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THE EVALUATION OF USEFULNESS OF ENERGETIC EFFICIENCY INDEXES OF DRYING SYSTEMS

Keywords

Drying system, energetic efficiency, energy efficiency indexes.

Abstract

The possible application of energy efficiency indexes is presented in the paper. Due to various drying conditions and various process variables the indexes' values cannot be quantified in fixed values. The method of defining critical index values is presented. The drying system can be evaluated as useful or useless in the given conditions. The energetic efficiency indexes are used in an expert system in order to evaluate and compare convective tower dryers. Various drier producers present different drying indexes. Due to a large variety of driers' quality coefficients, customers cannot compare different driers. The expert system can calculate the drying indexes based on the available data. The user of the expert system is informed which quality class the drier belongs to. If a few driers are evaluated, the expert system additionally ranges them.

Introduction

Newly designed and existing drying systems can be evaluated. The typical examples are the prototypes, specimen of pre-production batches, inspection lots of mass production and modernized installations. The user expects unequivocal information regarding the drying system's usefulness. The drying system's multicomponent evaluation could be carried out by an expert system with the values of efficiency indexes, which are calculated by process variables and previously formalized and implemented knowledge. The drying system, in the classification task, could be ascribed to one of two categories: useful or useless. The state of being a member of each class implies technological and economical evaluation. The schematic diagram of the expert system is presented in Fig. 1. According to the evaluation procedure it is necessary to maintain the following steps:

- making assumptions,
- identification of the drying system's configuration,
- determining the values of process variables in typical points of drying installation:
  - simulating the drying process in the identified drying configuration,
  - using data derived from exploitation tests,
- calculating the technology, energy and economy efficiency indexes,
- evaluation of energy and technology efficiency,
- evaluation of economic efficiency,
- estimating the usefulness of the evaluated system.

In order to evaluate the drying system in a complex way, it is necessary to know its technological and economical parameters. The purpose of this research was to evaluate the thermal energy efficiency of the drying system. The essential technological parameters, indispensable to reckon energy efficiency indexes are as follows:

- drying system configuration:
  - the size and furnishing of the drying column;
  - the type of the furnace and its capacity and thermal efficiency;
  - the air supplying and recirculating ducts specification and their dimensions, types, thermal insulation type and thickness, the kind of recirculation;
  - the specification of fittings, cyclones and fans.
- the values of process variables:
  - ambient air parameters: temperature, humidity, air-pressure;
  - the initial and final drying air parameters: the required temperature and humidity in the drying column inlet and in different installation points,
  - the initial and final material temperature and humidity;
  - the fuel expenditure, the values could be defined by the producer or could be determined during exploitation tests or upon heat balance calculation;
  - the electric power expenditure (installed power);
  - the weight of the installation which is heated up;
  - defined by the manufacturer drying capacity for different drying materials.

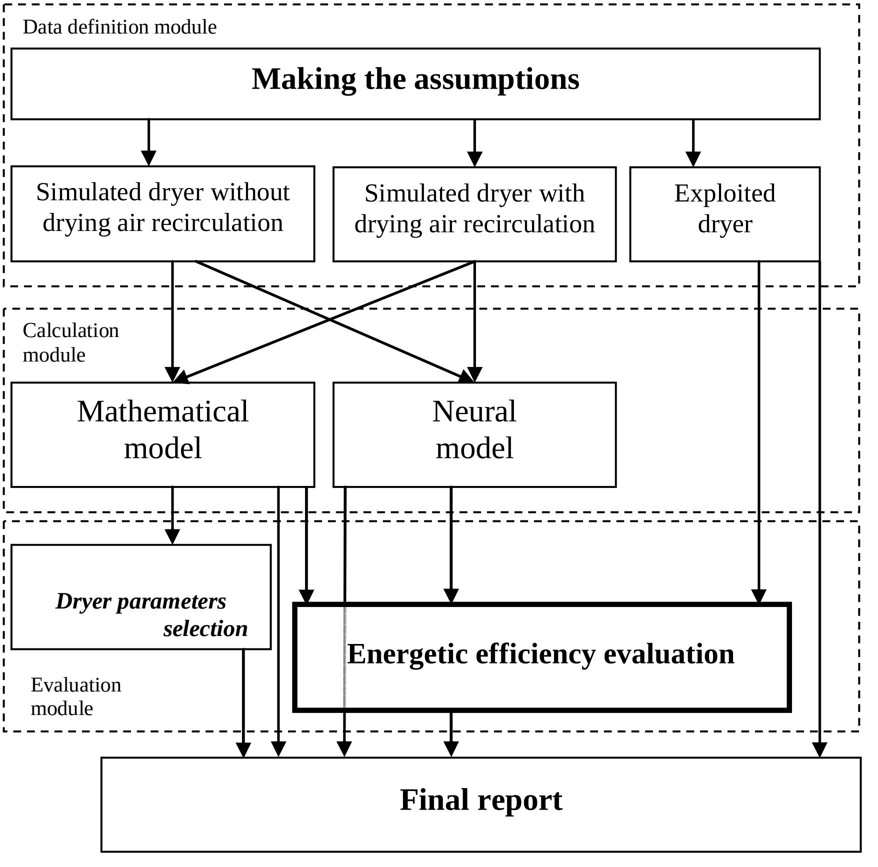

Fig. 1. The outline of the expert system on energetic efficiency evaluation of drying systems

1. Energetic efficiency indexes quantification

Energy evaluation includes heat, drying air and dried material expenditure upon the values of energetic efficiency indexes are defined [4]. Boundary values of energetic efficiency measures depend on process conditions. The unequivocal, arbitrary predetermining of energy efficiency indexes values is impossible and the boundary values must be calculated for every process according to the values of process variables. The boundary values calculation is presented using the examples of the thermal efficiency index (Eu/E') and the drying index (M"/M').

E_u/E' index describes which part of the inlet energy (E') determines the energy used for achieving water evaporation (E_u); it is the thermal efficiency of

the drying system. Denomination of boundary indexes values necessitates E_u and E' values analysis. The evaluated dryer is compared with a theoretical dryer, where material is dried to the same final humidity as in the real dryer. In the theoretical dryer, drying material is not heated up and the drying process is isenthalpic
[1, 2]. The procedure for defining the thermal efficiency of a theoretical dryer includes the following:

1. Dried material flux M' is the same as for a real dryer.
2. Initial and final dried material humidities are the same as for the real dryer.
3. Dry matter flux of dried material is calculated according to equation (1).
4. Drying air flux is the same as for the real dryer.
5. Final absolute air humidity is calculated upon equation of continuity (2).
6. Final relative air humidity is calculated according to equation (3). As an equilibrium, absolute material humidity was set up for the real, final absolute material humidity. The temperature value in equation (3) was established as the initial material temperature.
7. Final air temperature (dry thermometer temperature) was calculated (5) for final absolute air humidity x" (2), equilibrium relative humidity φ" and known barometric pressure p_z. The partial air pressure is calculated according to equation (4)
8. The final air enthalpy is calculated according to equation (6).
9. The initial air enthalpy is equal to final air enthalpy.
10. The enthalpy of ambient air blown into the dryer is calculated according to equation (6).
11. The heat flux lead in the theoretical dryer is calculated according to equation (7).
12. The heat used for evaporating the water is calculated according to equation (8-10), *a* and *b* coefficients depend on drying material.
13. Maximum thermal efficiency of the theoretical dryer is calculated according to equation (11).

The thermal efficiency of the evaluated dryer is compared with the thermal efficiency of the theoretical dryer with no heat recuperation. The boundary values of the thermal efficiency index are arbitrary (12, 13). The user could change them according to his demands, changing w_{db} and w_{dst} indexes values. The thermal efficiency index is assigned to a very good class as long as its value is higher than the value of the maximum value of thermal efficiency index of the theoretical dryer without drying air recuperation. For other thermal efficiency classes, the ranges are presented in Table 1. When a few dryers are compared, the higher thermal efficiency the better the dryer.

$$M_s = \frac{M'}{(1+u)} \tag{1}$$

$$x'' = \frac{\Delta u \cdot M_s + G_s \cdot x'}{G_s} \tag{2}$$

$$\varphi = 1 - e^{-\frac{u'' - 0,11303 + 0,01577 \cdot \ln t_m'}{0,07947}} \tag{3}$$

$$p'' = \frac{x'' \cdot p_z}{0,622 \cdot \varphi'' + x'' \cdot \varphi''} \tag{4}$$

$$t'' = \frac{235,7142 \cdot \ln p'' - 1511,635165}{23,579 - \ln p''} \tag{5}$$

$$I = G_s\ i = G_s \left[c_p\ t + \left(c_{pw} + r_0\right) x\right] = G_s \left[\left(c_p + c_{pw}\ x\right) t + r_0\ x\right] \tag{6}$$

$$\left(E'\right)_T = \left(Q_h'\right)_T = \left(I'\right)_T - I_z \tag{7}$$

$$Q_u = r_m \cdot \Delta M \tag{8}$$

$$\Delta M = M_s \left(u' - u''\right) \tag{9}$$

$$r_m = r\left(1 + a\ \exp\left(b \cdot u\right)\right) \tag{10}$$

$$\left(\frac{E_u}{E'}\right)_T = \eta_T = \frac{Q_u}{\left(Q_h'\right)_T} \tag{11}$$

$$\eta_{db} = w_{db} \cdot \eta_T \tag{12}$$

$$\eta_{dst} = w_{dst} \cdot \eta_T \tag{13}$$

Table 1. The boundary values for thermal efficiency index

The evaluation of thermal efficiency index E_u/E' (η_s)	The values of thermal efficiency index E_u/E' (η_s)
very good	$\eta_s \geq \eta_T$
good	$\eta_T > \eta_s \geq \eta_{db}$
satisfactory	$\eta_{db} > \eta_s \geq \eta_{dst}$
poor	$\eta_{dst} > \eta_s \geq 0$
useless	$\eta_s < 0$

Drying index *M”/M’* is a ratio of the inlet drying material flux to the outlet drying material flux. This index is a process of the efficiency index. The drying index values fall into the range of 1/(1+u’) to 1. The boundary values for drying index classes are calculated using equations (14-17) and presented in Table 2. Material should be dried to the humidity recommended for storing. It is possible to dry the material to equilibrium humidity (for storing conditions). Further drying is unprofitable, because the material will be humidified to equilibrium humidity anyway. When the index values are smaller than zero, the drying system is useless. The material was probably damaged by burning. Index values higher than 1 are assigned to an useless class. These values could testify material humidifying in the dryer. The values assigned to a very good class fell into the range between recommended and equilibrium humidity. When the drying index is higher than for equilibrium humidity, it is evaluated as good because even over-drying secures safe storing. The user is asked for the boundary material humidity determiners. The drying index values which fall into the range between indexes for boundary humidity and recommended humidity are evaluated as satisfactory. All drying index values less than calculated for material boundary humidity are evaluated as poor. When a few dryers are compared, the closer the drying index to the recommended humidity (in the very good class) the better the drying process (18).

$$\left(\frac{M''}{M'}\right)_c = \frac{1}{(1+u')} \tag{14}$$

$$\left(\frac{M''}{M'}\right)_r = \frac{(1+u_r)}{(1+u')} \tag{15}$$

$$\left(\frac{M''}{M'}\right)_z = \frac{(1+u_z)}{(1+u')} \tag{16}$$

$$\left(\frac{M''}{M'}\right)_g = \frac{(1+u_g)}{(1+u')} \tag{17}$$

$$\frac{\left|M''/M' - (M''/M')_z\right|}{(M''/M')_z} = \min \tag{18}$$

Table 2. The boundary values of drying index *M”/M’*

The evaluation of drying index *M”/M’*	The value of drying index *M”/M’*
very good	$(M''/M')_r \le M''/M' \le (M''/M')_z$
good	$(M''/M')_c \le M''/M' < (M''/M')_r$
satisfactory	$(M''/M')_z < M''/M' \le (M''/M')_g$
poor	$(M''/M')_g < M''/M' \le 1$
useless	$M''/M' > 1 \ \vee \ M''/M' < \frac{1}{(1+u')}$

2. The application of energetic efficiency indexes for the drying system

In order to evaluate the drying system, it is necessary to define a multidimensional space of the drying system characteristics and their values must fall into their particular ranges. The system will be evaluated as useful when the values of all considered characteristics belong to admissible ranges limited by boundary values. When the index values exceed the useful ranges, the dryer is evaluated as useless and unsatisfactory. The scope of the useful range of values was divided into four classes: very good, good, satisfactory and poor. The evaluation rate is determined by the worst index value (Fig. 2 presents the evaluation of the dryer basing on only two indexes).

There were two types of indexes identified: energetic efficiency indexes and process efficiency indexes. An example of the energetic efficiency index is thermal efficiency. An example of the process efficiency index is the drying index. The dryer is evaluated in these two categories.

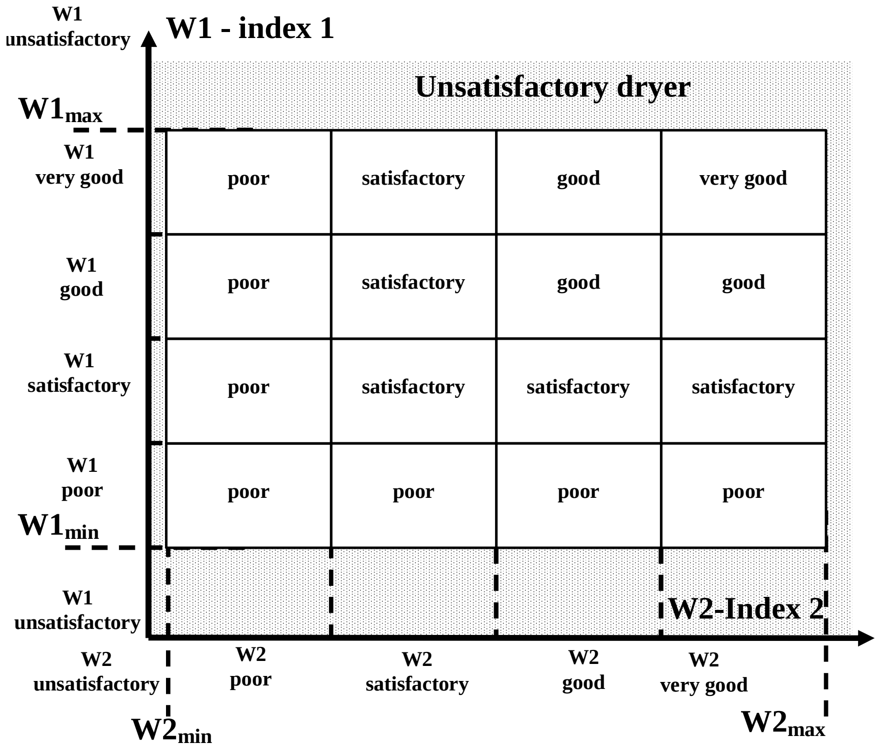

Fig. 2. Energetic efficiency evaluation of the dryer based on energy efficiency idex values

The list of symbols

Symbols

- η – thermal efficiency,
- G – drying air flux, kg/s,
- M – dried material flux, kg/s,
- Q – heat flux, J/s,
- E – energy flux, J/s,
- E_u – energy used for achieving water evaporation, J/s
- r – specific heat of evaporation, J/kg
- t – temperature, ^{O}C,
- u – absolute material humidity, kg/kg
- x – absolute air humidity, kg/kg,
- φ – relative air humidity, %

Indexes

- ‘ – inlet,
- ” – outlet,
- p – air,
- m – material
- pw – water vapour,
- s – dry matter, s
- w – water,
- z – surroundings, recommended
- 0 – in 0^{O}C,
- T – theoretical,
- c – entire,
- r – equilibrium,
- g – boundary.

Conclusions

This method of drying systems evaluation could be used for individual dryers and for comparing a few drying systems. The method was based on that presented in [3]. The energetic efficiency indexes used quotient measures calculated upon process variables [4]. The indexes' boundary values are calculated upon heat and mass balance. The admissible index values were divided into four usefulness classes. The complex dryer evaluation was based upon energy and process index values. The method was implemented with the expert system.

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Reviewer:
Andrzej BOCHAT

Ocena przydatności wskaźników oceny efektywności energetycznej systemów suszących

Słowa kluczowe

System suszący, efektywność energetyczna, wskaźniki oceny efektywności energetycznej.

Streszczenie

W pracy przedstawiono możliwości zastosowania wskaźników oceny efektywności systemów bioagrosuszących. Wartości wskaźników nie mogą być bezwzględnie skwantyfikowane, ponieważ zależą od warunków prowadzenia procesu suszenia oraz od wartości parametrów termodynamicznych mediów. Zaproponowano sposób określania dopuszczalnych wartości wskaźników, na podstawie których oceniany jest system bioagrosuszący. Wieloaspektowa ocena klasyfikuje system bioagrosuszący jako przydatny lub nieprzydatny użytkowo w danych warunkach eksploatacji. Dodatkowo urządzenia ocenione jako przydatne użytkowo klasyfikowane są do jednej z czterech zdefiniowanych klas przydatności.