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Analysis of heat flows in the eddy current wind generator

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Abstract. *In the paper are presented the results of the analysis of heat flows in the wind generator with permanent magnets and. SOLID-WORKS Flow Simulation software was used to determine the circulation and heat transfer and determine the quantitative relations of heat exchange through the thermogenerator at the variation of the heat transfer liquid flow rate from 10 to 3500 l/h. The obtained results will serve for the design of new thermal generators with permanent magnets for domestic hot water preparation systems using wind energy.*

Keywords: *thermogenerator with permanent magnets, heat transfer, convective heat flow, simulation; SOLIDWORKS Flow Simulation*

1. Introduction

The permanent magnet thermogenerator is a thermal generator for the direct conversion of mechanical energy generated by a wind turbine into thermal energy using eddy currents [1].

The basic purpose of the study is to analyze the heat flows in the eddy current wind generator to produce thermal energy by direct conversion of wind energy.

For this purpose, various constructive models of the thermogenerator with permanent magnets were developed to study the heat transfer fluid flow through the thermogenerator sleeves and, consequently, to determine a constructive model that is more thermally efficient. Simulations were performed using SOLIDWORKS Flow Simulation software for an ongoing analysis of heat flows through the thermogenerator, to understand the circulation and transmission of heat and to determine the quantitative relationships of heat exchange through the thermogenerator.

The study, development and implementation of these technologies would contribute to improve of the state in the rural sector in terms of hot water supply but would also lead to the achievement of the objectives of the Republic of Moldova on the use of renewable energies [2].

2. Simulation and analysis of heat flows in the thermogenerator

Heat flow is a quantity that characterizes the intensity of heat transfer. The heat transfer in the permanent magnet thermogenerator is mostly by convection, less by conduction. Convective heat transfer has the highest rate of thermal flows through the thermogenerator.

Convection is the process of heat transfer between the surface a solid body and a fluid, in the presence of a temperature gradient and which is due to the movement of fluid. Convection has two elements:

• Energy transfer due to random molecular motion (diffusion);

• Energy transfer by bulk or macroscopic motion of the fluid (advection).

The mechanism of convection can be explained as follows: as the layer of the fluid adjacent to the hot surface becomes warmer, its density decreases (at constant pressure, density is inversely proportional to the temperature) and becomes buoyant. A cooler (heavier) fluid near the surface replaces the warmer fluid and a pattern of circulation forms, figure 1 [4].

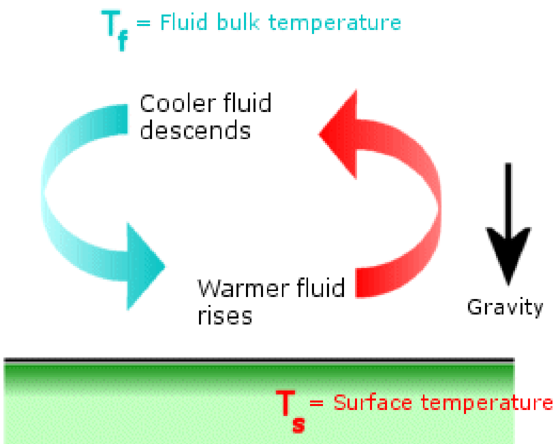

Figure 1. Convective heat transfer [4]

The rate of heat exchange between a fluid of temperature T_f and a face of a solid of area A at temperatureT_S, can be written as [4]:

$$Q_{convection} = \alpha \cdot A \cdot (T_S - T_f) \tag{1}$$

where α is the convection heat transfer coefficient. The units of α are $W/m^2 \cdot °C$. The convection heat transfer coefficient depends on fluid motion, geometry, and thermodynamic and physical properties.

The analysis of heat flows through the heat generator were developed in SOLIDWORKS Flow Simulation software for the following input conditions: liquid temperature in the inlet pipe T_1=11 °C, the sleeves imposed temperature T_0=60 °C, ambient temperature T_a=20 °C, the negligible heat losses P_{th}=0 and the liquid flow variation through the thermogenerator sleeves from 10 to 3500 l/h.

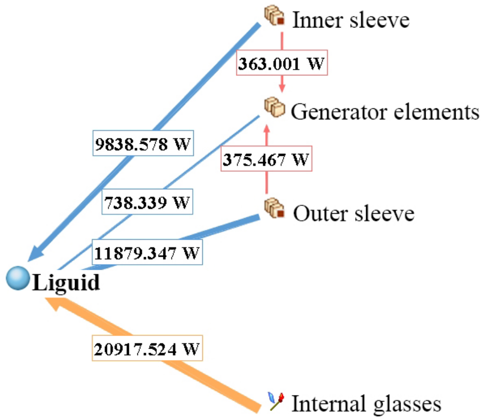

Figure 2. Heat flow in the direct inlet thermogenerator and the sleeves connected in series, T_0=60 °C

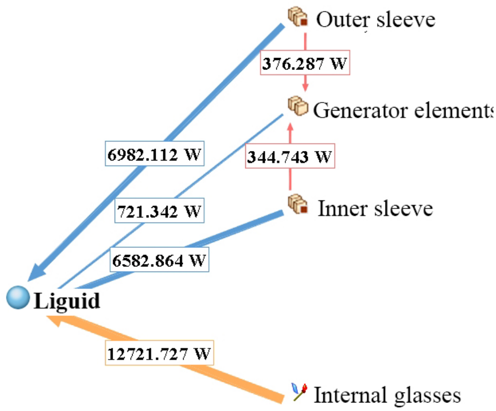

Figure 3. Heat flow in the direct inlet thermogenerator and the sleeves connected in parallel, T_0=60 °C

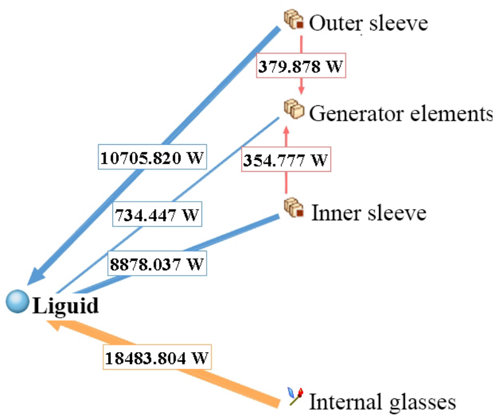

Figure 4. Heat flow in thermogenerator with direct inlet through internal pipe with sleeves connected in series, T_0 = 60 °C

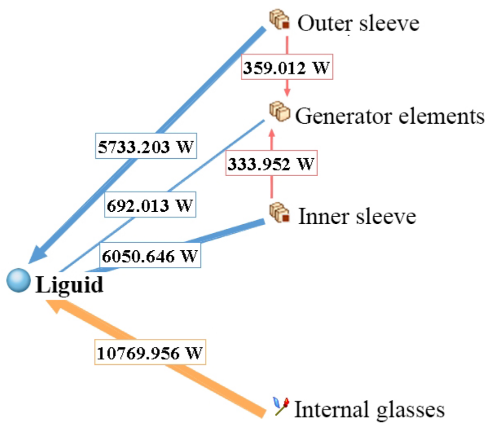

Figure 5. Heat flow in thermogenerator with direct inlet through internal pipe with sleeves connected in parallel, T_0= 60 °C

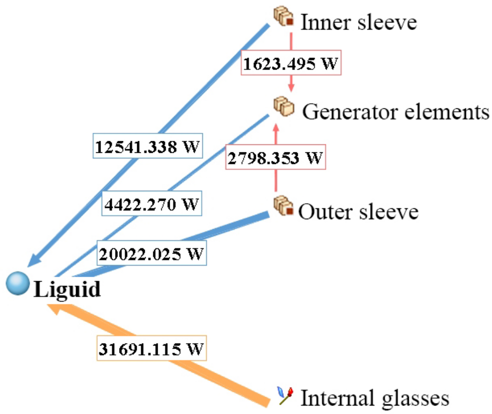

Figure 6. Heat flow in the thermogenerator with directioned inlet and sleeves connected in series, T_0= 60 °C

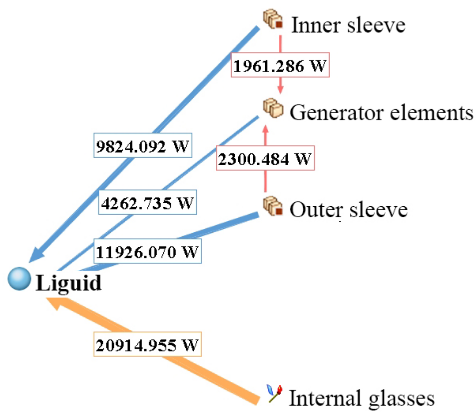

Figure 7. Heat flow in the thermogenerator with directioned inlet and sleeves connected in parallel, T_0= 60 °C

In the figures 2 – 7 are presented the conductive and convective thermal flows through the thermogenerator, at the flow rate of 1000 l/h, for each constructive model at the imposed temperature of sleeves T_0=60 °C.

Conductive heat flows occur between the glasses of inner and outer sleeves and all elements adjacent to them, in the figures are shown with red arrows. In any case, the heat from these elements is subsequently transmitted to heat transfer fluid by convection, in simulation conditions where thermal losses are negligible, P_{th}=0.

In turn, convective heat flows occur between the entire surface of the flow channel and the moving heat transfer fluid, in the figures they are shown with blue arrows. There are three major convective heat fluxes: from the outer sleeve, from the inner sleeve and from the other generator elements.

Separately, the convective heat flow only from the internal cups, which initially have a respective imposed temperature, is shown with orange arrows.

The internal glasses, mentioned above, with the imposed temperature of 60 °C, which are constructively part of the generator sleeves, are the outer glass in the inner sleeve and the inner glass in the outer sleeve, see [1, 3].

In accordance with the simulation conditions of heat flows, it should be mentioned that, initially, all elements of the generator, without the internal glasses, have a temperature equal to the ambient temperature T_a=20 °C.

Hydraulic losses or fluid energy losses, which are compensated by increasing fluid pressure to maintain a constant flow rate, are finally converted into heat energy.

These factors together influence of the liquid temperature in discharge pipe, possibly influencing the distribution of thermal flows through the thermogenerator and, as a result, the useful thermal flow of the thermogenerator.

3. The variation of useful heat flow in the thermogenerator depending on the flow rate

In the Table 1 are presented the results of simulations, regarding the variation of useful heat flow depending on the flow rate, for the imposed temperature of internal and external sleeves equal to T_0=60 °C, the liquid temperature in inlet pipe - T_1 = 11 °C, ambient temperature T_a=20 °C, negligible thermal energy losses P_{th}=0 and variation of liquid flow rate through the thermogenerator sleeves from 10 l/h to 3500 l/h.

The characteristic quantity for the heat transfer intensity is the heat flux absorbed by the heat transfer liquid, quantity denoted by $\dot{Q}$. In the given case, for the thermogenerator, the useful heat flow can be calculated using the expression:

$$\dot{Q}_{ut} = \dot{M} \cdot c_p \cdot (T_2 - T_1) \quad (2)$$

where:

$\dot{M}$ - mass flow, in kg/s;

c_p - specific heat of the heat transfer liquid, in $kJ/kG \cdot °C$;

T_2 - temperature of the liquid in the discharge pipe, in $°C$;

T_1 - temperature of the liquid in the inlet pipe, in $°C$.

According to the simulation results, variation of the useful heat flow for all constructive models, when sleeves is connected the in series and parallel, has the same shape of the curve, which can be characterized as follows: with increase in the flow rate of liquid through the thermogenerator, the value of useful heat flow also increases, figure 8.

This happens due to the fact that at a higher flow rate, the mass flow rate is also higher, respectively, in a unit of time, a larger volume of liquid passes through the thermogenerator sleeves and a larger amount of heat is absorbed, respectively.

The following were found:

1. In the constructive models with the sleeves connected in series, the useful thermal flow has a higher value compared to the same models but with the sleeves connected in parallel, figure 8. This is explained by the fact that when connected in series, the temperature difference$(T_2 - T_1)$, is higher than when the connection is in parallel, see [3].
2. It is observed that in the constructive model with directed intake, when connecting the jackets in series, the useful thermal flow presents the highest values, followed by the same model, only with the jackets connected in parallel. This is because in these constructive models, the total surface area of the flow channel is greater compared to the other models. The surface area of contact of the liquid with the surface of the flow channel is larger because inside the jackets metal sheet spirals are mounted to direct the flow of heat transfer liquid.

Table 1. The variation of useful heat flow depending on the flow rate $\dot{Q}_{ut}(Q)$, T_0=60 °C

Useful heat flow depending on the flow rate, for T_a=20 °C; T_0=60 °C; T_1=11 °C and P_{th}=0						
Flow rate, l/h	Useful heat flow $\dot{Q}_{ut}$, kW					
	Model with sleeves connected in series			Model with sleeves connected in parallel		
	with direct inlet	with direct inlet through internal pipe	with directioned inlet	with direct inlet	with direct inlet through internal pipe	with directioned inlet
10	0,55	0,55	0,57	0,55	0,55	0,57
50	2,33	2,28	2,82	2,05	1,99	2,80
100	4,00	3,84	5,46	3,36	3,19	5,32
500	11,98	11,18	21,44	8,28	7,99	14,76
1000	19,17	19,17	39,32	14,00	12,38	26,09
1500	25,59	27,48	56,34	18,87	16,63	35,82
2000	32,76	35,83	72,76	24,89	21,32	45,04
2500	38,71	44,05	88,76	31,23	25,84	53,97
3000	45,24	52,02	104,48	36,24	30,09	62,62
3500	52,49	60,12	120,07	41,72	34,88	71,01

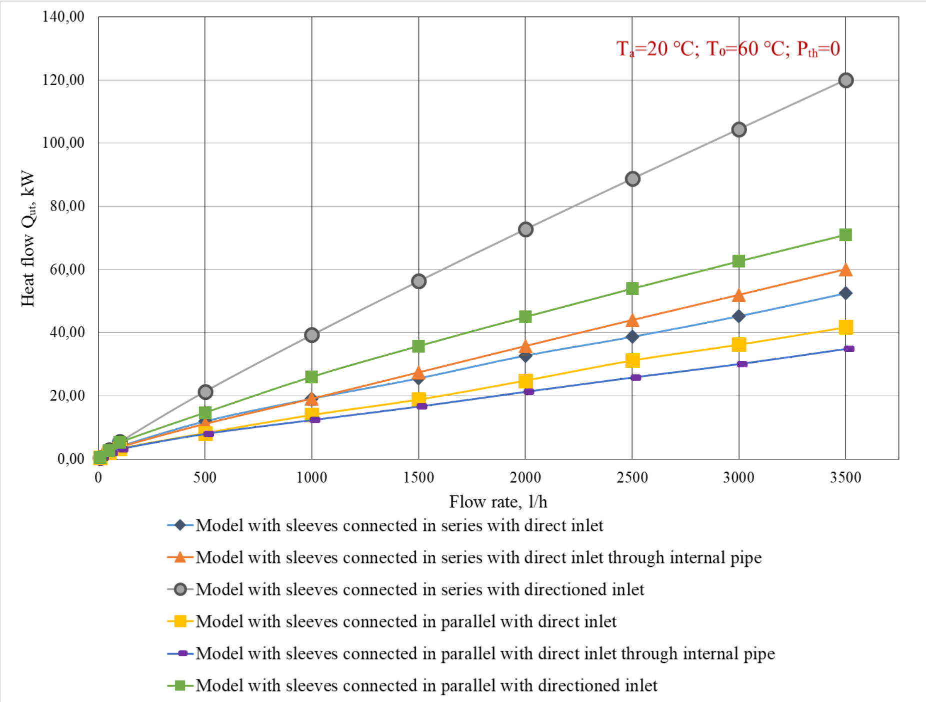

Figure 8. The variation of useful heat flow as function of the flow rate $\dot{Q}_{ut}(Q)$, **T_0=60 °C**

4. Conclusion

Were performed simulations to determine the circulation and heat transfer and to determine the quantitative relations of heat exchange through the thermogenerator depending on the flow rate, to variation through the thermogenerator sleeves from **10 to 3500 l/h**.

From the point of view of heat transfer efficiency, according to the results shown in table 1 and the heat flux variation characteristic, figure 8, the constructive model with directioned inlet with sleeves connected in series, has a higher heat transfer efficiency the heat flow values being significantly higher compared to the other models due to the fact that in this constructive model the total surface area of the flow channel is larger compared to the other models.

A positive effect on the thermal characteristics of the thermogenerator is attested because of mounting sheet metal spirals in the thermogenerator sleeves to directing the flow of heat transfer liquid. Both values of the temperature of heat transfer liquid in the discharge pipe and the values of the useful heat flows are twice as high compared to the other cases.

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