MODELISATION OF A BED ASH COOLER HEAT EXCHANGER

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1. INTRODUCTION

Nowadays thanks to the industrial development, the increase of standard of living, each country is trying to achieve new goals in terms of renewable sources. In case of Poland, is one of the best countries regarding to biomass.

Inside this topic there is some industries working in fluidized bed boilers with the aim to refresh the ashes obtained after the combustion of biomass and coal. At the same time, they are trying to achieve two goals, not only the refresh, even though reobtain the thermal energy from the ashes.

This thermal energy can be converted into electrical and be used to cover the energy employed during the process such as, the gas injection, removal ashes, transport the coal and go on.

In several factories after obtained the ashes they have to wait some days until the ash's temperature is reduced, as its temperature around 800-900ºC is hard to work and it is necessary achieve an available temperature for being moved to a secure place. The aim is reducing the time of this process.

On the other hand, from international governments have being passed some laws to reduce the quantity of emissions emitted to the atmosphere so, the study of fluidized bed boilers is interesting due to the among of chemical elements which are contained inside and finally, it could cause a reduction of them. Here the most important contaminant elements are NOx and SO2, of course there are more but firstly these two must be eliminated and after there will be included the CO2 and CFC.

In fluidized bed boilers, combustion occurs in a controlled manner throughout the home and recirculation system so that the residence time of the ignited particles is much higher than that of conventional boilers, these temperatures are usually lower than 850ºC. As ash softening and melting temperatures are not reached, no slag formation phenomena occur in the boiler.

In addition, the combustion temperature is below that of formation of nitrogen oxides of thermal origin, which limits the production of this pollutant.

In the combustion process, the sulfur present in the fuel is oxidized to produce SO2, which in conventional boilers escapes with fumes, unlike here it is combined in the boiler itself and thus the installation of a desulfurization process is avoided of gases.

2. FLUIDIZED BED BOILERS

The topic which is going to be studied is related to fluidized beds boilers, for this, the first step is explain what the fluidization is.

This process occurs when small solid particles are in suspension thanks to a fluid flow which comes from down to up overcoming the weight of these particles. Depending on

the speed of the flow the particles can be down, in suspension or leaving the boiler, so that the velocity must be controlled to maintain them inside of the boiler.

At the moment they are in suspension, they are rotating in the bed creating an excellent mixed. Normally, the solid matter is which is fluidized and the material which fluidizes can be either liquid or gas.

Now it will be represented Figure 1, which can be seen how the velocity of the flow affects in the process.

a) First case, the fluidization gas velocity is low and for that, it cannot overcome the weight of solid particles (fixed fluidized bed).
b) When the fluidization gas velocity rises until the process can work, is called minimal fluidization velocity.
c) Higher value of fluidization gas velocity, it is generated an expansion of fluidized bed.
d) If it appears bubbles inside the boiler and at the same time the fluidization gas velocity is the minimum is called bubbling fluidization.
e) The bubbles grow up moving the heavy particles to upper part and the smaller ones to the bottom.
g) If it appears bubbles inside the boiler and at the same time the fluidization gas velocity is elevated, the process is called turbulent fluidized bed.
h) Last case, when the velocity is too high an among of particles are thrown outside the boiler and the efficiency is reduced.
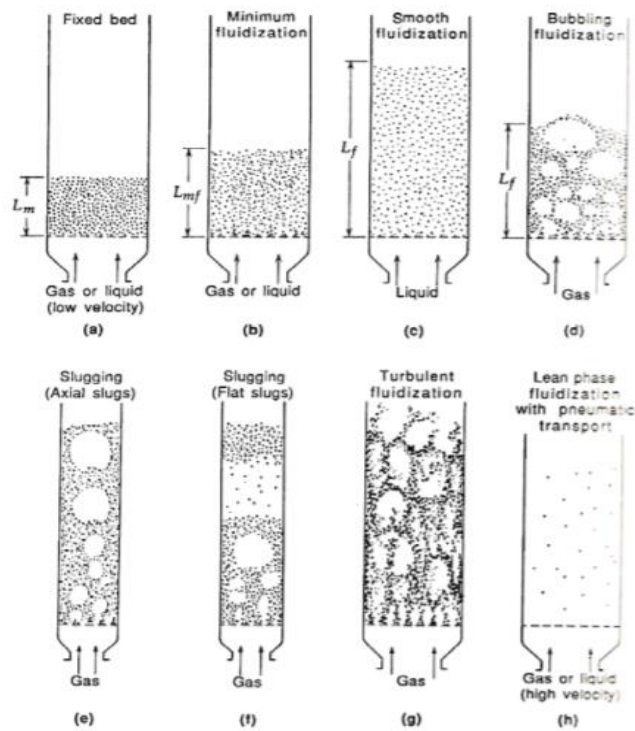

Figure 1:   How the flow affects

When it is used a gas jet to fluidize, if there is high speed and the particles are relatively big, the jet gas goes out like a jet moving all the particles up to the surface. The solids are moved down close to the jet nozzle and even inside the jet as it is shown in Figure 2.

Figure 2: Gas jet

Finally, there are going to show some advantages and disadvantages of fluidized bed boilers:

Advantages

1. The behaviour as a liquid of the particles lets an automatic continue control.
2. The quick mixture of solids lets us obtain an effective isothermal condition in the system.
3. The system is stable even when an abrupt change appears thanks to the good mixture of solids.
4. Perfect for high scale operations.
5. High heat transfers and matter between flow and particles in comparison to other types.

Disadvantages

1. Economic cost as a consequence of the mechanical energy required to impulse the flow and the equipment.
2. There are corrosion problems in the wall due to the abrasion.
3. The quick mixture of solids carries that exist different residence time and it produces problems of non-uniformity.

3. HOW THE BOILERS ARE

After this short explanation, it is time to explain how the boiler is, which is going to be studied. Looking at Figure 3, at the bottom part appears the gas injection in this case air, and the process starts. In one side it is found the entrance of fuel, it is provided from the hoppers, the way about how it is introduced will be studied later.

On the other side it can be found the second air entrance which is used to continue obtaining a good mixture and trying to convert it more uniform. And finally, the last part is the exit of the combustion gases which is situated at the top of the boiler.
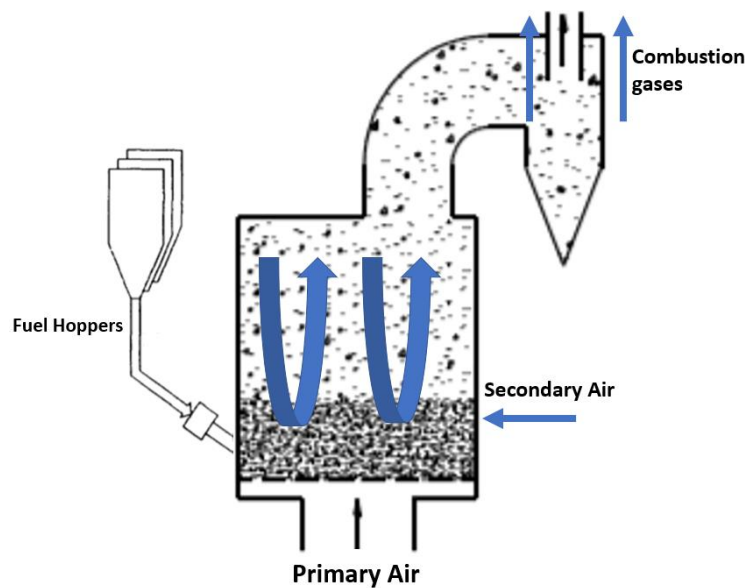

Figure 3: Boiler chamber

Following the explanation about our case, after and during the combustion there are being created some particles burnt or unburnt. All of them are deposited at the bottom of the combustion chamber. They must be removed and for achieve this goal, it is used a screw which is going to through away the ashes.

One more thing for finishing the explanation of this combustion chamber and related to the screw, is the way to introduce the air/gas inside the chamber. In the next Figure , it is shown the injectors, in our case they are not like " T " if not like " ɲ ". The reason is easy, if the process stops in any moment, all the ashes will be inside the injector, so it could create problems. At the same time, the air shoot is going down and it can move the ashes and helps to be sent to the screw.
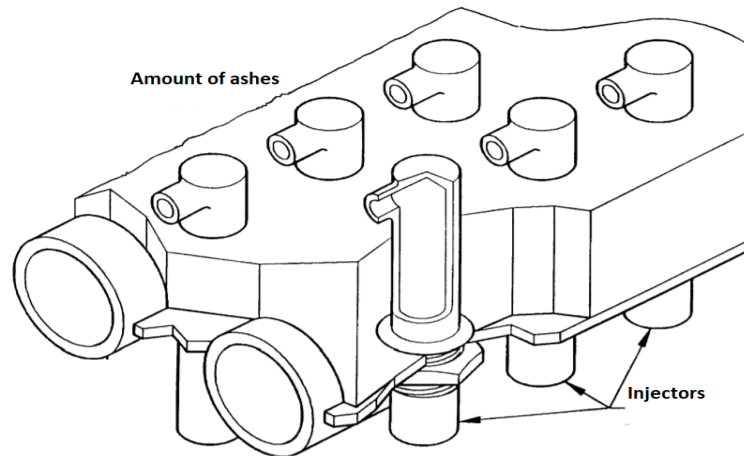
Figure 4: Injectors

4. TYPES OF BOILERS

Next step will be to explain how the fuel is introduced and at the same time differentiate between three kinds of boilers:

- Fluidized bed: Biomass is mixed with a medium (sometimes sand) and kept suspended in a mix with incoming air (It has been explained before)

- Grate-Firing: Biomass is placed on a grate and moves slowly through the boiler as it combusts with air being supplied through holes in the grate. (Figure)

- Pulverized fuel boiler: Biomass is grinded to powder and combusted. It achieves high efficiency but during grinding the feedstock requires energy. (Figure)
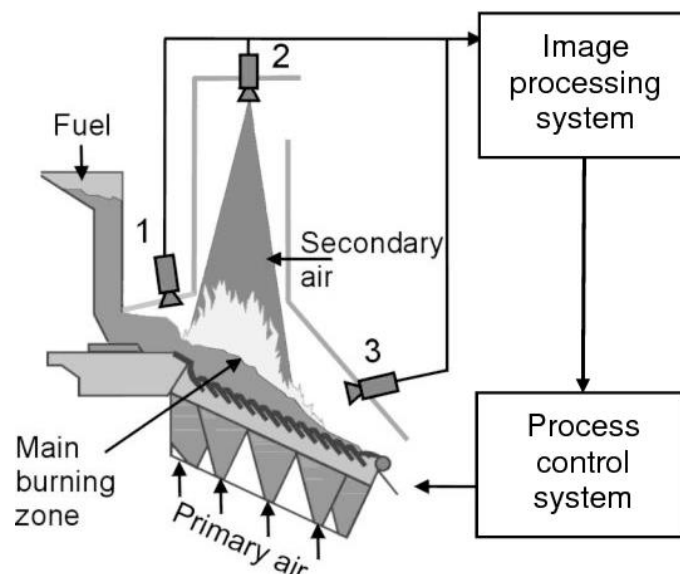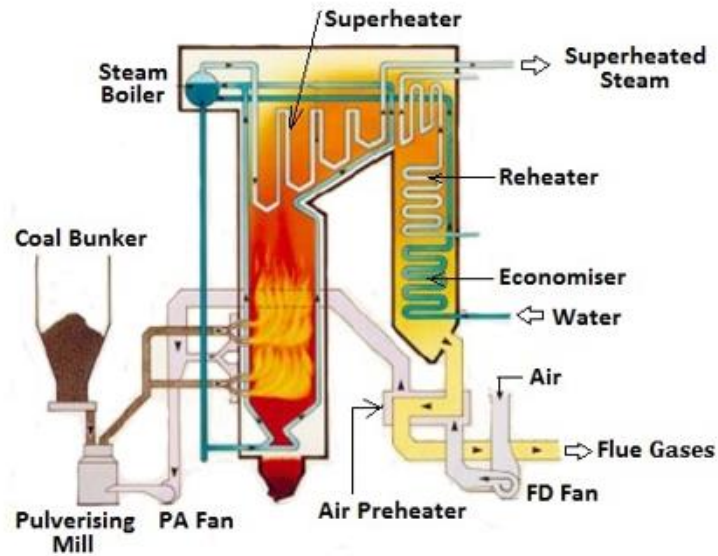

Figure 5: Grate-firing

Figure 6: Pulverised fuel

5. DESCRIPTION OF THE SCREW

Taking a sight to the figures 7,8 and 9, it can be created an image about how it is. This device drives water inside himself in two ways, one in the inner layer and the other one in the outer layer and in the middle the ashes are driven.

Using this methodology, the ashes give up its heat in two ways so it can decrease the temperature faster. The measurements are shown in the figures and the screw works in different velocities. It can change the speed between 20 and 80% regarded the nominal velocity. It can be fixed to minor velocity, until 10% but for security reasons is better do not do it, as the accumulation of ashes at that temperature can produce problems in the screw.
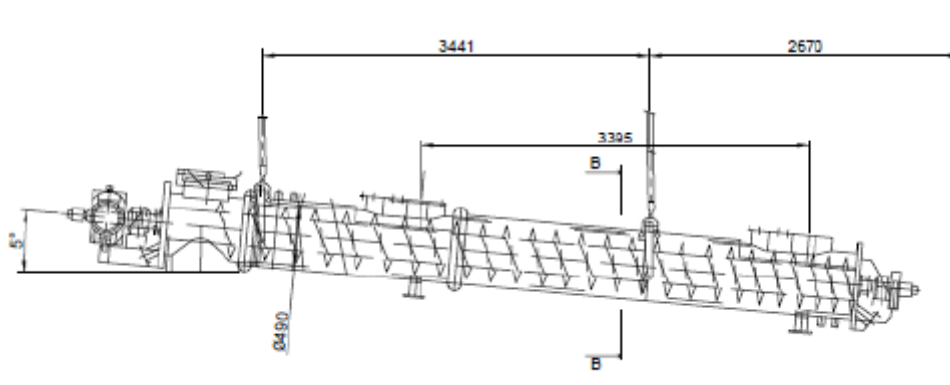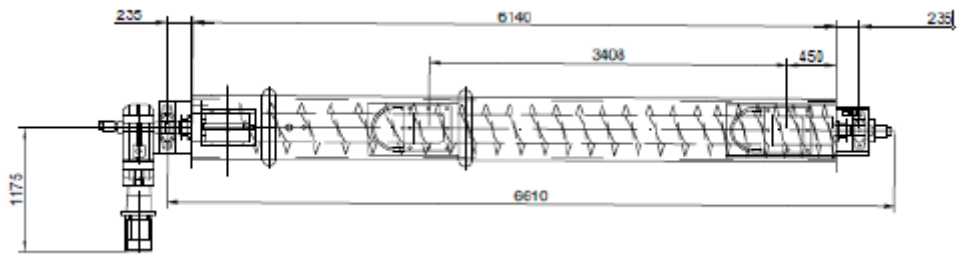

Figure 7: First view of screw
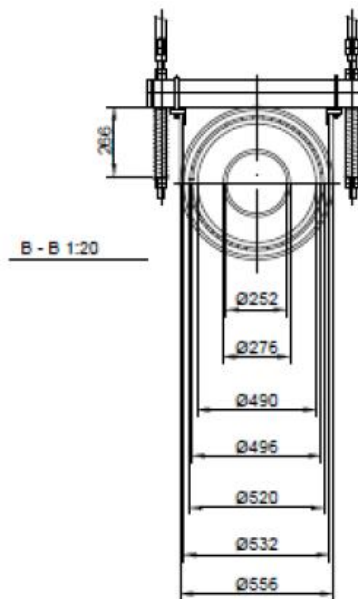
Figure 8: Second view of screw

Figure 9: Third view of screw

The study of this screw it does not means is the only one, the system is equipped with 7 more screws at the bottom of the boiler. Not all of them take the same quantity of ashes, it depends on the side which is analyzed. Normally, odd side accumulates more quantity of them and are called by 10, 30, 50, 70.

6. CALCULATIONS

a. Ashes flow rate

Once explained all about fluidized bed boilers, we are going to work in the behavior of our screw exchanger and for that, there will be studied heat transfers between water and ashes, behavior of water, ashes and steel, how the velocity affects, how the width affects and more features which will be explained.

One of the first values which can be calculated is the flow of ashes and for that, it is required to do a thermal balance between ashes and both flows of water, one in the shaft (inner layer) and other in case (outer layer).

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To prepare this thermal balance is given from the factory, a test varying the velocity of the screw, as it was mentioned, between 20 and 80% regard the nominal speed. The values are shown in Table 2 and in Table 1 coefficients which are known previously.

$$q_{va} * \rho_a * c_{pa} * (t_{ai} - t_{ao}) = \rho_w * c_w * \left(q_{vws} * (t_{wso} - t_{wsi}) + q_{vwc} * (t_{wso} - t_{wsi}) \right) \quad (1)$$

Where:

- q_v – heat transfer (m^3/h)
- ρ – density (kg/ m^3)
- t – temperature (ºC)
- c_p – calorific capacity J/kgC
- $a-$ ash , i – inlet, o – outlet, s – shaft, c – case

Cp water	4180	J/kgC
Cp ash	1005	J/kgC
ρ water	Varying	kg/m³
ρ ash	1021	kg/m³
Flow screw (q_{vws})	3,8	m³/h
Flow case (q_{vwc})	4,2	m³/h

Table 1: Coefficients

Velocity of Screw (%)	Inlet Temp Water (ºC)	Outlet Temp Water Case (ºC)	Oulet Temp Water Shaft (ºC)	Inlet Temp Ash (ºC)	Outlet Temp Ash (ºC)
20	26,3	50,6	46	332,1	106,7
40	26	56,6	50,3	327,8	109,2
60	25,9	61,9	53,8	337,6	120,9
80	26,1	67,5	57,5	351,8	128,8

Table 2: Values from test

As the Table 1 shows, water density varies depending on the temperature and it has to be calculated using another test which is shown in Table 3. Taking into account the variation of temperature between 10 and 60ºC and the test in which the temperatures are in the middle of some intervals, it is necessary to interpolate the values to obtain an accuracy value and this value is given in Table 4.

Water Temp (ºC)	Density (kg/ m³)
10	999,7
20	998,2
30	995,7
40	992,2
50	988,1
60	983,2

Table 3: Variation of water density

Aver Twat (ºC)	Water dens (kg/ m³)
38,45	992,7425
41,3	991,667
43,9	990,601
46,8	989,412

Table 4: Interpolated values

Before to show the flow of ashes obtained, Figure 4 shows the behaviour of ashes and water temperature is affected by speed variation. As it can be seen, the change of speed does not affect to ash's temperature as the variation is pretty small, for having a general idea, ash's temperature varies from 350ºC inlet position, to 120ºC outlet.
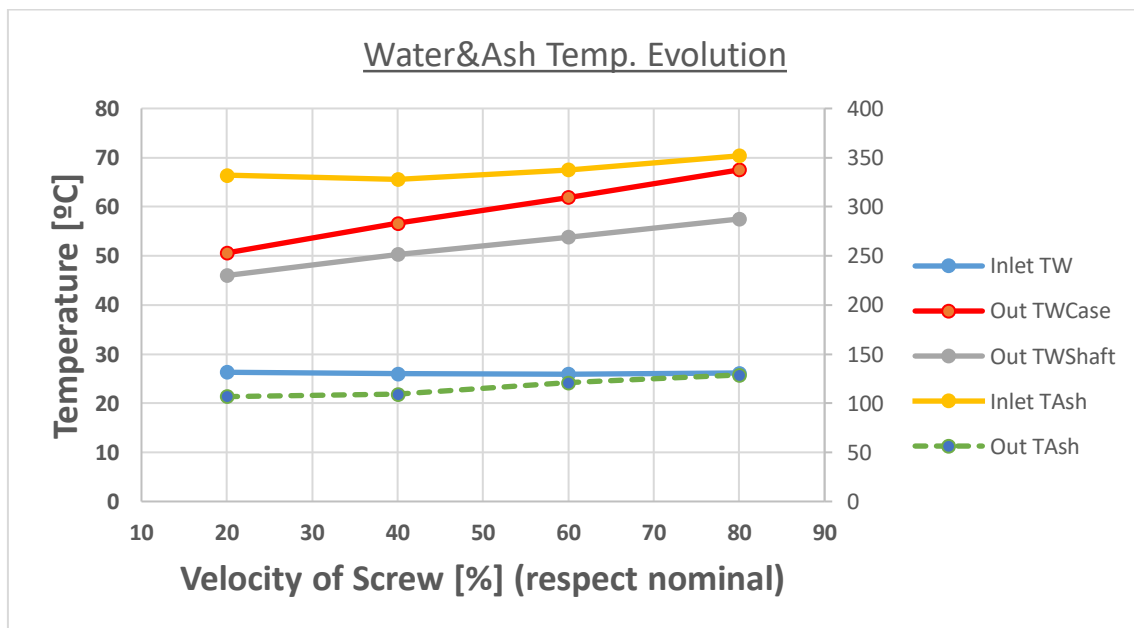

Figure 4: Evolution of Water and ashes depending on the temperature. Ashes temperature right axis

The short difference of temperature in the ashes also can be induced for having no same temperature in water inlet. Regarding to water temperature, speed changes affect water temperature because of the time in which exists contact in lower, so as ashes are moving faster the heat transfer is produced a higher temperature.

So finally, using Formula 1 and applying all the values obtained, the ashes flow are:

Qva (m³/h)
3,174
4,081
4,790
5,299

Table 5: Ashes flow

Obviously, the flow of ashes increases at the same time the revolutions per minute of the screw increases.

b. Degree filling cross-section

According this value, q_{va}, it is interesting to know how the degree of filling cross-section of the radiator with ash, works. For that it will be used:

$$q_{va} = u_p * S * \varepsilon \qquad (2)$$

Being:

u_p – linear velocity of screw

S – Surface in contact

ε - degree of filling cross-section

The screw linear velocity relations the frequency of movement of the screw with the step which is given. Every screw step is related to $d_s = 0.225$m.
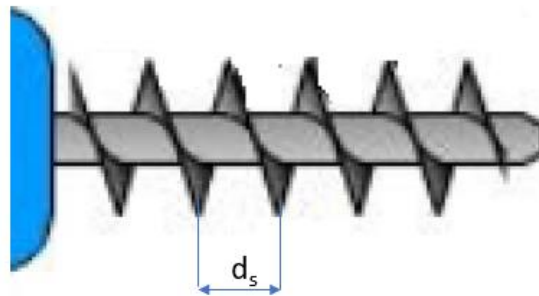

Figure 5: View of screw

So as the Formula 3 shows, it will be obtained different values depending on the frequency of rotation. Ds will be constant, but the % respect nominal speed will vary between 20 and 100 and it will give values for frequency and linear velocity showed in Table 6.

$$u_{p100} = d_s * f_{100} \qquad (3)$$

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Just for mention, when the screw is working at 100% it means is giving 10 rot/min, which has to be converted into rotations per second.

%		20	40	60	80	100
Frecuency (rps)	f_{100}	0,033	0,067	0,100	0,133	0,167
Linear velocity of screw	u_p (m/s)	0,008	0,015	0,023	0,030	0,038

Table 6: Values of linear velocity and frequency

Finally, the degree of filling cross-section obtained are the values showed in Table 7.

E (-)	0,72	0,46	0,36	0,30

Table 7: Values of degree of filling cross-section

Another important point of view is trying to make a mathematic model of this behaviour, for that, it would be interesting approximate the values to a polynomic equation, in this case of grade 2 or 3.

So, using the values obtained before and making value and the image of this value a table can be prepared, Table 8.

x_1	20	y_1	0,72
x_2	40	y_2	0,46
x_3	60	y_3	0,36
x_4	80	y_4	0,30

Table 8: Values for approximate the equation

With this values can be used the Formula 4 or the Lagrange interpolation method.

$$p(x) = Ax^2 + Bx + C \qquad\qquad (4)$$

Where substituting the values it can be obtained A=0,00015, B=-0,022 C=1,1, the representation appears in Figure 6. Using the other methodology, Lagrange, the line really follows the trend of painted points and for that the Formula 5 represents this values.
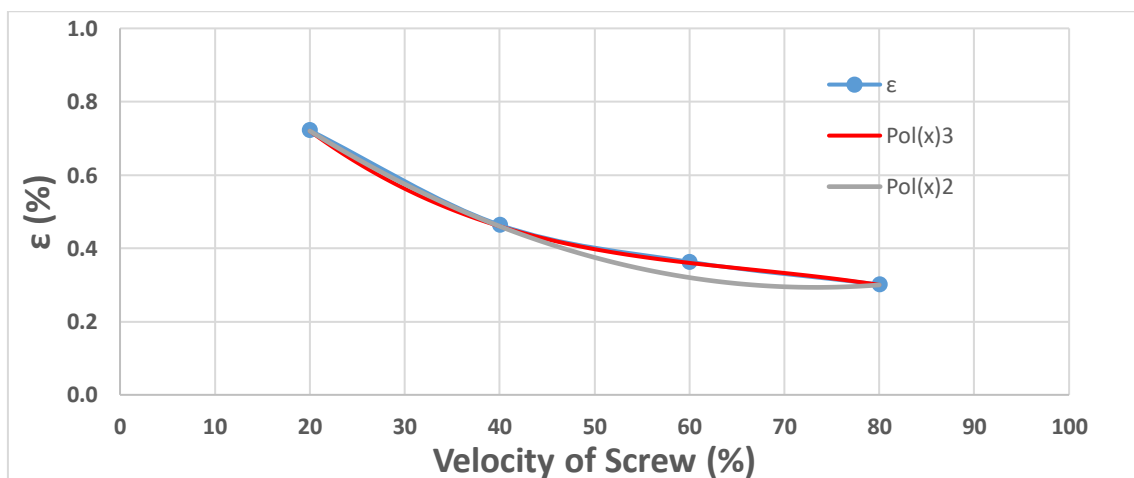

Figure 6: Evolution of degree filling vs screw velocity

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$$P(x) = -2{,}5x10^6 * x^3 + 5x10^2 - 0{,}036x + 1{,}26 \tag{5}$$

As it shows in the Figure 6 as it is raised screw speed, the degree of filling is reduced, it is like this because of does not exist a machine which push the ashes inside and is an spontaneous movement, more fore gravity.

c. Ashes surface in contact each moment

Studied this value, it is interesting to analyze at the same time the degree, how the ashes affect the surface inside screw and how affects in parts where the ashes are not touching them. Watching the Figure 7, it can be seen how when the ashes reduces its level, there are two surfaces with no contact, so that is the point to study.
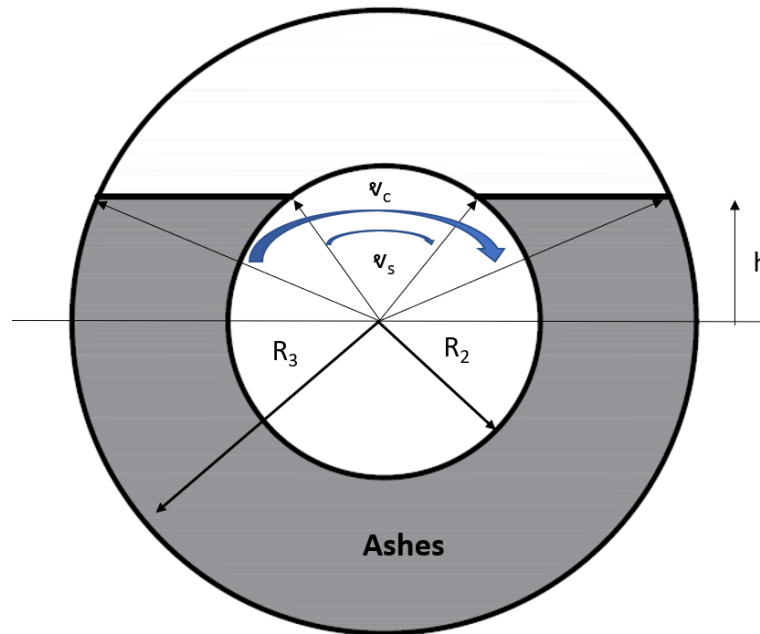

Figure 7: Ash exchanger

For this operation, it can be related the degree of filling with the surface covered. By means Formula 6. At the same time, it has to be described or prepared the value of two angles, v_s and v_c, which represent the degree of contact ash in outer surface and inlet surface. Between them there is a correlation as the Formula 9 shows.

$$\varepsilon = \frac{Se}{S} \tag{6}$$

$$S = (R_3^2 - R_2^2) * \pi \tag{7}$$

$$S_\varepsilon = R_3^2 * (\pi - 0.5v_c) + h * \sqrt{(R_3^2 - h^2)} + \begin{cases} -\pi R_2^2 & \text{for } h \geq R_2 \\ -\pi R_2^2(\pi - 0.5v_s) - h\sqrt{(R_2^2 - h^2)} & \text{for } h < R_2 \end{cases} \tag{8}$$

$$\tag{9}$$

$$\mathcal{V}_s = 2 * \mathrm{acos}\left(\frac{R_2}{R_3} * cos\left(\frac{\mathcal{V}_c}{2}\right)\right)$$

Being h = $R_3 cos(0.5\mathcal{V}_c)$ and radio R_3 = 0,266m and R_2=0,1375m

Watching Figure 7, and analysing the values of h and ε when h is equal to 0, it means that ε is 50% and at the same time, when h = R_3 it means is totally full. However, after to decrease to 50% is has to be studied and for that the Formula 8, takes different values depending on the h's value.

Using all the formulas it can be analysed this behaviour which is shown in Figure 8. Inside this graph, there are two moments which can be referred to the moment in which the inner surface is completely full but not the outer. Around 1,9 and 4,3 the chart slope changes, that moment inner surface starts to be not complete.
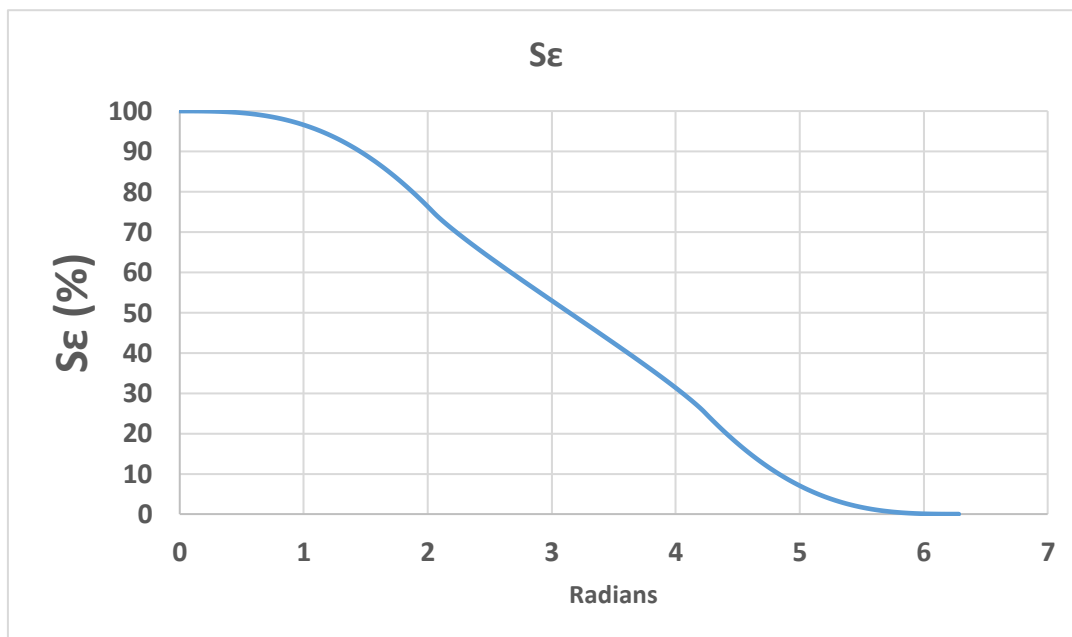

Figure 8: Evolution of Se

At the same time, it can be added the evolution of these two surfaces, inner and outer and compliment the explanation. As it can be seen in Figure 9, outer behaviour is constant, but it is not the same for inner. As it was said before, around 125° the inner layer is
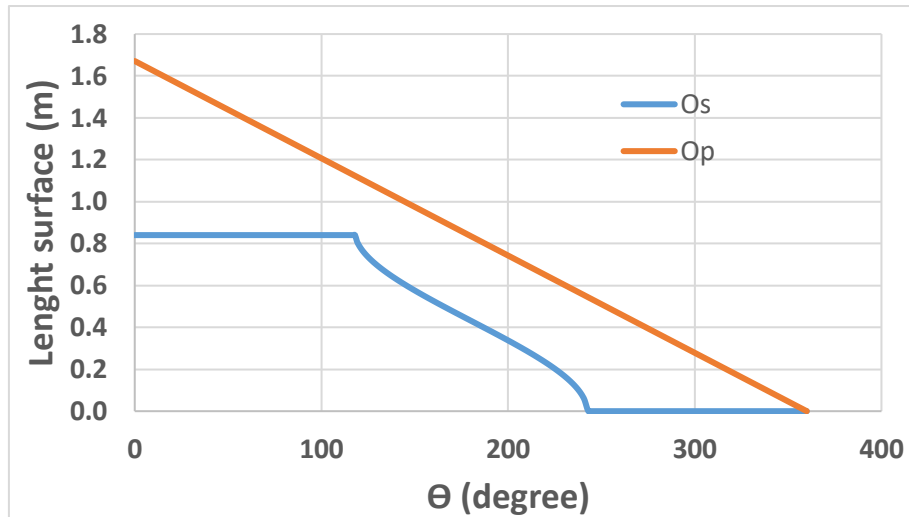
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Figure 9: Inner and Outer lenghts

completely full, but there is appearing the non-contact and around 245° the ashes do not touch the inner surface.

d. Heat transfer coefficients

Once obtained this analysis, it is time to connect them to the values of heat transfer, how the materials and width affect and how the temperature of ashes and water vary their properties.

As it was shown, there are three materials analysed here such as, water, ashes and steel. The easiest one is the steel due to its high use in a large range of constructions or whatever use. In this case, it can be check by means the Formula 10 having in mind the radius of each layer.

$$\alpha_s = \frac{\lambda_s}{R_0 \ln\left(\frac{R_0}{R_i}\right)} \tag{10}$$
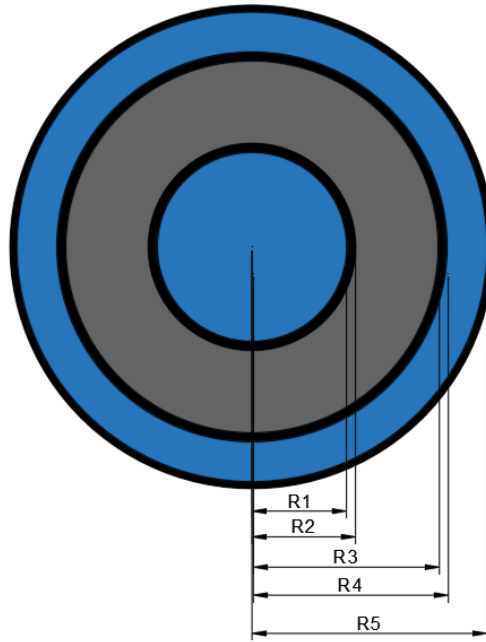
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Figure 10: Interior dimensions

The corresponding values for the radios showed in Figure 10 are:
- R1 = 0,126m
- R2 = 0,138m
- R3 = 0,248m
- R4 = 0,260m
- R5 = 0,266m

So, having in mind R_0 = R2 and R_i = R1 for inner layer and R_0 = R4 and R_i =R3, and using λs = 50 W/mK, the values for heat transfer coefficient are:

$$\alpha_{s12} = 3983 \text{ W/m}^2\text{K} \qquad\qquad \alpha_{s34} = 4067 \text{ W/m}^2\text{K}$$

Comparing both results, it can be assumed that the heat transfer coefficient can be 4000W/m^{2}K.

Next analysis is for heat transfer coefficient of ashes, for that, it will be used the Formula 11, which has in count the density, heat capacity, thermal conductivity and a value which has in count the time. This last characteristic has an amount of variables which are going to be studied following next formulas:

$$\alpha_a = 2\sqrt{\frac{\rho_a * c_{pa} * \lambda_a}{t_c * \pi}} \tag{11}$$

$$t_c = \frac{N_{min}}{n} \tag{12}$$

$$N_{min} = C * f_r^x \tag{13}$$

$$f_r = \frac{(2\pi n)^2 D}{2g} \tag{14}$$

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Where:

- ρ_a = 1021 kg/m^3
- c_{pa} = 1005 J/kgK
- C = 4
- x = 0,3
- g = 9,81 m/s^2

Nmin depends on mechanical properties of the exchanger of ashes, C is a factor taken for our decision and x is a potential factor. In Formula 14, the diameter is the sum of R2+R3.

So using the formulas, first is obtained the fr, after Nmin and finally the tc which is the discretization of the continuous process of ash mixing in the compartments, during which the ashes are treated as static and only the diffusion processes take place and the perfect mixture takes place between these compartments.

n (rpm)	n (rpm/s)	fr	Nmin	tc
2	0,0333	0,0009	0,4818	14,454
8	0,1333	0,0138	1,1069	8,302

Table 9: Coeficients dependind on rpm

Once these values have been obtained, it has to be in mind, that thermal conductivity of ashes depends on the temperature and for obtaining the heat transfer coefficient it has to be used this variation of λ in a temperature range shown in Table 11 whose behaviour follows a polynomic equation. And analysing the maximum and minimum velocity of screw the values obtained are in Table 10.

λ (W/mK)	T (ºC)	α (n=2)	α (n=8)
0,56	150	225,0	296,9
0,65	250	242,4	319,8
0,82	350	272,2	359,2
1,02	450	303,6	400,7
1,08	550	312,4	412,3
1,16	650	323,8	427,3

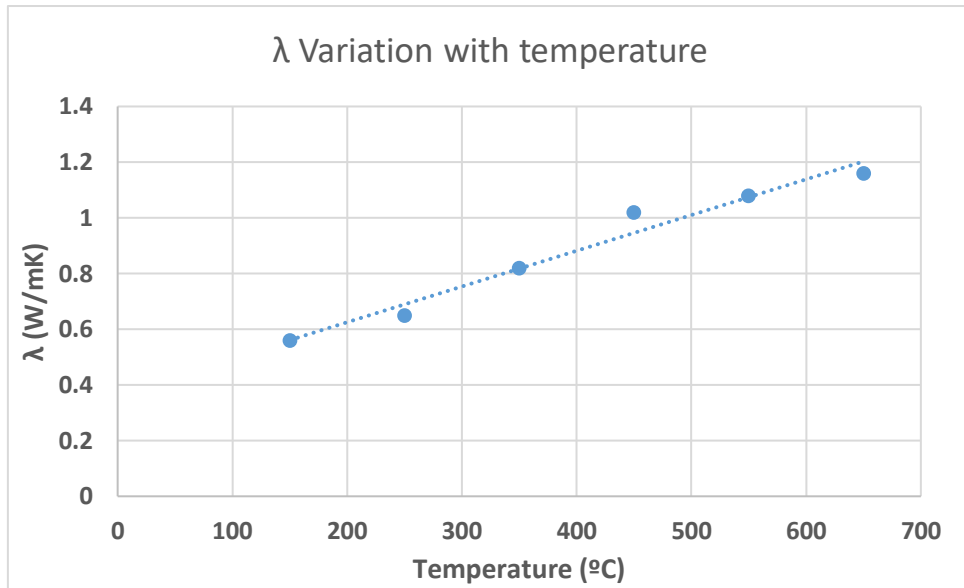*Table 10: Variation of thermal conductivity depending on the temperature*

Table 11: Thermal conductivity behaviour depending on temperature

Observing the Figure 11, comparing for both screw velocity, it can be checked that the behaviour is similar assuming the difference of temperature. It means, as higher screw velocity is and temperature is, higher will be the heat transfer coefficient, so the heat among transferred will be higher as the thermal conductivity is also increasing.
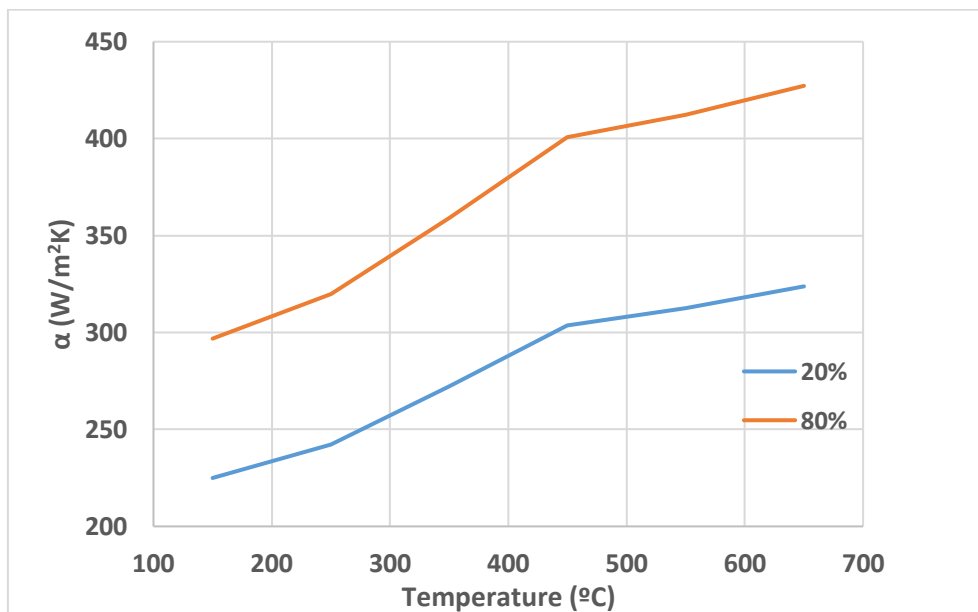

Figure 11: Heat transfer of ashes depending on the velocity of screw

Finished this step, just fault the water analysis. For that they will be used two formula which are different just for considering the friction factor or not. Establishing a number of Prandlt = 0,5 and two different Reynolds number 10000 and 25000, inside the interval let it, it will be obtained two different behaviour. Both analyses are created according to a difference of temperature so that the water's viscosity varies with it.

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$$N_u = \frac{\frac{\xi}{8} * R_e * P_r}{1{,}07 + 12{,}7\sqrt{\frac{\xi}{8}}\left(P_r^{2/3} - 1\right)} \qquad 10^4 \leq R_e \leq 10^6 \qquad 0{,}5 \leq P_r \leq 200 \quad (15)$$

$$N_u = 0{,}0059 * R_e^{0{,}9238} * P_r^{0{,}4} \qquad 2{,}5x10^3 \leq R_e \leq 2{,}5x10^4 \tag{16}$$

$$\xi = (1{,}82 * \log R_e - 1{,}64)^{-2} \tag{17}$$

Temp (ºC)	Formula 15		Formula 16	
	α_{case}	α_{shaft}	α_{case}	α_{shaft}
20	137,27	2882,74	442,04	9282,94
30	141,63	2974,18	456,07	9577,39
40	145,52	3055,99	468,61	9840,85
50	148,50	3118,56	478,21	10042,3
60	151,02	3171,50	486,32	10212,78
70	153,09	3214,81	492,96	10352,26
80	154,46	3243,69	497,39	10445,25
90	155,84	3272,56	501,82	10538,2

Table 12: Water heat transfer coefficient for Reynolds number = 10000

Temp (ºC)	Formula 15		Formula 16	
	α_{case}	α_{shaft}	α_{case}	α_{shaft}
20	216,64	4549,39	3709,08	77890,70
30	223,51	4693,70	3826,73	80361,35
40	229,66	4822,81	3932,00	82571,94
50	234,36	4921,55	4012,49	84262,39
60	238,34	5005,09	4080,61	85692,77
70	241,59	5073,45	4136,34	86863,08
80	243,76	5119,02	4173,49	87643,29
90	245,93	5164,59	4210,64	88423,50

Table 13: Water heat transfer coefficient for Reynolds number = 25000

Evaluating Table 12 and Table 13 for a range of temperature between 20-90ºC it can be obtained some conclusions. Using Formula 16, no taking care of friction factor, it shows instability according to the heat transfer, a small variation in Reynolds number increases really fast the heat transfer with this model, so the most proper equation will be Formula 15 which shows stability.

7. MATHEMATICAL MODEL

To continue with the analysis, it must be calculated the total heat transfer coefficient and for that it will be considered the water, ash and steel coefficient following the Formula 18 and Formula 19. This coefficient will be varied depending on the temperature, due to each time the value will be different.

$$\alpha_{a-s}^{-1} = \alpha_a^{-1} + \alpha_s^{-1} + \alpha_{ws}^{-1} \tag{18}$$

$$\alpha_{a-c}^{-1} = \alpha_a^{-1} + \alpha_s^{-1} + \alpha_{wc}^{-1} \tag{19}$$

Having this value, it is possible to study the heat transference occurred during the process and with this study will be created a model to achieve the knowledge of ashes behaviour. It consists in analyse two heat transference, one going to the water which is in outer layer, and the other one going to the centre.

$$Q_s(x) = \alpha_{a-s}(x) * dx * O_s * \big(t_a(x) - t_s(x)\big) \tag{20}$$

$$Q_c(x) = \alpha_{a-c}(x) * dx * O_c * \big(t_a(x) - t_s(x)\big) \tag{21}$$

All of them will have the difference the temperature between ashes which is touching its surface and water temperature. To create a model, it is necessary to analyse each distance of the screw so that, it will be taken each x+dx and analysed. For finally integrate all of them.

$$t_a(x + dx) = t_a(x) - \frac{\big(Q_c(x) + Q_s(x)\big)}{q_{va} * \rho_a * c_{pa}} \tag{22}$$

$$t_{ws}(x + dx) = t_{ws}(x) + \frac{Q_s(x)}{q_{vs} * \rho_{ws} * c_{ws}} \tag{23}$$

$$t_{wc}(x + dx) = t_{ws}(x) + \frac{Q_c(x)}{q_{vc} * \rho_{wc} * c_{wc}} \tag{24}$$

In case of the ashes temperature, Formula 22, the heat transferred to the water has to be subtracted due to it is losing temperature. And completely the opposite for the water, which is obtaining thermal energy.

Arrived to this point it is important to say that from Table 2 has been created the model, and for check if it is valid, another test was done which values are showed in next four tables.

Velocity of Screw (%)	Temp Ash EXP (ºC)	Temp Ash MODEL (ºC)	Error (%)
20	109,66	110,35	0,62
40	107,85	107,52	0,31
60	115,67	116,05	0,33
80	124,25	124,23	0,02

Table 14: Test and comparison Model vs Test, Ashes temperature

Velocity of Screw (%)	Temp Shaft EXP (ºC)	Temp Shaft Model (ºC)	Error (%)
20	47,34	48,21	1,83
40	51,68	52,26	1,13
60	55,2	53,76	2,6
80	58,98	54,76	7,16

Velocity of Screw (%)	Temp Case EXP (ºC)	Temp Case Model (ºC)	Error (%)
20	52,42	52,15	0,52
40	58,64	58,68	0,06
60	64,2	66,02	2,84
80	69,25	73,89	6,7

Table 16: Test and comparison Model vs Test, Case temperatures

Velocity of Screw (%)	Qtotal EXP (kW)	Qtotal MODEL (kW)	Error (%)
20	207,2	208,04	0,4
40	260,98	261,4	0,16
60	305,42	304,92	0,16
80	345,01	345,09	0,03

Table 17: Test and comparisong Model vs Test, Total Heat transfered

Once the mathematical model was obtained and the new test was done, plotting the previous four tables, it can be shown the behaviours and at the same time, the error between model and test which are really small and for this reason, it can be said that they show a similar imitation of its behaviour.

Watching Figure 12, Figure 13, Figure 14 and Figure 15, all of them show how the ashes temperature decreases in a exponential way, and both water temperature increase at the same time.
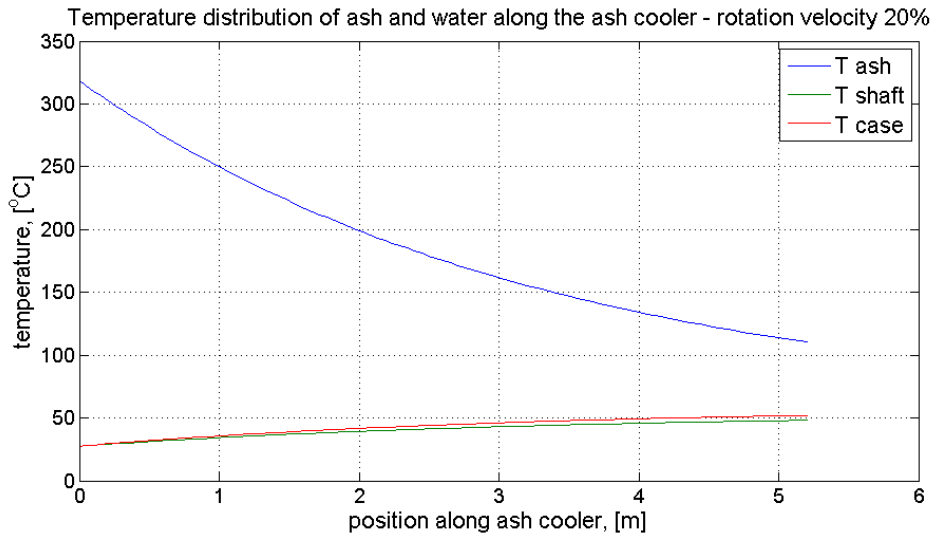
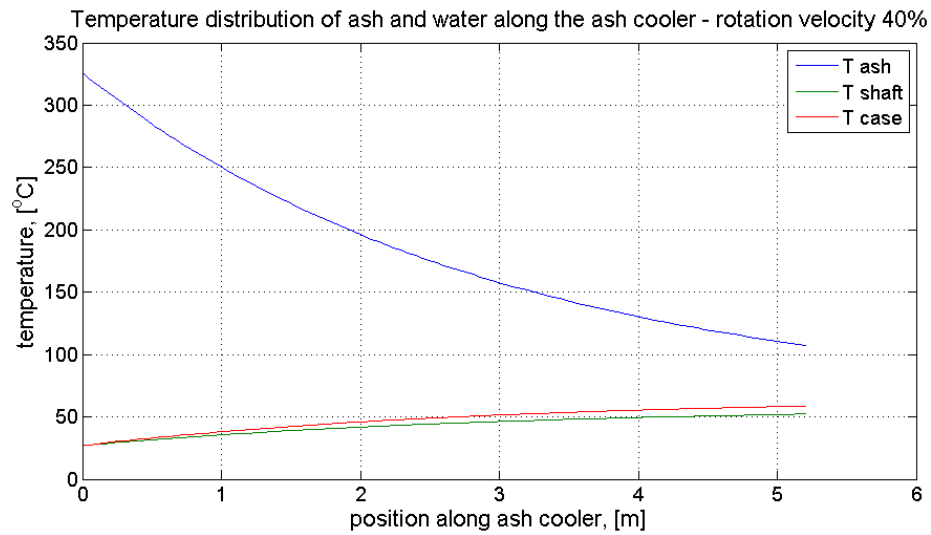*Figure 12: Temperature distribution of ash along the cooler at 20% of rotation velocity*

Figure 13: Temperature distribution of ash along the cooler at 40% of rotation velocity
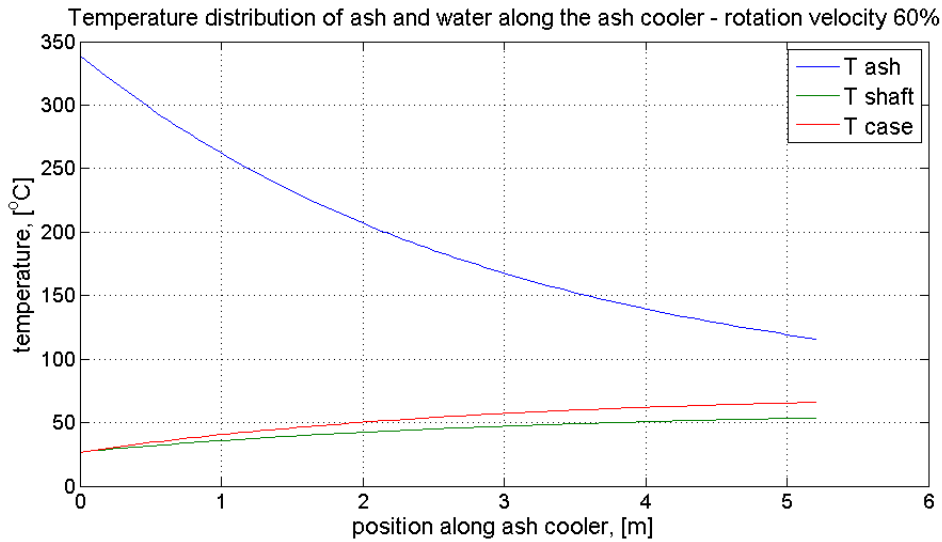
Figure 14: Temperature distribution of ash along the cooler at 60% of rotation velocity
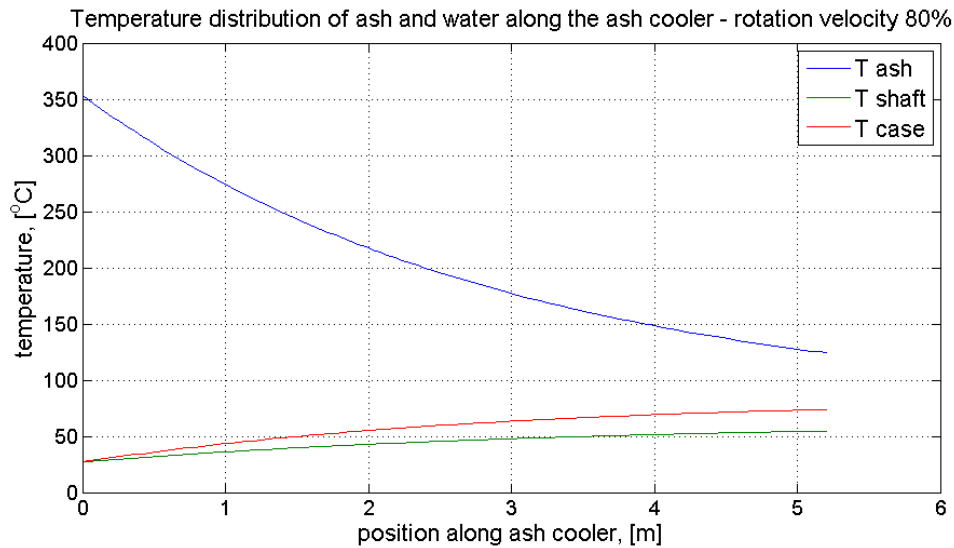

Figure 15: Temperature distribution of ash along the cooler at 80% of rotation velocity

8. CONCLUSIONS

The best way to prepare a mathematical model is analyse each parameter which is included in the desired process. In this case, first of all was calculated the ashes flow because of the difficulty to do it experimental due to there are some factors such as the gravity and the variation between one hole and another hole in the same bottom chamber.

After that, was studied every variation depending on the velocity of the screw and with that it can be achieved the behaviour touching full water or not.

Of course, there is always doubts of some parameters when temperature is changed as it was seen, ashes and water contain a variable thermal conductivity and because of that the heat transfer coefficient also changed.

According to all the values studied, finally the mathematical model achieves the values which are required to achieved. The low difference between experimental and model will let us knowing how the device is working and if in any moment is desired to study or make any change in the process, which affects the temperature of ashes, it can be analysed previously in every pc or laptop.

This sort of models helps the companies to save time, that is equal to money in every company, and resolve future doubts about how the process will work.

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