THEORETICAL INVESTIGATION OF HEAT PRODUCTION FEASIBILITY BY MEANS OF WIND MECHANICAL PLANTS
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ТЕОРЕТИЧНЕ ДОСЛІДЖЕННЯ МОЖЛИВОСТІ ВИРОБНИЦТВА ТЕПЛОВОЇ ЕНЕРГІЇ ЗА ДОПОМОГОЮ ВІТРОМЕХАНІЧНИХ УСТАНОВОК

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ABSTRACT

A widespread use of wind turbines can fully or partly provide energy for the consumers, but with due regards to certain investments and instability of energy generation. Technologies of using wind energy imply the conversion of the mechanical energy of a wind flow into the electrical or heat energy. The work is concerned with the estimation of the amount of heat in the process of heating liquid coolants and heat-transfer fluids when using wind mechanical plants. In the paper was made a numerical analysis of the temperature rise of the liquid which circulates in a closed loop of a gear-type pump, whose productivity is 3 l/m and which is driven by a wind turbine 5 kW of power capacity under a nominal wind speed of 7 m/s and under cycle duration of 2 s. The analysis showed that the temperature increased by 0.290 °K/s. If such wind speed is observed during one hour, the temperature of 100 kg of water will increase by 8.1°C. Heating of a heat-transfer fluid with a supply of mechanical energy to a working part can be achieved by a centrifugal fan. Assuming that the given process occurs without supplying and removing heat energy (it is adiabatic), for the capacity of 1.5 kW and under the revolution in a range of 1000….3000 r/m, the changes in temperature will range from 0.38 to 0.87 °K/s, but for the capacity of 7.5 kW and under 750 – 1500 r/m, the changes in temperature will range from 0.56 to 1.23 °K/s.

АБСТРАКТ

Широке використання вітроенергетичних установок може дати повну або часткову енергозабезпеченість споживача, але при врахуванні певних капіталовкладення та нестабільності вироблення енергії. Сучасні технології використання енергії вітру передбачає перетворення механічної енергії потоку вітру в електричну з подальшим перетворенням, за вимогою споживача, в механічну або в теплову енергію. Однієї із таких є технологія прямого перетворення механічної енергії, що надходить з валу ротора вітроустановки, в теплову.

Робота присвячена оцінці кількості теплоти в процесі нагрівання рідинних та газоподібних теплоносіїв при застосуванні вітромеханічних установок. За даною методикою проведено чисельний аналіз підвищення температури рідини, що циркулює за замкненим контуром шестеренчастого насосу продуктивністю 3 л/хв, привід якого здійснює вітроустановка потужністю 5 кВт за номінальної швидкості вітру 7 м/с та тривалістю циклу 2с. Аналіз показав, що підвищення температури становить 0,29^{0}К/с. Якщо така швидкість вітру буде спостерігатися протягом години, то температура 100 кг води підніметься на 8,1^{0}С. Нагрівання газоподібного теплоносія за рахунок підведення тільки механічної енергії до робочого органу, що здійснює його перемішування (рух), можливе за допомогою відцентрового вентилятора. Припускаючи, що даний процес проходить без підведення та відведення теплової енергії, тобто є адіабатним, для потужності 1,5кВт за зміни обертів в діапазоні 1000...3000об/хв., зміна температури складе 0,38...0,87 ^{0}К, а для потужності 7,5кВт за обертів 750...1500об/хв. – 0,56...1,23^{0}К.

INTRODUCTION

The production of clean energy in the world increases. The goal of this process is to reduce the level of greenhouse gas emissions (*Golub et al, 2017*). Besides, the energy strategy of each country is focused on providing with technically reliable, cost effective and ecologically safe energy resources in order to guaranty the improvement of population well-being (*Liu et al, 2021*). During the period of 2015–2020, the cost indices of heat and electric energy which comes from traditional sources increased as compared with those which use the sunlight and the wind energy, the energy of biofuel, the energy of waste gases utilization of waste heat and of geothermal heat and other types of a renewable energy (*Doytch et al, 2021; Cole et al, 2021*).

Paying attention to everything mentioned above, the use of wind turbines in the world increases (*Gönül et al, 2021; Li et al, 2021*). The use of wind turbines can fully or partially provide the consumer with energy (*Lawan et al, 2017*). But the development of wind turbines requires significant capital expenditures (*Zwarteveen et al, 2021*). Besides, in the process of wind turbines exploitation it is necessary to consider the wind factor and, as a result, an inconsistent energy production (*Dolara et al, 2017*). Modern technologies of using the energy of the wind implies the conversion of a mechanical energy of a wind flow into the electrical one with further conversion, by the consumer's demand, into mechanical or heat energy (*Aziz et al, 2017; Ali et al, 2021*). Such systems have a very low coefficient of using the wind energy – up to 30% (*Devashish, 2017; Niu, et al, 2018*). Thus, the scientific research for improving the efficiency of using the energy of wind are numerous.

The technology of the conversion of the mechanical energy, which comes from rotor shaft of a wind turbine, into the heat energy is one of the research lines. One of the variants of such a conversion is using waste heat from the wind turbine generators; e.g. the authors *Rostamzadeh et al, (2020)* suggest using waste heat in the demineralized water generator systems. Such systems have a somewhat higher efficiency factor. For example, a system of heating and cooling on the basis of waste heat with an efficiency factor of 45% is suggested (*Khalilzadeh et al, 2020*). But such systems are rather complicated as because they contain regenerators, heaters, absorbers, heat exchangers. Besides, they have a low efficiency factor.

Using of heat carriers is one more way of producing heat energy by means of wind turbines. But the complexity and a high cost of such heat pumps are the drawbacks of such systems (*Rieck et al, 2020*).

One more interesting technology lies in creating a store of pressed air, whose energy is already used, but the complexity and unreliability of the systems on using pressed air for energy needs are the drawbacks of it (*Mohammadi et al, 2017)*.

All above mentioned systems are not systems with a direct generation of heat energy. According to the research analysis, there are no investigations as to a direct conversion of mechanical energy, which comes from a rotor shaft of a wind turbine, into heat energy.

That is why the research on the feasibility of producing heat energy by means of wind turbines or by wind mechanical plants with a direct conversion of mechanical energy into heat energy is extremely important.

MATERIALS AND METHODS

The generation of heat energy when using wind mechanical plants is possible owing to the displacement of liquid in a closed space or by throttling of motive fluids through a choke or a safety valve. In the first case motive fluids are heated by the friction of fluid layers, and in the second case – by a sudden pressure jump during throttling.

The wind turbine for heat production, which is suggested by us, consists of a rotor with a hub which is firmly fastened on a shaft, *3* (*Golovko et al, 2014)*. A positive displacement pump *4* (fig. 1) which is located in a sealed ribbed tank *5* with motive fluids (mineral olive), is firmly joined to the same shaft.

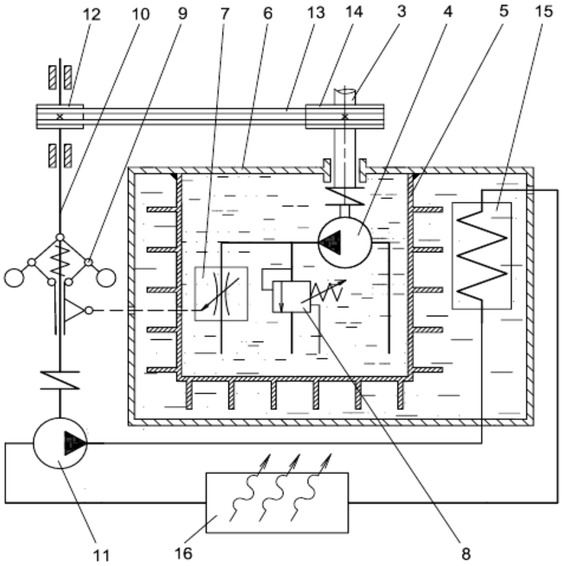

Fig. 1 - Wind mechanical plant for generating heat
(the explanation of positions is in the text)

Tank *5*, in its turn, is located in a container with a heat-transfer fluid *6* (water). A controlled choke *7* is subsequently installed in the pump-discharge line *4*. A safety valve *8* is installed in front of the controlled choke *7*. A regulating unit of the controlled choke *7* is kinematically connected with the movable part (sensitive element) of the centrifugal corrector *9* with weights which is installed on the shaft of the circulating pump *10*. On the same shaft *10,* are installed the circulating pump *11,* and the sheave *12,* which, by means of a wedge-shaped belt *13,* is cinematically connected with a low-speed pulley *14*, which is tightly installed on the main shaft *3*.

A heat exchanger *15* is installed in a container with a heat-transfer fluid *6*, the inlet into the heat exchanger is hydraulically connected with an outlet of the circulating pump *11*, and the outlet is connected with the consumer *16* of the generated heat energy, for example with a radiator of a hot-water heating. A starting Savonius rotor (*Yahya et al, 2021*) is tightly joined to the hub *2*.

The wind turbine on heat production works in the following manner. When the wind speed is sufficient (2.5…3 m/s) a rotary moment occurs on a starting rotor, under the action of this rotary moment the rotor starts running up to the design speed. Herewith, a hub *2*, the main shaft *3* and a shaft of a positive displacement pump *4* rotate. The positive displacement pump *4* produces the amount of fluid which is proportional to a rotor speed *1*. This fluid, coming through a controlled choke *7* loses a considerable part of energy which turns into heat. Thus, motive fluids from tank *5* will be heated. To remove the generated heat from the motive fluids, tank *5* is made with ribs and is installed in a container with a heat-transfer fluid *6*. A heat transfer fluid is heated as well, and the generated heat is supplied to the consumer *16* by a circulating pump *11*, which is driven by the shaft *3,* by means of a V-belt transmission *14, 13, 12,* as well as by the shaft of a circulating pump *11*. A centrifugal corrector *9*, whose movable joint responds to the rotations of the shaft *3*, is fastened on this shaft as well.

Its location is proportional to the deviation of the rotor rotations from rated values, that is why under the deviations of rotor rotations *1* it can move along the shaft *11* and, having a kinematic connection with the regulating unit of the controlled choke *7*, it can change its conductivity. When the rotor rotations increase, the conductivity decreases and additional resistance to passage of liquids is created, which results in the rise of the temperature. To avoid pressure increase under the increase of rotor rotation 1 in the pump-discharge line *4*, the safety valve *8* is installed. Under transfer of fluid through this valve the motive fluids is heated because the safety valve is also like a throttle. Thus, beside this, the rotor rotations of a wind turbine as well as its capacity are regulated, because when the rotor rotations increase, the loading on it increases due to the increase of resistance of the controlled choke.

Temperature rise per one closed cycle in a tight system will equal to (*Pratima Bajpai, 2018)*:

$$\vartriangle t = \frac{P}{\rho C Q} = \frac{981H}{\eta C} \tag{1}$$

where:

P – pump capacity;
C –specific weight of motive fluids;
Q – pump efficiency;
H – pump pressure;
η – pump efficiency factor;
ρ – specific density of heat-carrying fluid.

At the same time a driving moment on a pump shaft can be determined as:

$$M = \frac{30 \cdot Q H \gamma}{102\ \mu \pi n} \tag{2}$$

where:

n – shaft speed of a pump;
γ – fluid density.

Rotor shaft moment of the wind turbine equals (*Zhao et al, 2019)*:

$$M = \overline{M} \pi R^3 \frac{\rho_n v^2}{2} \tag{3}$$

where:

$\overline{M}$ – rotor shaft moment of the wind turbine, which can be determined by the results of the calculations of a rotor characteristic line;

R – rotor radius;

v – wind speed;

ρ_n – specific air density.

Speed rate on a rotor shaft:

$$n = \frac{30zv}{\pi R} \tag{4}$$

where:

z – rotor speed whose rate is determined by a characteristic line $\overline{M}$ =*f(z)*.

RESULTS

After building a characteristic line M=*f(n)* under v from initial values to reference values (controlled), these values are conformed to the multiplicator parameters (fig. 2).

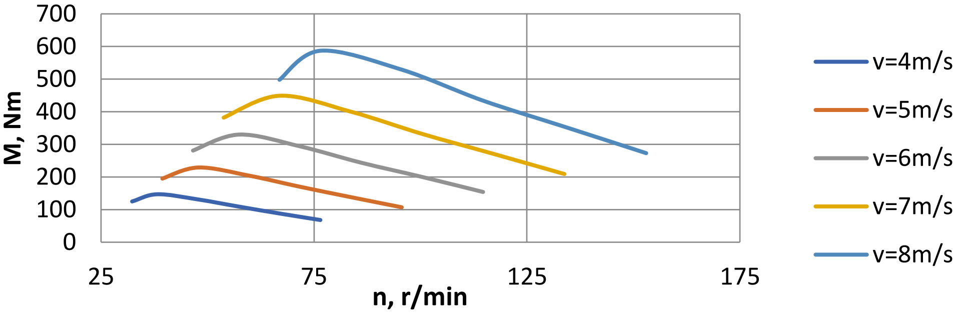

Fig. 2 - The dependence of a moment (*M*, Nm) on a rotor shaft on its speed (*n*, r/min), *v* – wind speed

The estimation of a temperature rise of the fluid, which circulates in a closed tube of a gear-type pump, whose productivity is 3 l/min and which is driven by a wind turbine 5 kW of power capacity under a nominal wind speed of 7m/s (fig. 3) and under cycle duration of 2 s, equals 0.29°K/s.

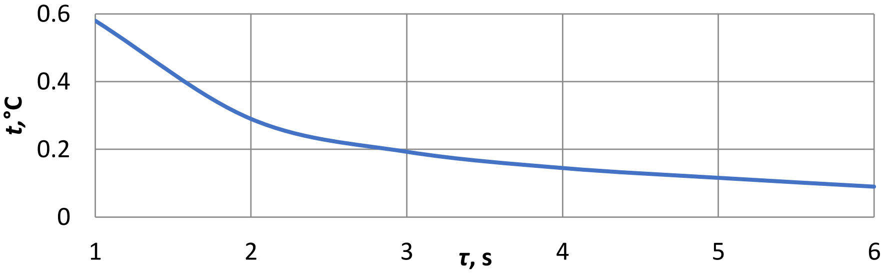

Fig. 3 - The dependence of a temperature rise of heat-transfer liquid (*t*,°C) on the technological cycle duration (*τ*, s)

Suppose, we need to determine by how many degrees the temperature of 100 kg of water will rise during one hour of heating under different rates of the wind speed. Suppose, during one hour the wind speed rate changes very little and the heat losses are not significant. Using previous dependences (fig. 2, 3) we will get as follows: under the wind speed of 8 m/s and the cycle duration of 2 s during the period of one hour, the temperature of 100 kg of water will rise by 8.1°C. The results of calculations under other conditions are given in fig. 4.

The process of heating of heat-transfer fluid by supplying only mechanical energy to the working part which makes it move (movement) is possible due to the centrifugal fan if the inlet and the outlet fittings are closed.

If we suppose that this process goes on without supplying and removing heat, that is the process is adiabatic, (under occurrence and non-occurrence of heat exchange with the environment), the parameters relationship of the body which is being heated will equal (*Rosa et al, 2021)*:

$$\frac{T_1}{T_2}=\left(\frac{p_1}{p_2}\right)^{\frac{k-1}{k}} \tag{5}$$

where:

T_1, T_2 – the inlet- and outlet temperature respectively during one cycle;

p_1, p_2 – the environmental pressure and the pressure in a functional area of a fan respectively;

k – the adiabatic index (for dry air in the range from 20 to 100⁰C it equals from 1.4 to 1.401).

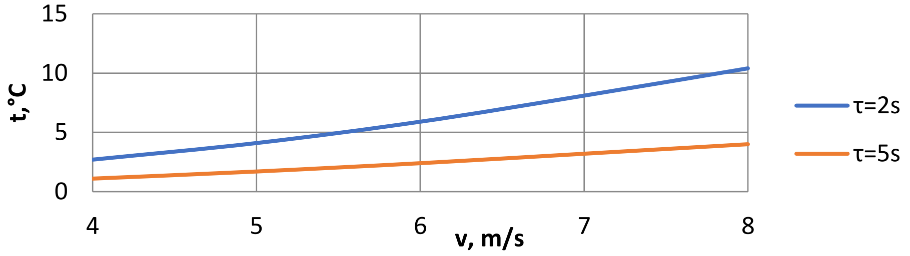

Fig. 4 - The dependence of the temperature rise (*t*,°C) of 100 kg of water on different rates of wind speed (*v*, m/s) and cycle duration (*τ*, s)

According to a given formula, the temperature at the outlet will depend on the pressure in a functional area that is on a drive capacity as well as on the number of rotations of the fan shaft. For example, for the capacity of 1.5 kWt and under the rotations change in the range from 1000 to 3000 r/m, the temperature change will equal 0,38...0,87°K, and for the capacity of 7.5 kWt under the rotations change in the range from 750 to 1500 r/m, the temperature change will equal to 0.56…1.23°K.

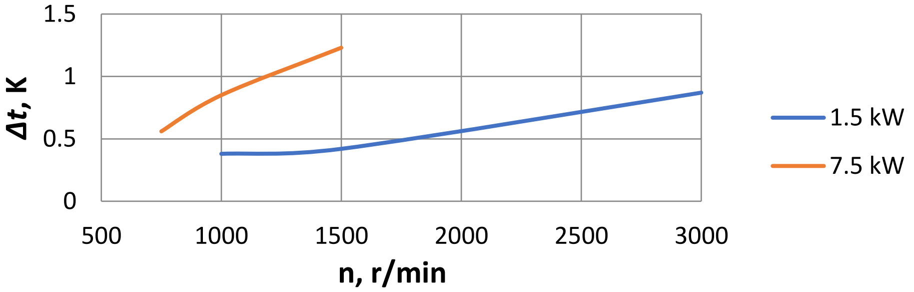

Fig. 5 - The dependence of the temperature rise (*Δt*, K) of a heat-transfer fluid on the rotation speed (n, r/min) of the fan shaft

Thus, it is principally important to use wind mechanical plants in order to provide the consumers' heat needs. But it should be taken into account, that under a low energy density of wind speed up to 8m/s, it is necessary to increase the size dimension of a wind turbine in order to increase the technological efficiency of heating. It should be mentioned that a twofold increase of a rotor diameter results in a fourfold increase of capacity on a shaft, but specific material costs per unit of capacity increase as well. The use of wind turbines is expedient on the areas with high potential, as a twofold increase of wind speed results in the eightfold capacity increase.

CONCLUSIONS

The amount of heat in the process of heating liquid coolants and heat-transfer fluids when using wind mechanical plants was estimated during the research. A numerical analysis of the temperature rise of the liquid which circulates in a closed loop of a gear-type pump, whose productivity is 3 l/min and which is driven by a wind turbine 5 kW of power capacity under a nominal wind speed of 7 m/s and under cycle duration of 2s, was made.

The temperature increased by 0.29^0K/s. If such wind speed is observed during one hour, the temperature of 100 kg of water will increase by 8.1^0C. Heating of a heat-transfer fluid with a supply of only mechanical energy to a working part, which makes it drive (movement), can be achieved by a centrifugal fan. Under the assumption that the given process occurs without supplying and removing heat energy (is adiabatic), then, for example, for the capacity of 1.5 kW under the revolutions changes in a range of 1000….3000 r/m, the changes in temperature will range from 0.38 to 0.870 K, and for the capacity of 7.5 kW under 750…500 r/min the changes in temperature will range from 0.56 to 1.230 K.

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