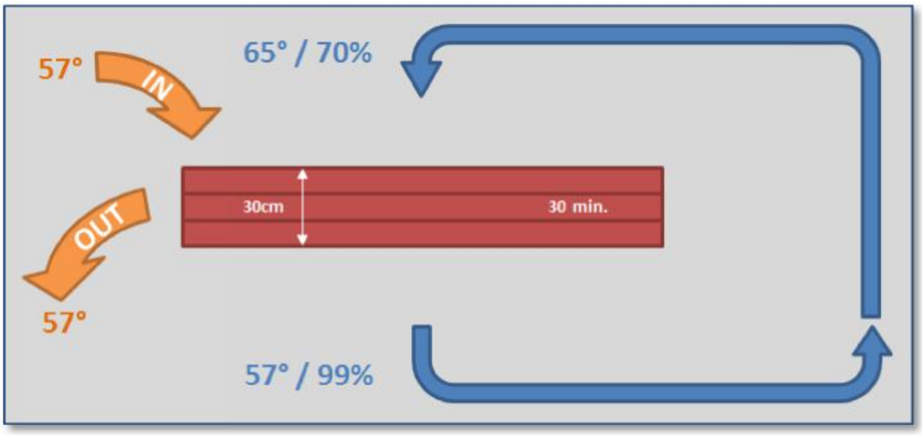

Figure 9: Simulation of the treatment disc in the drying tower.

Figure 10 shows that the product can be brought to and maintained at a temperature greater than 56°C by contact with air coming from the heating disc.

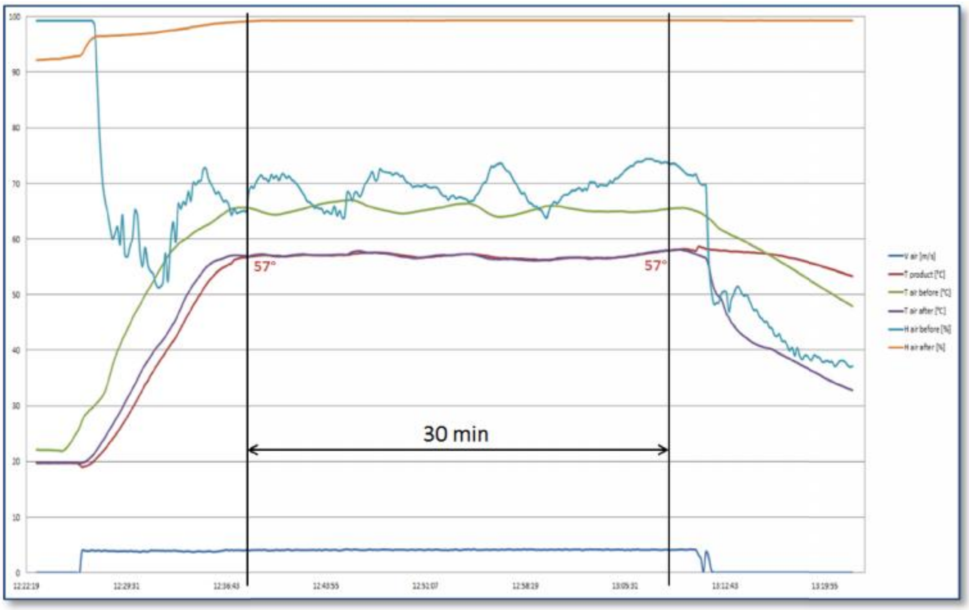

Figure 10: Results of the treatment test.

4.3 Conclusions of the study

This test confirmed the possibility of using the Dryer One for the heat treatment of wood chips as per the European directive 2000/29/EC and the international standard ISPM15 and opened the door to the tests detailed below.

5 Validation study on the prototype

Validation tests were performed under real conditions under the supervision of 2 independent organisations:

- The Service Publique de Wallonie (SPW) [Wallonia Public Service]
  Direction Générale Opérationnelle "Agriculture, Ressources naturelles et Environnement" (DGO3) [General Operational Directorate for Agriculture, Natural Resources and the Environment]
  Département de l'Etude du Milieu Naturel et Agricole (DEMNA) [Department for Studies in the Natural and Agricultural Environment]
  Laboratoire de Technologie du Bois (LTB) [Wood Technology Laboratory]
- University of Liège (ULg)
  Faculty of Gembloux Agro-Bio Tech
  Management of Forestry Resources

For more details on this study, refer to the report "Validation du procédé Dryer One pour le traitement thermique contre les organismes nuisibles appliqué aux plaquettes de bois destinées à l'exportation" [Validation of the Dryer One process against harmful organisms applied to wood chips intended for export] by Professeur Jacques Hebert from Gembloux Agro-Bio Tech, by Dr Benoit Jourez and M. Jean-Marc Henin of the Service Publique de Wallonie.

5.1 Presentation of the prototype

These tests were performed on the prototype of the Dryer One drying machine (Figure 11) which was modified beforehand to correspond to the description given in point 2 of this document.

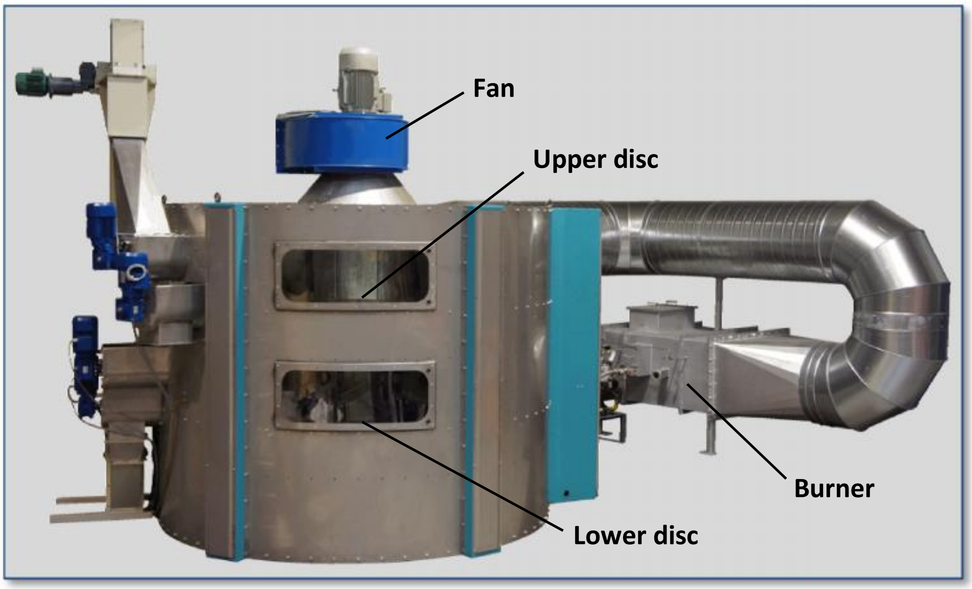

Figure 11: Prototype of the Dryer One drying machine.

The latter is equipped with different sensors. These are shown in figure 12.

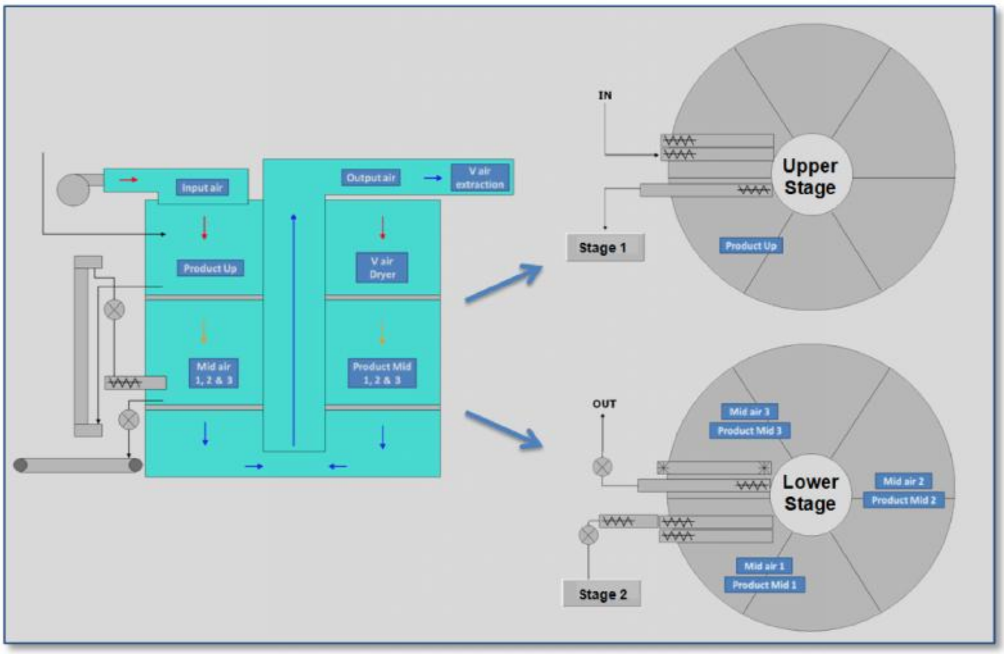

Figure 12: Sensors present on the Dryer One prototype.

- Input air: Temperature and moisture content of the input air (heating air), after the burner.
- Product Up: Temperature of the product at the end of the heating cycle (upper disc).
- Mid air 1, 2 and 3: Temperature and moisture content of the air between the 2 discs (treatment air). These 3 sensors are uniformly distributed:
    - Mid air 1: At product input on the lower disc.
    - Mid air 2: At the mid-point of the treatment cycle.
    - Mid air 3: At the extraction from the lower disc.
- Product Mid 1: Temperature of the product at the start of the treatment cycle (lower disc).
- Product Mid 2: Temperature of the product at the mid-point of the treatment cycle (lower disc).
- Product Mid 3: Temperature of the product at the end of the treatment cycle (lower disc).
- Output air: Temperature and moisture content of the output air in the extraction chimney.
- V air extraction: Air-speed in the extraction chimney.
- V air dryer: Air-speed in the Dryer One.

The temperatures and the moisture contents of the air at different locations were measured using HC2-IM sensors of the Rotronic brand.

The temperatures of the product at the different stages of the process were measured using infra-red sensors CT-SF22-C3 of the Micro-Epsilon brand.

The air speed in the chimney was measured using a hot wire sensor of type HD2903TC3.5 of the Delta Ohm brand.

The air speed in the Dryer One was calculated from the speed in the chimney by taking the ratio of the surface areas of the passages.

These measurements were monitored and recorded continuously throughout the tests.

A VarioCAM, infra-red camera was also placed above a conveyor belt at the output of the Dryer One. Thermal images were taken at regular intervals.

5.2 Test pieces with living larvae

During the tests, test pieces containing living larvae were introduced at regular intervals. These test pieces are shown in figure 13.

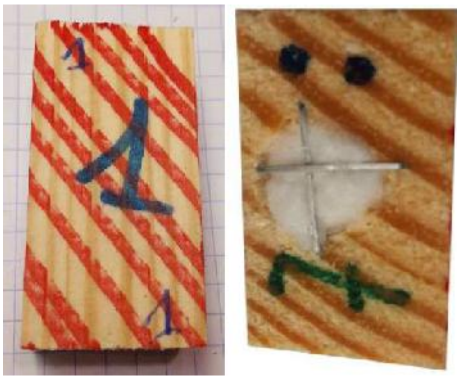

Figure 13: Test pieces containing living larvae.

They were test pieces of Scots pine sapwood (dimensions: 15 x 25 x 50 mm) containing Hylotrupes larvae (Hylotrupes bajulus) of variable sizes between 40 and 490 mg.

The Hylotrupes is a reference species in Europe for the evaluation of the effectiveness of wood phytosanitary treatments.

The larvae were extracted from the test pieces the day after the tests in order to check their mortality rate.

It is important to note that the size of the test pieces was greater than the size of the treated chips and that the size of the largest larvae was greater than what could be found in chips of this size. This ensures that if these larvae were destroyed, *a fortiori*, all those which could be present in the chips would necessarily be destroyed.

5.3 Test protocol

Each test started with the Dryer One filled with chips in order to be close to the steady state treatment conditions.

The Dryer One then functioned continuously for about 1h30 in 3 phases:

- Filling of the upper disc with chips selected for their storage temperature and moisture content: about 10 minutes.
- Continuous feeding with selected chips and introduction of test pieces: about 22 minutes.
- Continuous feeding with selected chips until recovery of all the test pieces: about 60 minutes.

The measurements taken at point 5.1 were recorded throughout the tests.

The mortality rate of the larvae was analysed once the following day and a second time the following week.

5.4 Repetitions

Eight tests were performed following this protocol: three tests with green chips stored at ambient temperature, three tests with dry chips stored at ambient temperature and two tests with green chips stored in a refrigerated lorry.

- Test 1 (01/07/2016) : Green chips (48.9%) and ambient temperature (17°C)
- Test 2 (11/07/2016) : Dry chips (33%) and ambient temperature (21°C)
- Test 3 (11/07/2016) : Green chips (55.1%) and ambient temperature (19°C)
- Test 4 (12/07/2016) : Dry chips (23.7%) and ambient temperature (22°C)
- Test 5 (12/07/2016) : Dry chips (18.6%) and ambient temperature (23°C)
- Test 6 (13/07/2016) : Green chips (54.3%) and ambient temperature (19°C)
- Test 7 (18/07/2016) : Green chips (49.5%) and cold temperature (4°C)
- Test 8 (18/07/2016) : Green chips (45.7%) and cold temperature (4°C)

5.5 Results

The following points summarise the results and conclusions of the study. For more details on this study, refer to the report "Validation du procédé Dryer One pour le traitement thermique contre les organismes nuisibles appliqué aux plaquettes de bois destinées à l'exportation" [Validation of the Dryer One process against harmful organisms applied to wood chips intended for export] by Professeur Jacques Hebert from Gembloux Agro-Bio Tech, by Dr Benoit Jourez and M. Jean-Marc Henin of the Service Publique de Wallonie.

5.5.1 Tests on green chips stored at ambient temperature

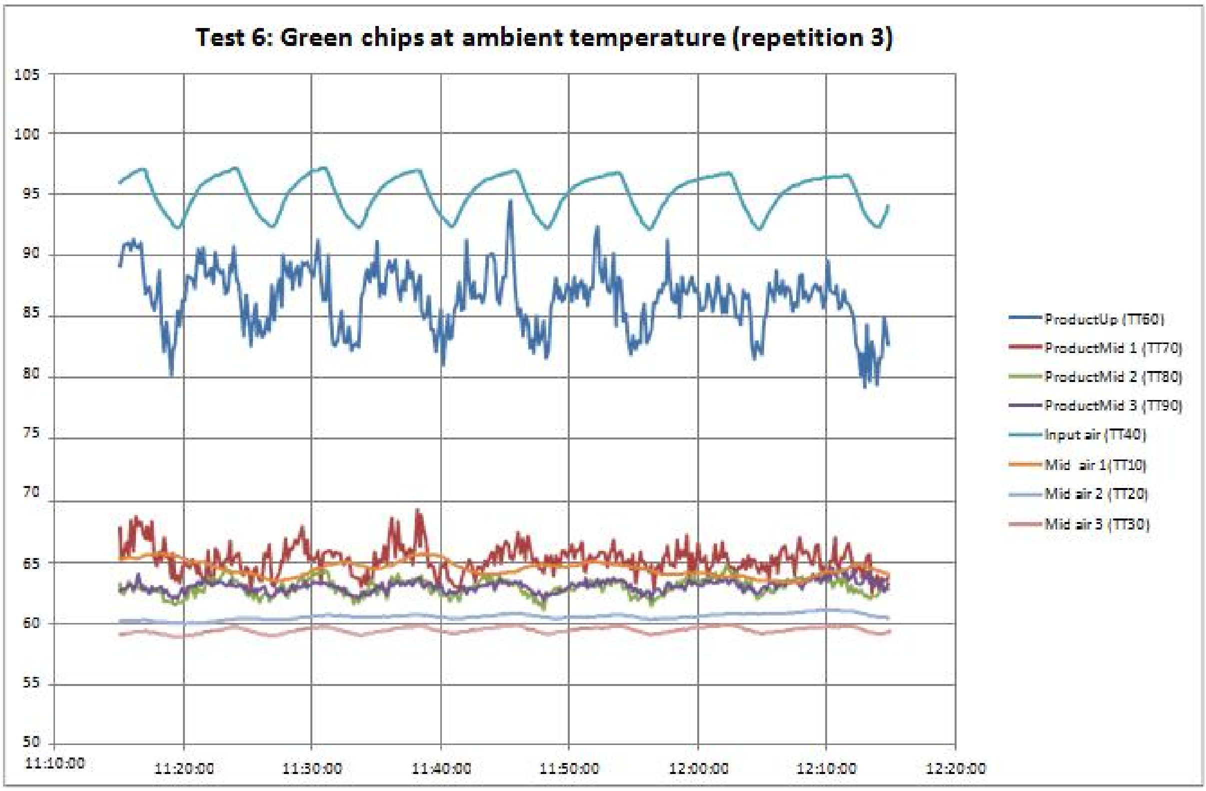

Figure 14: Temperatures recorded (expressed in °C) during test 6 on green chips at ambient temperature.

As shown in figure 14, the heated air at about 95°C (in blue) allowed the chips to reach a temperature of about 85°C at the output of the heating disc (in dark blue).

After having ceded a part of its energy to the product of the heating disc, the air remained at a temperature of between 65°C at the input to the treatment disc (in red) and 59°C at the output of the treatment disc (in pink).

During the transfer between the discs, the product cooled down to a temperature close to 65°C (in red). During the treatment, the product cooled slightly and remained above 60°C (in red at the start of the treatment, in green at the middle of the treatment and in purple at the end of the treatment).

It is important to note that because of the small size of the prototype (approximate scale: 1/20), a bucket elevator was necessary between the 2 discs. This elevator is not present in the industrial model (where the product passes from one disc to another by gravity) and which greatly increases the dwell time of the product outside of the dryer, hence the drop in temperature of 20°C between the 2 discs.

5.5.2 Tests on dry chips stored at ambient temperature

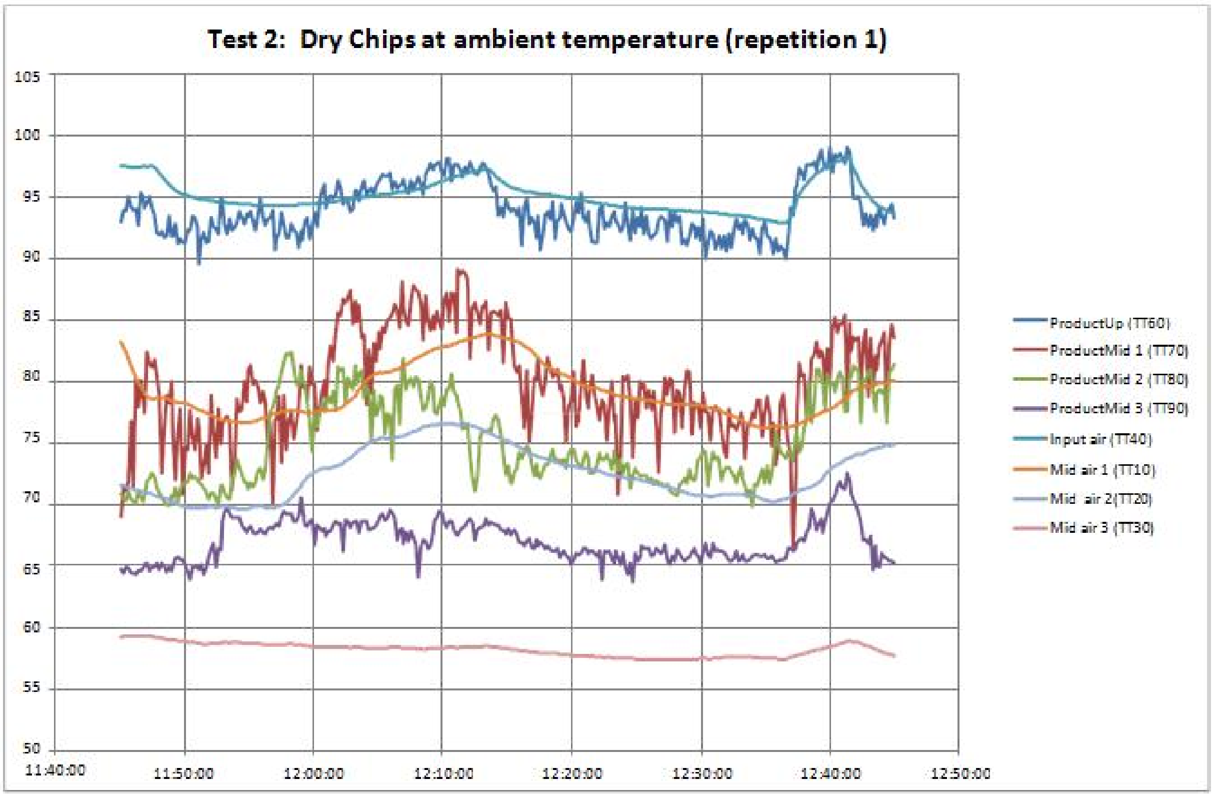

Figure 15: Temperatures recorded (expressed in °C) during test 2 on dry chips at ambient temperature.

The product being dry at the start, less energy is absorbed by water for its evaporation and the wood therefore absorbs more energy. In figure 15, it can be seen that for an equivalent energy input (input air temperature in blue) this produces higher temperature chips (in dark blue).

Compared to the case of green chips, the difference between the temperature curves at the start (air in orange and product in red), in the middle (air in light blue and product in green) and at the end of the treatment (air in pink and product in purple) is greater.

This is explained by the fact that once a large part of the water contained in the product is evaporated, if the energy input is maintained, the product temperature rapidly rises.

The treatment of the dry chips is therefore easier than the treatment of green chips.

5.5.3 Tests on green chips stored in a refrigerated lorry

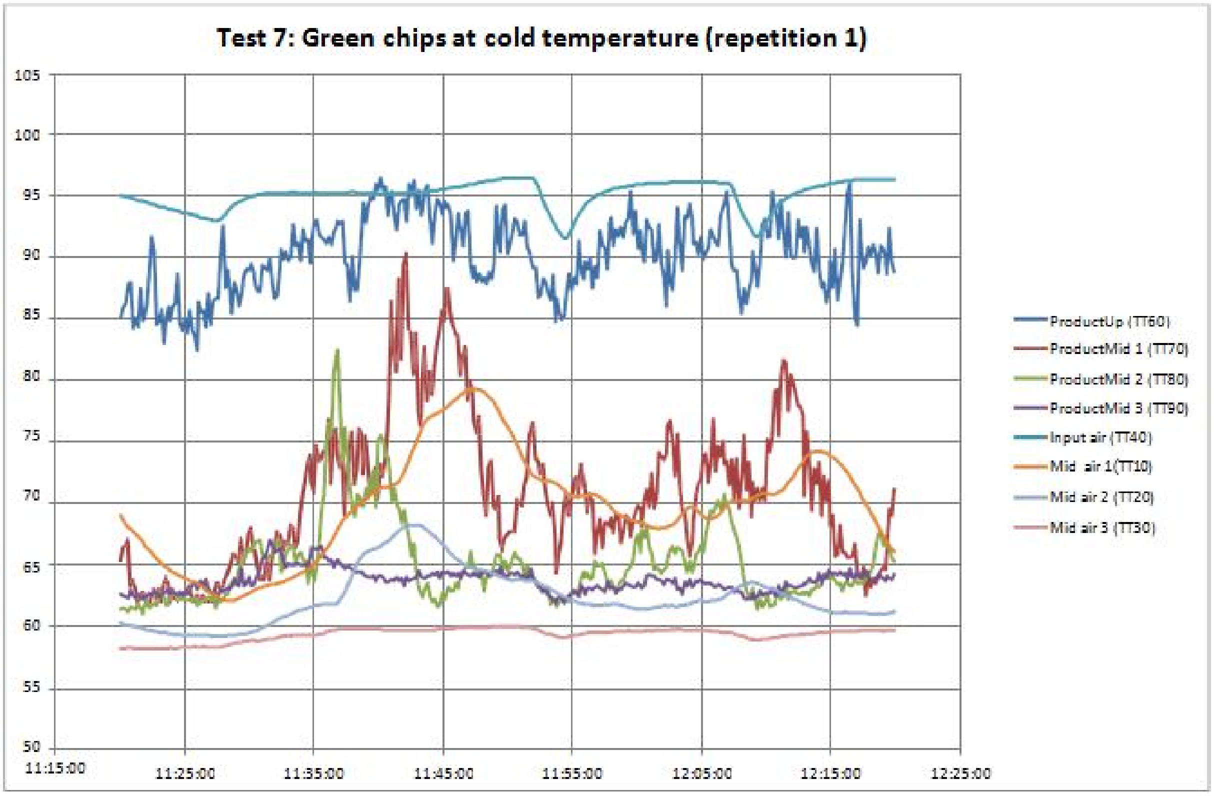

Figure 16: Temperatures recorded (expressed in °C) during test 7 on green chips at cold temperature.

It can be seen in figure 16 that the storage temperature does not influence the effectiveness of the treatment.

In fact, the heat transfer being directly proportional to the difference in temperature between the product and the air, when the product at 4°C is brought into contact with air at 95°C (in blue), the great difference in temperature results in the rapid heating of the product.

Because of this, the difference in storage temperature is rapidly bridged. And the treatment effectiveness is unchanged.

The greater variability of the curves can be explained by the moisture content of the chips being slightly lower than during test 6 (49.5% vs 55.1%). It is seen therefore, that the curves at certain times, tend towards a behaviour close to that observed at point 5.5.1 (at 11:30:00 for example) and, at others, to a behaviour close to that observed at point 5.5.2 (at 11:45:00 for example).

5.5.4 Thermal camera at extraction

Figures 17, 18 and 19 show examples of images taken during the different tests at the output of Dryer One.

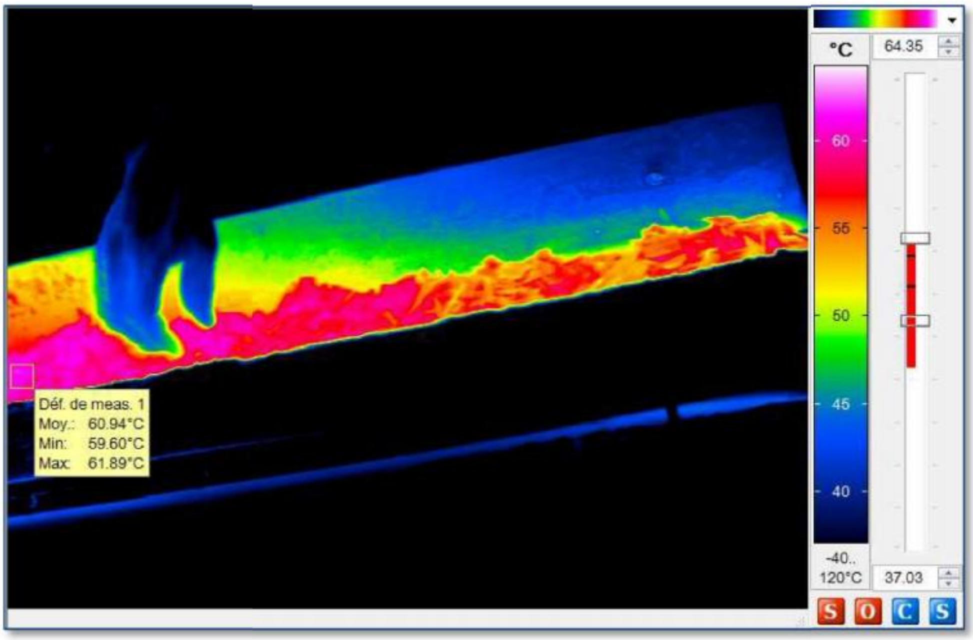

Figure 17: Thermal image captured during test 6 (see point 5.5.1).

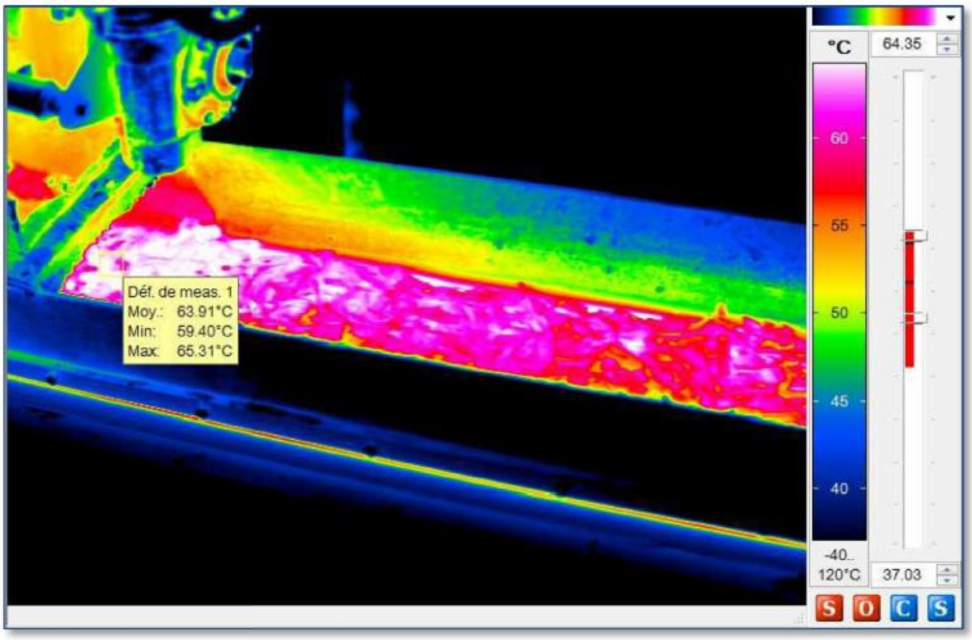

Figure 18: Thermal image captured during test 2 (see point 5.5.2).

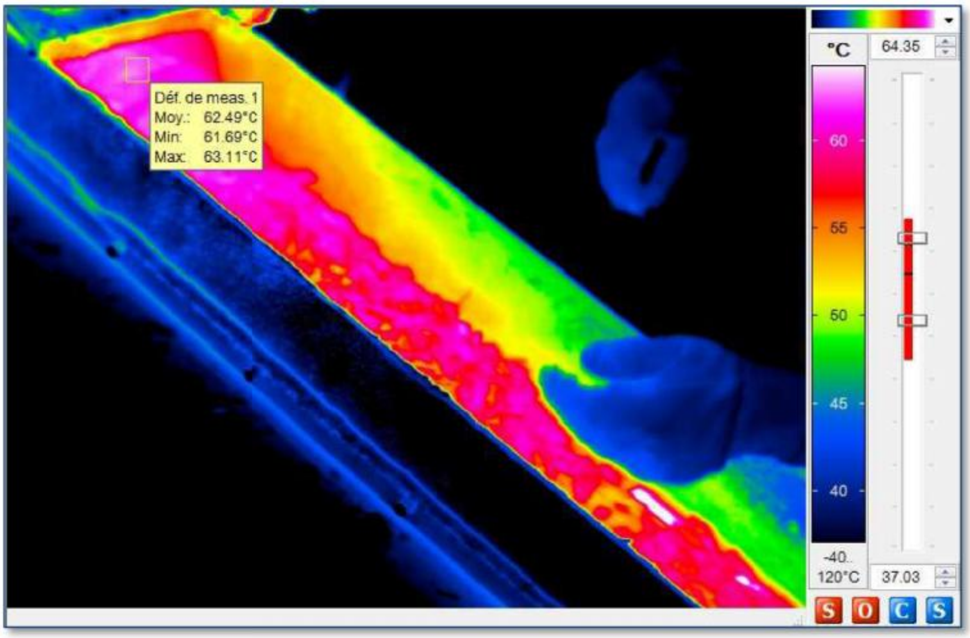

Figure 19: Thermal image captured during test 7 (see point 5.5.3).

In all cases, the product extracted from Dryer One is at a temperature higher than the 56°C required by the European directive 2009/29/EC and the International standard ISPM15.

5.6 Conclusions of the study

During the 8 tests performed under variable conditions, the requirements of the European directive 2009/29/EC and the International standard ISPM15 were always met and the mortality rate of the larvae introduced was 100%.

The industrial model, larger but based on the same process, schould offer the same guarantees of effectiveness.

The only restriction issues concerns the start-up phase of Dryer One. In fact, the steady-state conditions are not immediately reached and the chips coming out of the process during the first 40 minutes, must be managed differently. They can, for example, be re-directed to the stock of non-treated product in order to be re-treated correctly once the steady state conditions are attained.

In addition to ensuring the effectiveness of the process and the proper operation of Dryer One, rigorous procedures must be implemented to ensure the traceability of the chips treated.

6 Laboratory study

A laboratory study was performed, under the supervision of an independent organisation:

- University of Liège (ULg)
  Faculty of Applied Sciences
  Department of Applied Chemistry
  Product, Environment, Processes (PEPs)

This study was ordered for 2 main reasons:

- To validate the experimental results obtained in point 5 by the theory.
- To show that the measurements monitored by Dryer One are sufficient to ensure the control of the process and the traceability of the treated chips, the temperature at the core of each chip being impossible to be measured directly for obvious practical reasons.

For more details on this study, consult the report "Étude du traitement thermique contre les organismes nuisibles appliqué aux plaquettes de bois" [Study of the heat treatment against harmful organisms applied to wood chips], by Professor Angélique Léonard and Dr Ir Laurent Fraikin of PEPs.

6.1 Drying theory

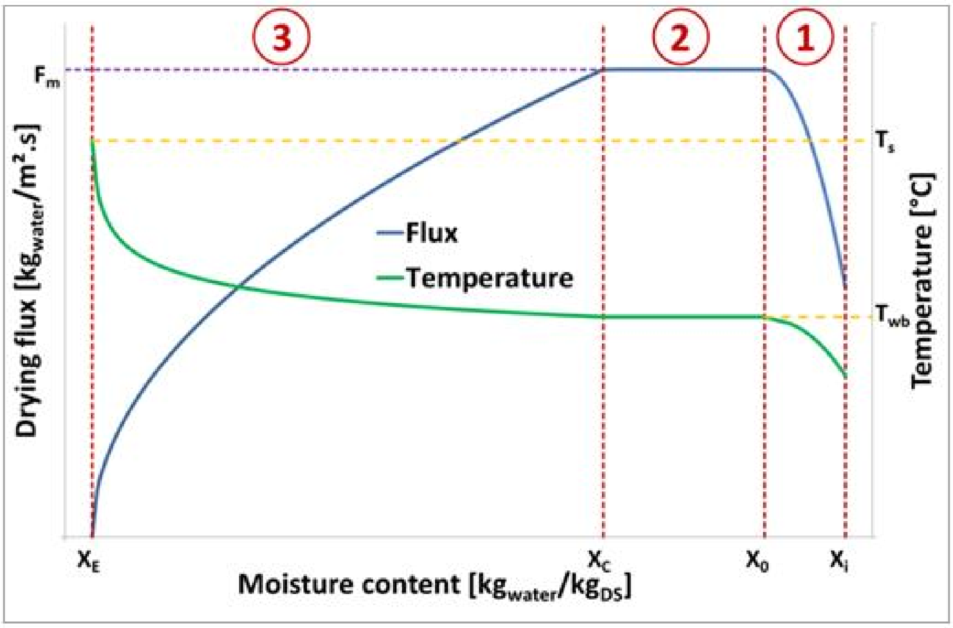

Figure 20: Theoretical drying curve.

Figure 20 above shows the theoretical evolution of the product temperature (in green) and the drying flux (in blue) as a function of the water content of the product during the convective drying of a rigid product such as wood.

The graph is read from right to left since the water content decreases during the drying.

It is divided into 3 stages:

- Stage 1 (temperature establishing): The green product loses water and heats up to arrive at a steady stage which depends on the air temperature and moisture content.
- Stage 2 (at constant temperature): All the heat transmitted by the air is consumed by the vaporisation of the water and the temperature of the product remains constant at the so-called wet bulb temperature (T_{th}). This phase lasts while the permeability of the product allows water to migrate from the core of the product towards its surface.
- Stage 3 (increasing temperature): When the water content decreases below a critical product water content, the surface of the product is no longer supplied by water and the heat transferred by the air is greater than the quantity required for evaporation. The temperature of the product increases up to the air temperature.

It is important to note that the wet bulb temperature only depends on the temperature and moisture content of the treatment air. Figure 21 shows the value of T_{th} for different “Temperature/Moisture” pairs, close to the conditions encountered in Dryer One.

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

Figure 21: Several wet bulb temperatures.

6.2 Presentation of the experimental setup

The PEPs has a convective drying tower shown schematically in figure 22.

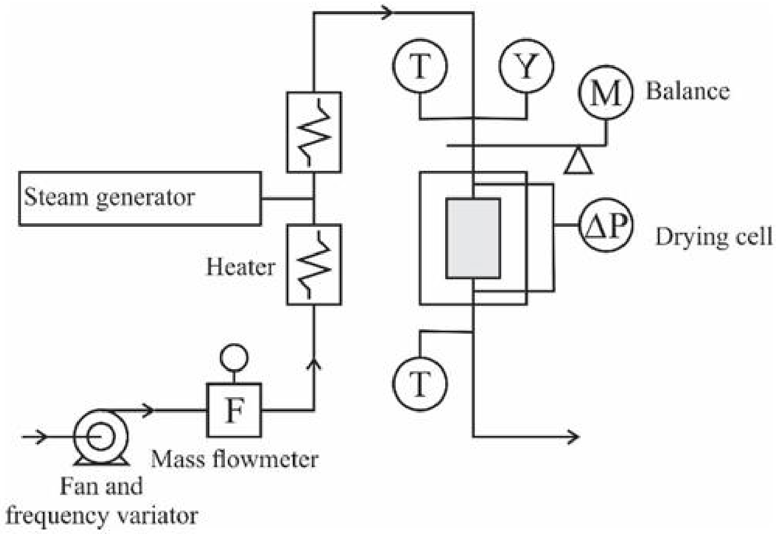

Figure 22: Diagram of the experimental setup.

This setup allows the input conditions of the 2 treatment phases to be reproduced and the product water loss (M), the upstream and downstream product temperatures (T), the moisture content of the input air (Y), the air speed (F) and the head loss generated by the product (ΔP), to be monitored in real time.

6.3 Reference sample

A wood chip test piece was selected amongst the largest of the sample and a thermocouple was inserted into the core of this chip (see figure 23). This was placed at the bottom of the product bed. The test thus was conducted under the most unfavourable conditions.

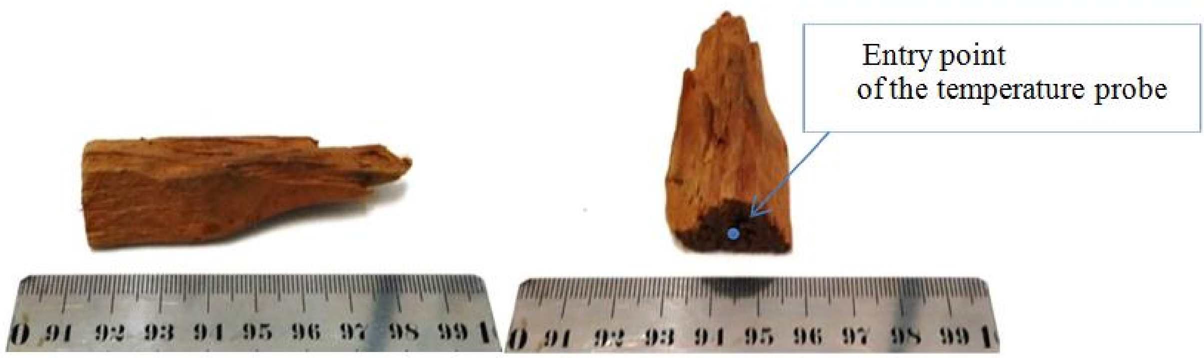

Figure 23: Reference piece.

6.4 Results

The following points summarise the results and conclusions of the study. For more details on this study, consult the report "Étude du traitement thermique contre les organismes nuisibles appliqué aux plaquettes de bois" [Study of the heat treatment against harmful organisms applied to wood chips], by Professor Angélique Léonard and Dr Ir Laurent Fraikin of PEPs.

6.4.1 Study of phase 1: the heating disc

This study consisted in establishing that the material arrived at a core temperature greater than 56°C in less than 10 minutes.

The input air conditions were the following:

- Temperature: 94.9 ± 1.6 °C
- Moisture content: 23.4 ± 1.0 %

Figure 24 shows the evolution of the different temperatures during this test.

It can be seen that, passing through the product air temperature drops from about 95°C (in red) to about 66°C (in green). This agrees with the tests performed on the prototype.

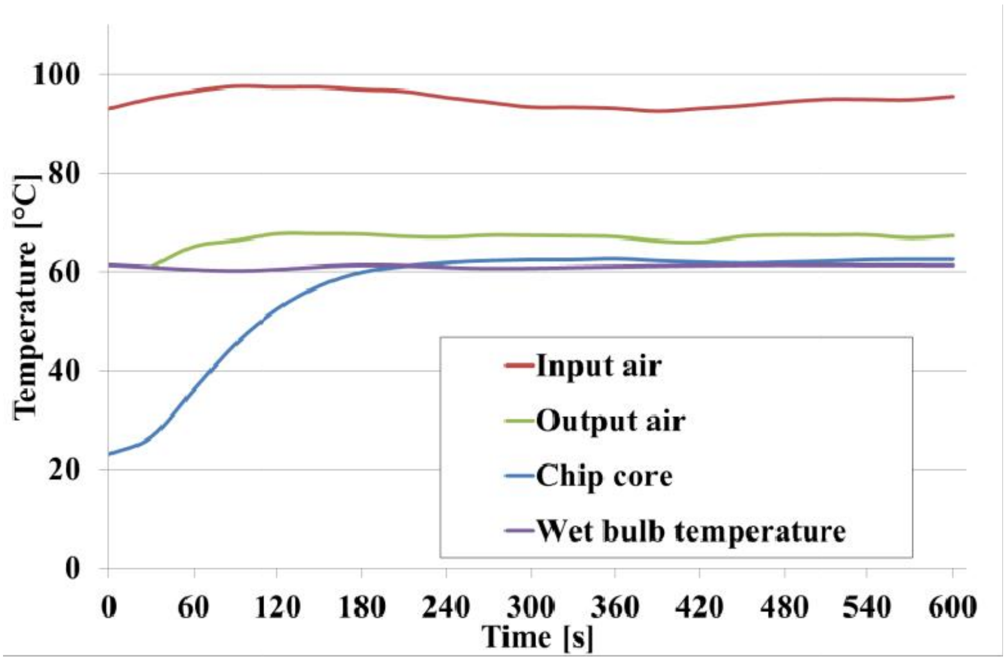

Figure 24: Monitoring of the temperatures during the heating phase

In addition, the core temperature of the reference sample (in blue) reached 60°C in about 3 minutes. The 10 minutes provided in the Dryer One process are largely sufficient.

It can also be noted that the core temperature of the product stabilised at about 62°C, which corresponded to the wet bulb temperature (in purple) under the "drying" conditions.

6.4.2 Study of phase 2: treatment disc

This study consisted in ensuring that the core temperature of the product stayed above 56°C during 30 minutes of treatment.

The input air conditions were the following:

- Temperature: 65.1 ± 1.0 °C
- Moisture content: 65.5 ± 5.1 %

This relative humidity corresponds to the maximum value allowed by the installation at this temperature. Under these extreme conditions, the filling system of the steam generator produced sharp drops in moisture content every 7 minutes. The influence of these drops is visible in figure 25.

These conditions are more unfavourable than the conditions encountered in Dryer One (about 80%). The results shown in figure 25 are therefore applicable to Dryer One.

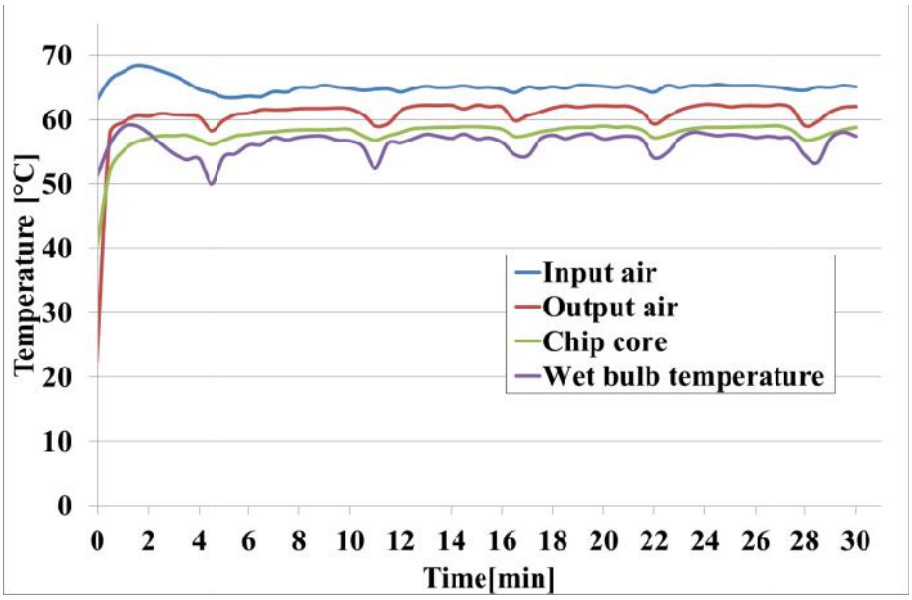

Figure 25: Monitoring of the temperatures during the treatment phase.

It can be seen that, passing through the product, the air went from a temperature of about 65°C (in red) to a temperature of about 62°C (in green) which is the same order of magnitude as during the tests on the prototype.

Throughout the test, the core temperature of the product remained higher than 56°C, even during the sharp drops of moisture content due to the limitations of the test installation.

It can be noted that, as during the previous test, the core temperature of the product always remained higher than the wet bulb temperature.

6.5 Conclusions of the study

Under the conditions encountered in Dryer One, the rise in temperature occured in less than 3 minutes. The 10 minutes inherent to the Dryer One process are more than sufficient. The remaining 7 minutes already participate (bonus) in the treatment of the product.

Then, the “Temperature/Moisture” pair of the treatment air allows the wet bulb temperature to be determined and this is the minimum temperature encountered in the core of the product during the treatment.

This observation is confirmed by the theory since the 10 minutes of heating allowed stage 1 of figure 20 to be performed as well as a part of stage 2, and indeed all of stage 2 and a part of stage 3 in the case of a dry product (as during the test presented at point 5.5.2 for example).

The monitoring and recording of these 2 data therefore allows the procedure and the traceability of the treated chips to be checked.

In addition, the wet bulb temperature being strongly linked to the moisture content of the treatment air, if need be, a moisturizing system can ensure that favourable conditions are maintained.

Lastly, in the case of chips which are dryer than those used during this study, the treatment is easier since stage 2 of figure 20 ($T_{core} = T_{th}$) is shorter and more easily passed through ($T_{core} > T_{th}$).

7 Conclusions

7.1 Duration and temperature of the treatment

During the different studies performed, the chips were always maintained at more than 56°C at core, during at least 30 minutes, as required by the European directive 2000/29/EC and the international standard ISPM15.

7.2 Rate of mortality of the larvae

During the validation study on the Dryer One prototype, of the 176 larvae introduced, none survived the treatment.

7.3 Safety margins

It is important to note that the use of the Dryer One prototype is an unfavourable case compared to the industrial model. In fact, the thermal insulation of the prototype is only crude compared to that of the commercialised model. In addition, the reduced dimensions of the prototype makes the presence of a bucket elevator between the two discs necessary, while the product rapidly passes from one disc to the other by gravity in the case of the real size model.

Then safety margins were taken in order to ensure that the tests were performed under unfavourable conditions:

- The treatment temperature aimed for was 60°C instead of the required 56°C.
- The moisture content of the test pieces containing larvae was greater than that of the chips.
- The test pieces containing the larvae were much larger than the chips.
- The largest larvae introduced are larger (and therefore more resistant) that those which could be present in the chips of the size of those treated.

7.4 Start-up of Dryer One

The following start-up procedure allows ensuring that all the chips are treated:

- Stage 1: Filling of Dryer One
  The Dryer One is started up and the 2 discs are filled. During this time, the layers not being full, the air passes easily through the holes in the layer. This treatment time is therefore not counted.
- Stage 2: Static treatment
  The 2 discs are stationary during 40 minutes, ensuring that all the product arrives at temperature (10 minutes) and is treated (30 minutes).
- Stage 3: Continuous treatment

The 2 discs are started up and the continuous process can begin. The product exiting during the first 40 minutes is therefore sufficiently (or even more than sufficiently) treated.

7.5 Check of the process and traceability of the chips

The laboratory tests have shown that, during the heating phase, and under the conditions encountered in Dryer One, the core temperature of the product reached the wet bulb temperature (T_{th}) after about 3 minutes.

Then the tests have shown that, during the treatment phase, the wet bulb temperature is the minimum temperature encountered in the core of the product.

In fact, during the treatment of green chips, the treatment occurred during stage 2 of figure 20 ($T = T_{th}$) and, during the treatment of dry chips, the treatment occurred during stage 3 of figure 20 ($T > T_{th}$).

From this, the surveillance and recording of the wet bulb temperature allows the process control and the traceability of the treated chips to be ensured.

To do this, the temperature and moisture content of the treatment air are measured at 3 positions of the treatment disc:

- At the start of the treatment, near to the introduction point of the product.
- In the middle of the treatment, equidistant between the introduction and the extraction.
- At the end of the treatment, near to the extraction of the product.

These measurements allow T_{th} to be calculated at these 3 locations.

If, for any reason, T_{th} drops below 60°C, the discs are stopped until T_{th} rises again to guarantee the treatment. In this case, T_{th} being strongly linked to the rate of humidity of the treatment air, it is also possible to accelerate the rise of T_{th} by steam injection.

Obviously, each batch treated must have T_{th} recorded throughout its treatment.

Thus, Dryer Ones provides an effective treatment for wood chips against harmful organisms as well as all the tools necessary for good traceability of the chips treated.

In addition, Technic One undertakes to raise the awareness of the customer to the fact that, other than the proper use of the tools made available by Dryer One, they have, on their side, other conditions to meet in order to be be able to export their product (flow management, logistics, etc.).