MODELING A RENEWABLE ENERGY SOURCE USING MATLAB

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ABSTRACT. As a result of the human progress, the energy consumption is constantly increasing all over the world. A major part of the produced electricity comes from natural fuels, which are decreasing year by year. A structural model of the alternative device, which allows to obtain electrical energy using thermal expansion and contraction of matters is proposed in this work. The MATLAB model of the device is presented and discussed.

KEY WORDS: thermal expansion and contraction, electricity generation, high pressure vessel, mathematical model.

1. Materials and Methods

1.1. Physical model

The physical model of the device is presented in Figure 1. The structure and principle of operation is as follows. The main reservoir (1), with a big volume, which can hold high pressure, is completely filled with the working fluid (in our case pure water) avoiding presence of air. As the temperature starts to increase, the working liquid begins to expand. Due to there is no extra volume in the reservoir, excess of working liquid comes to the transducer (3) through the connection pipe (2). The transducer (3) will transform the linear motion of the working liquid into circular motion and transfers into the generator (7) through the band drive (6). The water, passed the transducer (3) will flow to the small reservoir (4) through the connection pipe (2). The small reservoir (4) is equipped with the freely moving piston (5).

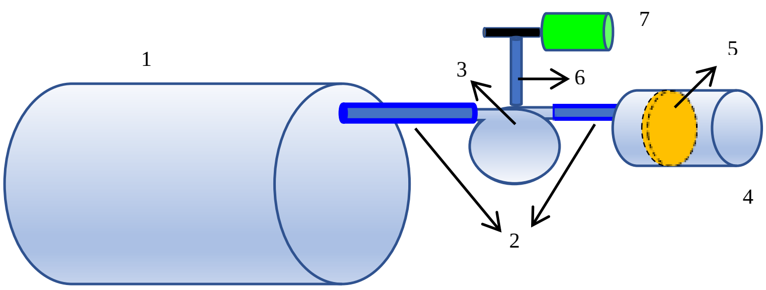

Figure 1. Physical model of the device. 1 – main reservoir, 2 – connection pipes, 3 – transducer, 4 – small reservoir, 5 – free moving piston, 6 – band drive, 7 – generator.

The transducer is like a positive displacement pump, shown in the Figure 2. Excess of water, under high pressure, will pass through the pump, rotate its blades, let say clockwise, and gather in small reservoir moving the piston (5). The generator (7) sets in motion through the band drive (6) and the electricity will be produced. This process continues until temperature ceases to rise. When the temperature starts to drop the working liquid in the main reservoir begins to contract and a vacuum is created here. The water from the small reservoir will be absorbed into the main reservoir. The water will pass through the transducer in opposite direction and rotate its blades counter-clockwise. The generator puts in motion and produces the electricity again. This process continues until temperature stops to drop. In such a way, the electricity is produced during both expanding and contracting of the working liquid.

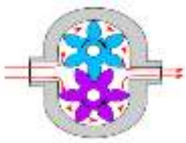

Figure 2. Positive displacement pump.

1.2. Mathematical model

The simplified model of device is presented in Figure 3. It illustrates temperature changes, changes of volume of working liquid, work executed during 24 hours, and power of the device. It was assumed, for simplicity, that the temperature of the working liquid changes synchronously with the changes of the air temperature. The amount of work (energy) obtained in isobaric process is calculated.

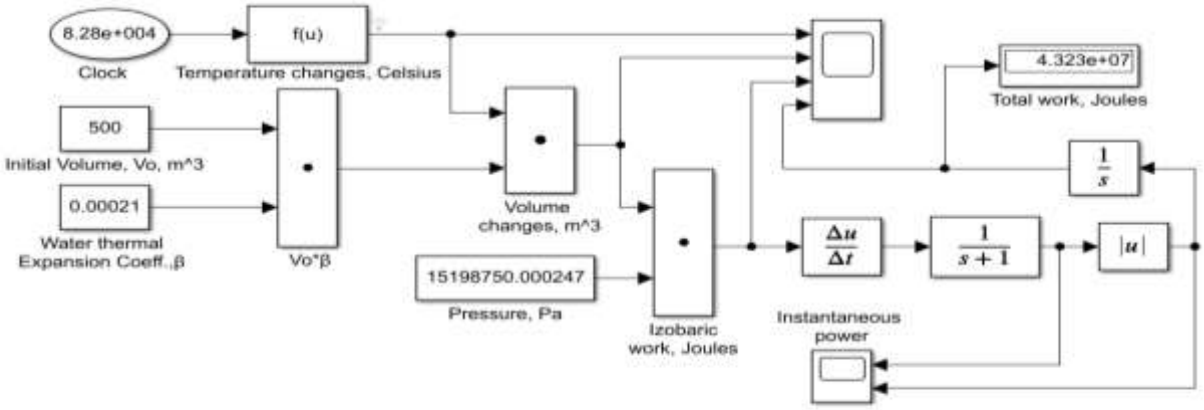

Figure 3. The simplified model of device.

The model simulates production of work by changing the volume of the working liquid at constant pressure, defined as

$$Work = P\Delta V, \tag{1}$$

where P – is the constant pressure in the main reservoir and ΔV – is the change in volume of the working liquid with time. The model calculates the summary work using data such as initial volume of the working liquid, its thermal expansion coefficient, pressure in reservoir and temperature changes in 24 hours.

The derivative block, with the initial output equal to zero, was used to calculate the instantaneous power. It should be taken into account that this block can be sensitive to the model dynamics in some cases. It is obvious, that the accuracy of the output signal is influenced by size of the time steps taken during simulation. So as to get a smoother and more accurate output signal from this block we need as smaller steps as possible. But again, the possibilities of the solver should be taken into account. The blocks that have continuous states have no problem with the solver, while when in the blocks such as the derivative, with the fast changes of input signals, cannot take smaller steps. Therefore, in some cases the output signal of the derivative block can include unwanted fluctuations depending on the model and driving signal dynamics. We were observed the unexpected fluctuations appeared at the initial output, which affected the desired picture of instantaneous power, and the transfer function block was used to avoid these inaccuracies.

2. Experiment with real temperature fluctuations

2.1. Curve fitting

To evaluate the capability of our machine we tried to realize its work in real temperature conditions. Hourly forecast of temperature fluctuations in Jizzakh town (Uzbekistan) in 24 hours for April 1 in 2023 was chosen [1]. Table 1 shows temperature changes from 12AM to 11PM.

Table 1. Temperature changes in Jizzakh town (Uzbekistan) from 12AM to 11PM on April 1, 2023.

Hours	12AM	1AM	2AM	3AM	4AM	5AM	6AM	7AM
T, °C	16	15	14	13	12	12	11	12

8AM	9AM	10AM	11AM	12PM	1PM	2PM	3PM
14	17	18	20	22	23	24	25

4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM
25	24	24	22	20	19	17	16

MATLAB curve fitting results.

Linear model Poly6:

$f(u) = p_1*u^6 + p_2*u^5 + p_3*u^4 + p_4*u^3 + p_5*u^2 + p_6*u + p_7$

Coefficients (with 95% confidence bounds):

p_1 = -2.098e-27 (-3.855e-27, -3.415e-28)
p_2 = 6.686e-22 (2.307e-22, 1.107e-21)
p_3 = -7.67e-17 (-1.182e-16, -3.521e-17)
p_4 = 3.668e-12 (1.812e-12, 5.524e-12)
p_5 = -5.89e-08 (-9.831e-08, -1.95e-08)
p_6 = 7.253e-06 (-0.0003384, 0.0003529)
p_7 = 15.88 (14.95, 16.81)

Goodness of fit:
SSE (sum square error): 3.752
R-square: 0.9926
Adjusted R-square: 0.9899
RMSE (root-mean-square error): 0.4698

2.2. Virtual experiment results

Changes in environment temperature, volume of the working fluid, instantaneous work, and total work obtained during the chosen period of time are presented in Figure 4.

The temperature drops from 16 °C to 11 °C during the first 6 hours, then increases up to 25 °C during the next 10 hours and drops to 16 °C again during the last 7 hours (Figure 4a). The volume of the working fluid and instantaneous work are change synchronously with the temperature changes (Figures 4b and 4c). The total work is calculated as accumulative value and shows the total value made during whole period considered (Figure 4d). The instantaneous power and absolute instantaneous power are presented in Figure 5.

3. Discussion

The temperature changes for a given period can be divided in to three parts. From the beginning it drops, then increases and drops again (Figure 4a). Changes in temperature, ΔT, leads to changes in volume of working liquid, ΔV, according to expression [2]:

$$\Delta V = V_0 \beta \Delta T, \qquad (2)$$

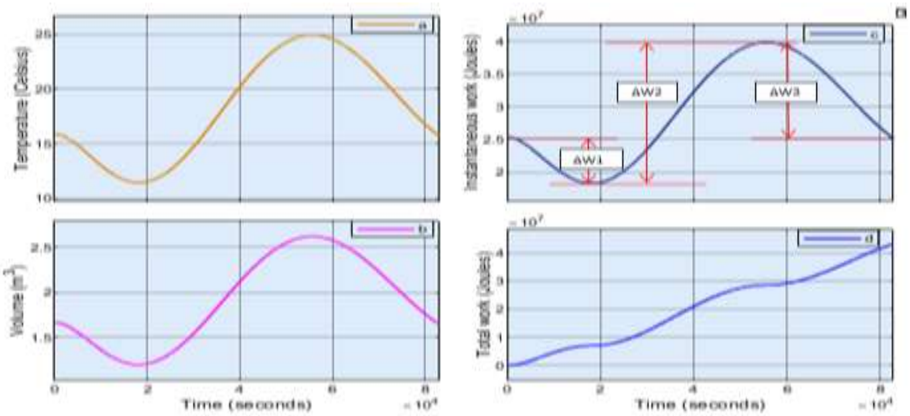

Figure 4. Daily changes in: a) environment temperature, b) volume of the working fluid, c) instantaneous work, and d) total work.

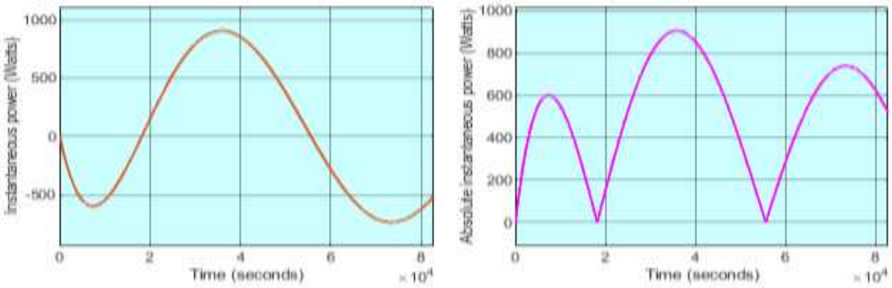

Figure 5. The instantaneous power (left) and absolute instantaneous power (right).

where V_0 is the initial volume of the working liquid and $\beta=210\cdot10^{-6}\ {}^oC^{-1}$ is the coefficient of thermal expansion of water [3], since in our experiments we are use the pure water as a working liquid with the initial volume 500 m^3. In reality, changes of volume of the working liquid will follow changes in environment temperature with some delay. Evaluating of this delay and taking it into account is not difficult, but requires the real experiments with the real reservoir. Because of that our research is in stage of design and for simplicity, we ignore the time delays and assume that the volume changes synchronously with the environment temperature (Figure 4b).

The work done due to expansion of the working liquid can be expressed as [4]:

$$W=PV_0\beta\Delta T, \quad (3)$$

where P is the pressure inside of the reservoir, and its constant value at temperature changes will be supported by the volume changes. According to our assumptions the instantaneous work also will change synchronously with the environment temperature which is seen from (2) and (3). The total work done during the considered period can be calculated as the sum of works performed in three periods of time (Figure 4c). The values of $\Delta W1$, $\Delta W2$ and $\Delta W3$ can be found from the matlab data: $\Delta W1=0.705e+07\ J$ is the work obtained from the starting point, when time t_s is zero until the temperature reaches the minimum (t_{min} = *18193.419 seconds*); $\Delta W2=2.152e+07\ J$ is the work obtained from the time t_{min} until the temperature reaches the maximum (t_{max}=*55625.985 seconds*); $\Delta W3=1.465e+07\ J$ is the work performed from the time t_{max} until the end of our virtual experiment (t_{end}=*82800 seconds*). The total work done during the 24 hours, *W=4.322e+07*, is very close to the value of total work indicated at the end of the experiment (Figure 4d and Figure 3).

Expressing the work, performed by our model in considered period, as energy, we get *4.322e+07 Watts/24hours* or *1800 kwt/hour*. If assume this amount of energy as an average value per a day, for a year we have 6.57e+05 *kwt/hour*. This value of energy is comparable with the energy produced by medium size wind turbines and solar panels in a year.

It can be seen from the above discussions, that the work will be performed during both temperature drop and temperature rise. In such a way, the power also cannot be negative as seen from Figure 5left. Therefore, instantaneous power should be presented as in Figure 5right.

In our previous research it was observed that liquid works well in expansion, but it did not give expected results in contraction. The phenomena were explained with the small intermolecular forces in liquids to compare with solids [3]. We face such situation with our device also. Here we have two options. On the one hand, it can be refused the work performed during the temperature drop, and this will reduce the efficiency of the device. But in the other hand, we can use contraction of solid materials [5] and create the hybrid system. The liquid will perform work during temperature rise by expansion. During temperature drop the vacuum will be created due to contraction of the liquid in the main reservoir and solid material will also contract, move the piston (5) (Figure 1) and help suction of the liquid from the small reservoir (4) into the main reservoir (1).

4. Conclusion

Preliminary calculations show that if design a hybrid model it will be possible avoid drawbacks and join advantages of both liquid and solid thermal expansion and this model will be not inferior to windmills and solar batteries. Because there are at least three possibilities to increase the power of a such device: the power is directly proportional to the pressure in the main reservoir and its volume; using the liquid and solid materials with a bigger coefficient of thermal expansion will lead to increase the power.

5. References

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