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Research of Woody Biomass Drying Process in Pellet Production

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Abstract **– This paper presents results of experimental research on wood chips and sawdust drying in a rotary dryer. Empirical models for the assessment of two dependent parameters of the drying process were created based on the results of experimental data.**

The mathematical description of the relationship between the independent variable – reduced sawdust moisture content – and dependent variable – specific fuel consumption – is represented by a linear equation.

Keywords **– drying process, wood chips, flue gas, moisture content, rotary dryer, temperature**

I. Introduction

Development and use of clean and renewable energy sources is fundamental towards reducing fossil fuel dependence and negative impact on the environment.

Wood pellets are an example of a clean renewable energy source and are considered as one of the fossil fuel substitutes [1]. Mixed biomass pellets have proven to be a more sustainable source of energy in international markets and with the appropriate support, these fuels have much potential in the future. The use of biomass pellets creates new market opportunities in the agricultural sector, reduces dependence on fossil fuels and cuts greenhouse gas emissions associated with their use [2].

Techno-economical analysis is always the starting point of a wood pellet production unit. Additional suggestions related to optimal plant localization and to the best use of the woody pellets as substitute of fossil fuels for heating, cooling and power generation purposes present alternatives with a positive impact of the whole action on the quality of the environment and on the recovery of soil fertility [3].

The moisture content of raw biomass is usually 30-60%. The material needs to be dried to circa 10-15% moisture content since dry biomass provides considerable benefits for combustion, such as improved operational parameters of the boiler and increased energy efficiency as well as reduced flue gas emissions, compared to fuels with high moisture. However, drying is an energy-intensive process.

From another point of view, drying is a major and challenging step in the pre-treatment of biomass for production of second generation synfuels for transport. Fagernäs et al. [4] define a concept for biomass pre-treatment in two different cases:

- a large-scale wood-based gasification synfuel production with a pneumatic conveying steam dryer;
- a small-scale pyrolysis process based on wood chips and miscanthus bundles with flue gas as a drying medium in a direct or indirect rotary dryer.

Dryers operate on the principle of simultaneous heat and mass transfer where water is removed from the product. A variety of biomass drying equipment is available on the market [5]. The most common biomass dryers applied in bio-energy plants are direct rotary dryers, but the use of steam drying technology is increasing [4].

Construction parameters and performance of the dryer are important factors affecting end-product quality, consumption of energy resources, and environmental and economic costs. Another important aspect to consider is the raw material of wood pellets. E.g., the use of sawmill residues for wood pellet production can be seen both as an environmental solution and as an extra economic benefit. The latter can be determined based on the production costs of wood pellets and energy consumption under different framework conditions [1].

The quality and properties of wood pellets depend on drying technology that is chosen for particular application. The most common biomass dryers use the principle of convection. Advantages and disadvantages of different drying technologies are evaluated based on such parameters as the drying medium, temperature and residence time. Selection of parameters depends on requirements of end-user equipment (boiler, oven or other) [6]. Hanning et al. [7] have calculated a 3–4 years payback time on the initial investment for two types of drying technologies of 40 MW power plants: utilization of flue gases and application of superheated steam.

Several authors discuss the effect of drying technology on pellet quality. For example, Ståhl et al. [6] evaluated the impact of two parameters – the moisture content and the emissions of volatile hydrocarbons – on the quality properties of wood pellets. Authors concluded that the level of volatile hydrocarbon emissions after drying depends on the residence time of sawdust in the dryer: drying technologies with longer residence time resulted in larger emissions of terpenes. Furthermore drying techniques can also affect the environment. Low emissions of volatile hydrocarbons would improve the energy content of the sawdust, and by decreasing air pollution improve the work environment and the environment in the surroundings of the dryers [6].

II. Modeling of Drying Process

Tasks of modelling of drying processes are several: to find optimal parameters of drying process, to keep high quality of product and to reach minimum consumption of energy resources.

Specific fuel consumption in this case is selected as energy efficiency indicator (Eq. 1) which depends on fuel consumption and the product produced.

$$b = \frac{B}{M_{2prod}} \quad (1)$$

where
b – specific fuel consumption, kg/t_{prod};
M_{2prod} – amount of dried material for the production of pellets, kg/h;
B – fuel consumption, kg/h.

Fuel consumption or the necessary amount of dried material for the operation of the furnace required for the drying process is calculated as follows:

$$B = \frac{Q_d}{LHV \cdot \eta_f} \quad (2)$$

where
LHV– lower heating value of fuel, MWh/t;
Q_d – heat capacity required for drying, MW;
η_f – furnace efficiency coefficient.

The given values for the calculation of the drying process are usually the amount of material, its moisture content at the inlet and outlet, temperatures and inlet parameters of the drying agent. Other group of parameters is following: the values of dried moisture content, weight change of the material during the drying process, drying agent consumption and heat consumption. These values can be obtained from the material and heat balance of drying process. The average drying agent parameter values are used for the calculation of the dryer.

First the amount of dried material is calculated using (3).

$$M_2 = M_{2prod} + B \quad (3)$$

where
M_2 – total quantity of dried material after the dryer, kg/h.

Further dried moisture is determined using following equation:

$$W = M_2 \frac{W_1 - W_2}{100 - W_1} = M_1 \frac{W_1 - W_2}{100 - W_2} \quad (4)$$

where
W – dried moisture, kg water;
W_1 – average moisture content of wood chips before the dryer, %;
W_2 – average moisture content of wood chips after the dryer, %;
M_1 – total amount of wet wood chips before the dryer, kg/h.

Knowing the amount of dried moisture, the amount of dry material after the dryer and moisture content of wood chips, the amount of wet wood chips before the dryer can be calculated using (5).

$$M_1 = \frac{W}{W_1 - W_2}(100 - W_2) \quad (5)$$

Consumption of drying agent is calculated following:

$$L = \frac{1000W}{d_2 - d_1} \quad (6)$$

where
L – consumption of drying agent, kg/h;
d_1 – moisture content of drying agent before the dryer, g/kg dry gas;
d_2 – moisture content of drying agent after the dryer, g/kg dry gas

The consumption of the drying agent is usually attributed to 1 kg of moisture excreted in drying process, according to (7).

$$l = \frac{L}{W} = \frac{1000}{d_2 - d_1} \quad (7)$$

where
l – specific consumption of drying agent, kg dry gas/kg water.

Heat consumption is determined using the heat balance of the dryer. Heat consumption is attributed to 1 kg of water. Dryer heat consumption q consists of heat q_k, which is supplied from the furnace, because there are no additional heaters in the dryer (Eq.8).

$$q = q_f \quad (8)$$

where
q – dryer heat consumption, kJ/kg water;
q_f – heat supplied from the furnace, kJ/kg water.

Heat supplied from the furnace is calculated as follows [1]:

$$q_f = l(H_1 - H_0) \quad (9)$$

where
H_1 – enthalpy of drying agent before the dryer, kJ/kg dry gas;
H_0 – enthalpy of drying agent before the furnace inflow, kJ/kg dry gas.

Dryer heat consumption and heat that will be supplied from the furnace can be calculated using the equation:

$$q = q_f = l(H_2 - H_0) + q_l \quad (10)$$

where

H_2 – enthalpy of drying agent in the outflow of the dryer, kJ/kg drygas;
q_l – heat loss from the dryer surface, kJ/kg water.

Heat consumption for heating the material and the amount of heat input with material moisture are not significant and compensate each other.

Heat loss from the dryer surface is calculated using (11).

$$q_l = \frac{Q_S}{W} \tag{11}$$

where
Q_S – heat loss capacity from dryer surface, W or kJ/h.

Dryer efficiency (the useful heat) is calculated following:

$$\eta_d = 1 - \frac{q_l}{q} \tag{12}$$

where
η_d – dryer efficiency coefficient.

Enthalpy of drying agent after the dryer cannot be determined with the help of H-d diagram, therefore (13) is used to calculate it.

$$H_2 = l(q_f - q_l) + H_0 \tag{13}$$

Enthalpy of drying agent after the dryer for each separate measurement is determined using the following equation:

$$H_{2n} = H_{1n}\eta_d \tag{14}$$

where
H_{2n} – enthalpy of drying agent after the dryer for an individual measurement, kJ/kg dry gas;
H_{1n} – enthalpy of drying agent before the dryer for an individual measurement, kJ/kg dry gas.

Knowing the drying agent parameters, internal heat balance of the dryer can be calculated:

$$\Delta = l(H_2 - H_1) \tag{15}$$

where
Δ – internal heat balance of the dryer.

Internal heat balance of the dryer determines the relationship between additional heat input and heat loss. There are three possible scenarios for a real dryer:

- If $\Delta = 0$, additional heat input in the dryer covers all heat loss. Drying takes place at a constant drying agent enthalpy, that is, $H_1 = H_2 = const$
- If $\Delta > 0$, additional heat not only covers all heat loss from dryer, but also increases the enthalpy of drying agent. That is $H_2 > H_1$
- If $\Delta < 0$, additional heat does not cover all heat loss from dryer (or there is no additional heat input) and the enthalpy of drying process decreases, $H_2 < H_1$.

By multiplying the moisture exerted in the dryer with the heat consumption of the dryer we obtain heat capacity necessary for the drying process.

$$Q_d = W \cdot q \tag{16}$$

where
Q_d – heat capacity necessary for the drying process, MW.

III. Data Processing and Result Assessment Model

An experiment was carried out in industrial conditions with a rotary dryer of sawdust and a wood chips furnace for generation of flue gases used as drying agent.

The model of data processing and result assessment includes experimentally measured data and an evaluation module that allows identifying potential solutions for operational improvements in the dryer. The algorithm of the model is presented in Figure 1.

Experimental data included measurements of the following parameters: outdoor temperature, inlet and outlet temperatures of gases, moisture content of raw material (wood chips and sawdust) and the product (wood pellets) at the inlet and outlet, capacity of dryer, and fuel consumption.

Calculations were carried out by applying equations describing the drying process presented in the chapter above. Statistical processing of data was performed to find analytical and graphical correlations between the variables. The relationship between independent and dependent variables was characterized by a regression model.

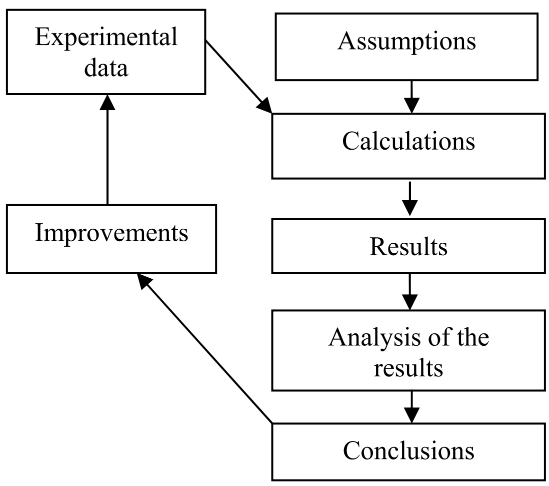

Fig. 1. The model of data processing and result evaluation

Two types of models were used for data processing: a single factor linear model and a multifactor linear model. Mathematical methods of statistics (correlation and regression analysis) were extensively used to acquire these correlations. Statistical data processing was performed in a specific order characterized below [8, 9]:

- Determination of the regression equation for the phenomena at issue. For this purpose, the most commonly used is the method of least squares;
- Statistical analysis of the resulting regression coefficient to assess its significance in the equation. This part of analysis is carried out with help of regression analysis, and;
- Identification of the independent and dependent variables of casual interaction (stochastic connections) closeness (correlation).

On the basis of empirical models, an evaluation of obtained data was done and relation between parameters was found. Results of the experiment presented necessity to improve process parameters of the drying technology. Therefore a repeated industrial experiment was carried out.

IV. Results

In this case regression equations corresponding to empirical correlation extraction and verification methodology were used. Based on the results, conclusions about the performance of equipment and necessary improvements to optimize designed performance were drawn. A few ideas are presented further.

The quality of pellets is affected by various parameters of the drying process. Results of the research present a linear dependence of pellet moisture content from flue gas saturation with water vapour (see Figure 2).

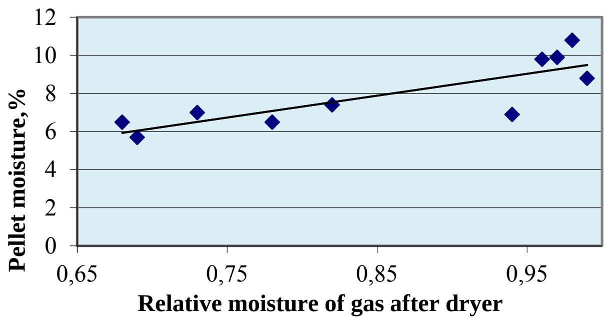

Fig. 2. Effect of flue gas saturation with water vapour on moisture content of pellets

Figure 2 shows good correlation between data presenting moisture content of pellets and relative moisture of gas after the dryer (R^2=0.7). Relation between both parameters indicates that lower level of flue gas moisture results in lower moisture content of pellets. Interconnection between the independent variable (gas saturation) and dependent variable (moisture content of pellets) is mathematically described by equation:

$$W_{pel} = 11.47\varphi_2 - 1.873 \tag{17}$$

where

W_{pel} – pellet moisture content, %;

φ_2 – relative moisture of gas after dryer.

Energy efficiency of the drying process depends from the moisture content of raw material and parameters of the drying process: inlet and outlet temperatures, quality and efficiency of combustion process and other factors.

Energy efficiency analysis of the drying process indicates changes in specific energy consumption. This energy efficiency indicator allows using a dependent variable – heat required to evaporate one percent of moisture from sawdust. The difference between initial and final moisture content of sawdust is selected as the independent variable in this case.

Data in Figure 3 show acceptable correlation between specific heat energy consumption per each percent of reduced sawdust moisture and the range of reduced sawdust moisture content in percents (R^2= 0.44). The results indicate that moisture content of pellets can be reduced at a higher level with minimal specific heat consumption. The mathematical description of interconnection between the independent variable – reduced sawdust moisture content – and dependent variable – specific heat consumption per unit of reduced moisture in raw material – is presented by the equation:

$$q_{hc} = 2.503 - 0.038\, dW_{sdust} \tag{17}$$

where

dW_{sdust} – reduced sawdust moisture content, %;

q_{hc} – heat energy consumption per each percent of reduced pellet moisture content, kJ/%.

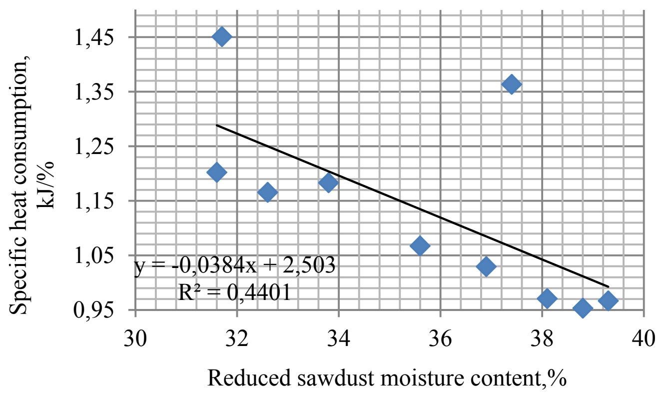

Fig. 3. Specific heat energy consumption depending on reduced sawdust moisture content

V. Discussions

Results of the experimental research allow proposing a number of substantial improvements in the drying processes and technologies related to improved energy efficiency by using waste products for pellet production and dryer material in combustion process. It allows obtaining less moist end-product due to reduced relative moisture content of flue gases.

Energy efficiency analysis of the drying process, presented in Figure 3, allows proposing for operational changes in process parameters to reach higher reduction of moisture in raw material at inlet and outlet of the dryer with minimal specific heat consumption.

The third proposal for improvements is related to reduction of moisture content in flue gases. This can be realized by condensing the vapour contained in flue gases after the dryer before the stack. The resulting heat energy can be used in the drying process. An additional advantage is the increased quality of pellets due to partial return of dry flue gases to the dryer.

VI. Conclusions

1. Research on the woody biomass drying process has allowed finding dependence of qualitative parameters and energy efficiency indicators of the drying process from independent variables – parameters of processes.
2. Relation between two important drying process parameters shows that lower moisture content of pellets can be reached at minimal level of flue gas moisture. A mathematical description of interconnection between the independent variable – gas saturation – and dependent variable – pellet moisture content – presents a linear equation.
3. Dependence of energy efficiency on reduced moisture content of sawdust proves that higher level of moisture reduction in raw material can be reached at minimal specific heat consumption. The mathematical description of interconnection between the independent variable – reduced sawdust moisture content – and dependent variable – specific fuel consumption – presents a linear equation.

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