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Performance analysis of two industrial dryers (cross flow and rotary) for ligno-cellulosic biomass desiccation

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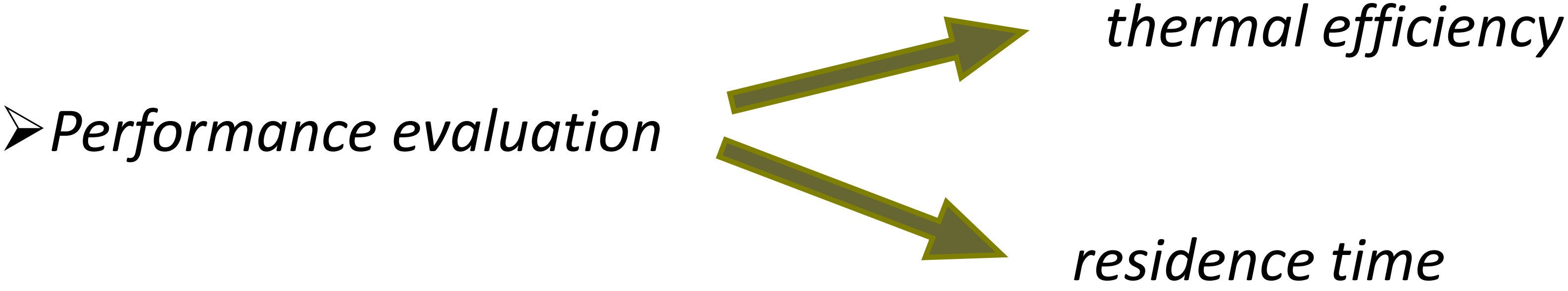
International Conference on Renewable Energies and Power Quality (ICREPQ'12)

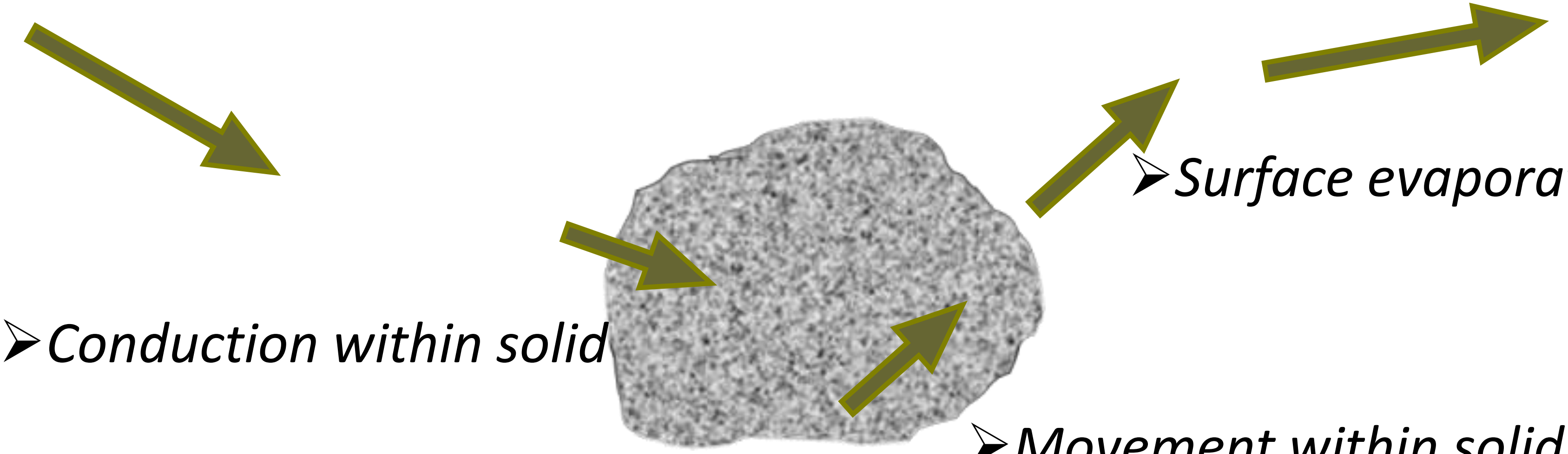
***Objectives*:**

Development and evaluation of analytical methods for the optimization of drying processes of ligno-cellulosic biomass.



- *Performance evaluation*
  - *thermal efficiency*
  - *residence time*
- *Sensitivity analysis*

The drying process



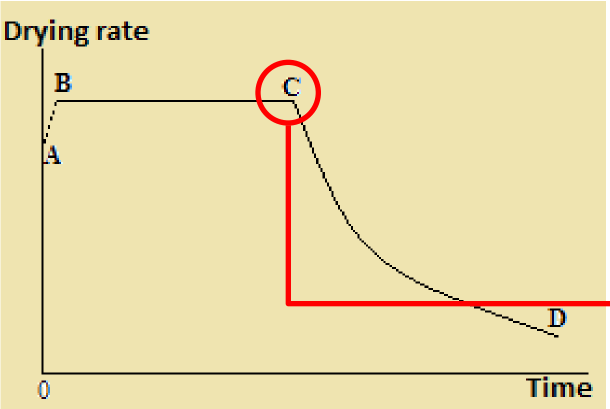
HEAT TRANSFER:

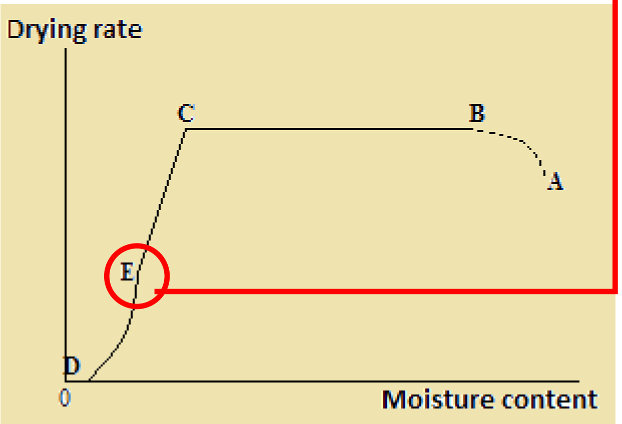
- *Convection or conduction*
- *Conduction within solid*

MASS TRANSFER:

- *Transport*
- *Surface evaporation*
- *Movement within solid*

The drying rate





AB ↦ WARM-UP PERIOD

BC ↦ CONSTANT-RATE PERIOD

CD ↦ FALLING-RATE PERIOD

→ *critical moisture content*

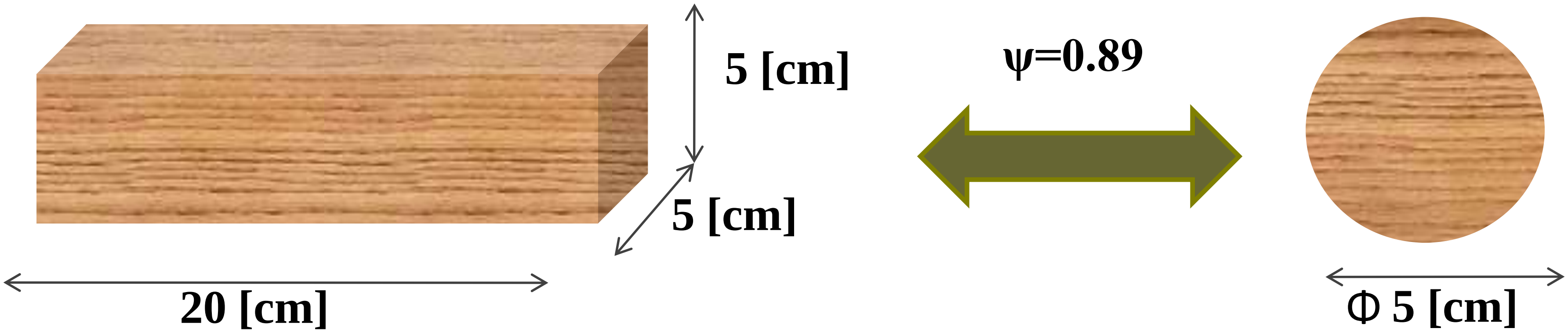
→ *equilibrium moisture content*

- In the constant-rate period ($X_c<X\le X_1$):

$$w_{DI} = k_Y \times [Y_r(t_m,X)-Y]$$

- In the falling-rate period ($X_r\le X\le X_c$):

$$w_D = w_{DI} \times [(X-X_r)/(X_C-X_r)]^n$$



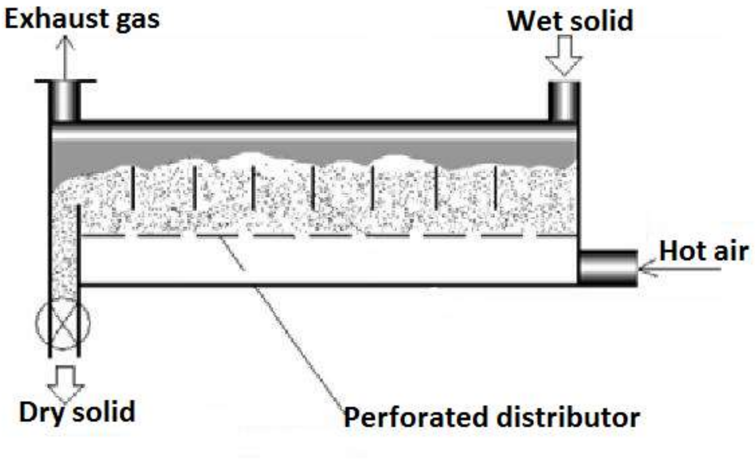
Data of oak wood chips (initial moisture content of 50%)	
Specific heat	4.53 [kJ/(kg×°C)]
Density	850 [kg/m^3]
Critical moisture content	0.4 [kg/kg]

Material porosity:

$$\varepsilon = 1 - \frac{\rho_p}{1530}$$

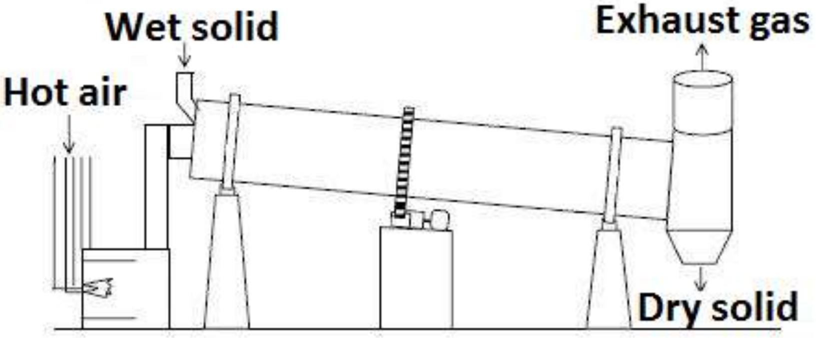
Data of fir wood chips (initial moisture content of 50%)	
Specific heat	4.968 [kJ/(kg×°C)]
Density	450 [kg/m^3]
Critical moisture content	0.31 [kg/kg]

Cross flow dryer



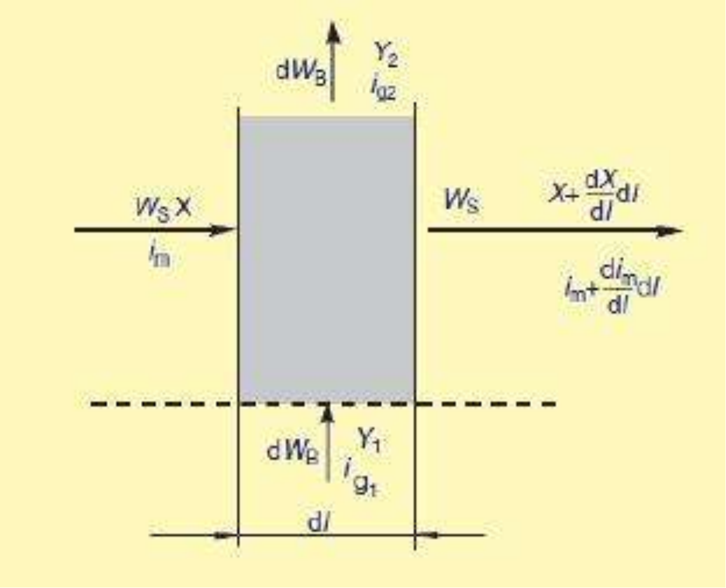
Co-current cross-flow dryer

Rotary dryer



Co-current rotary dryer without flights

The starting model



CROSS-FLOW DISTRIBUTED PARAMETER MODEL

The key parameters calculated with the original model were:

- ***the saturation vapour pressure and the latent heat of vaporization;***
- ***the relative humidity of the gas-liquid-solid system;***
- ***the equilibrium moisture content of the solid.***

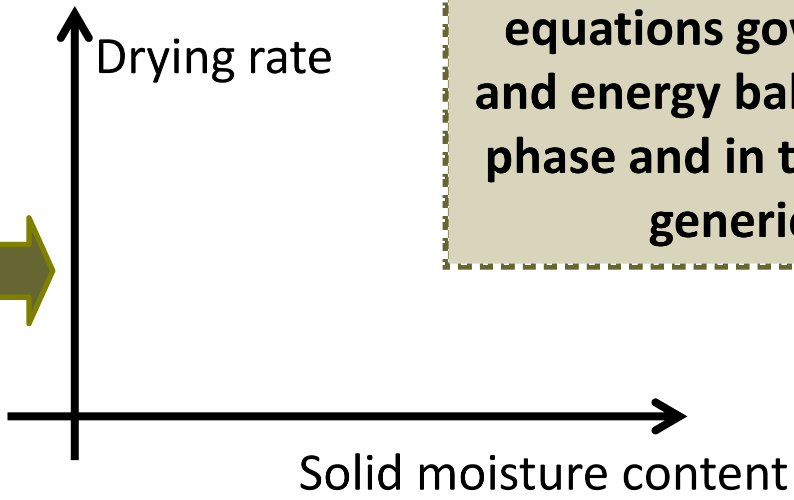
The new model

Assumptions

- *the inert gas is insoluble in the liquid phase;*
- *the gas behaves as an ideal gas;*
- *the liquid phase is incompressible;*
- *components do not react chemically.*

Once the flow rate, temperature and humidity for the inlet gas and for the wet solid were fixed and the dimensional characteristics of the dryer were defined, it has been developed a new model, implementing the equations governing the mass and energy balances in the solid phase and in the gas phase, in a generic element.

Software Mathcad®



Some of the improvements introduced in the new model:

With the developed model it is possible:

- *to achieve the graphs relating to the performance of humidity and temperature of the solid and gas according to the length of the dryer*
- *to determine the residence time of the solid*
- *to calculate the thermal efficiency, and in the case of the rotary dryer also the speed of rotation of the dryer.*

Wet biomass data:

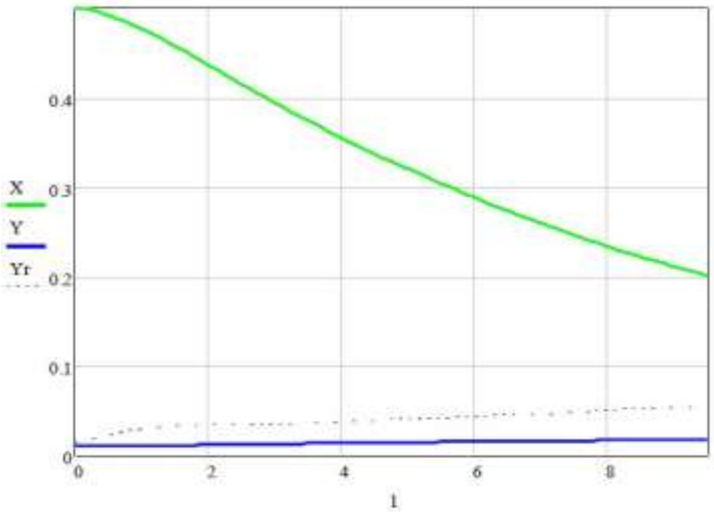
Wet material flow rate = 250 [kg/h]

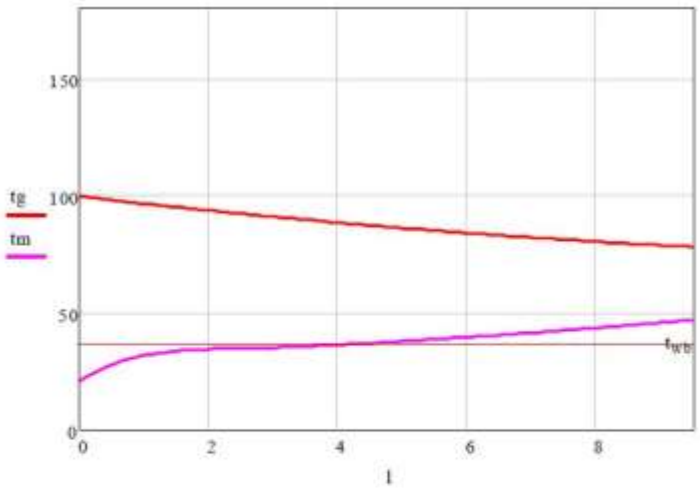
Initial moisture content = 0.5 [kg/kg]

Residual moisture content = 0.2 [kg/kg]

CROSS FLOW

Case I:





Input data:	
material	oak wood chips
gas flow rate	4 [kg/s]
gas temperature	130 °C
solid residual moisture content	0.2 [kg/kg]

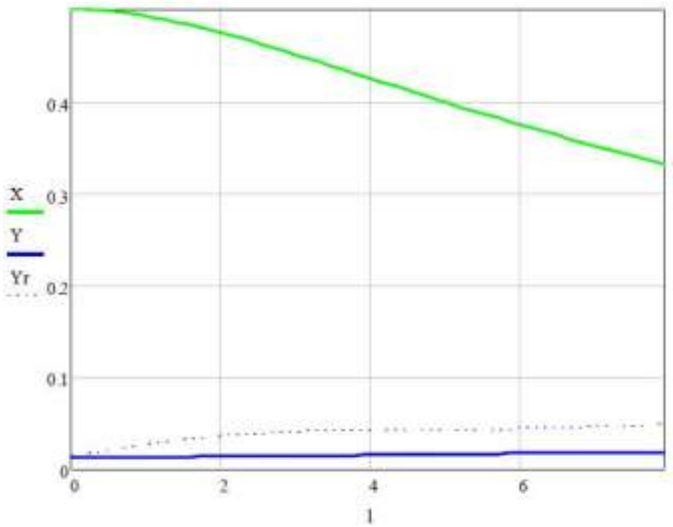
Output data:	
Solid temperature	46.524 °C
gas temperature	77.649 °C
Residence time	2.41 [min]
thermal efficiency	0.5
dryer length	9,52 [m]

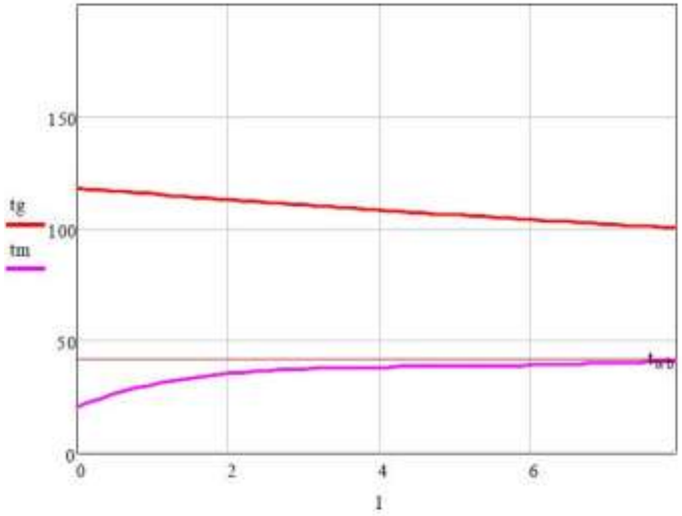
Dryer thermal efficiency:

$$\eta_T = \frac{t_{g1}-t_{g2}}{t_{g1}-t_{amb}}$$

ROTARY

Case I:





Input data:	
material	oak wood chips
gas flow rate	3[kg/s]
gas temperature	165 °C
solid residual moisture content	0.2 [kg/kg]

Output data:	
solid temperature	50.084 °C
gas temperature	88.086 °C
residence time	25.68 [min]
thermal efficiency	0.55
dryer length	7,92 [m]

Dryer thermal efficiency:

$$\eta_T = \frac{t_{g1}-t_{g2}}{t_{g1}-t_{amb}}$$

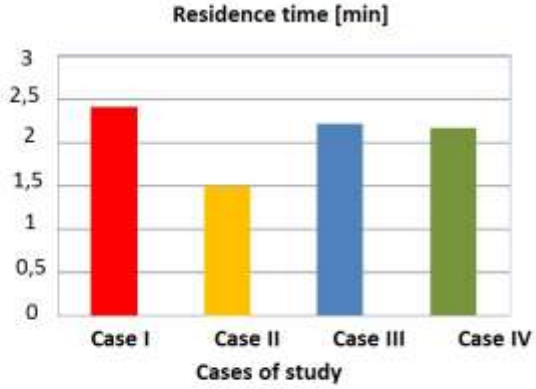
Case I: *oak wood chips*

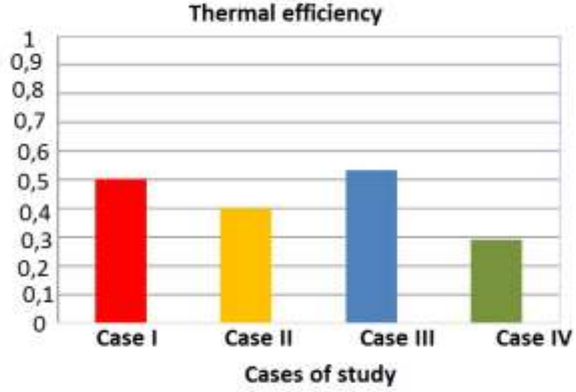
Case II: *fir wood chips*

Case III: *increase of the drying gas inlet temperature*

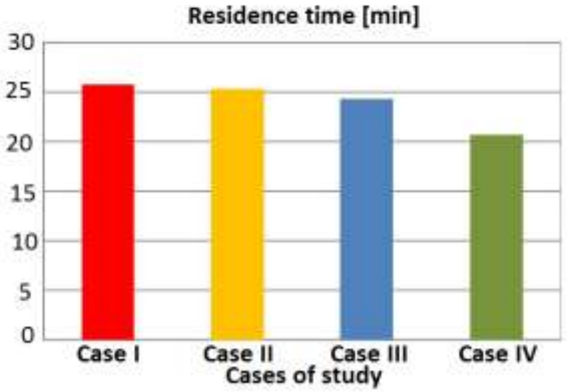
Case IV: *increase of the drying gas flow rate*

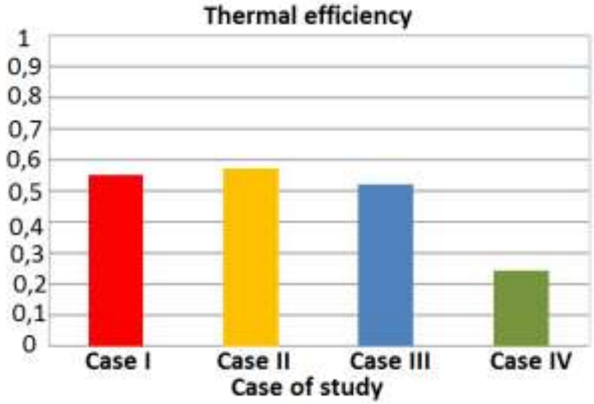
Cross flow Dryer





Rotary Dryer





Conclusions

The model responds to :

- *variations of temperature and flow rate of the drying gas;*
- *different types of chips used to feed the dryer;*
- *different values of critical and equilibrium moisture content, that characterize the various types of wood.*

In addition to these parameters, the amount of moisture to be removed and the geometrical characteristics of the dryer, particularly the length of the device, affect the residence time of the wet material inside the dryer.

Based on the results and the type of chosen biomass, the best performance are those of the cross-flow dryer, especially with reference to time of drying. The best thermal performance was found, instead, in the rotary dryer, with a worse drying time.

Thanks for your attention