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Ukrainian School of Mining Engineering

A concept to use energy of air flows of technogenic area of mining enterprises

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Abstract. Topical issues concerning the possibilities of effective energy generation on the basis of Ukrainian mining enterprises have been highlighted. Attention is drawn to one of the most challenging tendencies of nontraditional energy sources development in the process of wind-driven powerplant use. The plants consume energy of technogenic air flows. Operation schemes and engineering solutions as for the possibilities to involve nontraditional sources of energy resulting from operation of technogenic objects and industrial structures of enterprises (i.e. stopes, mine dumps, industrial facilities etc.) in power balance of a mining enterprise have been demonstrated. Energy efficiency of the wind-driven powerplants in the context of different operation schemes aimed at utilization of energy of technogenic air flows has been analyzed. Output of a wind-driven system as a component of technological segment of a mining enterprise making it possible to meet 20 to 44% of its power demand has been determined. The objective of the paper is to substantiate process solutions as well as technical and engineering ones as for the obtaining nontraditional energy sources basing upon introduction of wind-driven power plants.

1 Introduction

Energy independence is one of the most important criteria while estimating a level of national safety of a country. It relies upon principles of the reduced volatility, increased energy generation at the expense of proper sources, and increased efficiency of alternative power sources [1, 2]. The abovementioned stipulates sustainable and efficient progress of any industry of modern society [3, 4]. As the authors of [5, 6] mentions, technology is the driving force of industries. It is the powerful factor of achieving and maintaining competitive priority as well as insuring sustainable economic growth [7] as well as ecological problems solutions of post-industrial mining areas [8, 9].

In Ukraine, electrical energy generation by thermal power stations (TPSs), nuclear power stations (NPSs), and hydro power stations (HPSs) is considered as traditional

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process of energy production. Electrical energy generation by TPSs is high on the world list. Nuclear power industry is a separate branch of power industry.

Renewable power generation is a tool of technological leadership of any nation. According to the conclusions by 21st Conference of UNO on the problems of climate, which took place in Paris in December 2015, renewable power industry was determined as the key tool to reduce emissions of greenhouse gases to minimize effects of climatic changes [10, 11].

Currently, renewable energy sources (RESs) are experiencing intensive development stages [12, 13]. Solar energy and wind energy are the most active. A tendency to increase share of RES in the context of total energy balance is worldwide one [14]. The fact can be explained by the growth of investment in renewable power industry (in 2004 – 2016, annual average investment growth was 12.5%).

Ukraine demonstrates confident RESs growth as well. According to the data by the State Statistics Service, in 2004 – 2016, a share of energy generated by RESs increased from 1.7% (2384 thousand tons of o.e.) to 3.9% (3616 thousand tons of o.e.). Ukraine has high wind-energy resource which is sufficient to provide the development of large objects. It should be noted the electric energy, generated by wind power stations (WPSs) is the cheapest among other types of electric energy, generated at the expense of RESs [15]. Thus, according to information by Enerhorynok SE, a share of wind energy is only 2.54% (in terms of 0.66% share of the total electric energy sold to Ukrainian electric power pool in 2016) to be less to compare with solar energy (SE) and the electric energy, generated by small HPSs, which respective shares are 35 and 13% in the context of the total electric energy supply (Table 1).

Table 1. Shares in volumes of electric energy and its cost depending upon primary energy carriers.

Primary energy carriers	Share in the electric energy, %	Share in the cost of electric energy, %
NPSs	53.74	29.32
TPSs	31.78	45.96
HPSs (with exception of small ones)	6.21	5.23
TPPs	7.01	12.51
SHPSs	0.13	0.56
WPSs	0.66	2.54
SE	0.35	3.38
Biomass energy	0.06	0.24
Others	0.06	0.26
Total	100.00	100.00

Introduction of wind-driven power plants, utilizing the energy of natural air flow, provokes a number of problems connected with their operation under storm windflaws, under icing of windwheel and weather equipment, under sharp changes in physical landscape and climate.

Thus, the authors of the paper believe that utilization of energy of technogenic wind flows (TWF) within the territories of mining enterprises is one of the promising tendencies to develop nontraditional energy sources on the basis of wind-driven power plants. Progress of the process solutions as well as technical and engineering solutions concerning energy generation in the while wind-driven powerplants operating makes it possible to prolong life of mining enterprises. That is achieved by means of cardinal reorientation of coal mining; thus, changes in such principle mission of a mining enterprise as “coal mining → energy generation” take place.

2 Mathematical representation and description of using energy of air flows

Introduction of nontraditional energy sources into life cycle of mining enterprises is stipulated by the availability of a number of man-made objects and industrial structures at their territories. Such objects include: mine dumps, headframes, buildings of industrial sites of mining enterprises, shafts, and systems of permanent mine openings. Mining enterprises, terminating their operating life and those, being in a state of stagnation, are preferred [16, 17].

It is common knowledge that circulation of technogenic air flows within underground mine workings of abandoned mines depends upon the depression formed by natural draft at temperature-pressure difference in underground area and at the surface [18 – 20]. Underground air flow is heated owing to contact air-rocks heat exchange [21, 22].

Natural draft depression is the energy, generated by air unit volume of a source causing the natural draft; it is calculated with the help of formula [23]:

$$h_n = \frac{\rho_a \Delta H \left(T_{atm} - T_a\right)}{273 + T_a}, \tag{1}$$

where ρ_a is specific weight of a mine air, N/m^3; ΔH is difference between marks of a shaft collar, m; T_{atm} is average temperature of atmospheric air entering a mine, in a shaft collar, ºC; and T_a is average temperature of mine air, ºC.

Mine air flow involves much constant kinetic energy; moreover, it is powerful source to rotate wheels of underground wind-driven power plants with constant velocity and direction. The obtained kinetic energy of technogenic air flows within mine workings is used by means of mounting of a chain of wind-driven powerplants (Fig. 1) [24].

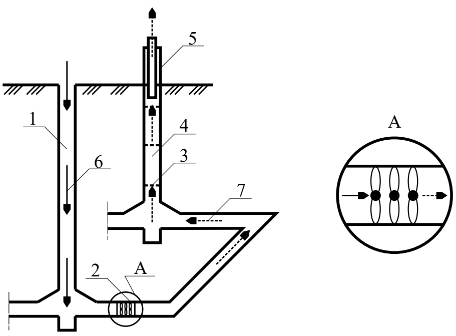

Fig. 1. Procedures to use energy of technogenic air flows within underground mine workings by means of wind-driven powerplants: 1 – supplying ventilation shaft; 2 – block of wind-driven powerplants of a development mine working; 3 – wind-driven powerplants of a shaft; 4 – ventilation shaft; 5 – overshaft tubular helium air heater; 6 – fresh air; and 7 – dusty air.

If wind wheels are located within mine workings, they rotate smoothly without any pulsation and frequency vibration of electric current. Their location in ventilation walls, air doors etc. is the simplest design solution. The authors of paper [25] mention: to evaluate air reserves countrywide, useful wind energy with minimum velocity is used; that is $v = 4.0$ m/s. In this context, the wind energy can be evaluated applying the simplified formula:

$$E = g \cdot v^3 \cdot t \cdot 1.34 \cdot 10^{-7}, \tag{2}$$

where E is energy efficiency of air flows, kWh/year; g is density of the air flow, kg/m^2; v is velocity of the air flow, m/s; t is time.

Formula (1) can also be used to determine energy efficiency of air flows in coal mines since a chain of wind-driven power plants is mounted in ventilation wells, shafts, drifts, main entries and airways, main gravity inclines and district gravity inclines, and inclines where maximum air velocity may achieve 15 m/s [26].

Hence, generating capacity of wind-driven power plants of a mining enterprise can be calculated on the formula (2) involving useful area of blade faces of wind-driven power plants:

$$E_S = \eta \cdot g \cdot v^3 \cdot t \cdot A \cdot 1.34 \cdot 10^{-7}\text{, kWh/year,} \tag{3}$$

where E_s is generating capacity of WDPP, kWh/year; η is the efficiency of a wind turbine and electric generator (0.25 for small turbines, and 0.6 for large ones which wattage is 2 MW and more); A is useful area of blades of wind-driven power plants, m^2; E is generating capacity of air flow, kWh/m^2.

Rotation velocities of electric generator and wind wheel are determined through the ratio of diameters of transmission wheels:

$$\frac{v_1}{v_2} = \frac{d_1}{d_2}, \tag{4}$$

where v_1 and d_1 are velocity and diameter of a connecting shaft, m/sec, m; v_2 and d_2 are velocity and diameter of electric generator shaft, m/sec, m.

Analytical research has helped determine the following: if length of a main haulage road is 3.0 to 3.7 km then wind-driven power plants are mounted at the distance of 20 m to extinguish vortexes of air flow behind the wind wheel. Hence, when the velocity of technogenic air flow is 1.65 – 3.16 m/s, then efficiency of the wind-power system may achieve 24.7 – 36.2 kW/hour. Monthly generation of electric energy will be 13.5 – 19.3 MW/hour.

3 Results and discussion

Heat exchangers (electroheating facilities), mounted in nearshaft mine workings, is one of the most helpful technical and engineering solutions [23]. Heated in such a way air flow with 1.19 to 1.04 kg/m^3 density and 2.56 – 4.79 m/s velocity passes through a heating member and moves up quickly along a shaft to the surface rotating 3.5 – 5.2 m diameter wind wheel of wind-driven power plants mounted within the shaft (Fig. 2).

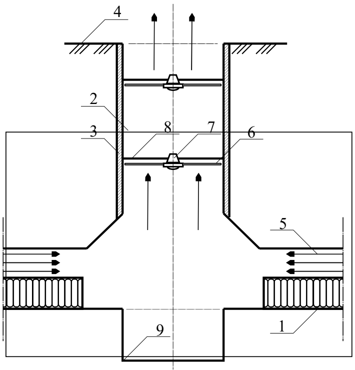

Fig. 2. Mounting scheme of wind-power devices in a mine shaft: 1 – heat exchangers; 2 – mine shaft; 3 – shaft timbering; 4 – earth’s surface; 5 – technogenic air flow; 6 – wind wheels of wind generators; 7 – electric generators; 8 – supports of wind generator; 9 – TAF from mine workings; 10 – drainage shaft.

Fig. 3 demonstrates graphs of changes in generating capacity of wind-power device using energy of air flows in a mine shaft under the conditions of natural draft depending upon air flow velocity and a diameter of a wind wheel.

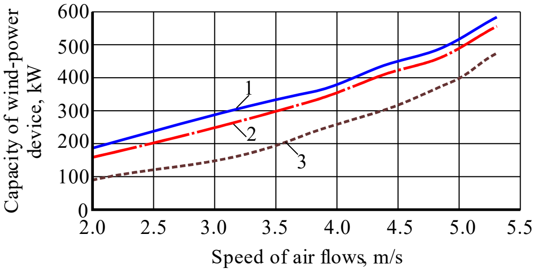

Fig. 3. Graphs of changes in generating capacity of wind-power device using energy of air flows in a mine shaft under the conditions of natural draft depending upon air flow velocity and a diameter of a wind wheel: 1 – 5.2 m; 2 – 5.0 m; 3 – 3.5 m.

Owing to constant directivity and smoothness of changes in the velocity of air flows, efficiency of mechanical energy turning into electrical one at wind-power devices in underground mine workings is 82 – 90%. Use of technogenic air flows, injected by main mine fans, is provided with the help of operation schedule with wind-power units in the shaft of outgoing air flow. In the design of the wind-driven power plants, a wind wheel is three-bladed; depending upon the device remoteness, the wind wheel is mounted in a diffuser to improve density as well as directivity of the kinetic air flow.

Analysis of the data, resulting from full-scale studies and analytical studies concerning air flow injected by main mine fan VOKD-30, has made it possible to determine aerodynamic characteristic of air flow line used to construct graphs demonstrating changes in rational operation parameters of wind-driven power plants mounted on a main mine fan [27].

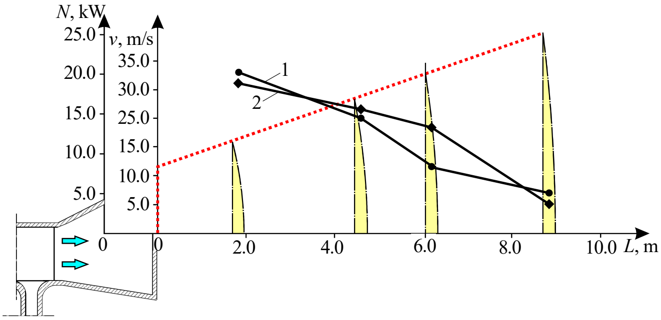

Fig. 4. Graphs of changes in operation parameters of a wind-driven power plant mounted on a main mine fan: 1 – a graph of changes in air flow velocity depending upon windwheel assembling on the outgoing flow of a main mine fan; 2 – a graph of changes in the wind-driven power plant capacity depending upon remoteness of windwheel assembling on the outgoing flow of a main mine fan.

Diffuser provides the improved density as well as directivity of the technogenic air flows on the windwheel within the design of wind-driven power plants. That increases electricity generating indices by 4.6 – 9.5%. Assembling location of the windwheel depends upon its effect on the ventilation system since incorrect selection may result in the significant increase in energy consumption by a main mine fan which in turn will make end product more expensive.

The use of the wind-driven power plants at the territories of mine dumps of mining enterprises is one of the examples of their efficient operation. First of all, rationality of the engineering solution concerning the use of mine dump energy depends upon the mine dump potential as well as availability of the marketable product consumers [28].

Fig. 5 demonstrates operation schedule to utilize air flow being formed at the expense of changes in the density of air flows in heat-generating supply line, mounted at the bottom of a mine dump [29].

Thermal flows, resulting from oxidation of such organic matters as sulphur, coal, carbonaceous rocks, timber etc., form air flows within man-made structures of industrial area of a mining enterprise [30 – 32]. Peculiarity of the technique is as follows: air flow is directed from outside of a mine dump through a pipe, mounted at the bottom of the mine dump. Diffuser is mounted on the outgoing air flow; windwheel of the wind-driven power plant is inside the diffuser.

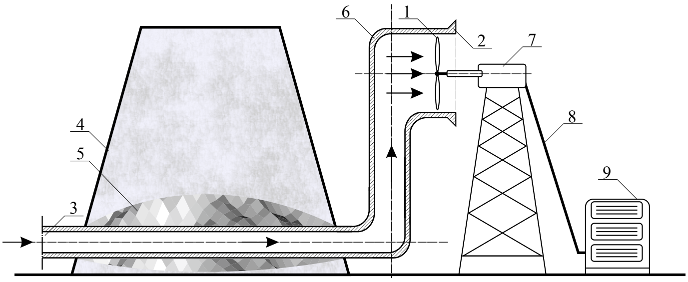

Fig. 5. Operation schedule to utilize energy of technogenic air flow while using heat generated by mine dumps: 1 – windwheel of a wind-driven power plant; 2 – diffuser; 3 – heat-generating pipe; 4 – mine dump; 5 – zone of active oxidation of the mine dump organic mixtures; 6 – thermal protection of the diffuser; 7 – electric generator of the wind-driven power plant; 8 – electric cable; and 10 – control box.

Active motion of air flow through heat-generating pipe is stipulated by pressure difference between ingoing and outgoing flows; it is determined by the formula:

$$\Lambda P = H\left(\gamma_{in} - \gamma_{out}\right), \text{ kg/m}^2, \tag{4}$$

where H is distance between axes of heat-generating pipe 3 and diffuser 2, m; $\gamma_{in} = f(t)$ is density of technogenic air flow depending upon temperature at the heat-generating pipe entrance 3, kg/m^3; $\gamma_{out} = f(t)$ is density of technogenic air flow depending upon heating temperature on the diffuser exit 2, kg/m^3.

In this context, $\Delta V_{(t)}$ velocity of the heated outgoing from the diffuser 2 airflow is determined using the formula:

$$v = \sqrt{\frac{2\Lambda Pg}{\gamma_{in}}} = \sqrt{\frac{2Pg\left(\gamma_{in} - \gamma_{out}\right)}{\gamma_{out}}}, \text{ m/s}, \tag{5}$$

Capacity of the wind-driven power plant is:

$$N_{B.y} = 0.000481 \cdot d^2 \cdot v^3 \cdot \eta, \tag{5}$$

where d is a diameter of a windwheel, m; υ is velocity of air flow, m/s; η is the wind-driven power plant efficiency.

Capacity of the wind-driven power plant depends upon the velocity of air flow, air density, area of the windwheel, and coefficient of the air flow use by the windwheel involving the diffuser effect. Rated capacity of the heat-generating pipe is 2.8 – 3.6 m^3/s if its diameter is 300 – 350 mm, and air flow velocity is 4.6 – 11.5 m/s. Graph in Fig. 6 demonstrates a characteristic of changes in capacity of wind-driven power plant depending upon windwheel diameter.

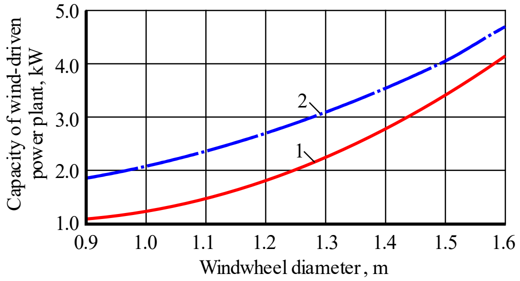

Fig. 6. Graph of changes in capacity of wind-driven power plant depending upon windwheel diameter and air flow velocity: 1 – 4.2 m; 2 – 9.5 m/s.

Relying upon the available minimum dimensions of mine dumps and heat-generating capacity of rocks, it is possible to mount up to 8 wind-driven power plants. The plants can become a part of the unified system of mining enterprise. Total capacity of wind-driven plants will be 11.7 – 45.2 kW; monthly electric energy generation will be 6.3 – 24.3 MW/hour.

Mine dumps, shaped in the form of a cone within a mine land allotment, take considerable area; their height is 42 – 124.5 m with average index of 58.14 m where average velocities of natural wind flows are 6.5 – 10.4 m/s, and maximum velocities are 15.6 – 22.7 m/s. Surfaces of mine dumps are used as areas, where wind-driven power plants are mounted and united into power system taking into consideration energy potential of wind and illiquidity of the dump to be mined as well as under the conditions of complete attenuation [33].

Wind-driven power plant capacity is determined taking into consideration changes in the two basic parameters: windwheel diameter $D_{w.h}$ and wind velocity V_v, m/s (Fig.7).

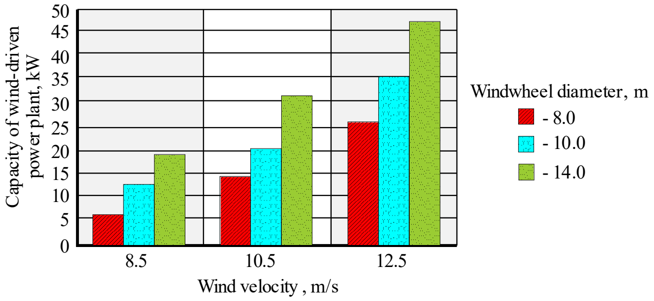

Fig. 7. Changes in the capacity of basic wind-driven device of WDPP depending upon changes in windwheel parameters and wind velocity.

Analysis of data in Fig. 7 makes it possible to select ideal parameters of a windwheel relying upon average determinants of wind velocity. In the context of similar wind velocities and increase in a windwheel dimensions with 2 m step, capacity of the wind-driven power plant experiences its 12% raise. If average dump height is 54 m, then total capacity of wind-driven system of the mine dump will be 15.4 – 71.8 kW depending upon diameter of a windwheel, wind velocity and the number of wind-driven power plants on the mine dump. Theoretical efficiency is 35.2 – 40.1%.

The authors used average data of the basic energy-generating objects (i.e. mine workings, shafts, mine dumps) [34 – 36]. Capacity of a wind-driven system as a component of technological segment of a mining enterprise makes it possible to meet 20 – 40% of its household and industrial requirements as for electric energy. Fig. 8 shows a graph of monthly generation of electric energy by certain segments of wind-driven system.

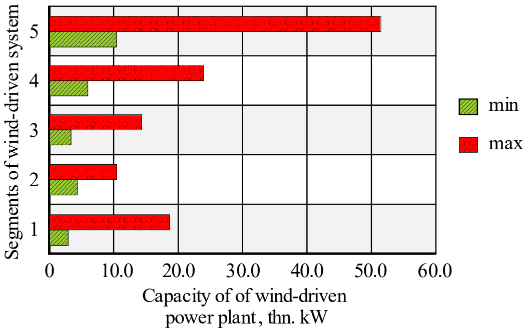

Fig. 8. Monthly electrical energy generation by certain segments of wind-driven system: 1 – wind-driven generators of technogenic air flows of mine workings; 2 – wind-driven generators of air flows of a mine shaft; 3 – wind-driven generators mounted on a main mine fan; 4 – wind-driven generators of thermal technogenic air flows of a mine dump; 5 – wind-driven devices of mine dumps, thousand.

Wind-driven power plants, mounted on mine dumps, are the most active sources to generate electric energy. Such a situation can be explained by significant velocities of air flows to compare with flows, formed underground.

4 Conclusions

The use of wind-driven power plants, basing upon mining enterprises, makes it possible to generate cheap electricity involving reduced prime cost of end product, improved environmental and social indices of the enterprise infrastructure. Formation of a system of wind-driven plants at the territory of basic objects of mining enterprise (i.e. buildings of industrial mine site, mine workings, mine dumps etc.) helps prolong life of the enterprise significantly.

It has been determined that wind-driven power plants, mounted on mine dumps, are the most productive sources to generate electric energy. Efficiency of wind-driven power plants, mounted in mine workings, is 1.2 – 2.1 times higher to compare with those, mounted in mine workings, shafts, and fan diffuser. Efficiency of wind-driven power plants, mounted at a dump surface, is 2.2 – 5 times higher to compare with other facilities. That makes it possible to substantiate the most rational engineering solutions concerning the erection of wind-driven power plants.

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