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Thermal and Physical Patterns of the Reversible Drying of Pellets in the Straight-grate Indurating Machines

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Abstract

Eventually, almost all straight grate traveling indurating machines for pellet production operating with a reverse supply of the heat carrier into the pellet bed. First of all, updraft drying begins and then downdraft proceeds (downward). However, selection of the parameters of this option is still empirical. In particular, a length of the drying first section with the heat carrier updraft (D1) fluctuates from 9 to 18 m. The studies have shown that the drying process in this section considers an over-watering (excessively high pellet moisture). There are two types of over-watering: the first type relates to condensation of water steam within the pellet bed and filling of the free pores of pellets and the second one is "super over-watering" of the pellets on the pellet bed surface as the free water drops. As a result of the experimental data comparison obtained on the indurating machines with an area 520 m^2 and the results of estimated experiments on the TOREX math model have shown that an increase of initial heat carrier temperature in the D1 section within 250-400°C reduces a total duration of the pellet drying. Albeit it causes an increase of the condensate discharge onto pellet bed surface. Afterwards, it leads to decomposition of the pellets and reduction of the pellet bed gas permeability.

Only by increasing the heat medium rate through the pellet bed (filtration rate) one can decrease the pellet drying time significantly and thereby decrease the amount of the condensate both in the pellet bed, and on the surface of the latter.

The special calculations have been performed to analyze the regularities of the reversible drying process.

Numerical simulation showed that there is an optimum value for the length of the first drying section. This value ensures the minimum total duration of pellet drying in a straight-grate (conveyor-type) indurating machine. Drying sections with updraft and downdraft are interrelated, and therefore the optimal sizing of the first section depends highly on the numerous factors.

Keywords

Straight grate traveling indurating machine; Over-watering; Pelletizing (pellet production); Condensate; Drying zone

Description

Drying of the pellet bed is a key factor in the course of pellet heat treatment at the IM, since it determines the production of machine and quality of the final product. Preheating of the pellet bed slows down with a low intensity of drying, especially in terms of lower level pellets. As a result, moisture removal from pellets is ongoing in the preheating zone. It affects the strength of the final fired pellets in a negative way. The capacity of the machine should be reduced in order to avoid the defected products. Excessive temperature intensification of the pellet bed preheating in the drying zone might cause a decomposition of pellets and formation of fines and dust.

The main feature of pellet bed drying is over-watering of pellets that occur as a result of condensation of water steam on the surface of pellets. The steam is being extracted by heat carrier from dried parts of pellet bed. Over-watered pellets have the highest drop number and are easily decomposed. To avoid this phenomenon, pellet drying in the pellet bed should be carried out with the heat carrier reversed at IM. This preserves the lower level pellets from overwatering as a result of preliminary heating by heat carrier during the updraft process of pellet bed in the drying zone 1. Notwithstanding, an overwatering of upper level pellets occurs. Those pellets are being fed to the drying zone 2 with downdraft heat carrier for further intensive drying.

The physical model of the pellet drying in the first section of drying zone (D1) could be presented as follows. In the course of updraft drying the heat carrier heats up the pellets, and increases its moisture content as a vapor. In this regard, temperature of heat carrier decreases. When the moisture content of the heat carrier reaches 100%, its temperature will be in equilibrium ("dew point"). Further cooling of the heat carrier by wet pellets will cause a moisture condensation and over-watering of pellets by 0.5-0.6% (absolute value) Condensation should proceed until the temperature of gas and pellets are equal in the current level. In this case, a moisture condensation is transferred to the upper (cool) level of pellets.

After the formation of excessive over-watering zone, a part of free (drop) moisture is being removed from the pellet surface by the gas flow and taken away from pellet surface and beyond the pellet bed. This is due to an actual speed of the gas flow in the channels between the pellets, which is over 5 m/s. The speed of air and water flow in the wind box (above the pellet bed) is getting reduced. Consequently, the coarse water drops are extracted to the pellet bed surface by a gravity force. This causes "super over-watering" of pellets by 0.8–1.2% (absolute value) which is supported by a sample analysis taken from the pellet bed surface (Figure 1).

Item 3 stands for the area within drying zone length where an extraction of drop moisture to pellet bed surface possibly occurs. An analysis has shown that an intensity of rain effect could be featured by the speed of conditional thickness (h) of the water film layer on the surface [1,2]:

$$\frac{dh}{d\tau} = \frac{g_{cB}}{\rho_{H_20} \cdot E} - K_y h$$

Where g**w** - estimated evaporation of free moisture from pellet bed, kg/ (m^2·min);

ρ**H$_2$O**- water density, kg/m^3;

E - Pellet bed porosity, m^3 voids/m^3 of pellet bed;

τ- Time, minutes;

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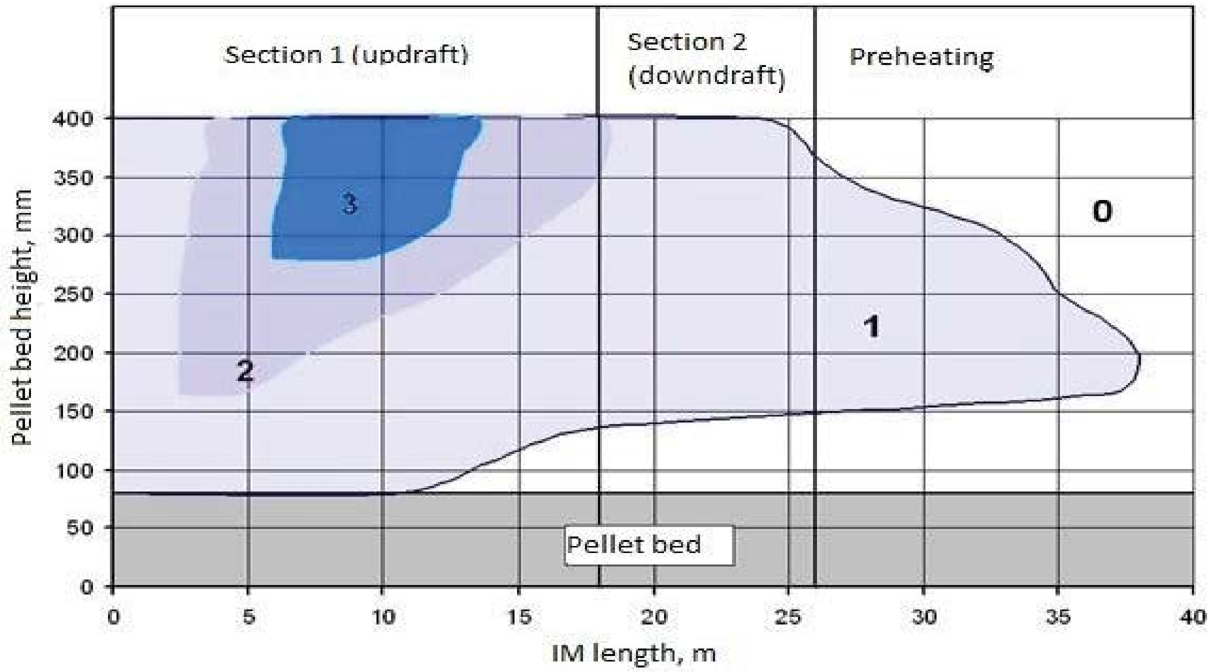

Figure 1: shows the estimated change of the pellet moisture within a height of pellet bed and length of drying zone. This estimation is peculiar for the longer length of the section with an updraft of heat carrier. All calculations are made using original mathematical models [1].

ky - entrainment ratio of drop water by gas flow above the pellet bed, 1/min (to be Determined by weighing conditions of water particles in the gas flow).

As per indurating machine operating conditions, the size of water particles taken away by gas flow above the pellet bed does not exceed 0.16 mm. The ratio of these particles (entrainment ratio) is tentatively 0.25.

The calculation results of "rain intensity" within the drying zone length with updraft of heat carrier at different filtration speed values of heat carrier are shown on Figure 2.

The coordinates within the length of IM are specified by dots (on the line 4). These coordinates correspond to completion of drop moisture extraction from the pellet bed, i.e. completion of the water film make up on the pellet bed surface. As per the diagram, a rain effect could occur even without the make up until the end of first drying zone if the filtration speed is low (up to 1.3 m/s). When the filtration speed and max thickness of a water film increase, the duration of rain effect could be significantly reduced. So, when W = 1.7 m/s, "rain" area is reduced to 30 %.

An initial temperature of the heat carrier in the direct recuperator strongly affects an intensity of the "rain". As it can be seen on (Figure 3), when the heat carrier temperature reaches 220°C (filtration speed is 1.5 m/s), rain effect is unlikely to happen. If temperature reaches 340°C, thickness of the water film on the pellet bed surface (intensity of "rain") is getting increased by 3.5 times.

Design analysis has shown that a moisture content of the supplied heat carrier is an important factor for "super over-watering" of the pellets on the bed surface. The data on Figures 2 and 3 are obtained when the heat carrier moisture content was 2% (volumetric). However, moisture content could raise up to 4.0–4.5%. Even if the gas from firing zone is partially used in the first section of drying zone. Under these conditions, as per the calculations made, it would be necessary to reduce the temperature of heat carrier down to 150–160°C in order to prevent a rain effect. Albeit is not reasonable due to required preheating of the lower bed in the first section of drying zone.

Thus, the developed design analysis of the formation conditions for "super over-watering" of the pellets on the pellet bed surface allows selecting the heat carrier parameters for drying zone 1. Those parameters comply with the specified bed height and prevent a decomposition of pellets on the bed surface in this zone.

However, a primary source of drop moisture is the steam condensation on the pellet surface within the bed volume. Absorption of condensate by pellets might occur by filling of the free pores and by formation of the resistant water film on the pellet surface. A common geometrical calculation shows that the water steam of 0.01 mm on the pellet surface is 0.15% from mass of the dry pellet. It is not possible to distribute the estimated mass of condensate between the pellet pores and surface. Therefore, the following formula is accepted. The estimated value of over-watering $\Delta b = b - b_0$, %, where b is the current value of pellet moisture and b_0 – its initial value. If we would ignore the presence of water film on the surface of over-watered pellets and assume that the condensate could fill all the pores of pellets, a max value of over-watering might be presented as follows $\Delta b_{max} = \varepsilon 1000 / \rho_{virtual}$, where ε - porosity of pellet (%), and ρ virtual

Δb% - virtual density of dry pellet (kg/m^3). The estimated data for green pellet bed with height 360 mm (bed 80 mm) are presented on the Figure 4 as distribution of the over-watering value of pellets within the bed height at different time.

This chart shows that max over-watering of pellets is observed during 1.5 min closer to the bed surface (in this case Δbmax = 0.56 %) Figure 4. In this very period, a surplus of moisture (condensate) is extracted to the surface of pellet bed as drops and films. This moisture cannot be absorbed by pellets.

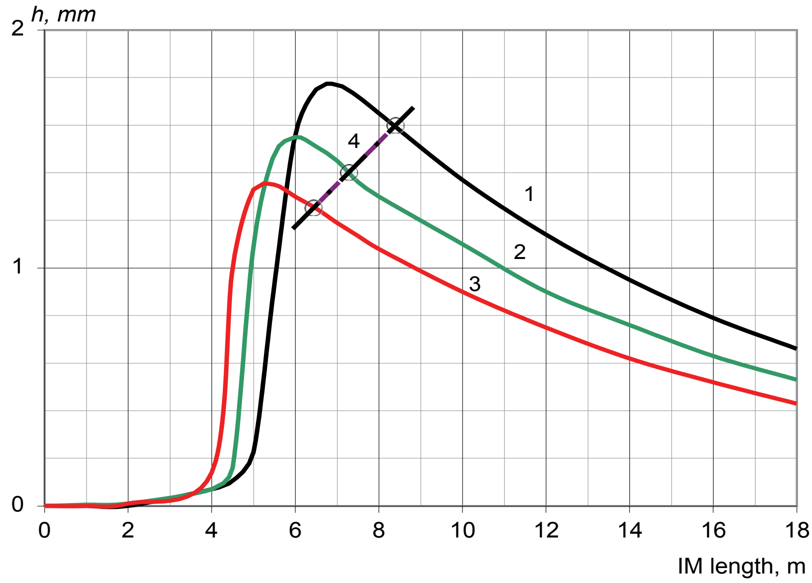

Figure 2: Changing of thickness of the water film surface (*h*) within the section 1 length of the drying zone at different filtration speed (*W*) of heat carrier with initial temperature of 280°C.
W,m/s **1** -1.3; **2** -1.5; **3** -1.7; **4** - end of make-up

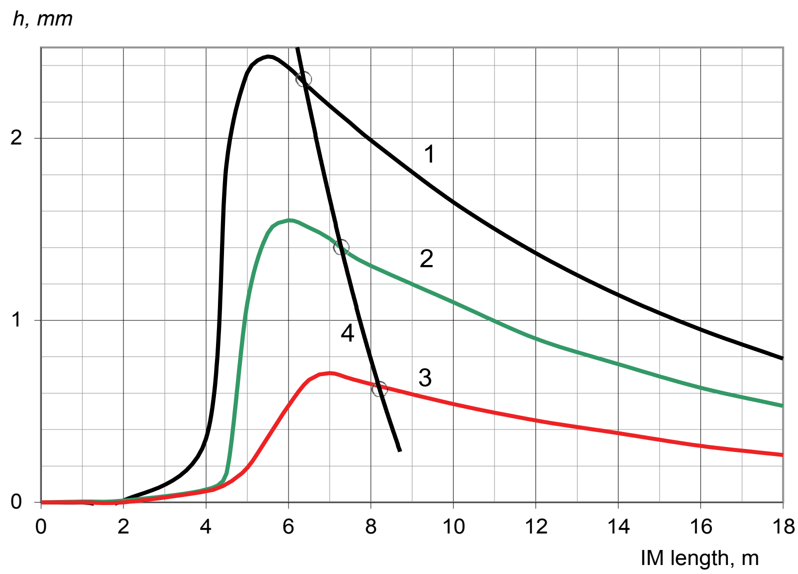

Figure 3: Changing of thickness of the water film surface (*h*) within the section 1 length of the drying zone at different filtration speed
W = 1.5 m/s. *T*, °C: **1**-340; **2**-280; **3**-220; **4** - end of make-up

Δb_{max}

The estimated data on the Figure 4 provide an insight for over-watering process of pellets within height of pellet bed temporally. The estimated quantity of free moisture *g*fm, % is used for quantitative comparison of over-watering within the bed volume at different modes and operating parameters of the drying zone.

Besides, a definition of general integral of the bed over-watering had been given. Its physical meaning lies in dimensionality (%·m·min). I.e. this is a product of over-watering value (absolute %) and current height of the over-watered bed (m), which is integrated for the whole period of over-watering in the bed under mentioned conditions. The named integral could also be interpreted as the general quantity of condensate absorbed by pellets to be evaporated during further drying process.

For instance, Figure 5 shows a dependence of over-watering characteristics on the heat carrier filtration speed and bed height.

Heat carrier reverse in the drying zone provides the features in the heat exchange type at this IM area. This is due to very short

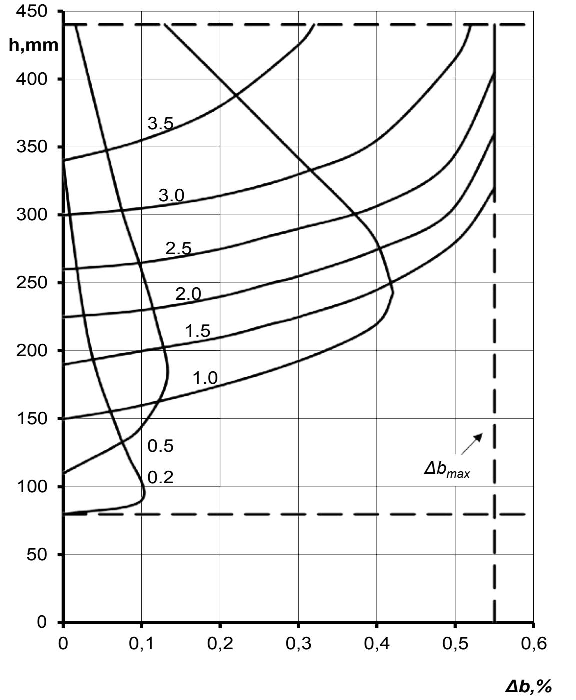

Figure 4: Distribution of the pellet over-watering (*Δb*, %) within the pellet bed height (*h*, mm from grate bars) during the heat carrier updraft. Curve figures-time from the beginning of drying, min; dashed lines - limits of the green pellet bed.

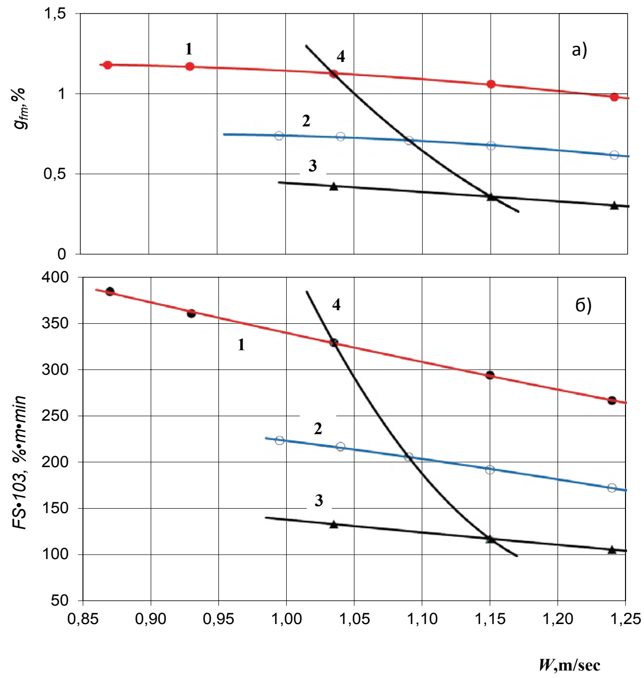

Figure 5: Dependence of the bed over-watering characteristics on the heat carrier filtration speed (w) in the first section of drying zone. a) amount of free moisture at the outlet of bed b) total over-watering of bed. Pellet bed height: 1- n_{bed} = 400 mm; 2- n_{bed} = 350 mm; 3- n_{bed} = 305 mm; 4 – Δ*P* = const, i.e. w is proportional to 1/H0.5

section of the drying zone with an updraft of heat carrier (C-1), which transfers moisture from the lower area of bed upwards. As a result, over-watering occurs in the upper area of bed and poor removal of moisture from bed. In such case, a moisture transition occurs from the upper area of bed into lower levels in the beginning of downdraft drying section. Drying of the bed begins only in the second section. The total duration of drying process is being determined by parameters of section (C-2), where a filtration speed is relatively low (0.6–0.7 m/s). In case of very long section (C-1), heat carrier losses are getting increased through the slide rails of IM. Besides, a condensate is extracted more intensively to the surface of pellet bed. Figure 6 shows the estimated progress of pellet drying in the lower part of green pellet bed (with height 360 mm) with a moderate length of section (C-1) - 11 m.

This chart shows that in the beginning of section with an updraft of heat carrier (C-2), the drying speed of the lower pellet bed is highly decreased due to moisture removal from the upper bed (Figure 6). But then the drying process is abruptly speeds up and completes at a distance of 90 mm from the bed. All further calculations have been made prior to completion of the drying process within entire height of bed. It turned out that the length of first section with heat carrier updraft strongly affects the total duration of the pellet bed drying. Based on the data for one of IM with an area of 520 m^2, the calculations have been conducted with different length of section (C-1) from 5 to 19 m with relevant displacement within the IM length of section (C-2).

The results of these calculations are given in the Figure 7. This figure shows that the duration of total drying process is minimized within 11-12 m (C-1) (Figure 7a). Over-watering of the pellets in the section (C-2) (area between the lines 1 and 2 on almost finished along this length (Figure 7b).

Figure 7c provides the estimated dependence of pellet temperature between pellet bed and hearth in the end of section C-1 on its length during preheating of bottom hearth layer. It can be seen that with an optimum length of section C-1 (11-12 m), the lower area of bed is heated up to 160-170°C. This temperature is sufficient to prevent a condensation of the water steam in the lower bed in the second section of drying zone (C-2) with updraft of heat carrier. It is notable, that the drying degree in the section is 15-20% which corresponds to an optimal length of section C-1. In other words, an essence of drying section by heat carrier updraft lies in the preheating and drying of lower bed. The basic mass of moisture is being removed from the bed in the section C-2 during updraft of heat carrier.

Simulation study has shown that an optimal length of section (C-1) depends on many factors. One of a main factor is the specific surface of pellet in the bed (size of pellets) and speed of belt (capacity) of the IM. Such factors as temperature and heat carrier filtration speed in the section (C-1) almost do not affect an optimal length of the drying zone section.

Conclusion

Based on the experimental and model studies the following has been shown: there are two types of the pellet over-watering. The first one is related to condensation of the water steam within the bed volume and its filling of free pellet pores. The second type stands for extraction of the drop (film) moisture to the bed surface and "super over-watering" of upper pellets due to a "rain" formation. The math model has been developed to calculate an intensity of the "rain" formation.

1. The model studies of the pellet drying process in the bed has shown that the length of first section of the drying zone with updraft of heat carrier is optimal. This ensures a minimum duration of entire

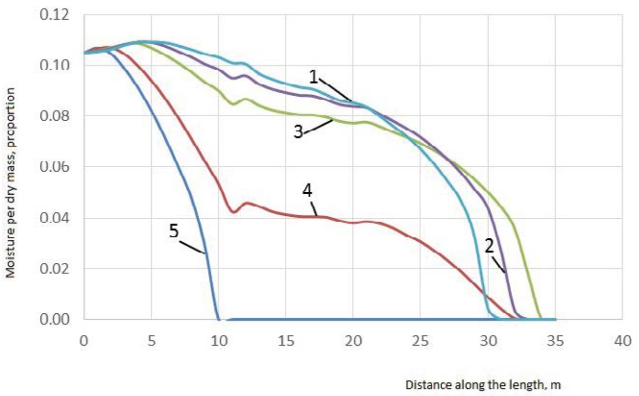

Figure 6: Distribution of the pellet moisture within the IM length if the length of updraft drying zone section (C-1) is 11 m, at the various levels (from grate bars):

1 - 223 mm; 2 - 193 mm; 3 - 163 mm; 4 - 103 mm; 5 – 75 mm.

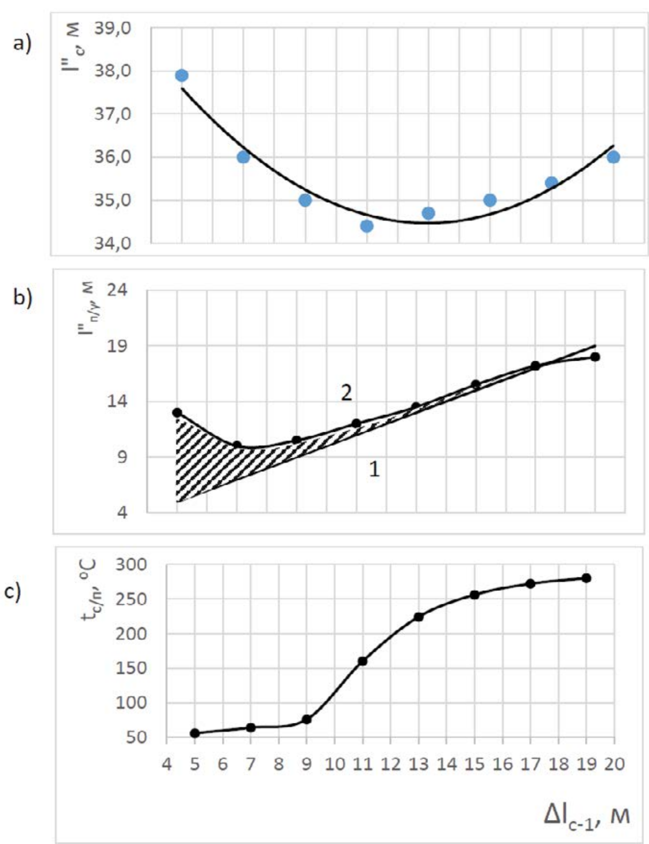

Figure 7: Dependence of drying zone parameters on the section length (C-1) Δlc-1

a) $l_{(c)}$ - duration of the overall drying process, m;

b) $l''_{p/u}$ - duration of over-watering process 1- in section (C-1), 2- general, m;

c) tpellet bed-hearth, °C – pellet temperature between the pellet bed and hearth (in the end of section (C-1));

pellet bed drying. Dependence of this optimum on the range of heat engineering parameters has been shown, including the size of pellets, IM capacity, and initial parameters of heat carrier.

2. Based on the results obtained with a numerical simulation, one can set the optimum parameters for the drying section of any indurating machine.

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