

# Numerical calculation of a sea water heat exchanger using Simulink software

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**Abstract.** To highlight the heat exchange taking place between seawater as primary agent and the working fluid (water, glycol or Freon) as secondary agent, I have used the Simulink software in order to create a new sequence for numerical calculation of heat exchanging. For optimum heat transfer we opted for a counter movement. The model developed to view the dynamic behavior of the exchanger consists of four interconnected levels. In the simulations was found that a finer mesh of the whole exchanger lead to results much closer to reality. There have been various models meshing, starting from a single cell and then advancing noticed an improvement in results. Simulations were made in both the summer and the winter, using as a secondary agent process water and glycol solution. Studying heat transfer that occurs in the primary exchanger of a heat pump, having the primary fluid sea water with this program, we get the data plausible and worthy of consideration. Inserting into the program, the seasonal water temperatures of Black Sea water layers, we get an encouraging picture about storage capacity and heat transfer of sea water.

## 1. Introduction

In order to study heat transfer taking place inside the of principal exchanger, between sea water and secondary working fluid; we have created a numerical program in the Simulink extension of the program Matlab.

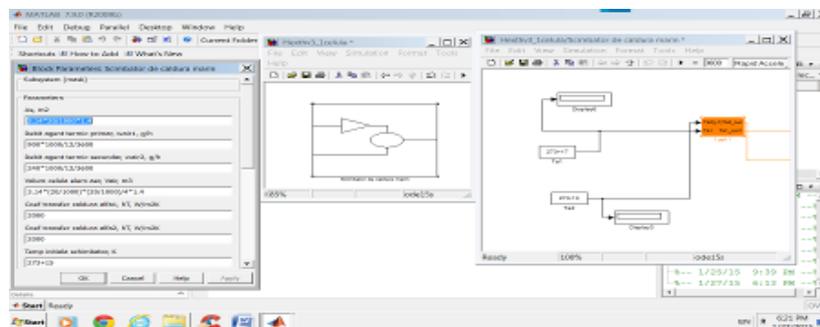
The Matlab platform (developed by Matrix Laboratory) is a development environment for numerical calculation and statistical analysis that contains the programming language of the same name. MATLAB allows matrix manipulation, viewing the functions, implementation of algorithms, creation of user interfaces and can interact with other applications.

Even though specializes in numerical computing, there are packages that allow it to interact with the computer algebra engine Maple. An additional package, Simulink, offers the possibility to carry out simulations of the dynamical systems using mathematical models. MATLAB is used extensively in industry, in universities and it's cross-platform, available under various operating systems: Windows, GNU/Linux, UNIX and Mac OS. As extension of the software package Matlab, Simulink provides a graphical user interface for the achievement of dynamic systems models represented in the block diagram. Can be simulated so linear and nonlinear systems, modeled in continuous time or discrete or a combination of both. Systems may have sampled portions with different sampling frequencies



## 2. Numerical calculation of the heat exchanger, with Simulink

System modeling is provided an intuitive graphical interface and very easy to use. The blocks are placed and interconnected with the help of the mouse which is a very big advantage (versus direct writing of differential equations that define a system). Simulink provides a very large collection of blocks such as signal generators, visualization tools, performing mathematical functions, linear and nonlinear components. The set of blocks supplied can be expanded at any time with new blocks-is provided complete documentation about how you can create a new block. More blocks may be grouped in a block at any time again, thus providing extended the analysis to a higher level of organization. Complex models is performed hierarchically by creating blocks grouped into subsystems. These subsystems can interconnect them resolving a single system where the sizes of input and output. After realizing the mathematical model of the system, the next step is a dynamic simulation by using one of the methods of numerical integration provided by the program (Ode45, Ode23, etc).



**Figure 1.** How to work the program Simulink.

Dynamic simulation of the analyzed system relies on knowledge of the system of differential equations, block scheme on and of course on the use of a method of numerical integration. The simulation results can be displayed both graphically and in the form of numeric tables. Using library blocks S-Functions you can create your own blocks, which integrates into existing schemes, made with blocks from standard library. A signal trajectory visualization require in a first step to create a mathematical model, implemented in Simulink by a block diagram. The next step includes the choice of method of integration and the minimum and maximum simulation model and visualization effects.

Creating models in Simulink means: building a block diagrams (schematics) based on the mathematical model of the system, arranged so that the resulting size of input-output.

*Modeling and State-simulating* a dynamical system contains two steps:-creating a model graphically using models of the core editor base of bookshop Simulink (modeling dynamic system). The dynamic model describing the mathematical equations of the system you want to recompile it, depending on the time, setting the sizes of input-output-condition. These equations can include algebraic equations, integrals and differentials.

*Simulation of operating regimes* of the system in a certain period of time. Simulinkul uses the information in the user input inside the model for practical achievement of simulation (dynamic system simulation).

### 2.1. Model initialization

During the boot process Simulinkul evaluates expressions parameters in mathematical model building blocks to determine their values, determines the quality of the signal (type and size), and check whether each block can accept signals generated by the input parameters. Also in this Simulinkul phase determines the required memory status parameters and the required simulation time determining

the sampling time of the existing blocks in the model in question and they sort in the order they must be run (executed)

2.2. Model execution

Simulink implementation phase assesses the status and succession sizes sizes output system on the time set (simulation time start-stop time) by using the information provided by the mathematical model of dynamic system. Simulinkul provides the ability for a system with both simulation step (fixed) and step variable. The difference lies in the fact that if you choose a variable step can improve the accuracy of the simulation by reducing the size of the step (useless steps will be eliminated). Also, you can choose the method of numerical integration Solver menu. Methods of integration of continuous systems are methods of classical numerical (Runge-Kutta, Adams, the Euler method, Rosenbrock mapsheets, etc.)

3. Mathematical modeling of heat exchange between sea water and working fluid

To detect thermal Exchange that occurs between sea water as the primary agent and working fluid (water, water with glycol or freon) as the secondary agent we used classical equations of heat transfer from heat engineering. They put the value of the two agents both flow and temperature differences occurring at their counter.

The first part of the heat exchange is made by convection; the two agents actually washed the walls of pipes while their heat. Step two is the heat transfer through conduction pipes in the wall.

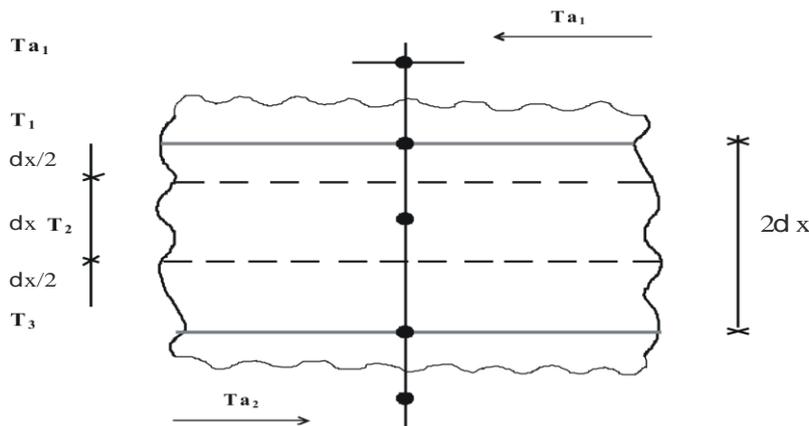


Figure 2. Elementary cell representation of heat transfer.

To be able to calculate the amount of heat the seawater ceded, and the spread of the secondary fluid temperature consider some key points of thermal exchange control which we call nodes. Thus the knot  $T_{a1}$  is poźionat in the middle of the current line of the primary fluid and indicates its temperature. The node  $T_1$  is located exactly at the contact with the exhaust pipe; heat balance equation are :

Nod  $T_{a1}$

$$\rho_a V_a c p_a \frac{dT_{ap\check{a}1}}{dt} = h_{T1} A_s (T_1 - T_{a1}) + w_{a1} c p_{ap\check{a}1} (T_{ai j+1} - T_{ap\check{a}1}) \quad (1)$$

Nod  $T_1$

$$\rho_m \frac{\delta_{xm}}{2} c p_m \frac{dT_2}{dT} = \frac{\lambda_m}{\delta_{xm}} (T_2 - T_1) + h_{T1} (T_{ap\check{a}1} - T_1). \quad (2)$$

The third landmark, is located in the middle of the respective pipe thickness.

Nod T<sub>2</sub>

$$\rho_m \delta_x c p_m \frac{dT_2}{dT} = \frac{\lambda_m}{\delta_{x_m}} (T_2 - T_1) + \frac{\lambda_m}{\delta_{x_m}} (T_2 - T_3) \quad (3)$$

The fourth landmark, is placed on the bottom of the pipe, at the contact with the secondary fluid

Nod T<sub>3</sub>

$$\rho_m \frac{\delta_{x_m}}{2} c p_m \frac{dT_3}{dT} = \frac{\lambda_m}{\delta_{x_m}} (T_3 - T_2) + h_{T2} (T_3 - T_{ap\ddot{a}2}) \quad (4)$$

The last control point and the temperature is in the current line of fluid; may write equation of heat transfer

Nod T<sub>a2</sub>

$$\rho_a V_a c p_a \frac{dT_{ap\ddot{a}2}}{dt} = h_{T2} A_s (T_3 - T_{ap\ddot{a}2}) + w_{ap\ddot{a}2} c p_{ap\ddot{a}2} (T_{ap\ddot{a}j+1} - T_{ap\ddot{a}2}) \quad (5)$$

Where:

$\rho_a$  - fluid density [kg/mc],

$V_a$ - volume of elementary cell [m<sup>3</sup>],

$c_{pa}$ -specific heat of fluid [J/kg K],

$h_{T1}$ - coefficient of heat transfer in boundary layer [W/mp K],

$A_s$ - area of elementary cell [m<sup>2</sup>],

$w_{ap\ddot{a}}$ -fluid flow [kg/s],

$c_{pm}$ - dpecific heat of metal [J/kg K].

Mathematical model in this case is iterative, and one is focused on the results that occur when the heat exchanger has reached thermodynamic equilibrium. Through a hold under a strict observation of the forming parameters of the Exchange, and taking into account the above five equations, we obtain a clear and credible view of the amount of heat transferred between the two fluids.

#### 4. The geometry and structure of the programme

The heat exchanger modeled through this program is the type of tube in tube and has 24 pipe with a diameter of 22 mm each. For an optimal heat transfer I opted for a counter-flow circulation.

The model developed in order to view the dynamic behavior of the exchanger consists of four interconnected levels. The first level is the basis for the programme. Here are the defined heat transfer equations and relations between them.

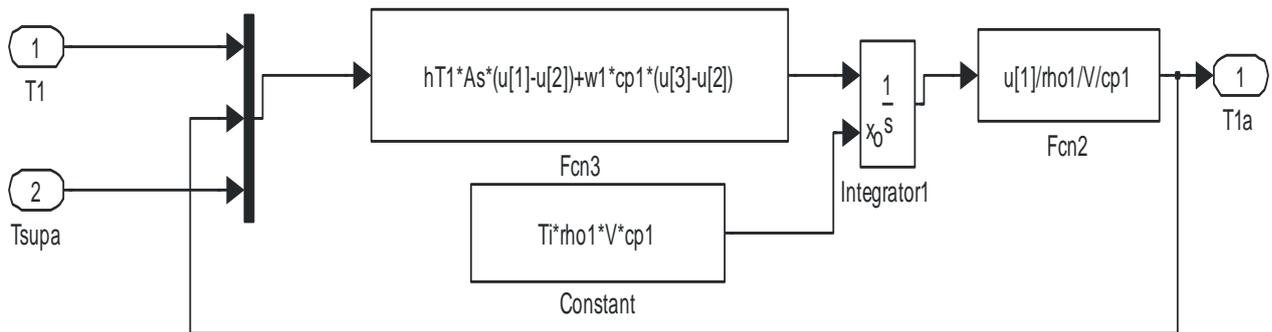


Figure 3. Block diagram corresponding to level 1.

In order to obtain credible data from the exchange of heat exchanger has been meshed into several basic cells. So in the second level we define heat exchange in blocks with all the processes taking place. To follow the temperature variation we attach oscilloscope blocks type. . Each block contains equations related and necessary part of the process.

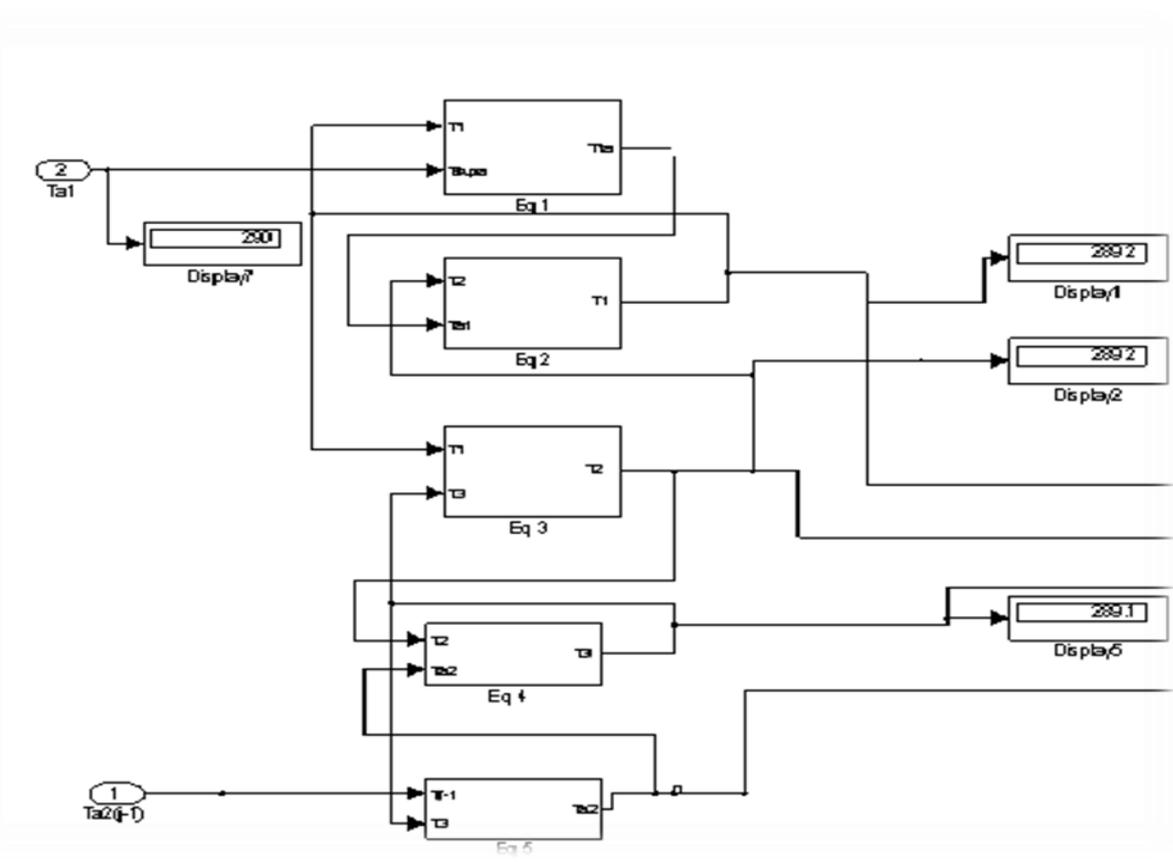


Figure 4. Block diagram corresponding to level 2.

As a result of simulations, it was found that a finer mesh of the whole exchanger leads to much closer to reality. There have been various mesh patterns, starting from a single cell and then moving I noticed an improvement in results. From one cell and up to five decades dates vary by becoming more accurate. After exceeding this number, the data tend to become constant, so I stopped with the mesh to five dozens of cells. First level presents an overview of the elements and is the interface that allows us to change the entry temperatures of the two agents, their characteristics and simulation mode.

**5. Study of heat exchange**

The program allows viewing, both created in the form of graphs and tabular form, of the data obtained. It generates a file with the extension .xls that provides temperature values for those five nodes where we want to make the study. You can view and a change in the interim after just ten cells using the oscilloscope function that is included in the program.

These are the partial data can show us whether or not the Exchange takes place and if I entered the data correctly. Time step is variable. The steps are closer one to each other when there is a significant exchange or distents when the Exchange diminishes, the latter being an effect of the heat exchanger to achieve balance. So it is possible to determine the time until the exchanger enters under constant operation.

*5.1 Sea water – technological water*

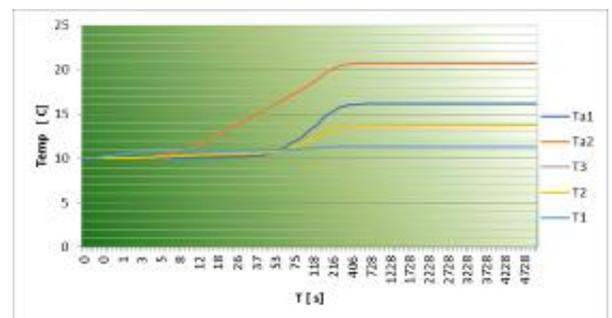
For the study of heat exchange in summer and winter I choose a variable time step and a total length of 5000 seconds

**Table 1.** Temperature variation in 5 nodes – summer.

Time	Ta1	Ta2	T3	T2	T1
s	°C	°C	°C	°C	°C
0.00	10.000	10.000	10.000	10.000	10.000
0.03	10.000	10.000	10.000	10.000	10.019
0.06	10.000	10.000	10.000	10.000	10.038
0.09	10.000	10.000	10.000	10.001	10.057
0.21	10.000	10.000	10.001	10.002	10.120
0.32	10.000	10.000	10.002	10.004	10.179
0.43	10.000	10.001	10.004	10.006	10.233
0.54	10.000	10.001	10.006	10.009	10.283
0.75	10.000	10.004	10.011	10.015	10.365
0.95	10.000	10.007	10.018	10.022	10.435
1.16	10.001	10.013	10.025	10.030	10.496
1.36	10.001	10.020	10.033	10.039	10.548
1.57	10.001	10.028	10.041	10.048	10.593
1.88	10.002	10.045	10.055	10.062	10.651
.....	.....	.....	.....	.....	.....
4828.29	16.159	20.735	13.758	13.722	11.357
4928.29	16.159	20.735	13.758	13.722	11.357
5000.00	16.159	20.735	13.758	13.722	11.357

**Table 2.** Summer simulation data.

Tsecondary agent	11	°C
T primary agent	22	°C
$\alpha_1$	2000	W/m <sup>2</sup> *K
$\alpha_2$	2000	W/m <sup>2</sup> *K
Ti exchanger	10	°C
$\lambda$ metal	385	W/m*K
$\rho_{metal}$	7874	kg/m <sup>3</sup>
$\rho_{primar}$	1050	kg/m <sup>3</sup>
$\rho_{secundar}$	1000	kg/m <sup>3</sup>
Cp metal	500	J/kg*K
Cp primar	4186	J/kg*K
Cp secundar	4186	J/kg*K



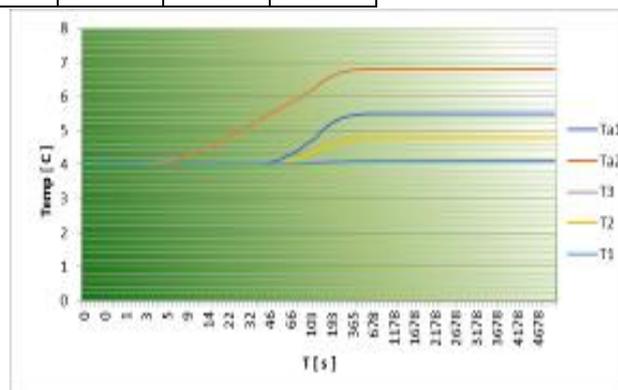
**Figure 5.** Summer temperature variation.

**Table 3.** Temperature variation in 5 nodes – winter.

Time	Ta1	Ta2	T3	T2	T1
s	°C	°C	°C	°C	°C
0.000	4.000	4.000	4.000	4.000	4.000
0.038	4.000	4.000	4.000	4.000	4.000
0.077	4.000	4.000	4.000	4.000	4.000
0.115	4.000	4.000	4.000	4.000	4.000
0.243	4.000	4.000	4.000	4.000	4.000
0.371	4.000	4.000	4.000	4.000	4.000
0.499	4.000	4.000	4.000	4.000	4.000
0.627	4.000	4.001	4.000	4.000	4.000
0.861	4.000	4.001	4.000	4.000	4.000
1.095	4.000	4.003	4.000	4.000	4.000
1.329	4.000	4.005	4.000	4.000	4.000
1.563	4.000	4.007	4.000	4.000	4.000
1.797	4.000	4.011	4.000	4.000	4.000
2.161	4.000	4.016	4.000	4.000	4.000
.....	.....	.....	.....	.....	.....
4877.591	5.487	6.805	4.795	4.784	4.103
4977.591	5.487	6.805	4.795	4.784	4.103
5000.000	5.487	6.805	4.795	4.784	4.103

**Table 4.** Winter simulation data.

T secondary agent	4	°C
T primary agent	7.17	°C
$\alpha_1$	2000	W/m <sup>2</sup> *K
$\alpha_2$	2000	W/m <sup>2</sup> *K
Ti exchanger	10	°C
$\lambda$ metal	385	W/m*K
$\rho_{metal}$	7874	kg/m <sup>3</sup>
$\rho_{primar}$	1050	kg/m <sup>3</sup>
$\rho_{secundar}$	1000	kg/m <sup>3</sup>
Cp metal	500	J/kg*K
Cp primar	4186	J/kg*K
Cp secundar	4186	J/kg*K



**Figure 6.** Winter temperature variation.

5.2 Sea water - water & glycol

For the study of thermal Exchange related to those two periods, keep variable time step and to limit the duration of all 5000 seconds. The solution used in the simulation is at the rate of 50% water and 50% glycol.

**Table 5.** Temperature variation in 5 nodes – summer.

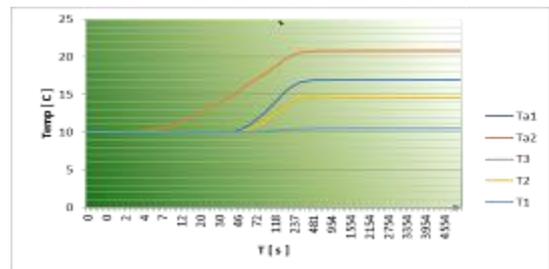
<b>Timp</b>	<b>Ta1</b>	<b>Ta2</b>	<b>T3</b>	<b>T2</b>	<b>T1</b>
<b>s</b>	°C	°C	°C	°C	°C
<b>0.000</b>	10.000	10.000	10.000	10.000	10.000
<b>0.031</b>	10.000	10.000	10.000	10.000	10.000
<b>1.365</b>	10.000	10.014	10.000	10.000	10.000
<b>1.571</b>	10.000	10.020	10.000	10.000	10.000
<b>1.365</b>	10.000	10.014	10.000	10.000	10.000
.....	.....	.....	.....	.....	.....
<b>4653.613</b>	16.928	20.768	14.584	14.548	10.445
<b>4753.613</b>	16.928	20.768	14.584	14.548	10.445
<b>4812.613</b>	16.928	20.768	14.584	14.548	10.445
<b>4853.613</b>	16.928	20.768	14.584	14.548	10.445
<b>4953.613</b>	16.928	20.768	14.584	14.548	10.445
<b>5000.000</b>	<b>16.928</b>	<b>20.768</b>	14.584	14.548	10.445

**Table 7.** Temperature variation in 5 nodes – winter.

<b>Timp</b>	<b>Ta1</b>	<b>Ta2</b>	<b>T3</b>	<b>T2</b>	<b>T1</b>
<b>s</b>	°C	°C	°C	°C	°C
<b>0.000</b>	4.000	4.000	4.000	4.000	4.000
<b>0.038</b>	4.000	4.000	4.000	4.000	4.000
<b>0.077</b>	4.000	4.000	4.000	4.000	4.000
<b>0.115</b>	4.000	4.000	4.000	4.000	4.000
<b>0.243</b>	4.000	4.000	4.000	4.000	4.000
<b>0.371</b>	4.000	4.000	4.000	4.000	4.000
<b>0.499</b>	4.000	4.000	4.000	4.000	4.000
<b>0.627</b>	4.000	4.000	4.000	4.000	4.000
<b>0.861</b>	4.000	4.001	4.000	4.000	4.000
.....	.....	.....	.....	.....	.....
<b>4442.791</b>	5.830	6.845	5.211	5.201	4.117
<b>4542.791</b>	5.830	6.845	5.211	5.201	4.117
<b>4642.791</b>	5.830	6.845	5.211	5.201	4.117
<b>4742.791</b>	5.830	6.845	5.211	5.201	4.117
<b>4842.791</b>	5.830	6.845	5.211	5.201	4.117
<b>4942.791</b>	5.830	6.845	5.211	5.201	4.117
<b>5000.000</b>	5.830	6.845	5.211	5.201	4.117

**Table 6.** Summer simulation data.

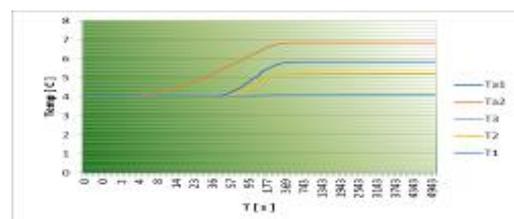
T secondary agent	10	°C
T primary agent	22	°C
$\alpha_1$	2000	W/m <sup>2</sup> *K
$\alpha_2$	1125	W/m <sup>2</sup> *K
Ti exchanger	10	°C
$\lambda$ metal	385	W/m*K
$\rho_{metal}$	7874	kg/m <sup>3</sup>
$\rho_{primar}$	1050	kg/m <sup>3</sup>
$\rho_{secundar}$	1000	kg/m <sup>3</sup>
Cp metal	500	J/kg*K
Cp primar	4186	J/kg*K
Cp secundar	3286	J/kg*K



**Figure 7.** Summer temperature variation.

**Table 8.** Winter simulation data.

T secondary agent	4	°C
T primary agent	7,17	°C
$\alpha_1$	2000	W/m <sup>2</sup> *K
$\alpha_2$	1125	W/m <sup>2</sup> *K
Ti exchanger	10	°C
$\lambda$ metal	385	W/m*K
$\rho_{metal}$	7874	kg/m <sup>3</sup>
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Cp metal	500	J/kg*K
Cp primar	4186	J/kg*K
Cp secundar	3286	J/kg*K



**Figure 8.** Winter temperature.

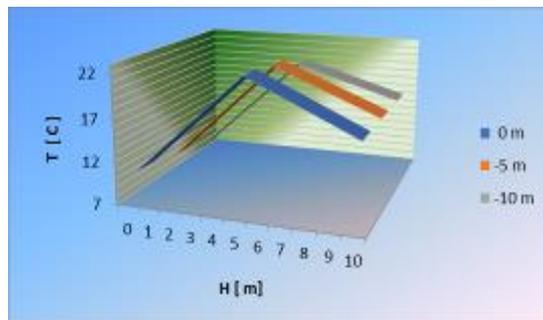
## 6. Conclusions

Studying heat transfer, which takes place in the primary exchanger of a sea - water heat pump using improved program, we could give plausible data and worthy to be taken into account. If we insert in the program the seasonal variation of water temperature in the Black Sea, we obtain a joyful picture regarding the high energy potential of sea water. At the same time, thanks to new technologies of heat transfer, which are implemented through heat pumps, sea water can be consider an alternative source of renewable energy.

Being a numerical simulation program with variable time step, some output data may not concure with reality; therefore need to be analysed and compared with those in the experiment. Data reveals both the ability and the performance of the primary source of machinery used in the extraction of thermal energy.

The amount of heat that can be extracted from sea water varies both with the depth and seasonality. This can range from a couple hundred joules up to some tens of kilojouli depending on the type and power of heat pumps used.

Depth	Spring	Summer	Fall	Winter
0	10.32	22.12	16.31	6.91
5	9.41	21.49	16.36	7.17
10	8.49	20.07	16.33	7.44



**Figure 9.** Temperature variation in the Black Sea, during a year, depending on the depth.

Important is the average each season in part establishing a fixed depth from which water is extracted. This average is the basis of the technical and economic calculation which relates to the entire system.

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