CASE STUDY ON THE THERMODYNAMIC CALCULATION OF THE BLAST FIBRE DRYING TUNNEL USING GEOTHERMAL WATER

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Abstract. This paper presents the thermodynamic calculation of the flax and hemp drying tunnel using geothermal water. The case study helps the initiation of a complex study on the effects of the geothermal water chemism on the technical-crop melting process. The solution chosen for melting seems to be complicated by the existence of the secondary agent circuit (the running water), but which is necessary in case of a worsening effect of the fibre properties, caused by the geothermal water chemism.

1. Introduction

The hydro-geothermal perimeter of Oradea is part of the Aleşd – Oradea – Felix hydro-geothermal system, which in turn is part of the regional Mesozoic hydro-structure of the northern part of the Pădurea Craiului Mountains. The aquifer covers the western terminal area of the northern Apuseni Mountains, an area which is part of the sunken foundation of the Pannonian Depression, but also of the western half of the Neogene depression of Vad – Borod. In a regional context, the area of Oradea lies in the south-eastern part of the Carpathian-Pannonian region, by the eastern border of the Pannonian Depression.

This paper presents the thermodynamic calculation of the flax and hemp drying tunnel using geothermal water. Our industrial application, using geothermal water for melting and drying flax and hemp was designed to harness the water from the well no. 1720. The maximum flow which can be exploited from this well in an artesian regime, namely without installing a depth pump or one at the head of the well, is of 30 l/s for the free forcing into the atmosphere. The well is placed at the Western end of the perimeter of Oradea, it produces geothermal water with a temperature of 76°C, from a depth of 1800 - 1900 m.

The constructive variant of the flax and hemp processing centre will look according to the diagram in Figure 1 [4]. The melting process was described in prior papers [5]. During the drying process, the solution which is imposed by the particularities of the technological process is that of a multicellular drying tunnel. Each cell will be used for removing a fraction of the total humidity which is to be extracted; the heating of the drying air is best done using one wide-surface heat exchanger (radiator) for every cell. We have nine drying cells, and besides we have that last cell, the tenth, which will be a conditioning cell in which the material (the stems) is sprayed with a fine mist in case it has been dried for more than it would have been necessary, therefore if its humidity risks to lower under 12 %.

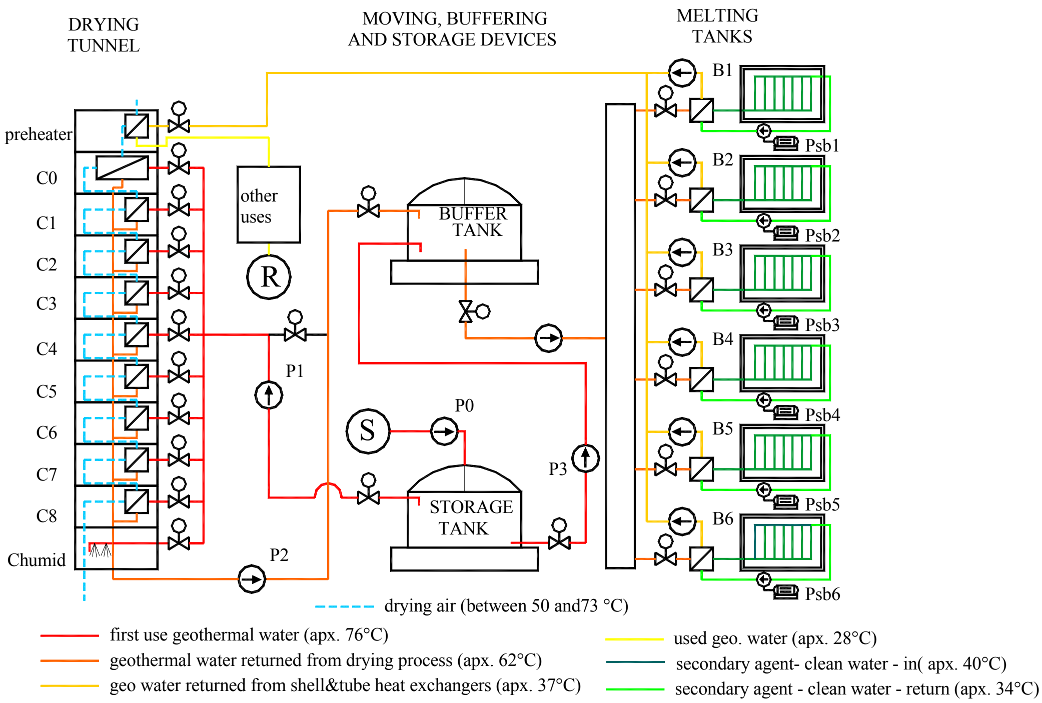


Fig. 1. Functioning diagram of the flax and hemp processing centre

2. Thermodynamic aspects of wet air drying. The Mollier Diagram

The humidity of a certain material containing water can be reduced by several methods [1]: separating humidity mechanically (squeezing), which is done by using specially designed presses, by centrifugation or by using the filtering installations through vacuuming; chemically, the humidity can be reduced by using humidity absorbing (hygroscopic) substances; and finally, thermally - the humidity removing process by evaporating water and removing the vapours formed is called drying. In the last case, the drying agent, which can be the hot air or the burning gases, emits the necessary heat for the evaporation of the water and takes over the formed vapours in order to evacuate them from the installation.

Using air as a drying agent is based on the physical (thermodynamic) processes suffered by the water vapours found in the air. In order to finally design a drying device (tunnel), we need to know the laws according to which the heat exchanges and the substance exchanges between the air and the humidity at the surface of the material take place. These aspects of using the wet air for technical purposes are treated in many sources ([6], [9], [1], [8]). The differences among them are not fundamental, but insignificant, at the level of notations and information structuring. The sources [3], [1], and [7] also offer examples of applications of the using of wet air in technology, especially as far as the cooling towers, the air conditioning devices, but also the drying equipment (tunnels) are concerned.

The diagram which is most commonly used in order to solve wet air problems is the Mollier diagram, described in source [6] and offered in source [7] in a sufficiently large format (or scale) so that it can provide relatively precise results.

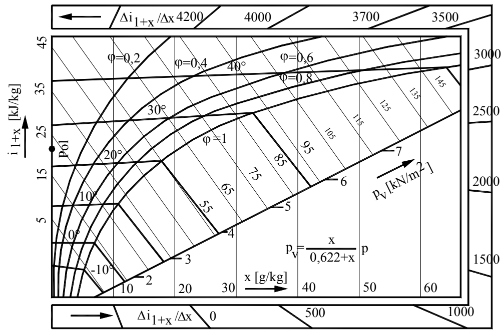


Fig. 2. The rough layout of the Mollier Diagram

The Mollier Diagram (see **fig. 2**) is based on the relation of determination of the composition enthalpy of the unsaturated field:

$$i_{1+x} = c_{paer}t + x \cdot \left(c_{pv}t + r\right) = 1.004t + x \cdot \left(1.866t + 2500\right) \quad (1)$$

which contains the values of the air physical constants: c_{paer} = *1.004* kJ/kgK, and the vapour physical constants: c_{pv} = *1.866* kJ/kgK, *r = 2500* kJ/kg, at the standard atmospheric pressure of p_B = *760* mm Hg.

3. The thermodynamic calculation of the cellular drying tunnel

When using a simple tunnel drier, like the one in **fig. 3**, we use only one ventilator for taking and carrying the whole air flow and only one heat exchanger for preparing the hot air. For the humidity flows that must be extracted, these devices should be huge.

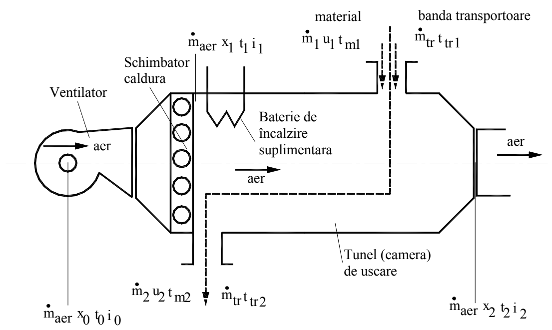
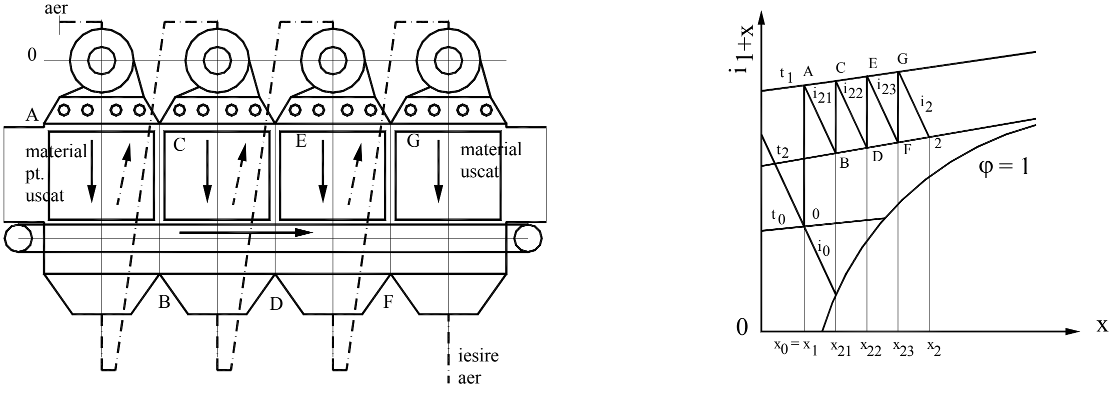


Fig. 3. Layout of the hot air drying equipment

This is why, in practice, this solution is very rarely adopted and different variants of drying tunnels are built: *with intermediate heating processes*, *with recirculation*, *with intermediate and recirculation heating processes*, or *in a closed circuit*.

According to the descriptions given in sources [2], [10], and [11], the drying-conditioning tunnels used for flax and hemp are of an "intermediate heating” type, that is, the air – in a lower flow than the one used in the simple tunnel – is aspirated and heated in a relatively small exchanger, then it passes through/over the damp material, but only past a section of the whole tunnel, which is called a cell, it takes over only a part of the total humidity which should be extracted and then it is aspirated by the ventilator of the next cell, which sends it to its own heat exchanger and again through/over the material, in order to extract a new humidity fraction.



a) Equipment layout ***b) Process representation in i_{1+x} - x***

Fig. 4. Intermediate heating drier

Sometimes one ventilator serves 2 to 4 cells, if pressure losses are covered by the compression ratio of the ventilator (π_V = *1,1* – maximum value); its flow, although it is lower than the one of the ventilator in the simple tunnel, is still high enough, and the cells function in series, not in parallel. The main layout and the evolution of the wet air transformations in the Mollier diagram are presented in **Fig. 4a** and **b**.

The total length of the drying tunnel is divided into several areas, and the air is heated at the entrance to every area, using intermediary heating batteries (fig. 4 b). These heat the same air flow between the same two temperatures, t_2 and t_1, being therefore identical, except for the first battery which heats the air at the value of the atmospheric temperature, t_0. The maximum temperature in the drier can be lower the one in the one-step drier and the possibility of establishing relatively high values of t_2 (as compared to t_0) allows the air to take over a much higher quantity of humidity. Since through the layout of several successive drying steps, the value of x_2 rises considerably, it means that the necessary air flow lowers very much. The necessary heat flow for drying does not lower too much, because, although the air flow lowers, i_2 rises in the same proportion in which the flow lowers, because in fact the same weigh rate of humidity must be evaporated. But by lowering the air flow, all previously discussed losses and also the necessary ventilators (or ventilator) have a lower flow. Drying is more even and can be done at lower temperatures.

X - the absolute humidity of the air at the entrance

A cross section through the tunnel, designed according to [2], is presented in **fig. 5**.

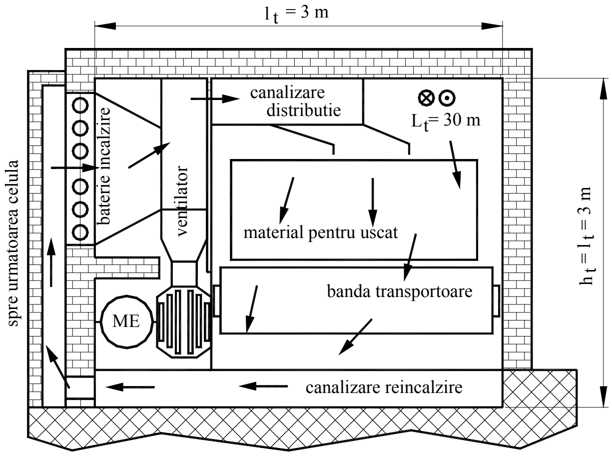


Fig. 5. Cross section through the multicellular drying tunnel, with intermediate heating processes

For the drying tunnel that we have designed for the flax and hemp processing centre, the evolution has the aspect in the diagram presented in fig 4. b, except for the fact that the number of cells is different. It can be noticed that the transformation between the chosen parameters implies nine cells. The same air flow passes through all these cells.

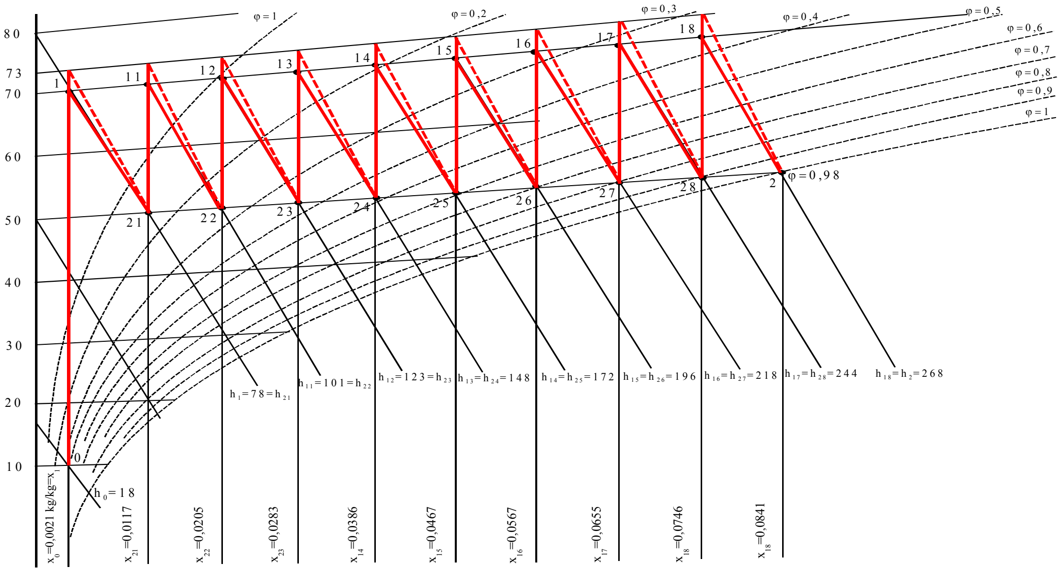


Fig. 6. Evolution of the transformations which take place in the drying tunnel

The full line indicates the ideal process, without losses, where the heating should be done up to 70°C, and the drying of stems would be done based on the isenthalpic cooling of the air (it gets cold, but the enthalpy remains the same, being present in the additional humidity included in the air).

The dotted line represents the non-isenthalpic successive cooling processes, a part of the initial enthalpy being used in every cell in order to compensate for the losses that appear (conduction through the tunnel walls, radiation, leakages).

By drawing the evolutions in the real Mollier Diagram [7], we have obtained:

- The status of the air at the entrance, the multi-annual average values: the temperature of $t_0 = 10$ °C and the relative humidity of $\varphi_0 = 40$ %.
- Out of the Mollier Diagram, we have taken the starting point values: the absolute humidity of the air at the entrance, $x_0 = 2.1$ g/ kg = 0.0021 kg/kg and the enthalpy $i_0 = 18$ kJ/kg.

The transformation from 0 to 1 takes place inside two exchangers, that is in the air preheater from 0 (in winter), 10 (in spring – autumn) and 20 (in summer) to 33°C, and then in the radiator of cell 0 (the one with an extended surface), where heating takes place from 33 to 73°C.

The first heating battery, the one with an extended surface heats the air up to the values of point 1 in the previous applications: $t_1 = 70$ °C and the enthalpy of $i_1 = 78$ kJ/kg. From now on, we impose a temperature fall of 20 °C on every cell, the drying taking place at a constant enthalpy, up to the intermediate temperatures of $t_{2i} = 50$ °C. Each battery at the entrances to the next cells will reheat the air at the intermediate temperatures of $t_{1i} = 70$°C.

The transformation between the chosen parameters implies nine cells, which will be crossed by the same air flow. The first cell will have a heat exchanger capable of transmitting more heat (60 kJ/kg), and the other ones will be identical, each transmitting an average energy of approximately 24 kJ/kg. The points which represent the corners of the transformation dotted line have the following characteristics, read on the diagram, grouped in **Tab. 1**:

Tab. 1. Values of the parameters in the significant points of the cellular drier

Point (status)	Temperature t [°C]	Abs. humidity x [g/kg]	Rel. humidity φ [%]	Enthalpy i [kJ/kg]	Heat received Δi [kJ/kg]
0	10	2.1	40	18	60
1	70	2.1	2	78	
21	50	11.7	16	78	23
11	70	11.7	7	101	
22	50	20.5	27	101	23
12	70	20.5	11	124	
23	50	28.3	38	124	24
13	70	28.3	15	148	
24	50	38.6	49	148	24
14	70	38.6	19	172	
25	50	46.7	59	172	24
15	70	46.7	23	196	
26	50	56.7	70	196	24
16	70	56.7	27	218	
27	50	65.5	80	218	26
17	70	65.5	32	244	
28	50	74.6	91	244	24
18	70	74.6	36	268	
2	50	84.1	98	268	-

Sizes are affected by the precision limit of reading on the diagram, but the scale is sufficiently large, the values are relatively precise, especially the absolute humidity values and the enthalpies, which are read directly on the vertical and the oblique scale, respectively. The reading of the relative humidity, especially at low values, is less precise, due to the curve scale which must be followed, but it can also be worked only with the absolute humidity, as long as evolutions take place only in the unsaturated field.
We determine the air flow using the following relation:

$$\dot{m}_{air} = \frac{\dot{m}_a}{x_2 - x_0} = \frac{0.6612}{0.0841 - 0.0021} = 8.063 \text{ [kg/s]} \quad (2)$$

and the relation

$$\dot{m}_{aer\,u} \cdot i_0 + \dot{Q}_{tus} = \dot{m}_{aer\,u} \cdot i_1 = \dot{m}_{aer\,u} \cdot i_2 \quad \text{[W]} \quad (3)$$

where:

- $\dot{Q}_{tus}$ is the thermal flow received by the air in the drying tunnel from the heating battery [W]
- i_0, i_1, i_2 are the mass enthalpies of the wet air at the entrance to the tunnel, after having passed by the heating battery, and at the exit of the tunnel, respectively [kJ/kg]
- $\dot{m}_{aer\,u}$ is the wet air flow [kg/s]

we calculate the necessary thermal power on all cells:

$$\dot{Q}_{tus} = \dot{m}_{aer\,u} \cdot i_2 - \dot{m}_{aer\,u} \cdot i_0 = 8.063 \cdot (268 - 18) = 2015.75 \text{ [kW]} \quad (4)$$

In the layout presented in **fig. 4** we can notice that the cross section dimensions remain the same: $l_t \times h_t = 3$ m × 3 m; we have two drying cells, but also the last cell, the tenth, which will be a conditioning cell in which the material (the stems) is sprayed with a fine mist in case it was dried for more than it would have been necessary, therefore if its humidity risks to lower under 12 %. By adopting a 3-meter length for a cell, we obtain a total length of $L_t = 9 \times 3 + 3 = 30$ m for the tunnel. Considering all this, we can say that the mentioned losses change, but only slightly, because the exit temperature is now of 50 °C instead of 27 °C. It's the temperature for which losses have been calculated, and the lower air flow implies a lower average speed and therefore a slightly lower convection coefficient inside, which means lower losses due to convection that make up for the increase of the ones having to do with the heating of the drying and transportation materials; from a percentage point of view, these losses do not increase too much, being of maximum 5.5%. The problem raised here is the evaluation of losses due to leakages, which as far as real constructions are concerned, can be of up to 30 % of the necessary heat coming from the tunnel without leakages. In order to compensate for these losses, we shall increase the necessary heat for drying with 20 %, of which about 5% are losses due to the heating of materials and losses into the environment, and 15 % are losses due to the hot air going out through the leakages of the tunnel. The final value will be:

$$\dot{Q}_{tus\ final} = 1.2 \cdot \dot{Q}_{tus\ calculat} = 1.2 \cdot 2015.75 = 2420 \text{ [kW]} \quad (5)$$

In order to ensure the transfer of this increased thermal power into the air used for drying, the air in every cell will be heated a little more, up to 73°C, following that drying be done once with the lowering of the air enthalpy, as in the layout presented in fig. 3b. Points *1i* will be found higher on the verticals, but points *2i* will remain in the same position. A heating of up to 75°C would be ideal. It would cover the 20% loss increase, but since geothermal water at the source only has 76°C, heat exchangers with a very large surface would be necessary.

3. Conclusions

In the drying process, the solution imposed by the particularities of the technological process is that of a multicellular drying tunnel. A fraction of the total humidity which is to be extracted will be removed from every cell. It has been noticed that the heating of the drying air is best done using heat exchangers with very large surfaces (radiators), one for every cell.

The thermal calculation of the necessary heat exchange surfaces has allowed for the design of heat exchangers of usual types and sizes for the radiators in the drying tunnel. The exchangers can be purchased from the market or they can be made to order by specializing producers, since the chosen solutions don't raise any technological problems.

4. Bibliography

1. Badea, A, Necula, H. and others: *Echipamente şi instalaţii termice (Thermal Equipment and Installations),* E.T. Bucharest, 2003.
2. Botta, A., Bondar, T.: *Călăuza muncitorului din industria de prelucrare primară a inului şi a cânepii (Flax and Hemp Primary Processing Industry Worker's Guide)*, The Centre for Technical Documentation and Publications of the Ministry of Light Industry, Bucharest, 1970.
3. Carabogdan, Gh., Badea, A., and others: *Instalaţii termice industriale – Culegere de probleme (Industrial Thermal Installations – Set of Problems), vol. II,* Editura tehnică, Bucharest, 1984.
4. Indrie, L., Gherghel. S., Prichici, M.: The Analysis of the Technological Processes of Flax and Hemp Melting Using Geothermal Water, from the Perspective of Thermal Energy Consumption*, The Bulletin of the Polytechnic Institute of Iaşi, Engineering Department*, Tome LII (LVI), Booklet 5C, Polytechnic University "Gh. Asachi:, Iaşi, 2006, pp. 853-860.
5. Indrie, L., Gherghel, S., Almăşan, I.: Using the Heat from Geothermal Waters for the Melting and Drying of Flax and Hemp, *Proceedings of the International Symposium „Research and Education in innovation Era"*, Section III, Engineering Processes and Technologies, 16-18 November, Arad, 2006, pp. 187-192.
6. Neacşu, E.: *Bazele Termotehnicii (Bases of Heat Engineering),* I.P.T.V.T. Publishing House, Timişoara, 1991.
7. Pimsner, V., Vasilescu, C. A., Petcovici, A.: *Termodinamica tehnică. Culegere de probleme (Technical Thermodynamics. Set of Problems)*, E.D.P. Bucharest, 1982.

8. Vlădea, I.: *Instalaţii şi utilaje termice (Thermal Installations and Machines)*, E.T., Bucharest, 1966.
9. ***: *Manualul inginerului termotehnician (Heat Engineer's Handbook), vol. II*, Editura tehnică, Bucharest, 1986.
10.***(collective directed by Brânzan, I.N.)**:** *Reguli de exploatare tehnică în intreprinderile de in. Depozitarea, decapsularea şi topirea tulpinilor de in (Rules of Technical Exploitation in Flax Factories. Flax Stem Deposition, Shelling and Melting)*, Ministry of Agriculture and Food Industry, The Flax, Hemp and Cotton Trust, Bucharest, 1977.
11.***(collective directed by Brânzan, I.N.)**:** *Reguli de exploatare tehnică în topitoriile de cânepă. Prelucrarea mecanică a tulpinilor de cânepă (Rules of Technical Exploitation in Hemp Retting Pits. Hemp Stem Mechanical Processing)*, Ministry of Light Industry, Silk, Flax and Hemp Industry Centre, Bucharest, 1974.