ANNALS of the ORADEA UNIVERSITY.

Fascicle of Management and Technological Engineering, Volume VI (XVI), 2007

MATHEMATICAL MODEL OF FLAX AND HEMP PROCESSING CENTRE WITH THE HELP OF GEOTHERMAL WATER

Liliana INDRIE, Sabina GHERGHEL, Marius ŞUTEU, Mariana PRICHICI
University of Oradea, Faculty of Textiles and Leatherworks
e-mail:lindrie@uoradea.ro

Key words: mathematical model, flax, hemp, geothermal water

Abstract. The mathematical model shown in this paper and completed in Excel allows the analysis of seasonal and daily variations of the thermal energy needed for flax and hemp processing centre using geothermal water. The program determines the quality that can be processed at one point out of the proposed batches and re-routes the exceeding quantities towards the next productive cycle. Starting from the meteorological data and the loads, the program also determines the required discharges for each tank or for each drying cell, the outlet temperatures, as well as the positions of some adjustment elements (bottom stirrer, obturator blades, etc.). In this way are determined mathematically the possibilities' limits for the center processing. If projecting was fulfilled in order to make for the losses in the most unfavorable conditions, the program allows the study of the center's energy needed in varied conditions.

1. General considerations about the preparation of the mathematical model and the simulation of the center's performance in diverse working conditions

As a result of the structure's design and the main constitutive elements of flax and hemp processing centre using geothermal water both for the preparation of the melting agent and heating the air for drying, design that consisted in sizing the melting tanks, the drying tunnel, the necessary heat exchangers (grills on the bottom of the tanks, water-water exchangers for the preparation of warm water for melting, respectively the radiators needed for preheating and heating the air for drying the melted material) as well as sizing the pumps and ventilators necessary for the circulation of working fluids [1], [2], we have worked out a mathematical model for a detailed description of the designed centre conduct in other environmental conditions than the ones it was initially designed.

For designing the structure and the constituent elements [3], [4], we have started from the geothermal water available, an inflow of 30 l/s, which is fed during cleaning of the tanks between two melting cycles and is emptied during the melting-drying cycle. The thermal energy needed, meaning the inflow necessary by the working agent, depends on two groups of factors: the size of the technical plants batches available at a certain point for melting, respectively drying, and the present environment conditions (the temperature of the surrounding environment, air humidity and especially the wind speed). The logics for sizing the center's constitutive elements consists in correlating the available thermal potential with the batches' size that can be processed at a certain point, *not for the medium seasonal conditions (spring-autumn), but in the most unfavorable seasonal conditions,* meaning in winter conditions, when the thermal energy required is higher as compared to mass unit of melted, respectively dried material. Still, we haven't done the measuring for the most unfavorable conditions which can appear during winter (the absolute minimum for air temperature and the absolute maximum for wind speed), but for average values that can appear during winter. The center's designed structure implies the use of falling geothermal water, the total inflow to be used initially for the preparation of warm air for the drying tunnel, then the geothermal water resulted after drying is to be used in the melting tanks and a small part of the repressed water is to be used for the air preheated. For the structure mentioned and for the environmental conditions in cold season we have obtained the possibility of simultaneous processing of two batches of plants of over 100 tones each: a batch being melted in four tanks of 19 × 9,5 × 2,2 m, and the other batch being dried in a drying tunnel provided with nine drying cells and an air pre-heater. In the context of sizing the center for average winter conditions it is obvious that a certain number of days per year (with lower temperatures and higher wind speeds), the center will not process big batches, working only with three tanks, respectively with a smaller load of the transporting belt from the drying tunnel. It is also obvious that during some summer days the geothermal water source potential could insure work with five tanks and bigger batches for drying.

That is why the preparation of a **mathematical model,** for a detailed description of the designed center conduct, in other environmental conditions than the ones it was originally designed, is necessary. By a mathematical model of flax and hemp processing center we understand a set of relations that determine the existing consumption (inflow) of geothermal water, both globally, meaning in the entire centre, and locally, for each heat exchanger, collector or tank, separately. These inflows, initially unknown, can be determined according to the relations from specialty literature, which are kind of the reverse of the relations used for the designing calculus; actually the situation is not that simple, determining the inflows implies iterative calculus and a supplementary determination of some outlet temperatures, initially unknown. Together with the preparation of the program it was necessary to create **40 user functions** in Visual Basic, functions which return the sizes required for the program, from the interpolation functions which approximate the air and water proprieties to calculus functions for the similitude criteria specific to thermal convection, up to the complex functions of iterative determination of nonlinear systems solutions with two unknown factors (inflow and outflow temperature).

Both for the design and the performance of the mathematical model for a set of variables, the environmental conditions (air temperature and humidity, wind speed) are part of the input data category, but if for the design, annual or seasonal average sizes were adopted (in our case we talk about average sizes for the cold season), when operating the mathematical model, these are momentary values and can take any values. For the design, the geothermal water inflow available has become input data, while for the performance of the mathematical model, the momentary inflow (consumption) of geothermal water is one of the outlet sizes – the most important one. Of course, taking into account that we can give any values for the environmental conditions, *the mathematical model should notify if the needed inflow of geothermal water is higher than the one available.* This is achieved by limiting the number of tanks which can operate the melting simultaneously. The cellular construction of the drying tunnel works in such a way that for a relatively high variation in the environmental conditions, the geothermal water consumption does not vary very much, with the exception of the preheater consumption – which is made of 36°C used water anyway, which is plentiful – and possibly the consumption of the first cell radiator. For cells 1…8 the geothermal water consumption for the radiators does not vary a lot considering the environmental conditions, because we have chosen fixed limits for heating the air (from 50 to 73°C), and the thermal content variations are not very high, even if it starts from different values of air initial humidity.

Regarding the loading of melting products, respectively drying, these were outlet sizes for the design, but are also input sizes for the performance of the mathematical model. The mathematical model will limit the size of the batches accepted for processing, if we want to process too large batches, the mathematical model decides how much of the melting batch can be processed, following that the rest of the batch to be processed together with the next melting batch. Regarding drying, loading the tunnel in a certain cycle should be equal with the size of the batch melted before, and to make it easier we have set two equal batches within the same cycle.

The same role inversion takes place for the design, respectively for the mathematical model and for the exchangers' dimensions. For the design, the heat exchange surfaces and the flowing transversal sections were outlet data, their size being determined by the environmental conditions and the geothermal water available. On running the mathematical model these sizes represent input data, being the same ones (established in the design phase), for any loading scenario and any weather conditions.

The mathematical model was conceived for the « spread sheet » type of program, just like Excel. It should be mentioned that the program can compute a set of outlet data (inflows and temperatures) starting from a set of input data (loads and environmental conditions). Choosing different sets of input data, possibly sets of values which describe the variation of these sizes in time (for example every hour during one day), we will obtain the consumption variation (global and punctual) in the centre for the same time interval. We can truly say that running the mathematical model in this manner represents a simulation of the processes that take place in the processing center for the respective time interval. Actually running the mathematical model does not represent the performance simulation, but only a time succession of the different equilibrium states between conditions, loads and consumption, **that is <u>the simulation of a perfectly automated system</u> with an instantaneous adjustment.**

2. Running the mathematical model and the performance simulation in different seasonal conditions

The mathematical model written for the adaptation of the conduct of the technical plants processing center was tested for three sets of environmental conditions: winter, spring – autumn and summer. Only the environmental conditions change: the average air temperature (and the water drawn form the environment), the average speed of wind and air humidity.

As study interval we have taken a whole day (24 h) from the biological phase. The environment sizes variations were considered as taking place after some sinusoidal functions. For each of the sizes mentioned we start from the average seasonal size: for temperature we have 0°C – for winter, 10,2°C for spring – autumn and 20,82°C for summer, for wind speed we have 13,8 m/s for winter, 12,8 m/s for spring – autumn and 10,8 for summer, and for the air relative humidity the three values are 50%, 40% and respectively 30%. These values are reached during one day at the following hours 6^{00}, 18^{00} and again at 6^{00} the second day when the cycle is completed. The variation amplitude of these sizes was chosen for each season: 10°C for temperature, 3 m/s for wind speed 10% for relative humidity. What differs is the variation direction: for the temperature we have an increase starting from 6^{00} in the morning, the maximum is reached at noon, at 12^{00} and the minimum at midnight at 24^{00}. For humidity, respectively wind speed we have chosen that the minimum values should be reached at noon and the maximum ones at midnight.

These environmental conditions are shaped according to the weather data available and they represent the most probable evolutions for a typical day of winter, spring or autumn, respectively summer. The program can run other average values, other types of variations and other amplitudes or even sudden variations of the parameters. The graphical representation of the evolution of these environmental parameters is given in figure 1 – for winter, figure 2 – for spring autumn, respectively figure 3 for summer.

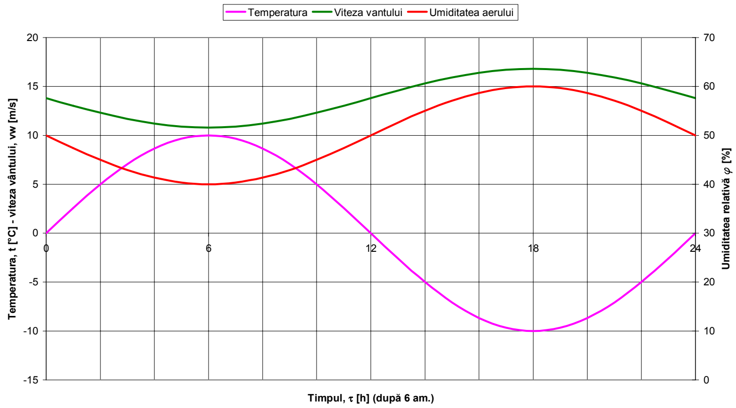

Figure 1. Environmental parameters variation-winter

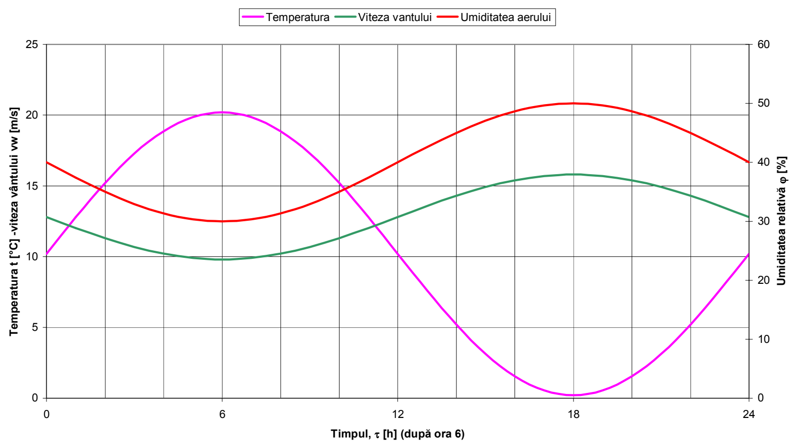

Figure 2. Environmental parameters variation-spring-summer

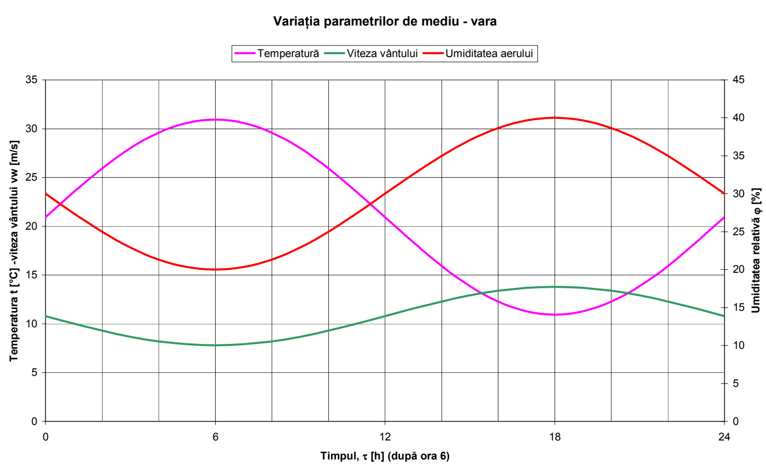

Figure 3. Environmental parameters variation-summer

What also changes between seasons are the proposed loads, the technological melting process always taking precedence. We have inserted as data batches that will allow complete loading of a random number of tanks. Of course, any value could have been proposed, but in that case the program would have redirected a portion to the next melting cycle. For drying we have kept the size of the batch calculated in the project for the winter, which gives a null redirected quantity only in winter conditions. No quantity is redirected to the next cycle during summer either, moreover it is been noticed that the drying tunnel could have been loaded up some more. On the other hand the batch proposed for spring-autumn is larger than the acceptable batch size and a certain quantity, relatively small, will be redirected to the next drying cycle. It has been noted that *the equality between melting and drying batches can only be maintained during winter*, and in summer larger batches can be melted while the acceptable batch size for drying varies a lot less. Of course, *the technological drying process could take precedence, but then not all the melting tanks that could be loaded that season will be loaded*.

It can be noted, after studying the results of the three cycles that environment changes cause very slight variations of the geothermal water consumption at the drying tunnel. This was to be expected because the tunnel losses were calculated as **fixed percentage** and not depending on environmental parameters. This isn't wrong, because losses through convection and radiation through the tunnel's walls are very small compared to the main thermo-energy consumption of the tunnel, used for removing humidity. Because there are no seasonal variations regarding the removed humidity, it means that **the drying tunnel will use about the same quantity of geothermal water, regardless of season**. The slight variations are due to variations in the parameters on the air at the entrance, but these variations *are taken over and leveled by the air pre-heater*, where substantial variations in the level of used inflow can be observed, based on season as well as time of day. These aspects are better underlined if we look at the graphical representations of the required geothermal water at the drying tunnel and air pre-heater. It can be seen that the needed geothermal water has the same sinusoidal dependency (the blue curves in figures 4, 5 and 6), but the amplitude of the variations are very low compared to the average.

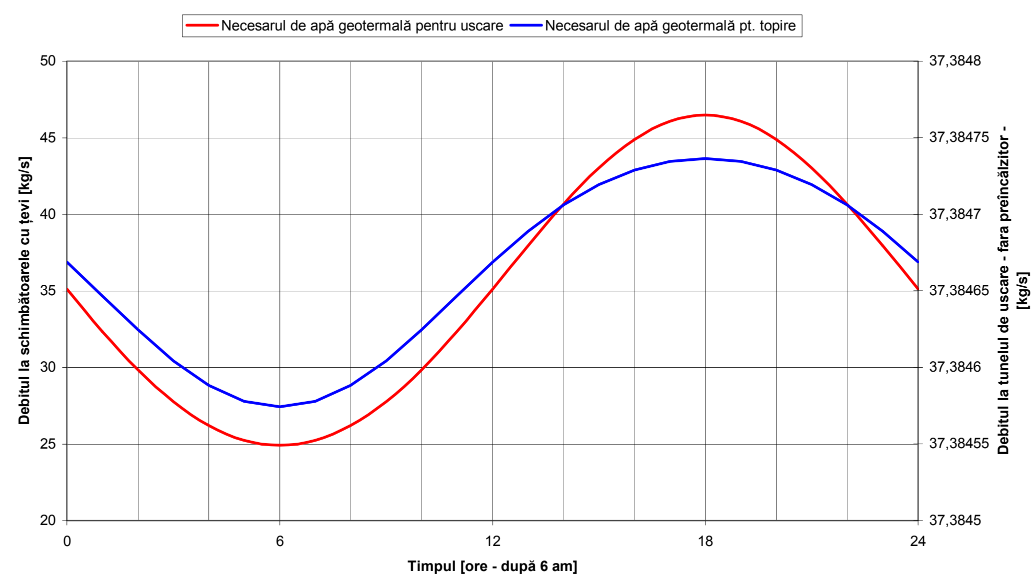

Figure 4. Geothermal water consumption-winter

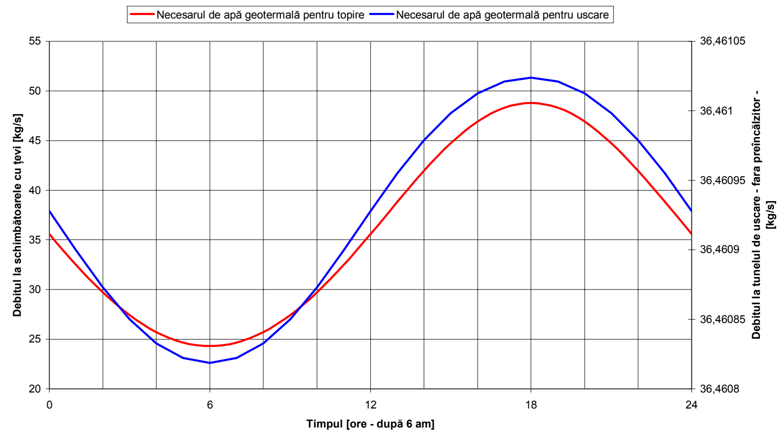

Figure 5. Geothermal water consumption-spring-autumn

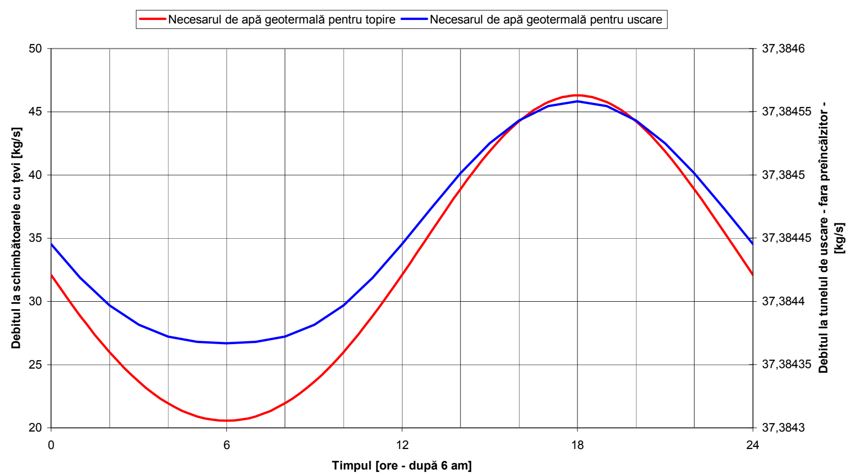

Figure 6. Geothermal water consumption-summer

If the same scale as the one for geothermal water needed for melting was used (the red curves), then the blue curves would actually be straight lines. The maximum calculated variation is very small compared to the average value: around one gram per second more or less, relative to an average inflow during winter of 38,3845 kg/s! The same average necessary inflow shows for the summer season, the maximum variations being even smaller, under 1 g/s. For the spring and autumn seasons the average inflow is somewhat lower, 36,4609 kg/s, this is due to the fact that since melting has precedence the accepted batch is 3500 kg smaller.

In the resulting graphics we have modified the scale for the geothermal water inflow necessary for drying in order to underline the sinusoidal variation aspect, which proves the correctness of the mathematical model. Practically, the inflow for the drying tunnel is multi-constant and only depends on the accepted batch. The same is not true for the inflow necessary for the air pre-heater, pre-heater which practically takes over the variations of the environment parameters for the drying process. The curves which reflect the variations of the needed used geothermal water (approx. 36 – 37 °C) are shown in figure 7, 8 and 9 and are the curves drawn in light blue.

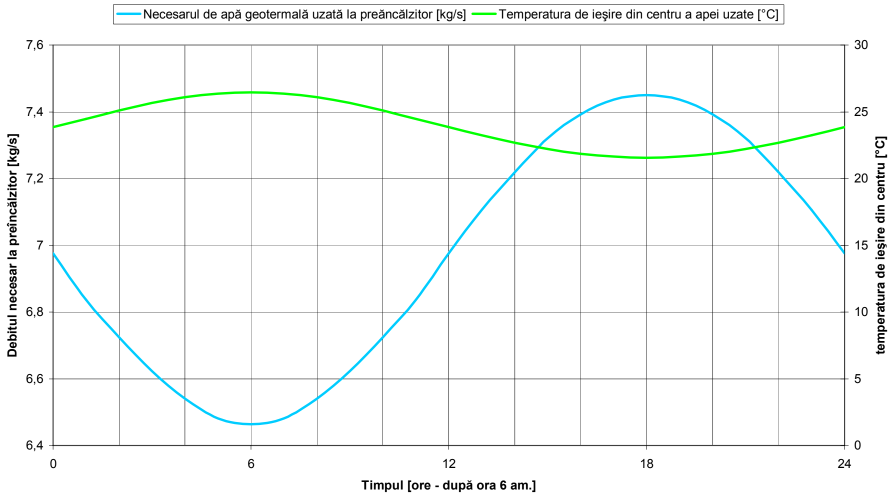

Figure 7. Inflow of the pre-heater and the temperature of used geothermal water-winter

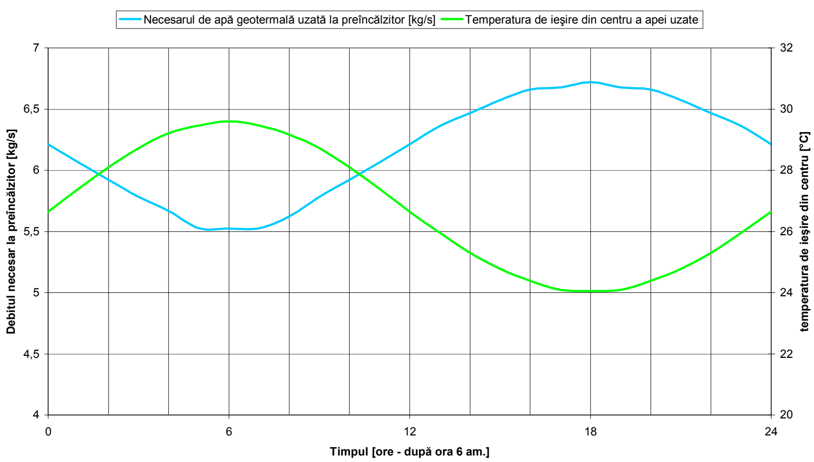

Figure 8. Inflow of the pre-heater and the temperature of used geothermal water-spring-autumn

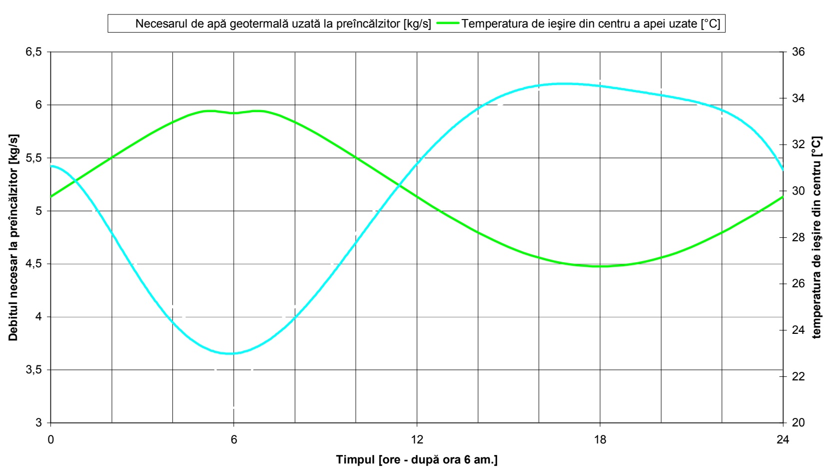

Figure 9. Inflow of the pre-heater and the temperature of used geothermal water-summer

We see that in this case the required inflow also has a sinusoidal variation, or almost sinusoidal. For the winter season, the average stock needed is 6,976 kg/s, the variations during one day being ± 0,511 kg/s, which is 1kg/s between noon and midnight. For spring and autumn the usage at 6^{00} o'clock and 18^{00} o'clock is 6,612 kg/s, but at midnight the usage rises 0,495 kg/s while at noon it drops more, with 0,690 kg/s. This is explained by the fact that the atmospheric temperature nears that of the air exiting the pre-heater, the small difference in temperature on exit forcing – if the exchange surface is the same – larger flows than the ones demanded by direct proportioning. This phenomenon is even more obvious for the summer season, where for an average needed stock of 5,44 kg/s there is a maximum increase of 1,24 kg/s in the requirements at night, but a drop in the required stock of 2,30 kg/s at noon, which is due to the fact that the temperature of the air on entering the pre-heater and that of the air exiting it are getting even closer! This substantial reduction of the level drop in temperature modifies the aspect of the curve in figure 9 (as opposed to the multi-sinusoidal in figure 7) and makes it look flatter in the night part, in the portion of maximum consumption.

Regarding the melting process, the daily required inflow for melting for a tank varies with the season, but since the number of tanks that can work simultaneously differs from season to season (4 in the winter, 5 in the spring and 6 in the summer), the daily average consumption of geothermal water is about the same for melting. For the winter there is a daily average inflow of 8,78 kg/s per tank, a total required stock of 35,12 kg/s with a maximum of 46,47 kg/s at midnight and a minimum of 24,91 at noon. For the spring and autumn the required stock for a tank is smaller, 7,12 kg/s, but the total average consumption implies a slightly bigger inflow than for the winter, meaning 35,59 kg/s with a maximum of 48,77 kg/s at midnight and a minimum of 24,32 at noon. Increasing the number of tanks to 6 for the summer period, when the needed average inflow per tank drops to 5,35kg/s, does not lead to an increase in total inflow, which is only 32,10 kg/s, with a maximum of 46,29 kg/s at midnight and a minimum of 20,56 at noon. The important part is that *regardless of season, even if the inflow required at the moment for melting (at night) is greater than what is available at the center - which is 37,5 kg/s – the average values of the requirements do not surpass this value, as they remain in the 32 – 36 kg/s interval.* These variations are taken over by the collector tank from the drying tunnel radiator pressing, which at the start of the biological phase must have a certain remaining quantity of geothermal water, which can be calculated based on the maximum inflow fluctuations for the season with the greatest consumption level. The intermediary buffer tank must contain when starting a certain quantity of geothermal water which will insure that the level will not drop under zero even in maximum consumption circumstances on the mantle pipes exchangers from the melting tanks. This quantity can be calculated precisely by graphical integration of the area between the red curves from figures 5, 6 and 7 and the horizontal line that marks the average consumption value.

The results obtained for the seasonal average values of total consumption level, confirm, since they are lower than the absolute maximum available at the centre (37,5kg/s), the correctness of the design, of the mathematical model and the decision module for melting and drying batch acceptance. Even if only one of the averages mentioned would have surpassed the maximum available inflow, the mathematical model, especially the decision module would have to be modified.

In figures 7, 8 and 9, we have drawn, beside the required geothermal water at the pre-heater, the temperature of the geothermal water that leaves the centre (the light green curves) which is important for possible later usages, or for re-injection. The values vary between 22 and 27 °C – in the winter, 24 and 29 °C – in the spring and autumn and between 28 and 34 °C – in the summer.

In figures 10, 11 and 12 I have drawn the variations of the secondary agent requirements (the orange curves), and the opening angle of the obturator blades. We see the same tendency towards sinusoidal variations; for the opening angle, the dependency between the angle and the passing surface necessary for the re-circulating water makes this curve to look rougher than other dependencies, with an oscillating variation of the curve's slopes at different points, hence the bumpy aspect of the curves. Still, the average tendency of the variation is a sinusoidal curve, which validates the mathematical model for calculating this parameter.

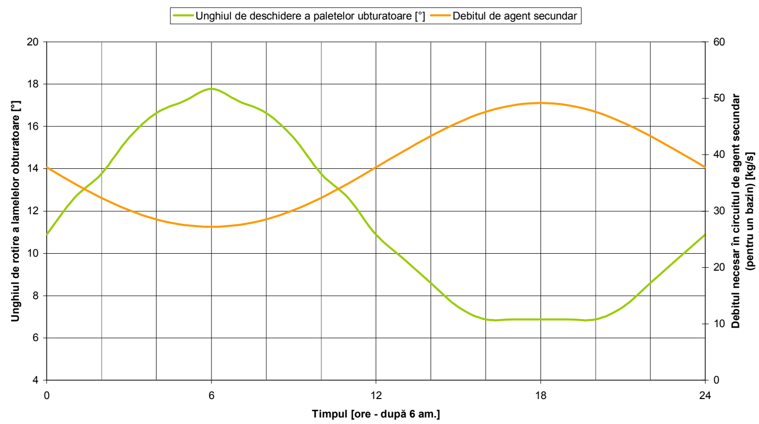

Figure 10. Inflow needed by the secondary agent and the opening angle of obturator blades – winter

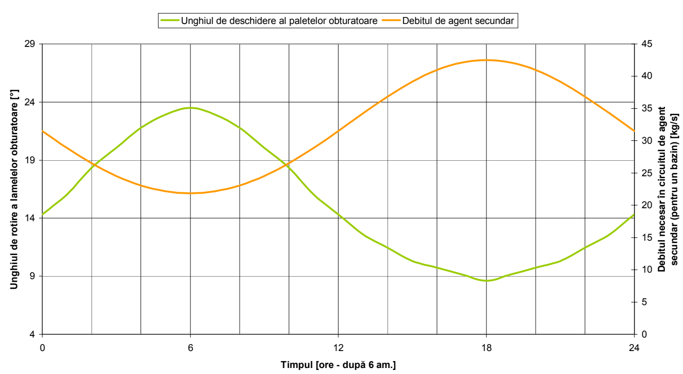

Figure 11. Inflow needed by the secondary agent and the opening angle of obturator blades – spring-autumn

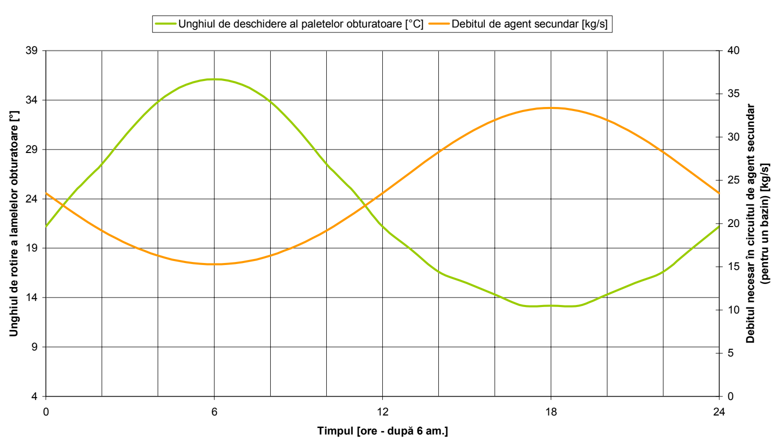

Figure 12. Inflow needed by the secondary agent and the opening angle of obturator blades-summer

3. Conclusions

As a conclusion, the mathematical model conceived for the technical plants processing center, starting from the data established at the design phase is confirmed as being correct and efficient – by the results obtained while running the model for different season conditions and for the environmental parameters variations along a whole day for each season. For the sinusoidal variations of environmental parameters we have obtained sinusoidal variations for the geothermal water consumption in the melting tanks, for the second agent consumption in the grill exchangers and even in the radiators from the drying tunnel cells, even though in this case the consumption variations were very low. The same sinusoidal rates, slightly distorted as a result of the causes mentioned before were obtained for the inflow needed for the air pre-heater and for the rotation angle of the obturator blades. The charts obtained and the curves outlined following these charts allowed us to establish the differences between different values according to season.

Another conclusion that can be drawn from studying the running results is that the storage tank should not be very big as it will only collect a quantity equal to the one that can be stored during the maximum inflow of the probe, that is 30kg/s during one day, which allows the addition of 7,5 kg/s during the working period. In exchange the intermediary tank between the pressing of the drying tunnel radiators and the input in the mantle pipes exchangers which prepare the secondary agent for the melting should be sensitive as it also has the role of buffer tank. This tank should contain a considerable amount of geothermal water when starting the production cycle (remaining quantity of water for melting) in order to insure the necessary of maximum consumption for melting during the night, regardless of season. The level in this tank will drop during the night to almost zero, but during the day it will exceed the starting level. Important is that at the end of melting the respective batch, the geothermal water level in the buffer tank should be the same as the beginning of the cycle, fact that, according to our operations, is achieved during all the three seasons. The necessity of this tank was not highlighted in the design phase, but it became obvious after running the program.

References

1. Muntea, C., Câmpeanu, A.: *Transfer de căldură. Probleme (Heat Transfer. Problems)*, ANA Publishing house, Cluj-Napoca, 1997.
2. Neacşu, E.: *Bazele Termotehnicii (Thermo-techniques Bases),* I.P.T.V.T. Publishing house, Timişoara, 1991.
3. 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*, Buletinul Institutului Politehnic din Iasi, secția Construcții de maşini, Tomul LII (LVI), Fascicula 5C, Universitatea Politehnică Gh. Asachi, Iaşi, 2006.
4. Indrie, L., Gherghe, S., Almăşan, I.: *Designing the equipment for the melting and drying of flax and hemp using geothermal water*, Anals of the University of Oradea, Fascicle of Management and Technological Engineering, Volume V (XV), Oradea, 2006.