CONSTANTA MARITIME UNIVERSITY

FACULTY OF NAVAL ELECTROMECHANICS

DOCTORAL THESIS

RESEARCH ON THE USE OF SEA WATER THERMAL ENERGY WITH APPLICATIONS IN DESIGNING MARINE HEAT PUMP

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SUMARY OF THESIS

This work deepens the side of scientific research into heat pumps , namely that which relates to the use of the energy potential of sea water in these systems .

The research had as first element starting study ways in which heat is produced both for domestic consumption and for industrial, with the adverse impact they have such installations on the environment.

The thesis was focused on the possibility of using temperature gradient provided by seas and waters of the oceans as an alternative and renewable source to be exploited in the production of heat in water-water type heat pumps.

Mathematical calculation involving heat transfer taking place in marine heat pump was done numerically by using two computer programs and have been validated experimentally on a stand using a model at the scale of 1:1.

Thus, this present work demonstrates, with scientific arguments, that the energy stored in seawater can represent, using it in an unconventional production of energy, namely a heat pump, a key element in the future development of a society based on renewable energy.

Key words: Marine heat pump, Fluid Mechanics, sea thermal gradient.

CONTENT

Chapter I

Introduction

The research had the first startup item, the study of the ways in which heat is produced for both domestic consumption and industrial, with the adverse impact that these plants have on the environment.

The thesis thus developed, is **important** because studies a way of using one of the types of renewable energy that nature offers us, and get the experimental validation of the effectiveness of its use within the system of marine heat pump.

It is also **appropriate** because in the current context of population growth and resources plummeting around the world, brings a new approach to the relationship between man and nature, with regard to the reduction of pollution, and that opens up new perspectives on how to research and explore this type of resource .

Chapter II

Marine energy potential

Ocean waters hold a huge energy potential that can be harnessed to produce electricity. The main energy sources taken into account, at least at the level of the current technique, refer to: marine currents, tides, waves, winds and temperature differences of marine water.

The conversion of thermal energy of the seas and oceans of water is a process that uses the natural temperature difference between the surface and depth.

The most common systems are based on the following three cycles: open cycle,closed loop and hybrid cycle ; all in the system requiring a working fluid , a condenser and an evaporator.

In terms of heat , the Black Sea continental seas presents the features located in the temperate zone , whose essential feature is the very large temperature differences are recorded in the layer of water between winter and summer .

Vertical distribution of water temperature depends on the thermal regime of the atmosphere and dynamic factors of the sea (currents and waves) , producing mixture of water bodies.

Thoroughly mix of water reaches generally 100-150 m depth and , rarely , 200 m .

Intermediate water masses and deep though they are in an ongoing exchange , but slowly , with the upper strata are subject to slight variations

Sezon	T_{0m}	T_{5m}	T_{10m}	T_{20m}	T_{30m}	T_{50m}
Iarnă	6,91	7,17	7,44	7,67	7,84	7,60
Primăvară	10,32	9,41	8,49	7,27	6,51	6,09
Vară	22,12	21,49	20,07	13,81	7,96	6,92
Toamnă	16,31	16,36	16,33	16,18	13,16	9

Table 2.1. Mean Season (1971 - 2011) of deep water temperatures , Constanta .

Chapter III

Current state of research on marine heat pump

3.1 Evolution of heat pumps

Simply put, a heat pump is an electrically driven mechanical device that absorbs thermal energy from a single location and transfer to another.
Name heat pump is relatively new for most of the heating systems ; and as such it is regarded as an innovation , entering the market in the 80s .

In 1851 the Frenchman F. Carré , designs first commercially successful cooling system that uses ammonia absorption. This was the first refrigeration machine that had a major success within the industry. Heating with heat pumps become competitive between 1919 and 1950 .

During this period , the heat pump for space heating and domestic hot water have been developed from the first prototypes that have been proven reliable in terms of economy.

Chapter IV

Marine heat pump system

Marine heat pump is based, in general, an open-loop; That is , water is Extracted from the sea through filters Some , Stored in a buffer tank (depends on functional scheme chosen) and then pumped to a heat exchanger where it meets a primary working medium (water, a mixture of water and glycol or direct freon) , releases the heat and then it is discharged back into the sea.

The first part of the installation of heat pump consists of marine feed pipes , pumps , filters and retention basin .
They are a key element in the functioning of the entire system having a pretty big impact in terms of global energy consumption thanks to the extraction pumps .

The cost of operating transport sea water can be reduced dramatically by using a gravity siphon system instead of a conventional suction system that requires a fairly large amount of electricity.

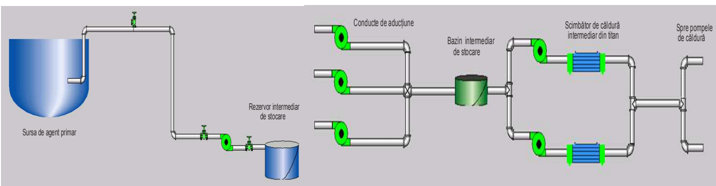


Fig.4.1 Scheme of marine heat pump system .

Chapter V

The dynamics of heat transfer in a primary heat exchanger of a marine heat pump

To highlight the heat exchange taking place between seawater as primary agent and the working fluid (water, glycol or freon) as a secondary agent we used classical equations of thermodynamics heat transfer.

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 washe the walls of pipes while the heat transfer is made . Step two is the heat transfer through conduction through the wall pipe.

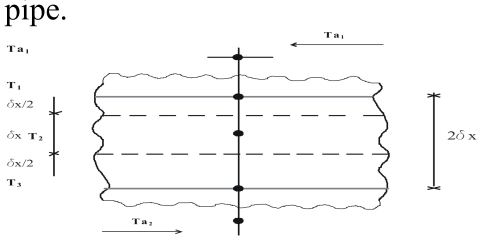


fig 5.1Elementary cell representation of heat transfer.

In order 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 is positioned in the middle of the T_a1 line of the primary fluid and indicates its temperature. The node is located exactly at T_1 in contact with the pipe; heat balance equation are:

Nod T_{a1}

$\rho_a V_a\ cp_a \frac{d_{T_{apă\,1}}}{dt} = h_{T1}\ A_s\ (T_1 - T_{a1}) + w_{a1} cp_{apă1}\ (T_{ai\ j+1} - T_{apă1})$ (5.1)

Nod T_1

$\rho_m \frac{\delta_{x_m}}{2}\ cp_m \frac{dT_1}{dT} = \frac{\lambda_m}{\delta_{x_m}}\ (T_2 - T_1) + h_{T1}(T_{apă1} - T_1)$ (5.2)

The third point of reference is located in the middle of the respective pipe thickness .

Nod T_2

$\rho_m \delta_x cp_m \frac{dT_2}{dT} = \frac{\lambda_m}{\delta_{x_m}}\ (T_2 - T_1) + \frac{\lambda_m}{\delta X_m}(T_2 - T_3)$ (5.3)

The fourth landmark T_3 , is placed on the bottom of the tube in contact with the secondary fluid.

Nod T_3

$\rho_m \frac{\delta_{x_m}}{2}\ cp_m \frac{dT_3}{dT} = \frac{\lambda_m}{\delta_{x_m}}\ (T_3 - T_2) + h_{T2}(T_3 - T_{apă\,2})$ (5.4)

Last checkpoint is in the current fluid line side ; being able to write the equation of heat transfer :

Nod T_{a2}

$\rho_a V_a\ cp_a \frac{d_{T_{apă2}}}{dt} = h_{T2}\ A_s(T_3 - T_{apă2}) + w_{apă2} cp_{apă2}\ (T_{apă\ j+1} - T_{apă2})$(5.5)

The heat exchanger modeled by this program is type tube in tube and has 24 pipes with diameter of 22 mm each. 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 .

The first level is the basis for the program. Here are defined heat transfer equations and relations .

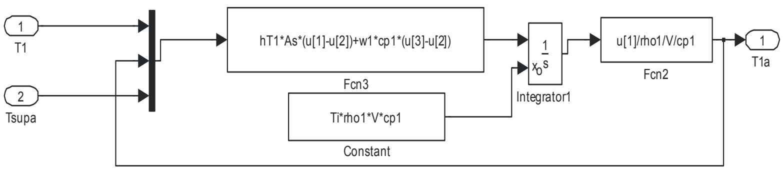


fig 5.2 The block diagram appropiate level one .

In order to obtain credible data from the exchange of heat, the exchanger has been meshed into several basic cells.
So the second level we define cell heat exchange in the form of blocks with all the processes that take place .To be able to track changes in temperature effectively we attach blocks type oscilloscope. Each block contains equations related and necessary part of the process.

Sea water - process water

To study heat transfer in summer and winter we chose a variable time step and a total duration of 5000 seconds.

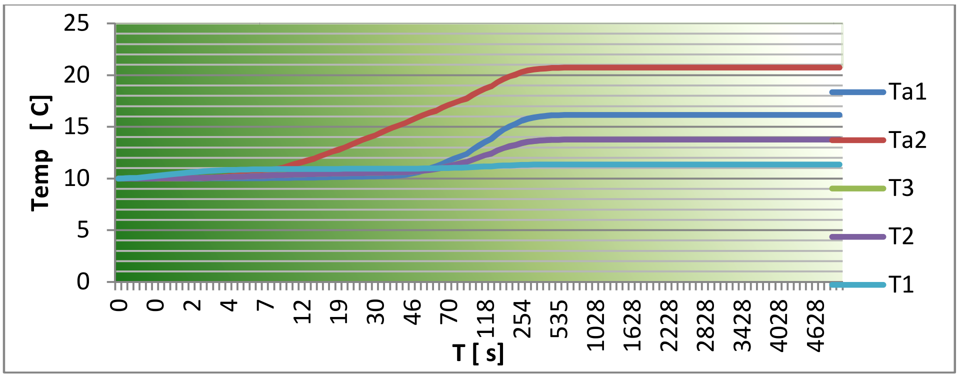


fig 5.3 Summer temperature variation

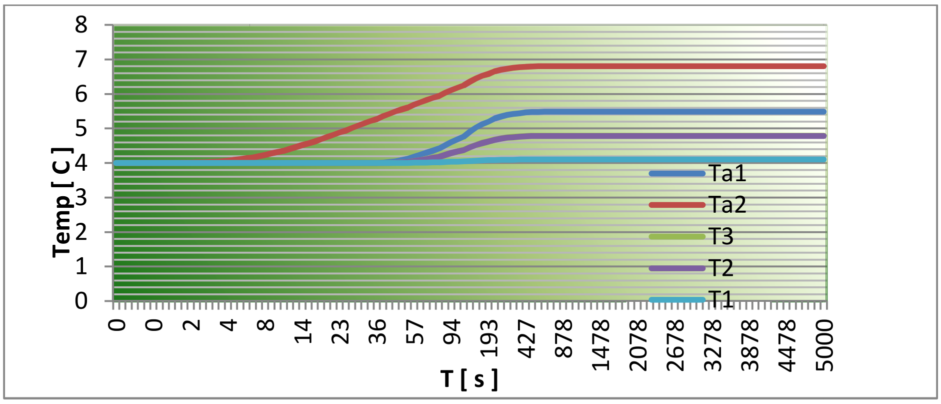


fig 5.4 Variation in winter temperatures

Data reveals both the ability and the performance of the primary source of machinery used in the extraction of thermal energy.

Chapter VI

Study of heat exchange by using CFD

6.1 Geometry and mesh heat exchanger

Heat exchanger geometry achievement in program Ansys-Fluent was quite elaborate, because the module dealing with the design of front borrows many of the functions of the CAD design.
For this simulation I have built a multitubular heat exchanger in countercurrent, with two passes, made up of twelve copper tubes bent so as to form a "U" profile for each pipe.

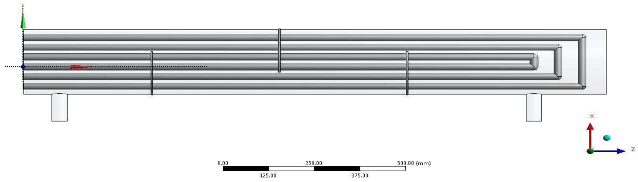


Fig. 6.1. Profile multitubular heat exchanger.

Tubes of beam diameter is 22 mm ; and the number of input and output sockets is 42.4 mm (11/4 inches) and a length of 100 mm.
The cover the bundles of pipes are inserted is made of steel with an inner diameter of 108 mm

To intensify the heat exchange between the primary fluid, sea water, and the secondary, I attached three bullying with the shape of the arc of a circle, with a thickness of 5 mm at a distance of 200 mm. The latter have a length equal to 2/3 of the inside diameter of the heat exchanger.

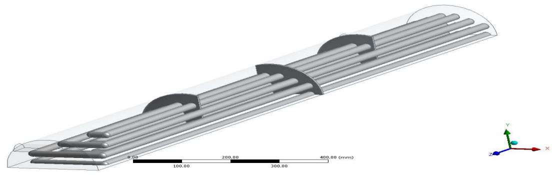


Fig. 6.2. View - baffle exchanger

Thus the primary exchanger of marine heat pump has the following geometrical characteristics: length: 660 mm; diameter: 108 mm; diameter heat pipes: 22 mm copper ;bullying: 3 pieces with thickness of 5 mm spaced 150 mm apart from each other.

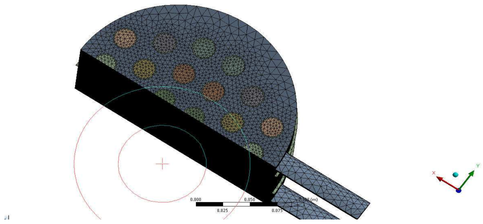


Fig. 6.3. Mesh-exchanger section.

Since exchanger geometry presents a regular shape could achieve a structured network composed of : 1,032,574 nodes , 2,228,283 tetrahedrons , 1,248,473 edges of shape and 109,899 hexagon .

This domain is composed of very small cells in order to be able to view a smooth and precise distribution the same time as the temperature , velocity and pressure
I modeled the flow using the model of turbulent frictional (complying with his equations Navier-Stoks) for a an unsteady flow
Thus in 2315 iterations the solution converged, but the cell fluid has not reached to travel throughout exchanger.
Unsteady flow (speed varies in time and space) characterizes Navier Stokes equation.

To solve the equations numerically , we have set a time step , Δ t . The amount of time step is chosen depending on the type of geometry and flow
As values of reference, the recommendations found in the program between five and ten iterations.

6.2 Representation parameters that characterize heat exchange

In Figure 6.4 are shown , changes in temperature along the flow direction , on the outside and on the inside of the heat exchanger .

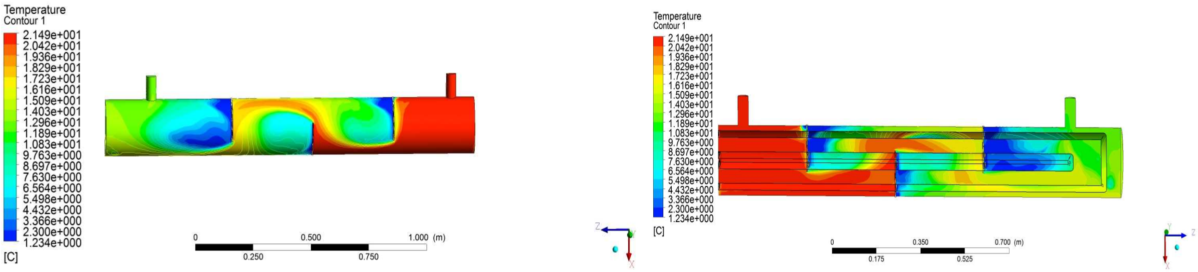


Fig. 6.4 The summer variation of the temperature on the surface of the exchanger .

The simulation was made for the two seasons, summer and winter, in order to be able to detect the amount of heat that can be extracted from sea water at the same depth, i.e.-5 m

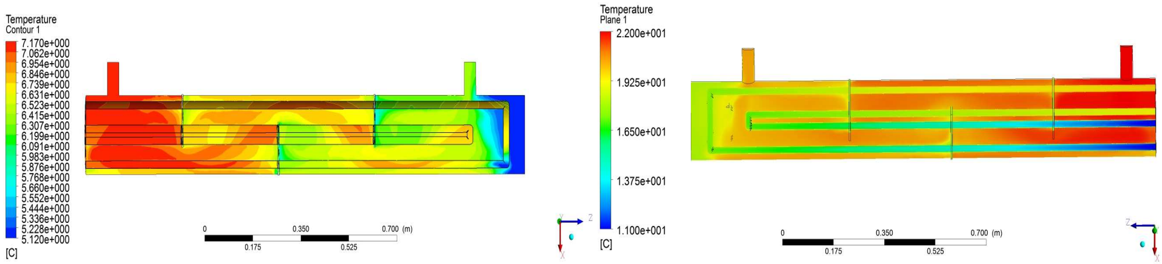
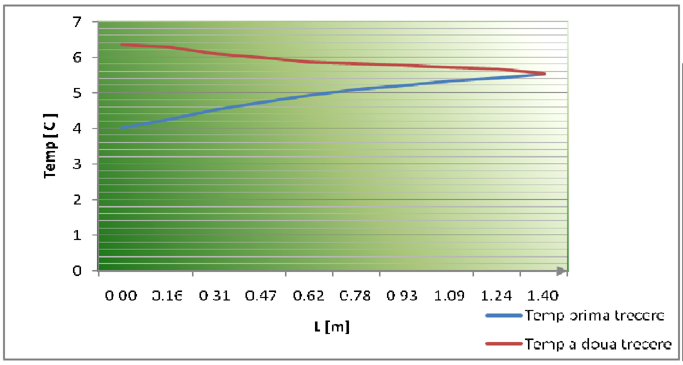


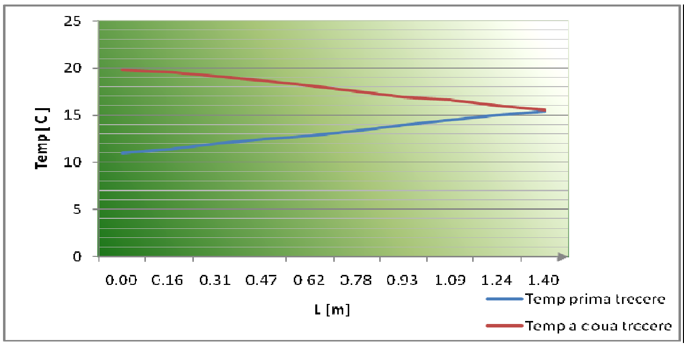
Fig. 6.5 The winter variation of the temperature on the surface of the exchanger



	Temperatură [C]	
Z [m]	I	II
0	4.00002	6.35085
0.155556	4.23062	6.28052
0.311111	4.50793	6.10561
0.466667	4.72866	5.99856
0.622222	4.93008	5.86251
0.777778	5.08743	5.82772
0.933333	5.21343	5.77259
1.08889	5.33697	5.72005
1.24444	5.42724	5.6821
1.4	5.52694	5.55071

Fig. 6.6 Secondary water temperature variation , winter, measured in current line

Figure 4.1 illustrates the variation in temperature along the line of current in the two passages. It can be seen with temperature increases until the secondary agent elbow pipe, the return of stagnating along its, and then continue increasing until exiting the exchanger.
The same simulation is shown in Figure 6.7 but for the summer condition.



	Temperatură [C]	
Z [m]	I	II
0	11.00000	19.8125
0.155556	11.38842	19.58655
0.311111	11.95320	19.15442
0.466667	12.43880	18.68225
0.622222	12.85002	18.10251
0.777778	13.36859	17.5221
0.933333	13.99012	16.9325
1.08889	14.46621	16.56877
1.24444	15.01224	15.9772
1.4	15.40125	15.52772

Fig. 6.7 Secondary water temperature variation , summer, measured in current line

Chapter VII

Experimental validation of the obtained data

7.1 The experiment

It was performed in one of the laboratories Constanta Maritime University which is mounted a heat pump water - water type (fig.7.11) , model MDS50D Meeting, the primary fluid flow 1700 [l / h].

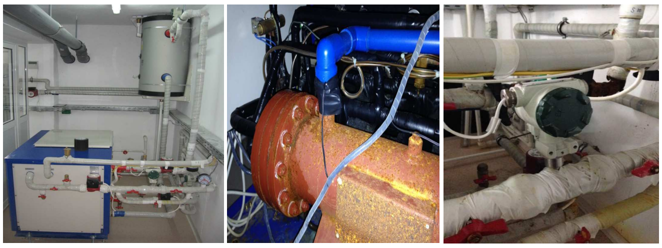


Fig. 7.1 Water-water- heat pump model

The heat pump uses soil water as a primary agent and can switch to extract water from Lake Ovidiu (water temperatures and properties being quite appropriated to seawater's). This machine is part of an installation that consists of a series of laboratory heating fan , two bivalent boilers connected to a series of solar panels and photovoltaic panels all interconnected with a system of observation and recording platform named Xweb500 .

It was tried as the primary agent flow should be approximately equal to the one from the simulation, meaning 1m/s , and the flow of the second one ranged between 0,1 and 0,3 m/s

Fig. 7.2 Collecting data

To highlight the capacity to generate energy seawater , the experiment had carried on a long time.

It has lasted six months, during which we stored data on water temperature, outdoor temperature and indoor lab , pressure , power consumption and not least of plant efficiency.

The obtained data were correlated with those presented by INMH study regarding the annual average temperatures of the water of the Black Sea. For each season in part I chose the most eloquent days when there were benchmarks temperatures
The programul records non stop data . The two study periods were very important so i choose the winter and the summer period.
For each period in the party have chosen 108 reference values and have watched the effects along the whole process culminating with the efficiency of the heat pump.

The figure 7.4 presents the obtained values for the primery and secondary agent, after mesurments on the heat exchanger . You can notice a smoother variation of increasing them, in view of the gradual warming of the primery agent , due to the increase in temperature.

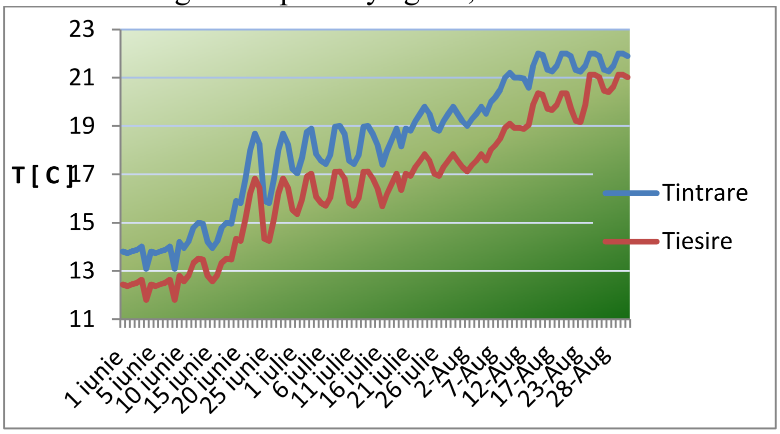


Fig. 7.3 Temperature graph of two agents in the summertime.

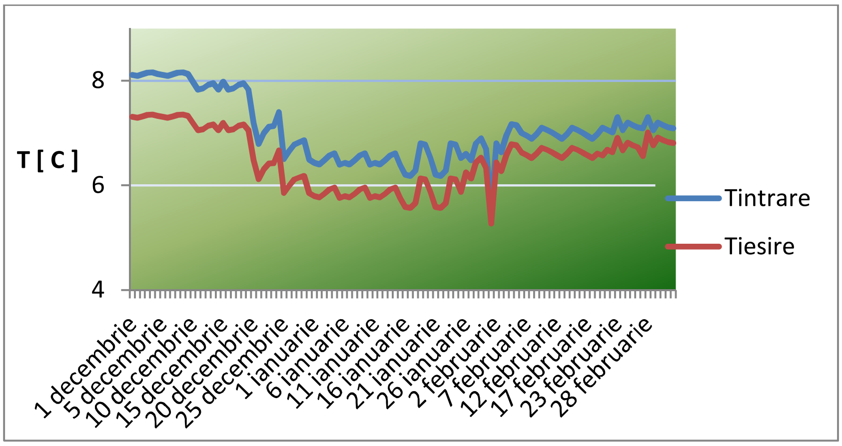


Fig. 7.4 Temperature graph of two agents in the wintertime.

7.2 Comparing the values of the efficiency coefficient

Efficiency coefficient is a key ele in assessing the energy performance of such installations
He is the first landmark that outlines us an overview of the duration energy consumption and obtained additional comfort .

As can be seen in Figure 7.5 , measurements were made of temperarturilor two agents involved in the heat exchange between 1 December- February 28 .

Measurements are made in 15 to 15 minutes, but to be brief I chose to present only six daily measurements at an interval of five days

It was considered secondary agent as constant temperature around 4 degrees Celsius and thru measurements we could compute the performance of sources.

It varies between 1.97 and 2.83 , depending on the time and temperature of seawater .

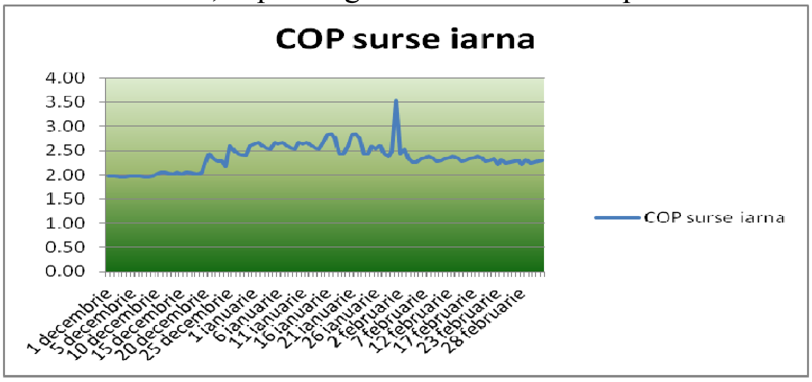


Fig. 7.5 Graph of the variation of COP in the wintertime.

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COP sources in summertime

Data for the summer outlining situation , were collected during the months of June , July and August .

As in the previous case , they have been taken into account only six daily values .

The values obtained are remarkable having regard to the depth to which water can be extracted .

Values vary between 2 and 6 which requires the use of water as a main option as a warming agent in the future.

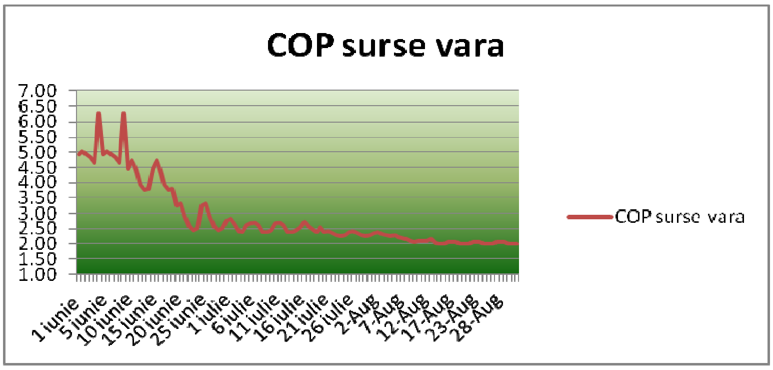

Fig. 7.6 Graph of the variation of COP in the summertime.

7.3 Comparative analysis of the obtained data

Regarding comparative analysis of data from experiment and simulation using two programs , I created tw

o charts explicit defining , in a way quite clearly , the real situation .

Summertime

T_{in} primary agent	T_{in} secondary agent	T_{out} secondary agent	
22	11	20,735	**Simulink**
22	11	20,350	**Experiment**
22	11	19,813	**Ansys**

Tab. 7.1 The comparative situation in the summertime

For comparison we presented in Table 7.1 temperatures obtained from three experiments.
Primary flow temperature has been chosen as a monthly average , and the second agent was considered constant at an average value .

T_{in} primary agent	T_{in} secondary agent	T_{out} secondary agent	
7	4	6,845	**Simulink**
7	4	6,630	**Experiment**
7	4	6,351	**Ansys**

7.4 Conclusions

Main simulation program used in the present thesis , namely Ansys Fluent is versatile evolving program that spans over three decades.
This application developed by me in the PhD program may be used to obtain some very good benchmark results and for greater accuracy can move on to using Fluent software .
Thus the average relative error between Ansys program results and experimental results is 4.39 % and the average relative error between the two is 7.78 % digital programs .

ChapterVIII

Personal contributions and further research directions

8.1. **Personal contributions**

1. Design and implement a program for numerical calculation of heat transfer that takes place in a tubular exchanger in the marine heat pump .
2. Comparative analysis of two numerical calculation programs : Ansys Fluent and Simulink.
3. Validation of newly created numerical program in the Simulink extension of MATLAB.
4. Study of heat transfer using CFD.
5. Experimental validation of the data obtained with CFD.
6. Proposed solutions to improve heat extraction from seawater using marine heat pump .

A first solution would be to build a network of underground pipes and a constant supply of the collector basin (an underground cloud). The next step is very obvious, namely installing water-water heat pumps in specific locations to use sea water as primary agent.

7. Implementation of a heat pump system in the city of Constanța.

By creating this project we want to fill up , even to replace where appropriate , using heat and hot water , using our Black Sea water temperature gradient .

As can be seen in the two pictures below, bringing water from depths of up to 10-15 m is not a major obstacle.Here is a pipe that carries water for broadening beaches; the process is very similar, and in the case of heat pump.

Fig. 8.1 Pipeline transport raw material (primary agent)

8.2 Directions of further researches

One of the first directions and the easiest , is the improvement of the computation program created in Simulink platform extension Matcad.
You can create other blocks and can write new routines to simulate not only the heat exchanger but also the functioning of the entire system of marine heat pump; attach the study closely the variation in temperatures and speeds, and the phenomena of conduction and convection. Such simulations can be made with different types of heat pumps which use marine different refrigerants, optimizing the whole system.

Chapter IX

Final conclusions

The present thesis demonstrated with scientific arguments, that the energy stored in seawater can represent, using them in an unconventional production of energy, namely a heat pump, a key element in the future development of a company based on renewable energy.

In conclusion it can be said that the use of thermal energy sea water into a heat pump, embedded, for starters in a mixed system, can have major benefits with respect to enhancing the comfort of occupants, to reduce the consumption of conventional fuels and last but not least polluting emissions.

Selective Bibliography

[1] Apetroaei Şt., Evaluarea şi prognoza bilanţului apei din sol, Editura Ceres, Bucureşti, 1983.
[2] Dinu D., – Hydraulics and hydraulic machines, Editura Sigma Trading Metafora, Constanta, 1999
[3] Dinu D. - Mecanica fluidelor pentru navigatori, Editura Nautica, Constanţa, ISBN 978-806-8105-11-6, 2010
[4] F. Memet , Preda A.- An analysis of the performance of an ejector refrigeration cycle working with R134a,ModTech Conference, Mamaia 2015, Published under licence by IOP Publishing Ltd • IOP Conference Series: Materials Science and Engineering,Volume 95, conference 1.

[5] F. Memet , A point of view on Otto cycle approach specific for an undergraduate thermodynamics course in CMU, ModTech Conference, Mamaia 2015, Published under licence by IOP Publishing Ltd • IOP Conference Series: Materials Science and Engineering,Volume 95, conference 1.
[6] Florescu Iulian, Mecanica Fluidelor, ed Alma Mater Bacau 2007.
[7] Institutul Național de Cercetare Dezvolatre Marină " Grigore Antipa" - Evaluare inițială a mediului marin I.N.C.D.M ,2012
[8] Iordache F si Băltărețu F - Modelarea și simularea proceselor dinamice de transfer de căldură, Matrix Rom 2002
[9] JIPA, D, (1987), Analiza granulometrică a sedimentelor: semnificaţii genetice, Editura Academiei Republicii Socialiste Romania, 128 p.
[10] Preda A.-Study regarding marine heat pump , Constanta Maritime University Annals, Year XII vol 17, ISSN 1582-3601, Constanta 2012
[11] Preda A., Acomi N. - Minimizing the heat flow lost by a ballast tank using insulation, Constanta Maritime University Annals, Year XII vol 17, ISSN 1582-3601, Constanta 2012
[12] Preda A., Scupia A. - Energy review on a maritime energy transfer system for comercial use, Advanced Materal Research Vol. 837, pag 763.
[13] Preda A., Scupia A. - Numerical computation of an unconventiol device using finite volume method. ModTech International Conference Modern Technologies in Industrial Engineering 27-29 June 2013, Mara Hotel, Sinaia, Romania
[14] Prisecaru T, Vilag V; Afterburning Installation Integration Into a Cogeneration Power Plant with Gas Turbine by Numerical and Experimental Analysis , Editura INTECH Open Access Publisher, 2011, ISBN 9533076119
[15] Scupi Andrei-Alexandru , teza de doctorat " Cercetări privind dinamica sistemelor de tracțiune neconvenționale și a aparatelor de sustenație "- 2013.
[16] Tudor Darie - Procese de transfer termic în câmp electromagnetic, Conferinţa Naţională de Termotehnică, Cluj-Napoca, 1995.