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Exergic analysis of the installation for controlled dehydration of fine particulate products

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Abstract. An installation is designed for dehydration of fine-particulate bulk products in the active hydrodynamic mode. A thermal system for heat-mass transfer during rapeseed dehydration in the active hydrodynamic mode is assessed for thermodynamic efficiency. Diagrams of thermal and exergy balance for heat-mass transfer processes are presented and heat exchange and exergy analysis are performed. Exergy loss by rapeseed dehumidification are calculated. The research results show that the greatest loss of exergy occurs due to irreversibility of dehydration processes during the phase transformation, as well as due to the pressure drop in the device.

1. Introduction

In post-harvest processing, dehydration of grain and oilseeds to reach specified humidity is an important process [1,2]. Analysis of drying system designs used for post-harvest processing of seeds, which are fine-particulate bulk products, shows that they generally lack recirculation loops and are characterized by low intensity of heat-mass exchange [3,4]. For example, for rapeseed drying the following grain dryers are used: continuous flow shaft dryers, column (modular) and tower (bunker) ones. Using them, it is not possible to dehydrate seeds to a necessary level in one drying cycle. To intensify dehumidification of rapeseed, safflower, quinoa and amaranth seeds, which are colloid complexes with a capillary porous structure, it is useful to adopt constructive approaches for grain dryer construction that efficiently implement an active hydrodynamic mode [5-7].

This research aims to provide thermodynamic evaluation of grain dryer thermal system for fine-particulate bulk products with active use of a hydrodynamic mode, using rapeseed as an example.

2. Research object and methods

The object of this research is a thermal system of heat-mass exchange by controlled dehydration of rapeseed biopolymer complexes with colloidal capillary porous biomaterial structure.

As a thermal system, an original installation is used for heat and mass exchange of fine bulk products. It operates in an active hydrodynamic mode. The installation configuration with main structural elements is shown in Figure 1.



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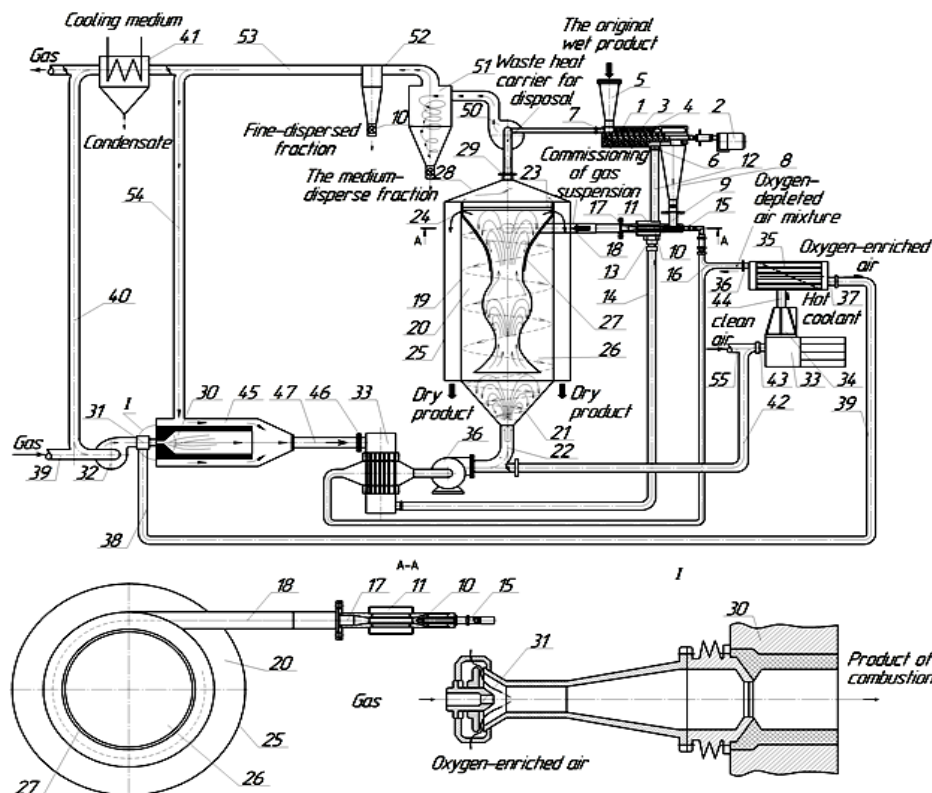


Figure 1. Installation for heat-mass exchange by fine-particulate bulk product processing: 1—a transporting screw conveyor, 2—a transporting screw conveyor drive, 3—a jacket, 4—screw winding, 5, 6, 7, 8, 9, 13, 15, 18, 21, 22, 28, 29, 36, 37, 43—branch pipes, 10—an injector, 11—an injector's heating jacket, 12, 14, 16, 38, 39, 40, 42, 44, 46, 47, 48, 49, 53, 54, 55—pipelines, 17—an output nozzle, 19—a cylindrical chamber, 20—a mass exchange device for drying in the active hydrodynamic mode, 21—a converging cone, 23—a reflector (fender), 24—an output window for waste gas suspension, 25—housing, 26—a hollow insert with alternating narrow and flared parts, 27—an adjustable section channel for vapor phase removal, with a cover in the form of a diffuser; 30—gas-fueled heat generator, 31—a burner, 32—a gas blower, 33—a heater, 34—a compressor, 35—a membrane generator, 41—a condenser, 5—heat exchanger, a heater; 50—an exhaustor, 51—a cyclone; 52—a filter.

The advantages of this installation over similar systems are ensured by the following design and construction features:

- For pre-drying of the product, a transporting screw conveyor with a mounted jacket is used. It provides preheating, partial dehydration, which guarantees moisture removal by intensifying the internal heat-mass exchange.
- A fan, cyclone and filter consecutively mounted at the outlet of a mass transfer unit provide robust and reliable cleaning of a heat carrier.
- An output duct of the membrane generator for oxygen-depleted air mixture connected with an injector intensifies dehumidification.
- An output duct of the membrane generator for oxygen-enriched air connected with a gas-fueled heat generator burner provides robust combustion.

For the purpose of thermodynamic evaluation of dryer's thermal system functioning, exergy analysis was conducted [4, 8].

Each element of the system is regarded as an independent thermodynamic system. The robustness of each element of the system is estimated by comparing the exergy at the point of entry with the loss of efficiency in it, i.e. with the loss of exergy in the result of irreversible processes that occur in this element

due to both internal and external irreversibility. This approach provides information about the possibility of improving any element and allows for perfecting the system. This is the main purpose of the exergy analysis method. The analyzed system (Figure 1) is characterized by material, thermal and exergy balances.

The method of calculating exergy losses in the process of rapeseed dehumidification (evaporation) uses thermal and exergy balance of the control surface. The robustness of heat-mass exchange is estimated by analyzing the given material flows using exergy based on the second law of thermodynamics [4,9]. The exergy of material and energy flows, as well as internal and external exergy losses, form the exergy balance of a thermal system.

3. Energy analysis of heat-mass exchange by bulk product processing

A simplest method of thermodynamic analysis of energy technology systems (ETS) is based on the first law of thermodynamics. This method allows for estimating energy losses in the whole ETS and its separate elements. It also reveals ETS elements that generate the greatest losses.

Based on energy efficiency calculations, a diagram (Figure 2) is created. It successfully demonstrates heat flows and losses in the thermodynamic system of the installation for heat-mass exchange of fine-particulate bulk products.

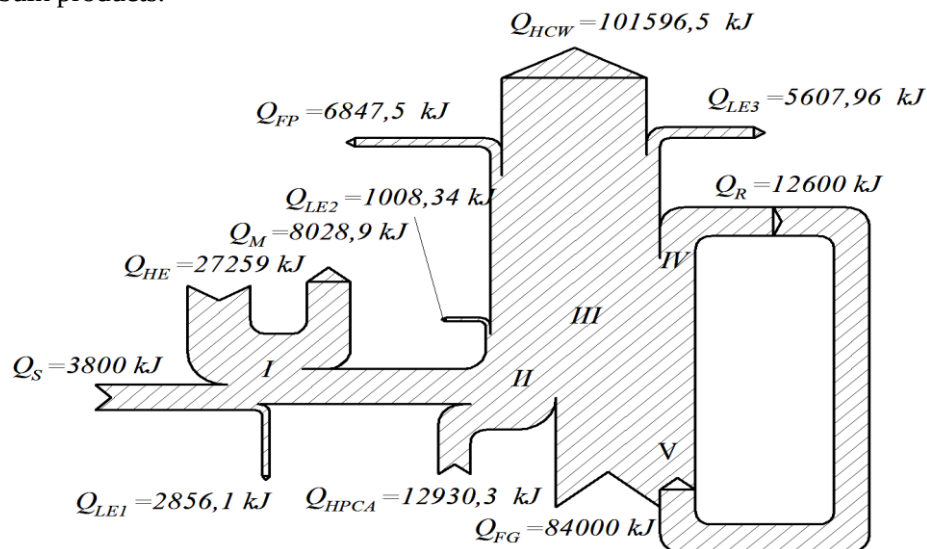


Figure 2. Heat balance of the installation for rapeseed dehydration. I—dehydration by electroconductive method, II—convective drying of the product, III—main product drying, IV&V—regeneration of the heat carrier.

Heat balance flows the installation by rapeseed dehydration are designed in the Table 1.

Table 1. Designation of heat balance flows for a rapeseed dehydration system

Flow Notation	Tread Name
Q_{HCW}	Heat carrier waste (flue gases)
Q_{HE}	Heat to remove excess moisture from the product
Q_{HPCA}	Heat of the heated, pneumatic conveying air
Q_{FG}	Energy of the main coolant (flue gases)
Q_{FP}	Heat leaving the finished product
$Q_{LE1}, Q_{LE2}, Q_{LE3}$	Heat loss to the environment
Q_M	Moisture energy evaporated from the product
Q_S	Source heat
Q_R	Heat of the regenerated heat carrier (flue gases)

4. Exergy analysis of heat-mass exchange by bulk product processing

The energy method has a significant disadvantage: it does not take into account the value of different types of energy, i.e. its practical usefulness, which is incorrect from the point of view of the second law of thermodynamics. In real life processes, energy loss is due to irreversibility. Currently, two methods of thermodynamic analysis of systems that take into account irreversibility of thermodynamic processes are used: entropy (a cycle method) and exergy ones. Both methods are based on the second law of thermodynamics and essentially solve one task of determining efficiency losses and irreversibility losses for ongoing processes. However, the exergy method can be used to perform more robust thermodynamic analysis of ETS and find the most productive ways to reduce energy consumption while increasing technological performance.

The exergy method of analysis relies on the extensive use of exergy, which represents the maximum amount of work a substance can perform in a reversible process with the environment as a heat source, if at the end of this process all types of matter involved in it reach thermodynamic equilibrium with all components of the environment [10-12]. It is a universal method for researching various processes of energy conversion based on thermodynamics. All real-life processes are irreversible, and in each case irreversibility is the reason of decreasing process efficiency. This is due to the decreasing energy quality.

For the purpose of studying ETS, the exergy balance was calculated.

Prior to balance calculation, a system to be examined was determined. For that, it is mentally separated from other objects by a control surface, and exergy of all flows of matter and energy passing through it are considered in the exergy balance.

Graphically, the exergy balance of rapeseed dehydration is represented in Figure 3. The highest energy loss occurs due to the irreversibility of moisture removal processes as moisture undergoes phase transformation, as well as pressure drop in the device in the active hydrodynamic mode. During dehumidification of rapeseeds steam and condensate are discharged, which corresponds to 90.13% in the heat balance and around 75.35% in the exergy balance. The total loss of exergy on the control surface during dehumidification of rapeseeds in the device in the active hydrodynamic mode is 17.4%.

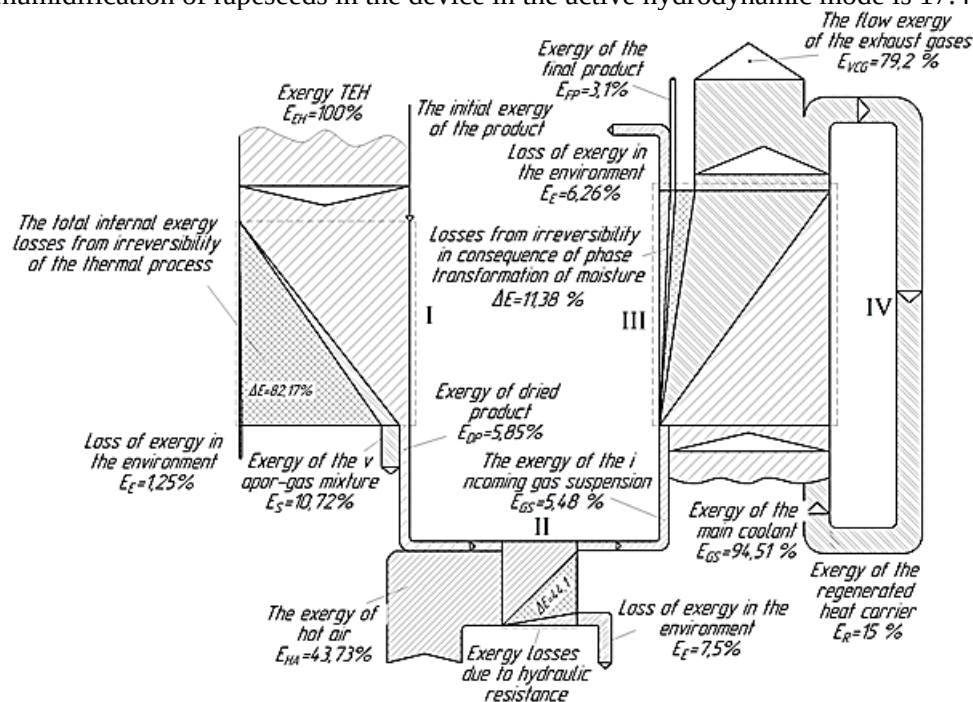


Figure 3. A diagram of exergy analysis by rapeseed dehydration. I—conductive drying of bulk products; II—input of bulk material into the device; III—drying of seeds in the main installation; IV—regeneration of a heat carrier.

5. Conclusion

By post-harvest processing of grain and oilseed crops, it is necessary to address the task of their energy-efficient dehydration to a necessary humidity level. The applied exergy analysis allowed for thermodynamic efficiency assessment of a thermal system of heat-mass transfer during rapeseed dehydration in the active hydrodynamic mode. Exergy losses by dehydration of rapeseeds were calculated, which are regarded as a biopolymer complexes in the structure of colloid capillary porous material.

Flows of material of the dehumidification control surface are identified since all exergy transformations are carried out as interaction of these flows. The described installation with heat carrier recirculation has also proven to be energy- and exergy-efficient for post-harvest dehydration of such fine-particulate products as safflower seeds, quinoa and amaranth, which feature a multicomponent structure of biopolymers.

Identification of exergy and heat flows and their analysis for rapeseed processing in the active hydrodynamic mode is an important step to create a resource-efficient process system for obtaining bioproducts with a specified level of hydration of biopolymer complexes.

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