MODELLING AND SIMULATION OF A PULP DRYER

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Summary

The following article describes the development of the model of a sugar beet pulp dryer for the sugar industry

This is a distributed model represented with partial derivatives. The various balances of the discretised model are shown, and some tests with the simulation model are performed.

Key Words: Drying dynamics, distributed systems, matter and energy balances.

1 INTRODUCTION

Dryers are widely used in industry. The purpose of drying is to eliminate a liquid substance from a solid matrix through evaporation by supply of heat.

In the case of the pulp dryers used by the sugar industry, the purpose is to evaporate the water in the sugar beet pulp after its sucrose has been removed. This dry pulp is a subproduct from sugar mills and is used as food for cattle.

Pulp drying is necessary because demand is not high enough to find a use for all of the pulp produced in the press. It therefore needs to be dried so that it can be stored without damaging it.

2 DESCRIPTION OF THE PROCESS

The pressed pulp is dried by setting it in contact with hot gases produced by the combustion of natural gas at a furnace at the head of the dryer. Preheated air is used for the combustion of the natural gas. This air flows through a ring where heat is exchanged with the walls of the furnace. The fumes from the furnace are mixed with a CO_2 current so that their temperature is reduced. The gases that exit the dryer are routed towards a stack. Figure 1 shows a diagram of the drying section.

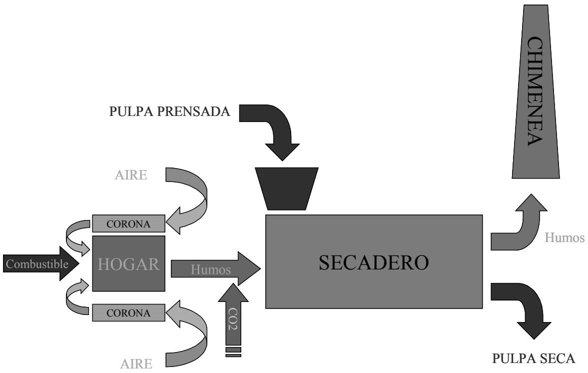

Figure 1. Drying diagram

Wet pulp is introduced through one of the ends of the rotating drum, configured to allow the liquid and gas phases to come into contact. The pulp releases water when it comes into contact with the hot gas, and solids-gas convection is used as the main transport mechanism.

The following figure shows a diagram of the dryer.

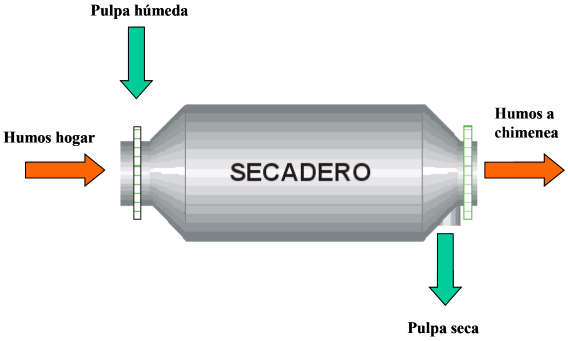

Figure 2. Diagram of the dryer.

The dry pulp is sent to the pelletisation section, where it is prepared to serve as food for cattle. The vent stack has cyclones to collect part of the pulp that could have been dragged by the drying gases.

The rotating drum used for the drying is a simple mechanism. It is equipped with an interior mechanism that serves to increase the heat transfer between the drying gases and the pulp. It has cross-shaped trays that disseminate the product in individual heaps throughout the section of the drum (Figure 3). By rotating, the drum moves and mixes these heaps, thus forming a pulp curtain that enhances contact with the drying gases [1].

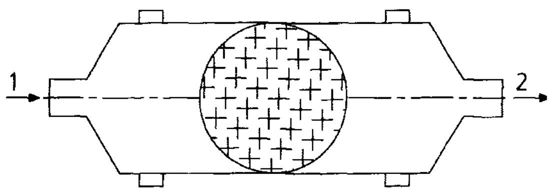

Figure 3. Layout of the crosses inside the dryer

The optimum design of this piece of equipment is very important because the dampness of the pulp at the outlet must remain within certain fixed margins. If the pulp at the outlet is too damp it could rot during storage, but if, on the other hand, it is too dry inside the dryer, fuel consumption increases. Furthermore, in an extreme case, the total lack of water in the pulp could cause the transfer of the heat supplied by the gas towards the walls of the dryer, thus making it potential source of fire inside the dryer.

3 MATHEMATICAL MODEL

3.1 MODELLING HYPOTHESES

The following hypotheses have been assumed for the modelling of the dryer:

- The pulp has been considered to be divided into two parts: an external section formed by water alone (where evaporation occurs towards the gas phase) and an internal part where there is a transfer of water towards the external section.
- Only two components have been considered in the solid phase: dry matter and water.
- An average concentration of water within the pulp is assumed. The transport of matter within the pulp is therefore not taken into consideration.
- The movement of the pulp is ideal with plug flow throughout the dryer.
- The size of the pulp is considered even, i.e , a potential size distribution has not been taken into consideration.
- The gaseous phase behaves as an ideal gas
- Pressure is constant in the whole dryer
- The energy balance has been performed jointly with all the pulp, disregarding the distinction made in the case of the transfer of matter between the internal and external sections. The temperature of the pulp is therefore assumed to be homogeneous
- The profiles inside the pulp, both as regards humidity and temperature, are flat.
- The temperature of the pulp is homogeneous both in the interior and the exterior
- Heat transmission by radiation inside the drum is not taken into consideration.
- The internal structure of the drum is not taken into consideration when creating the model
- Water diffusion within the solid occurs in a single direction
- No heat losses have been considered
- No heat transmission has been considered from the fumes to the drum structure

3.2 DISTRIBUTED SYSTEM

Inside the rotating drum, the process variables change over time and throughout the dryer. We have a distributed system described by equations in partial derivatives [8]. It will therefore be necessary to perform a discretisation of the variables that depend on time and distance so the dryer will be divided into n areas, and each of these will be considered to have the perfect mix (i.e: the properties at the outlet of each stage are equal to the properties inside the stage). These areas will be interconnected in such a way that the outlet of a stage will be the inlet of the following one. In the case of the dryer, the pulp and the gas flow in parallel currents. Whenever a parameter of an equation depends on the distance within the dryer, it will appear with subindex j, referring to the discretisation area it belongs to. This discretisation has been performed by means of lines [10], [12]. For further information about discretisation, check [5].

3.3 TREATMENT OF THE SOLID PHASE

The solid phase is formed by the pulp from the spent cossettes from the diffuser. This pulp does not have uniform size because the cossette cutters do not provide a single size, but have sizes set between limits which are not very well defined. Taking this size distribution into consideration adds complexity to the problem, so it will not be taken into consideration for the time being.

The pulp is assumed to be divided into two parts: a surface part (formed by a layer of water) and an internal part (formed by the pulp and its corresponding part of water).

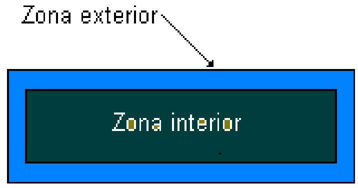

Figure 4. Different areas of the pulp

Thus, the exterior area transmits heat by conduction to the interior of the pulp while the interior transfers matter to the exterior.

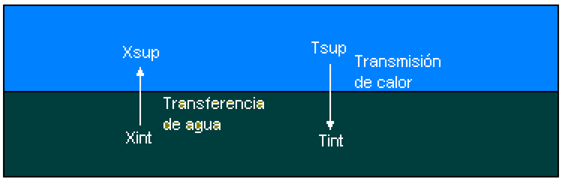

Figure 5. Matter and energy transmission between the different areas of the pulp

Different figures can therefore be calculated for the humidity in the exterior and the interior of the pulp.

3.4 MODEL EQUATIONS

Several matter and energy transfer phenomena take place during the drying process. As regards the transfer of matter, firstly there is the evaporation of surface water, and secondly, a diffusion process from the interior towards the surface by capillarity. As regards energy transfer, the most important is the energy transfer from the fumes to the pulp (used by water for its evaporation).

3.4.1 Drying Areas

There are two different behaviour areas in the drying process: the constant drying area and the decreasing drying area [3].

The pulp in the constant speed drying area is supposed to be covered in a homogeneous layer of liquid. This layer is maintained until the surface moisture drops below a critical value and the surface starts to dry. This leads to the decreasing drying area, where the drying speed is limited by the speed of water transfer from the interior of the pulp. If the evaporation speed of the water is too high and there is not enough water reaching the surface by diffusion, the pulp heats up and may potentially catch fire inside the dryer.

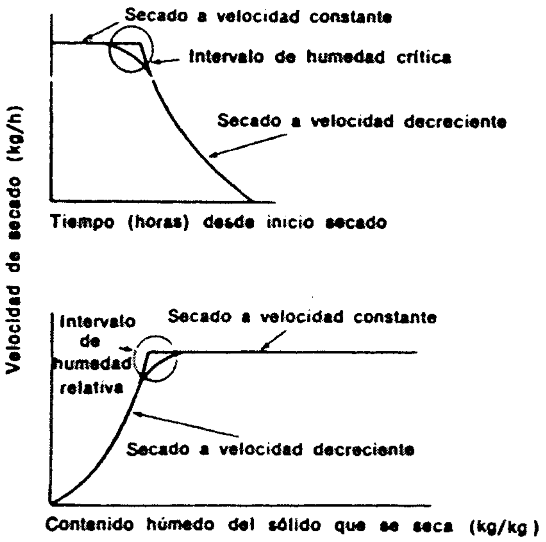

Figure 6. Drying Curves

In order to model this phenomenon, the damp surface has been defined on the basis of a rate per unity, representing the quotient between the surface moisture and the critical moisture (1 always means that the surface moisture is greater than the critical moisture).

$$S_{h,j} = \max\left(\min\left(1, \frac{X_{\sup,j}}{X_c}\right), 0\right) \quad (1)$$

Where $S_{h,j}$ is the damp surface in phase j, $X_{\sup,j}$ is the surface moisture in phase j and X_c is the critical moisture (kg water/kg dry solids).

The assumption is therefore that if the surface moisture is above a critical value there will be no problems of excess drying. Whenever this figure drops below 1, the surface of the pulp is understood to be running out of an exterior water film, so the heat used to evaporate the surface water starts heating the pulp surface directly. This leads to problems with the increase of temperature inside the drum.

3.4.2 Mechanical Energy Balances

The fume velocity will be calculated as the volumetric flow through the free transversal cross section for the drum flow.

The free transversal cross section for the flow will be the transversal cross section of the drum minus the space taken up by the pulp and the internal structure of the drum.

The fumes velocity at the inlet of the dryer is calculated as:

$$v_{h,1} = \frac{F_{h,1}}{Secc - \left(m_{p,1} / \rho_p\right)} \quad (2)$$

Where $F_{h,1}$ is the volumetric flow of the fumes (m^3/s) and Secc is the transversal cross section of the drum in m^3 and ρ_p is the density of the pressed pulp (kg/m^3). This density is assumed to be constant and equal to 325 [2]

The volume inside the dryer is calculated on the basis of the diameter and the length of the dryer:

$$V = \frac{\pi}{4} D^2 \cdot L \quad (3)$$

Where V is the volume of the dryer (m^3), L is the length of the dryer (m) and D is the diameter of the dryer (m).

The speed at which the pulp exits each of the stages of the dryer is supposed to be proportional to the speed at which the fumes flows through the dryer, as well as being proportional to the rotation speed of the dryer: the more the dryer rotates, the more pulp carried by the gas current is discharged. It is also inversely proportional to the amount of mass in that area of the dryer, because the greater the mass, the greater the difficulty the gas current will have to move it:

$$v_{p,j} = \frac{k_v \cdot v_{h,j} \cdot v_{rot}}{m_p} \quad (4)$$

Where $v_{h,j}$ is the speed of the fumes in phase j (m/s), $v_{p,j}$ is the speed of the pulp in phase j (m/s), v_{rot} is the speed of rotation of the dryer (s^{-1}) and k_v is an adjustment constant (kg/s)

3.2.3 Matter Balances

As set out in section 3.2, n equations are obtained from the equation of the distributed matter balance (one equation for each discretisation phase). These equations correspond to the global balances for each area.

3.2.3.1 Matter Balances with Respect to the Pulp

In systems where only one of the components of the mix is transferred it is very useful to perform the balances with a basis free of the component being transferred. The concentrations will therefore be expressed in units of kg/kg of dry solid matter.

In this case, the matter balances will be performed with a water-free basis, since it is the only component whose composition varies throughout the system.

The concentrations with the water-free pulp will be calculated as:

$$C^*_{p,i} = \frac{C_{p,i}}{\left(1 - C_{p,H2O}\right)} \quad (5)$$

Where $C^*_{p,i}$ is the concentration free of component i in the pulp, $C_{p,i}$ is the concentration of component i in the pulp, $C_{p,H2O}$ is the concentration of water in the pulp.

The mass flows will also be expressed as free of water. In order to distinguish the mass flows clearly, the substance-free flows will be marked with an M, while the total flows will be marked with a W.

W[=] kg dry solid matter /s
M[=] kg total solid matter /s

The mass flow of dry pulp entering the dryer, expressed as free, will be:

$$W_{pe,1} = M_{pe,1} \cdot (1 - C_{agua,1}) \quad (6)$$

The pulp mass in each stage is calculated

$$m_{p,j}' = W_{pe,j} - W_{ps,j} \quad (7)$$

The masses of dry solid matter will suffer no variation throughout the length of the dryer because of the effect of the transfer of matter, but only because of the effect of transport.

This flow will propagate as follows:

$$W_{ps.j-1} = W_{pe,j} \quad (8)$$

As set out in the modelling hypotheses, part of the moisture of the pulp is considered to be at the top and part of it at the bottom.

The surface moisture is taken as being 2% of the internal water. This value is characteristic of the moisture from the pulp presses in sugar mills.

$$X_{tot} = X_{sup} + X_{int} \quad (10)$$

Where X represents the moisture levels, expressed in kg/kg ss.

The only component where a phase by phase balance is performed is water. Since the balances for the rest of the components are performed as free of said components, the concentrations of the non-transferred substances remain at a constant level throughout the dryer.

$$C^*_{p,i,j} = C^*_{p,i,j+1} \quad (11)$$

$C^*_{p,i,j}$ is the concentration of substance i in the pulp in phase j and $C^*_{p,i,j+1}$ is the concentration of substance i in the pulp in phase j+1.

3.2.3.2 Balance of Matter with Respect to the Surface Moisture of the Pulp????

Water from the interior of the pulp reaches the surface by diffusion. Furthermore, there exists also a flow of water evaporating from the surface. Taking this into consideration, the balance of surface moisture in the pulp will be as follows:

$$\frac{dS_j X_{SUP,j}}{dt} = W_{pe,j} X_{SUPe,j} - W_{ps,j} X_{SUPs,j} - A\frac{h}{\lambda}(T_G - T_S) + k(X_{INT} - X_{SUP}) \quad (12)$$

Where the term $A\frac{h}{\lambda}(T_G - T_S)$ refers to the speed of evaporation and $k(X_{INT} - X_{SUP})$ refers to the flow of water from the interior of the mass of pulp towards the exterior, S is the mass of dry solid matter in each phase (kg/s), A is the transfer area (m^2), h is the heat transfer coefficient (W/m^2 C), λ is the water vaporisation latent heat (J/kg), X are the moisture levels (kg H2O/kg of dry solid matter), T are the temperatures (ºC) and k is a diffusion constant (kg/s).

3.2.3.3 Matter-Pulp Internal Moisture Balance

The only phenomenon that takes place inside the pulp is the transfer of water towards the exterior. With this in mind, the balance of internal water???? will be as follows:

$$\frac{dS_j X_{INT,j}}{dt} = W_{pe,j} X_{INTe,j} - W_{ps,j} X_{INTs,j} - k(X_{INT} - X_{SUP}) \quad (13)$$

3.2.3.4 Matter-Gas Balance

As in the case of solid matters, it is useful to perform the matter balances for the gas assuming they are water-free. The way of calculating the water-free compositions is the same as with the solids.

$$C^*_{h,i} = \frac{C_{h,i}}{\left(1 - C_{h,H2O}\right)} \quad (14)$$

Where $C^*_{h,i}$ is the concentration free of component i in the fumes, $C_{h,i}$ is the concentration of component i in the fumes and $C_{h,H2O}$ is the concentration of water in the fumes.

As set out above, this means that the concentrations of all the components, except water, remain constant throughout all of the dryer.

$$C^*_{h,i,j} = C^*_{h,i,j+1} \quad (15)$$

The free mass flow during the gas phase is also kept constant:

$$W_{hs,j} = W_{he,j+1} \quad (16)$$

Where $W_{hs,j}$ is the mass flow of the fumes from phase j (kg/s) and $W_{he,j}$ is the mass flow of the fumes entering phase j (kg/s).

3.2.3.5 Balance of the Moisture of the Gas

The balance of the moisture of the gas is very simple because the only phenomenon that takes place is the transfer of evaporated water which is incorporated to the gas phase. The moisture balance is therefore as follows:

$$0 = W_{he,j} Y_{e,j} - W_{hs,j} Y_{s,j} + A\frac{h}{\lambda}(T_G - T_S) \quad (17)$$

Where $Y_{e,j}$ is the moisture that enters phase j and $Y_{e,j}$ is the moisture at the exit of phase j.

3.2.4 ENERGY BALANCES

The energy balances are slightly more complex than the matter balances. There are many phenomena associated to the transfer of energy, such as heat flows from the gases towards the pulp, heat flows from the gases to the structure of the dryer, heat transfer within the pulp, heat flows associated to the transfer of matter, radiation, etc.

A model that took all these characteristics into consideration would be very complex, and a great amount of currently unavailable data and parameters would be necessary. Some simplifications have therefore been made.

Therefore, only a single heat transfer between the gas and the pulp, caused by the difference in temperature, has been taken into consideration, as well as a heat transmission associated to the water transfer between the pulp and the gases.

3.2.4.1 Energy to Pulp Balance

As set out above, one heat transfer has been considered between the fumes and the pulp, and one matter transfer has been considered between the pulp and the fumes. This can be seen as follows in the energy balance:

$$\frac{dm_{p,j}\cdot H_{p,j}}{dt} = W_{pe,j}H_{pe,j}\left(1+X_{TOTe,j}\right) - W_{ps,j}H_{ps,j}\left(1+X_{TOTs,j}\right) + Q_j + X_{evap,j}(\lambda + H_{ags,j}) \quad (18)$$

Where $m_{p,j}$ is the mass of wet pulp in phase j (kg ss), $H_{p,j}$ is the enthalpy of the wet pulp in each stage, which equals the enthalpy at the outlet of phase j ($H_{ps,j}$) (kJ/kg), $H_{pe,j}$ is the enthalpy of the wet pulp at the outlet of phase j (kJ/kg), X_{evap} is the amount of water which is evaporated (kg/s), calculated with the following equation:

$$X_{evap,j} = A\frac{h}{\lambda}(T_{G,j} - T_{S,j}) \quad (19)$$

In this case, the flow of heat between the pulp and the fumes is multiplied by $S_{hum,j}$, so when this coefficient is lower than 1 (i.e: the surface does not have enough of a layer of water) part of the heat will be transferred to the internal part of the pulp and will not only be used to evaporate the surface water.

Q_j is the heat flow that the pulp receives from the gases during phase j. This heat is provided by the following equation:

$$Q_j = Ah(T_{G,j} - T_{S,j}) \quad (20)$$

That is, it is proportional to the temperature difference between the pulp and the water.

3.2.4.2 Energy to Gas Balance

During the gas phase there is a heat transfer associated to the amount of water which is being evaporated and a heat transfer towards the pulp because of the temperature difference. The balance is thus as follows:

$$0 = H_{he,j}\left(W_{he,j} + Y_{e,j}W_{he,j}\right) - H_{hs,j}\left(W_{hs,j} + Y_{s,j}W_{hs,j}\right) - Q_j + X_{evap,j}(\lambda_{,j} + H_{ags,j}) \quad (21)$$

$H_{he,j}$ is the enthalpy of the wet gas that enters phase j (kJ/kg) and $H_{hs,j}$ is the enthalpy of the wet gas that exits phase j (kJ/kg).
The last term refers to the water which evaporates because of the enthalpy during the gas phase.

4 RESULTS IN THE SIMULATION

This section will present an analysis of the behaviour of the model described above during the simulation.

The number of discretisation phases needs to be optimised. For this purpose, the number of discretisation phases is represented against the moisture at the outlet. The result is considered optimum when the solution is not significantly different after adding or removing a discretisation element.

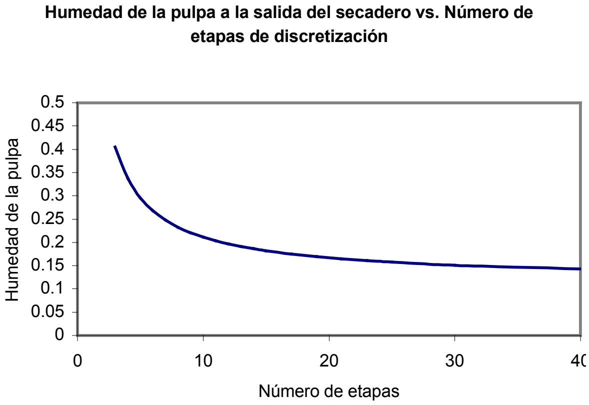

Figure 7. Determination of the number of discretisation phases

The number of phases has been set at 20.

To perform the simulations, a series of boundary conditions have been established: the conditions of the natural gas entering the dryer, the conditions of the air that enters and the conditions of the pulp that enters the dryer, as well as the pressure inside the dryer.

The experiment was run in the following conditions:

- Pressure inside the dryer: 1 bar
- Temperature of the fumes at the inlet: 698 ºC
- Mass flow of the fumes at the inlet: 32.7 kg/s
- Composition of the fumes at the inlet:
  - Water: 6.6 %
  - CO_2: 76.0 %
  - N_2: 17.3 %
- Temperature of the pulp at the inlet: 40 ºC
- Mass flow of the pulp at the inlet: 13.5 kg/s
- Composition of the pulp at the inlet:
  - Water: 77.8 %
  - Dry matter: 22.2 %

4.1 RESULTS IN STEADY-STATE

The only real data available for the dryer are the moisture at the outlet and the temperature of the fumes, which coincide with the values obtained during the simulation. The rest of the values during steady state will be validated qualitatively and the profiles inside the dryer will be analysed so that the results obtained are logical and take the expected form.

4.1.1 Moisture and Temperature Profiles of the Pulp

Figure 8 shows how the moisture of the gas increases as it gets closer to the outlet of the dryer. This is logical because the gas acquires the moisture of the pulp throughout the dryer.

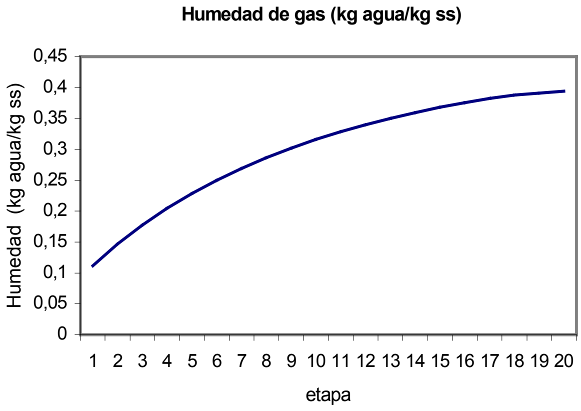

Figure 8. Moisture profile of the gas

It can also be seen how the moisture of the pulp decreases as it gets closer to the outlet of the dryer. This is evident because the pulp becomes drier, so its moisture is therefore reduced throughout the dryer.

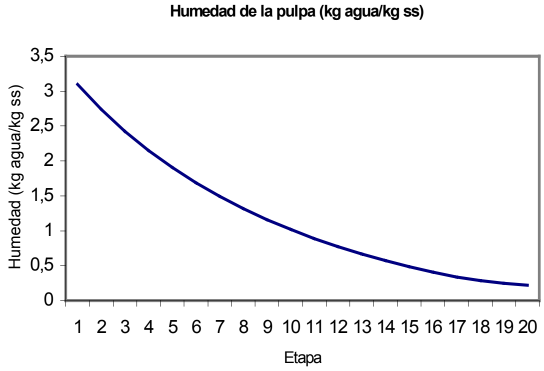

Figure 9. Moisture profile in the pulp

The following figure shows the temperature profile of the pulp and the fumes for this process. The temperature of the pulp can be seen to be constant throughout the whole dryer, except in the last part. This is because the exterior surface of the pulp along the last part of the dryer has already started to dry up and part of the heat transmitted by the gases is transmitted directly to the pulp, thus increasing its temperature.

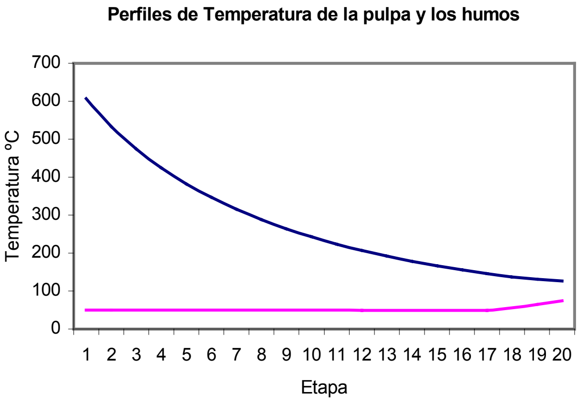

Figure 10. Temperature profiles of the pulp and the fumes

4.2 RESULTS IN NON-STEADY-STATE

A series of dynamical experiments have also been performed to verify that the system operation is correct. No real data are available for comparison with the system, but the analysis will be performed on the basis of the knowledge of the process.

A series of valuable experiments have been performed.

4.2.1 Increase in the Amount of Pulp Entering the Dryer

The system's response when there is an increase in the amount of pulp entering the dryer can be determined, in particular the response of several variables when there is an increase in the amount of pulp from 13.5 to 15 kg/s.

When the amount of pulp entering the dryer increases, the moisture at the outlet increases considerably. This is logical, since the amount of pulp entering the dryer has increased, and therefore the amount of water, but the mass of gas (which has the energy for evaporation) remains the same.

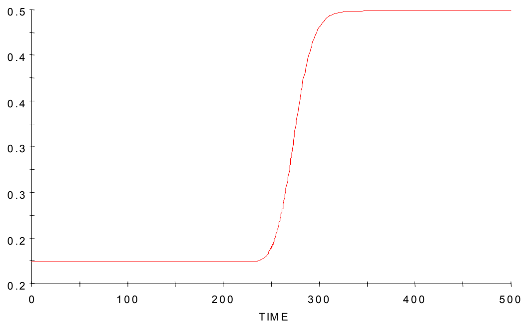

Figure 11. Moisture of the pulp at the outlet of the dryer.

The evolution of the moisture throughout the various stages of the dryer can be seen. The moisture gradient is greater and has a greater delay the closer we get to the dryer outlet.

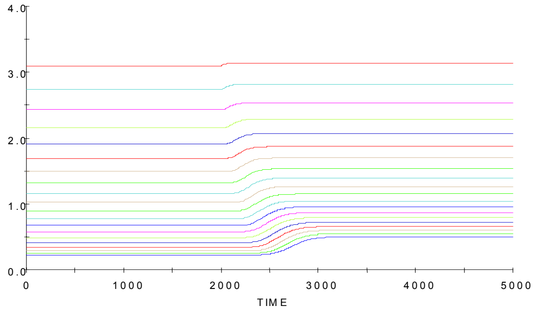

Figure 12. Moisture of the pulp at the various stages of discretisation of the dryer.

To get an idea of what takes place inside the dryer, a 3D representation can be created to show the evolution of the moisture over time and distance throughout the dryer.

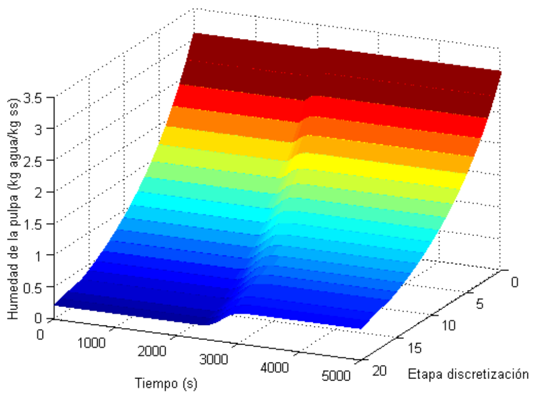

Figure 13. 3D representation of the evolution of moisture vs. time vs. distance when there is an increase in the moisture of the pulp.

The representation of the evolution of the pulp over time (figure 14) shows how temperature is reduced because, since there is a larger amount of pulp, the heat flow needed for the pulp to maintain that temperature is greater. The second, equally-as-important effect is that when the moisture of the pulp increases, the pulp at the outlet of the dryer is moister at the outside, so the increase in the temperature witnessed under normal conditions with the reduction of the outside moisture does not occur. The temperature is therefore constant throughout the whole dryer.

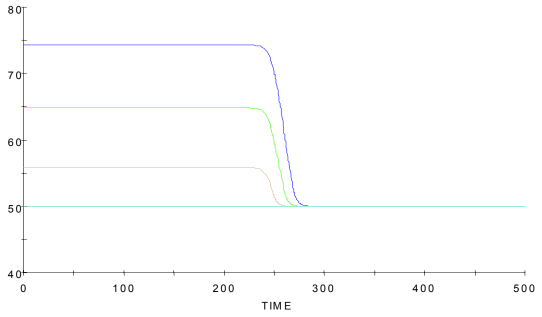

Figure 14. Temperature of the pulp at the different discretisation stages of the dryer

In the case of the gases, an increase in the amount of pulp causes an increase in the moisture at the outlet. This is because a reduction in the temperature of the pulp means the difference in temperature between the gases and the pulp is greater, so the amount of water which evaporates is also greater.

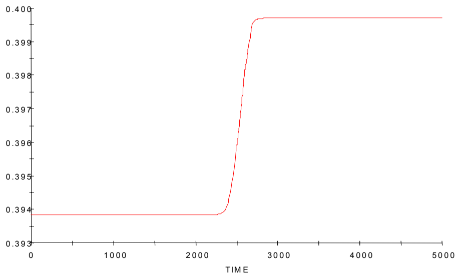

Figure 15. Moisture of the gases at the outlet of the dryer

The outlet temperature of the gases is reduced because when the temperature of the pulp drops and the amount of water that evaporates increases the amount of heat supplied by the gas is greater, and thus its temperature is reduced.

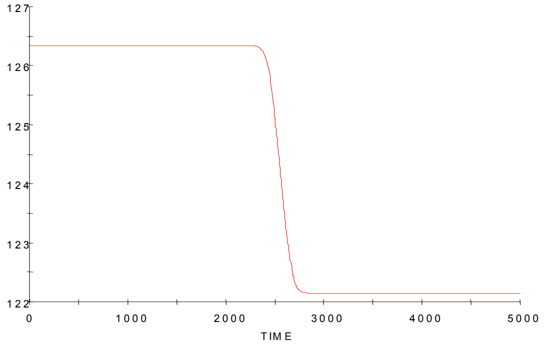

Figure 16. Temperature of the fumes at the outlet of the dryer

4.2.2 Increase in the Amount of Drying Gas that Enters the Dryer

For this test, the gradient of drying gases entering the dryer that will be used will range from 32.67 to 36 kg/s.

The moisture content of the gases is suddenly reduced because because the speed of the gas is high, and since there is a greater amount of gas in the dryer, the concentration of water in the gases almost instantly drops quickly. After a delay there is a small increase in the moisture, only for it to drop again after that.

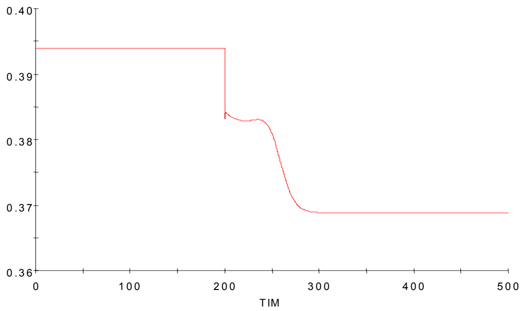

Figure 17. Humidity of the gases at the outlet of the dryer

This occurs because when the amount of gas increases initially, the amount of water that evaporates is also increased, so the moisture of the gas increases. However, as more water evaporates from the pulp, the surface moisture of the pulp is reduced, so the area of the dryer where heat is supplied to water and to pulp also increases. That is, a greater amount of heat is used to heat the pulp. Thus, even if the amount of water which is evaporated in the dryer is increased, the concentration of fumes in the dryer as a whole is reduced.

The following figure shows how the area where heat is supplied not only to evaporate the water but also to heat the pulp is where this second drop in the moisture of the gas can be found.

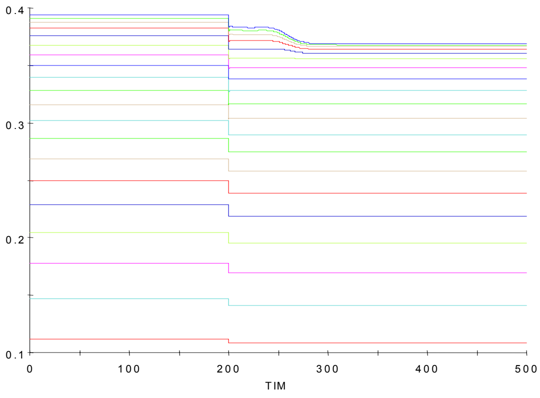

Figure 18. Moisture of the gases at the various discretisation stages of the dryer.

The temperature of the fumes can be seen to increase throughout the dryer. This is logical because when the heat supply increases, the temperature of the fumes in the whole dryer also increases. The final section of the dryer is where the pulp is heated, and this heating is further increased because the thermal difference between the pulp and the gases is reduced, thus reducing the heat flow too.

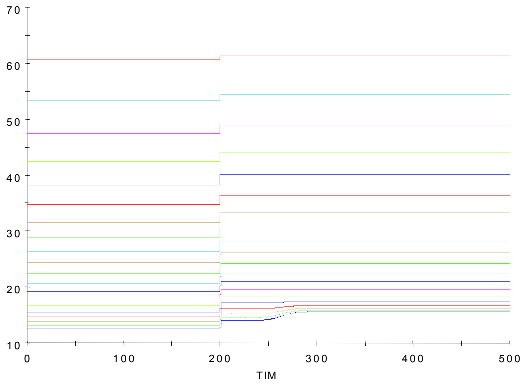

Figure 19. Temperature of the fumes at the various discretisation stages of the dryer

In the case of the pulp, the moisture is reduced as expected. Since the heat supplied is greater, a greater amount of water is evaporated.

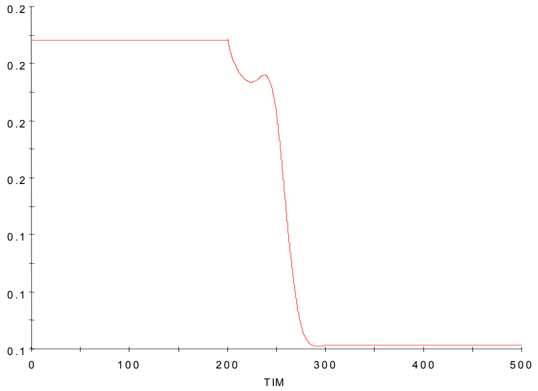

Figure 20. Moisture of the pulp at the outlet of the dryer.

The temperature of the pulp can be seen to increase dangerously during the last stage. The area with surface pulp can also be seen to increase up to 6 stages.

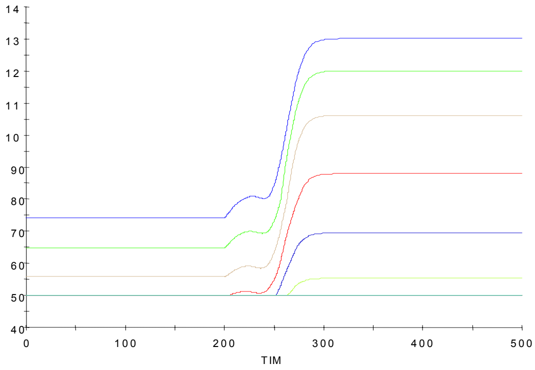

Figure 21. Temperature of the pulp in the various discretisation stages of the dryer

4.2.3 Variation in the Moisture Content of the Solid Elements

Another useful example to check the operation of the dryer is what happens when there is an increase in the inlet moisture of the pulp.

Below is what happens when the weight of the concentration of water at the inlet changes from 0.77 to 0.82 rate per unity.

The moisture at the outlet can be seen to increase, as expected, because the amount of heat supplied does not increase and cannot absorb the increase in the amount of water in the pulp.

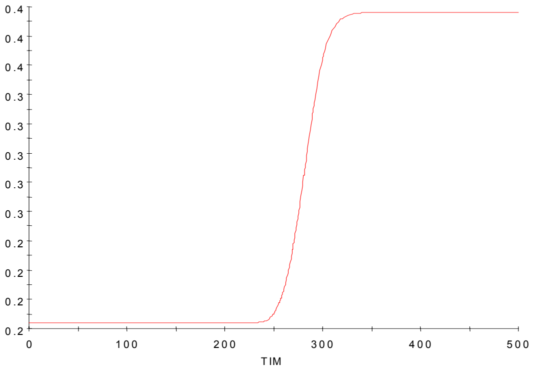

Figure 22. Moisture of the pulp at the outlet of the dryer.

The moisture of the pulp throughout the dryer is gradually increased and retarded.

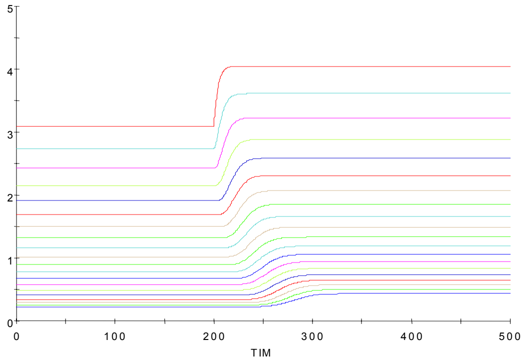

Figure 23. Moisture of the pulp at the various discretisation stages of the dryer.

In the case of the temperature, the same effect applies as in the case of an increase in the pulp entering the dryer. Since the surface moisture increases, there is no heating of the pulp.

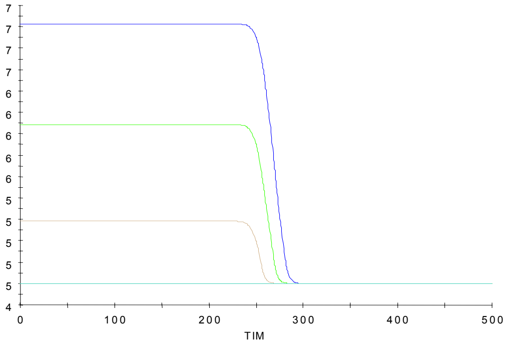

Figure 24 Temperature of the pulp during the various discretisation stages of the dryer.

In the case of the fumes, the moisture can be seen to increase only slightly because even if the amount of water introduced is greater, the amount of heat supplied is the same and the excess water introduced cannot be increased.

The small increase witnessed is caused by the reduction in the temperature of the pulp in the final stages of drying.

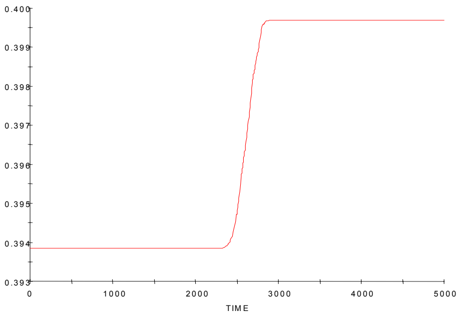

Figure 25. Moisture of the gases at the outlet of the dryer.

In fact, in the first stages where the temperature is constant, the moisture of the gas remains constant (the amount of evaporated water only depends on the temperature difference between the pulp and the gas).

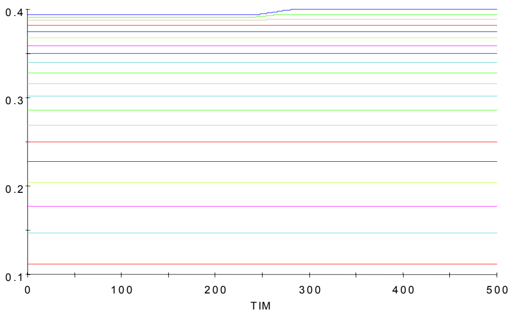

Figure 26. Moisture of the fumes at the various discretisation stages of the dryer.

Consequently, the temperature of the fumes is reduced, but only in the stages where there is a reduction in the temperature. When the thermal gradient increases, the gas loses some of its energy.

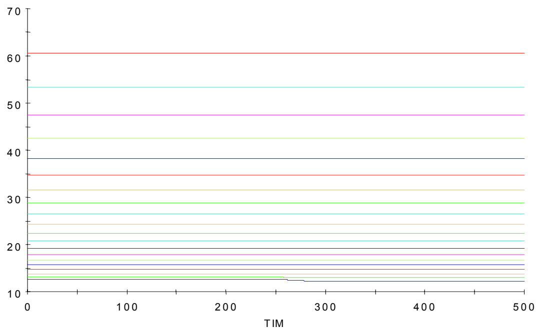

Figure 27. Temperature of the fumes at the various discretisation stages of the dryer.

4.2.4 Increase in the Rotation Speed of the Dryer

The rotation speed of the dryer was reduced for this experiment from 1 to 0.2 rpm.

There was an immediate sudden reduction in the velocity of the pulp. This is caused by the stop of the dryer, which causes the curtain motion of the pulp, and therefore the time it is exposed to the gas current that drives it, to be reduced.

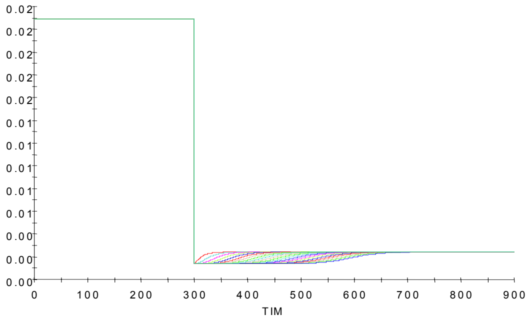

Figure 28. Pulp velocity at the various discretisation stages of the dryer.

This reduction in the speed causes an increase in the pulp mass in all the stages of the dryer.

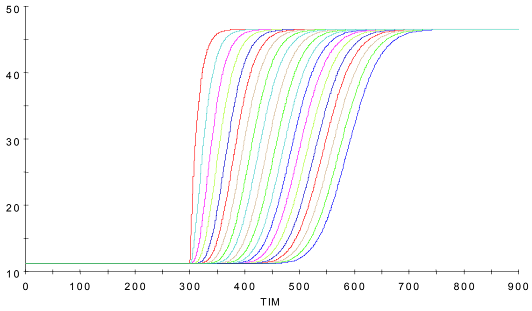

Figure 29. Pulp mass at the various discretisation stages of the dryer

This change affects all the variables of the dryer momentarily. As an example, the figure below shows how the pulp exiting the diffuser is suddenly reduced when the rotation speed drops. This happens until the mass accumulated reaches the end of the dryer. After some time, the balance is recovered because the inlet flow is constant and the outlet flow must remain constant too.

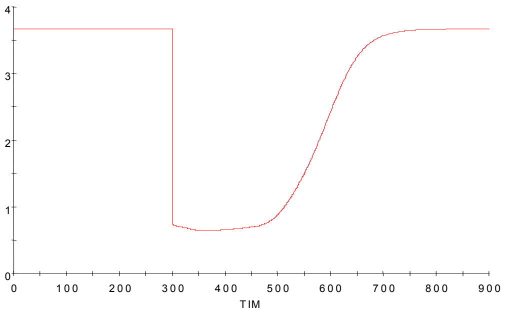

Figure 30. Pulp flow at the outlet of the dryer.

5. CONCLUSIONS

A model for a pulp dryer was created, described in partial derivatives. After the discretisation of the variables and a series of simplifications, the model was implemented in Ecosim and the simulation carried out.

The simulation of the model obtained shows that the results in steady state with the same boundary conditions coincide with the data of a real sugar mill. The dynamic results cannot be contrasted due to a lack of real data, but they are coherent with available knowledge of the process.

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