

The Development of Equipment for the Disposal of Solid Organic Waste and Optimization of Its Operation

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Abstract. The paper describes the developed system for the thermal utilization of solid organic waste, which can simultaneously process the paper, wood, rubber, plastic, etc. A method for improving the efficiency of the equipment, due to optimization of the gas extraction system was proposed. The influence of the characteristics of installed equipment and modes of their work on energy savings and efficiency of the gas extraction system was also determined. Optimization work which includes the introduction into the exhaustor control system of the frequency converter, can save up to 70% of electricity and increases the life of the equipment.

1. Introduction

During the development of technological processes and equipment design there is always an issue of energy efficiency. This is especially important in the development of equipment for thermal disposal of various kinds of solid organic waste in the furnace and boiler units. In most cases, disposing of wastes has a small economic benefit, and sometimes is a very costly process [1].

During the designing of equipment for the disposal of solid organic waste, including solid wastes there are always lots of complicated problems. This is primarily due to the morphological composition of wastes that come to recycling. The waste may consist of the following organic materials: paper, wood (furniture), textiles, various plastics, rubber, etc. [2, 3, 4, 5]. Another important characteristic is the fractional composition of the waste, which can vary over a wide range [6, 7]. Such a diversity of species and sizes of raw materials greatly complicates the calculation and design of the equipment.

Secondly it's an environmental problem. Power plants that use solid waste as fuel are a continuous source of toxic emissions into the atmosphere. With the constant increase in the number of equipment disposing solid organic waste by thermal methods the problem of clearing of gases becomes very important [8, 9, 10, 11].

There are currently many samples of industrial installations for the thermal disposal of various solid waste using incineration technology, pyrolysis and gasification. However, not all technologies are energy-efficient and environmentally friendly when you need to dispose all types of waste. For example, some installations use only the process of burning. The disadvantage is the allocation of soot and toxic substances in the disposal of plastic waste, such as rubber, plastic resin, polyethylene, etc.



[12]. In other technologies after waste incineration, there is a neutralization of combustible components of waste gases only and non-flammable components (fly ash, heavy metals, etc.) are released into the atmosphere [13]. Some installations may not operate at high temperatures and as a result do not allow to dispose solid waste containing polymer materials such as rubber and hard combustible materials [14, 15].

All the above factors need to be considered in the development of new equipment for the processing and disposal of solid organic wastes of different origin. As a result, the aim is to develop an installation that will allow to process solid organic waste, comprising: wood, textiles, rubber, plastics, resins, polyethylene and other polymeric materials.

2. Description of the developed object

The developed equipment related to waste disposing technology combines two methods of thermal processing of raw materials: incineration and pyrolysis. The scheme of developed equipment is shown in figure 1.

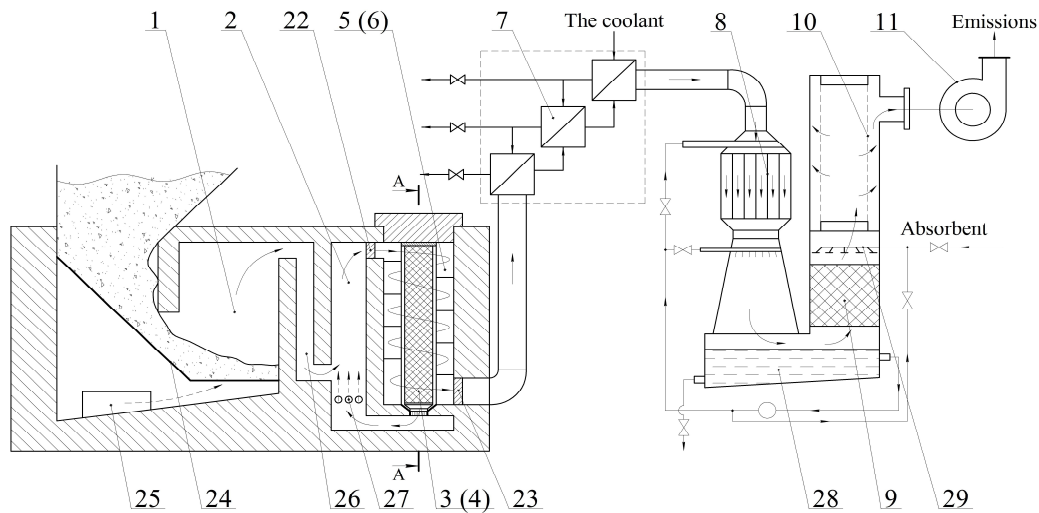


Figure 1. The installation for thermal disposal of solid wood wastes

Installation for the thermal disposal of solid organic waste consists of the incineration batch furnace 1; post-combustion chambers of exhaust and pyrolysis gases 2; removable pyrolysis chambers 3-4, installed in the cyclonic shaft 5-6 (figure 2); the heat exchanger 7 and cleaning unit of gases emitted into the atmosphere. The cleaning unit consists of series-connected scrubber as the Venturi tube 8, a packed absorber 9, the separator 10 and the exhauster 11.

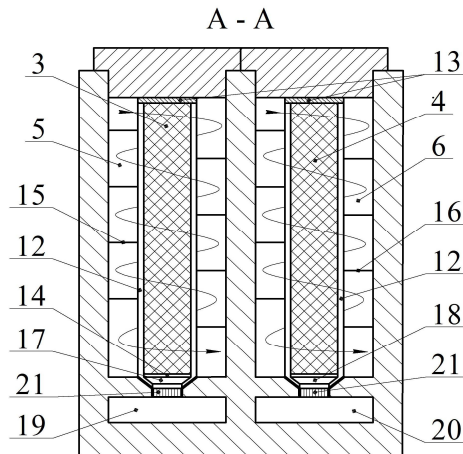


Figure 2. General view of the pyrolysis chambers

The device operates as follows: pre-sorting of waste occurs with the release of polymeric materials such as rubber, plastic, resin, polyethylene, etc. Further, wastes containing polymer materials are charged into the removable pyrolysis chamber 3–4, and the remaining waste is burned in the incineration batch furnace 1. Pyrolysis chambers 3–4 (figure 2) are the same and have the frame 12, hermetically closing lid 13 and support gas distribution grid 14 for extraction of the pyrolysis gases.

Removable pyrolysis chambers 3–4 are set in to the cyclonic shafts 5–6 which have the tangential entering of exhaust gases in the upper part and helical inserts 15–16 for even distribution of gas flow in the shaft. At the bottom of the shafts there are outlets (taps) 17–18, which are designed for sealing engagement of the pyrolysis chambers with pyrolysis gas outlet channels 19–20. The outlets (taps) 17–18 have a special partition 21 which is designed to prevent the leakage of exhaust gases from the shaft in the post-combustion gas chamber 2. After setting the pyrolysis chambers in to the cyclonic shafts they are sealed by lids. Cyclonic shafts operate alternately, and the process of switching on and off is done by valves 22–23. So when you turn on one cyclonic shaft the other is disconnected. An alternate operation of shafts is necessary for discharging waste pyrolysis chamber and its cleaning from carbon residue and loading of a new batch of solid wastes containing polymer materials.

Waste burning in the incineration batch furnace 1 is performed in the horizontal part of the grate 24. The supply of oxygen required for combustion and removal of ash is carried out through a hatch 25 at the bottom of the chamber. The exhaust gases formed during incineration and pyrolysis gases through outlets 26 and 19–20, respectively, enter the post-combustion chamber 2. There it is mixed with oxygen supplied via the channel 27. As a result of post-combustion of exhaust and pyrolysis gases in oxygen the gas temperature rises to 1400 °C. From the post-combustion chamber 2, the heated exhaust gases enter the cyclonic shaft 5–6 for warming of removable pyrolysis chambers 3–4. The exhaust gases from cyclonic shaft are fed into the heat exchanger 7 for cooling to a temperature of 40–55 °C and production of thermal energy. For efficient operation the heat exchanger consists of three cascaded units operating in countercurrent mode.

Next, the cooled exhaust gases are cleaned in consecutively installed Venturi scrubber 8, the packed absorber 9 and the separator 10. The Venturi scrubber 8 is a frame with the tube unit placed in it, diffusers and nozzles placed at the top of the apparatus. The power fluid is sprayed evenly in the diffuser and interreacts with the exhaust gases. After that the power fluid flows into the receiving tub 28. The packed absorber 9 is located vertically above the receiving bath 28 and is provided with nozzles 29 for supplying the dispersed absorbent. Venturi scrubber 8 and a packed absorber 9 have a total absorbent circulation system. The packed absorber 9 at the top is connected to the separator 10 to remove moisture from the gas phase.

After separator 10 cleaned and cooled to 25–30 °C flue gases are removed from the exhauster 11 to the atmosphere.

3. Discussion of the developed results

Analysis of optimization methods of various fuels' combustion showed that most of the energy costs are associated with the operation of the gas extraction system. The costs depend on the gas flow rate and pressure loss on installed machinery [16]. Also, a significant impact on energy losses have modes of the equipment due to the creation of significant pressure oscillations before the exhauster [17]. Therefore, in most cases, the throttles and control valves are installed in the gas extraction system. These elements create an additional flow resistance and allow the pressure to ensure stable performance in the gas extraction system.

Not only throttle affects on the magnitude of the losses in the regulation but also the exhauster that has a certain power. For example, when the old exhauster is replaced by a new one its characteristics may be slightly different, that will lead to a change in the pressure range of the gas extraction system. All these factors can lead to the loss of up to 45% of the energy of the nominal capacity of the equipment, and as a result to reduction of the energy and economic efficiency [18].

To solve the problem of minimizing the losses associated with pressure control in the gas extraction system, it is necessary to eliminate hydraulic resistance by opening all control valves.

However, it is possible if the regulatory process will be carried out directly by exhauster. Theory of exhauster operation and experimental studies (figure 3) show that the change in the motor speed changes the characteristics of the equipment pressure [19, 20]. In figure 3 the curve 1 corresponds to the nominal pressure characteristic, while curves 2 and 3 – are to discharge characteristics at low speed.

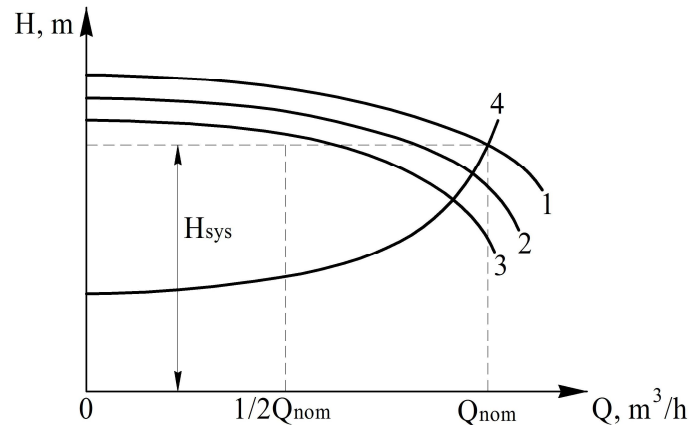


Figure 3. Changes in exhauster characteristics (1, 2, 3) due to the changes in rate of rotation: 1 – 1000 r/min 2 – 900 r/min; 3 – 750 r/min; 4 – system characteristic

If to set the operation of exhauster motor in a way that it would change its rotation rate during the changes of process parameters: gas flow rate and inlet pressure, it would be possible to adjust and stabilize the pressure in the gas outlet without energy loss. When using such regulation method the pressure loss is eliminated since there is no throttle elements.

Based on the analysis of the data the method of pressure regulation in the gas extraction system was developed. The method consists in introducing the frequency converter in power system of exhauster. Control scheme is shown in figure 4.

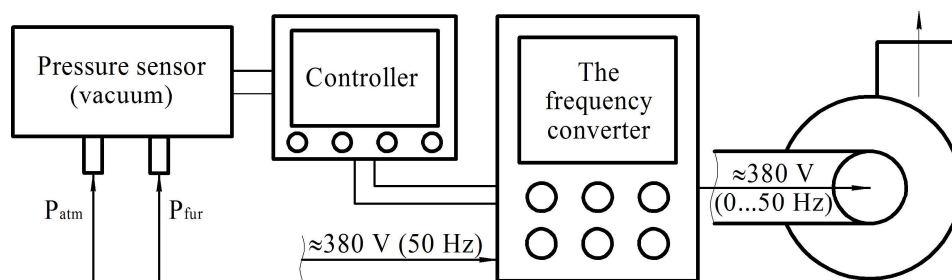


Figure 4. Pressure control scheme in the gas extraction system

The frequency converter is an electronic device which controls the rotation rate of motor due to variations in the amplitude and frequency of the electric voltage.

The proposed method of regulating pressure in the gas extraction system allows not only to reduce energy consumption but also to optimize the process [21]. For example, you can change the efficiency of the exhauster by changing the motor rate rotation, depending on the gas flow (figure 5).

From the graph (figure 5) it is seen that the maximum efficiency with a reduction in the rotation rate decreases and moves to the left. Analysis of changes in the exhauster rotation rate during the changes in flow rotation shows that a decrease in consumption may reduce the rotation rate. If we consider the exhauster operation for less than the nominal flow (vertical lines A and B), it is more efficient for these modes to operate at low speed. In this case, the efficiency of the exhauster is higher

than when operating at the nominal speed. Thus, the decrease in rotation rate according to the load process does not only save energy consumption, but also improves the efficiency of exhauster.

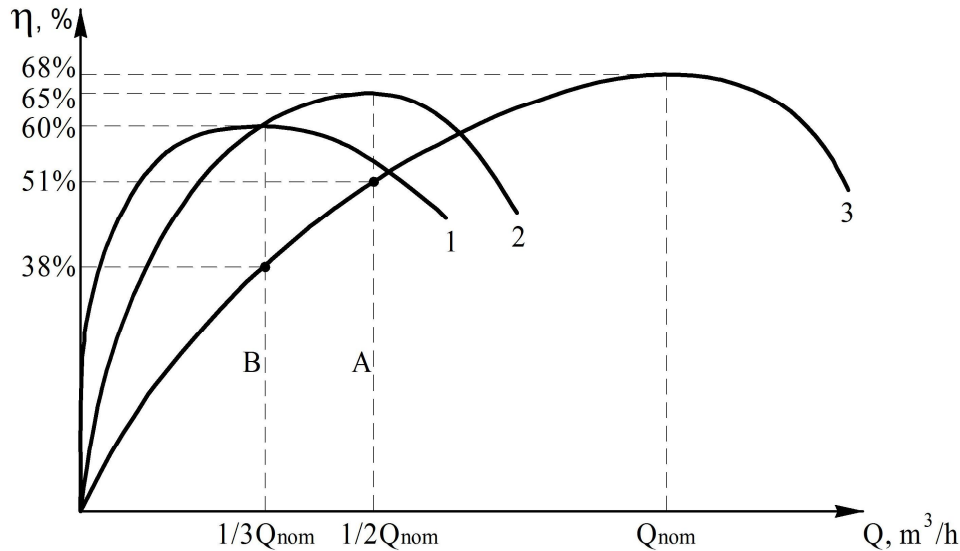


Figure 5. Changing in coefficient of exhauster efficiency depending on the performance when changing the rotation frequency: 1 – 750 r/ min; 2 – 900 r/ min; 3 – 1000 r/ min

Also, the dependence of power consumption on the relative gas flow at the throttle regulation and when using the frequency converter was analyzed (figure 6).

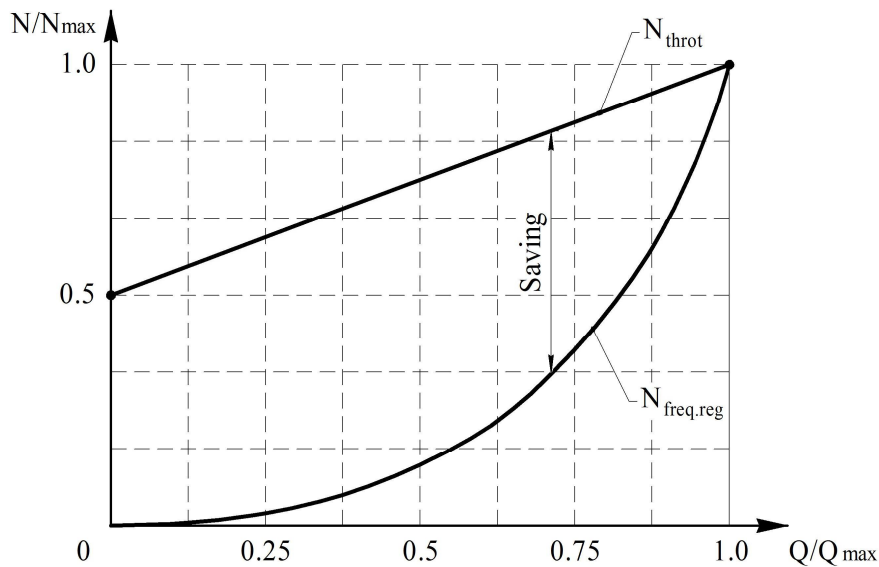


Figure 6. The dependence of the exhauster power consumption on the gas flow while using a frequency converter and throttle control

According to the received data the power consumption by using frequency control, as opposed to the throttle control is curvilinear and provides energy savings. To calculate the reduction value of the power consumption and obtain reliable calculations, it was proposed to use the scaling laws [1]:

$$\frac{N_1}{N_2} = \frac{n_1^3}{n_2^3} \quad (1)$$

$$\frac{H_1}{H_2} = \frac{n_1^2}{n_2^2} \quad (2)$$

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \quad (3)$$

That is, the reduction of power consumption is in proportion to the reduction in engine speed in the third degree. Data show that even in the systems with a constant flow rate it is possible to get an effect from the application of frequency converter. The total reduction in energy consumption by using frequency regulation can be up to 70%, even with perfectly matched equipment operating in variable flow systems.

4. Conclusions

The set of proposed technical solutions in the development of installation for thermal utilization of solid organic waste can simultaneously dispose different types of solid waste, including rubber, plastic, and others. Also, a joint post-combustion of the pyrolysis gases with the exhaust gases contributes not only to reduction of harmful emissions into the atmosphere, but also increasing of installation efficiency. In addition, the introduction of frequency control system of exhauster operation provides:

- reduction in valve wear;
- gradual inclusion of exhauster and access to the operating mode;
- full motor protection;
- increase in motor life;
- noise reduction, which is particularly important at the the exhauster location next to the residential or office space.

The practice of using frequency converters to control the exhausters, fans and pumps proves the feasibility of creating a special process control systems [22]. This approach can significantly reduce operating costs and improve working conditions. Modern frequency converters allow to monitor more than 20 parameters of electric motor status. Processing of these parameters allows for deep diagnostics of the equipment and the carried processes. There is an opportunity not only to respond to the evolving accident, but also to warn it which is more important for power assets [23].

Development of equipment for waste utilization using a frequency converter, in which the frequency control is carried out in conjunction with a variety of process parameters is very important. This not only reduces the consumption of electric energy, but also saves energy resources of the entire system. It is advisable to use frequency converters as components of technological process automation complexes. Such solutions make it possible to obtain an additional effect, which is obviously more than just saving electricity.

Notation

H – pressure, Pa; Q – gas expenditure, m³/h; η – efficiency, %; N – power, Watt; n – rotation frequency, r/ min.

Subscripts

fur – furnace; atm – atmosphere; nom – nominal; max – maximum; sys – system; throt – throttle; freq.reg – frequency regulation.

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