**IOSUD - Universitatea Politehnica Timişoara**
**Şcoala Doctorală de Studii Inginereşti**

# STUDIES AND RESEARCH ON ENERGY EFFICIENCY OF HEAT PUMPS IN A RECIRCULATING AQUACULTURE SYSTEM

**Doctoral thesis –Summary**

For Obtaining the Scientific Title of PhD fromPolitehnica University Timisoara in the Field of Mechnaical Engineering

by

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The thesis is structured in 8 chapters and 1 annex. The first 5 chapters being introductory and supporting chapters in which the thesis is motivated, the current state of research in the field is analyzed and the necessary notions are introduced for the rest of the thesis. The following chapters describe the research activity carried out on a heat pump installation. The last chapter is reserved for the conclusions and the presentation of personal contributions. In Annex A present at the end of the thesis are presented the data of the 4 simulations that were performed on the heat pump installation.

## Chapter 1. The objective of the research

Aquaculture is the field that has registered the fastest evolution in the world, among all branches of agriculture. At present, this sector of activity provides a rather low percentage of consumable aquatic products. Among aquatic organisms, fish have the largest share of fish in world aquaculture production. At present, intensive research is being carried out in order to establish the most appropriate breeding systems and technologies for species with high economic value, aiming to achieve a high level of competitiveness on the world market and to achieve a protection of stocks in natural waters.

Fish farming technology in recirculating aquaculture systems is a technology with a high electricity consumption. An important percentage of production costs is spent on energy consumed. Analyzing the energy-related components of the costs, it was observed that the amount of thermal energy required for heating or cooling the water in the pools, represents about 40 ÷ 60% of the total energy consumed by the system (depending on how cold the winter is , respectively how hot in summer). For this reason, it is necessary to use the most efficient solutions for producing the thermal energy necessary for this type of system. According to some studies, this is possible by using heat pumps which, during cold periods, extract the caloric energy contained in the environment, in surface water, groundwater, soil or even air and transfer it to the water in the pools, ensuring a constant temperature. The same installation also ensures the cooling of the pool water during the summer.

This paper presents research on recirculating aquaculture fish farming systems, methods of heating and cooling water traditionally used in this type of system, general considerations on the use of renewable energy through heat pumps, theoretical elements on their operation , the current state of development of heat pump installations worldwide and in the country, areas of use and demonstration of the efficiency of the use of a water-water heat pump by reducing the consumption of electricity for both heating and cooling water from a recirculating aquaculture system as well as for heating or cooling the hall in which this type of system operates. The use of research results for the practical demonstration of the viability and advantages of this technology compared to other heating or cooling methods is envisaged.

## Chapter 2. Considerations regarding recirculating aquaculture fish farming systems

This chapter describes this type of fish farming technology, reviews the technical problems that occur during the operation of a recirculating aquaculture system, these being the foundation of the carrying capacity and water flows required for ensuring optimal environmental conditions in terms of oxygen content and nitrogen compounds, management of solid particle control in the recirculating aquaculture system, in correlation with the intensity of production and the amount of food administered, use of appropriate biological filtration systems to maintain the concentration of compounds nitrogen in the optimal field imposed by the requirements of the crop species, the use of high-performance technical equipment for heating / cooling the water in the system, the use of oxygenation (aeration) systems according to the ecophysiological and technological peculiarities of the crop species, the use of monitoring and control of carbon dioxide and water alkalinity in the culture system, control of micro suspensions and dissolved organic matter, optimization of technological management, by integrating fish farming technology with water quality conditioning technologies. The specific issues regarding the treatment of water in recirculating aquaculture systems as well as the technological conditions regarding the assurance of water quality in this type of systems were discussed.

## Chapter 3. Methods of heating / cooling the water in recirculating aquaculture systems

This chapter presents the classic methods of heating and cooling water from recirculating aquaculture systems such as electric water heaters for pools, electric water heaters with direct mounting on pipes and various types of heat exchangers have been reviewed. The subchapter on water cooling processes in recirculating aquaculture systems discussed methods and installations for water cooling, coolers and cooling systems and types of water cooling systems that have constructive versions usable for heating.

## Chapter 4. Heat pumps

This chapter presented the operating technology of heat pumps, discussed the technical evolution of these installations and heat sources (soil, water, air). Also in this chapter we discuss the principle of operation of heat pumps, about the operating regimes of a heat pump (monovalent, bivalent, alternative bivalent and partially alternative bivalent)

A classification of heat pumps was made (according to the mode of realization of the operating cycle, as well as the shape of the drive energy, according to the installed power, according to the field of use.

The main types of heat pumps were reviewed according to the primary energy source used (air-to-water heat pump, water-to-water heat pump, ground-to-water heat pump)

Heat pumps provide the technology needed to use solar energy stored in water, soil and air in the form of environmentally friendly energy. Heat pumps get about three-quarters of the energy needed for heating from the environment. The widespread use of alternative energy sources is hampered by daily or seasonal variations in the energy source.

Heat pumps are systems that convert energy and can raise the temperature from a low to a high degree. With these we can obtain temperatures of up to 50-80 $C^0$. By using any method of heating a living space or domestic hot water, pollutant emissions such as soot, sulfuric acid, carbon monoxide, nitrogen oxides and carbon dioxide are produced. These pollutant emissions pose a danger to the environment and contribute to the increase in the greenhouse effect. In the case of the use of electricity and district heating for heating, emissions of harmful substances occur during its production in thermal power plants or district heating centers. Even if the heat pumps run electrically, thus increasing the consumption of electricity, there will still be a reduction in the total consumption of conventional fuels when traditional heating systems are replaced. Thus, using heat pumps will reduce air pollutants. In general, separate technological installations are used for both heating and cooling of water in recirculating aquaculture systems. In the case of low flow rates, electrical equipment (electric heaters) mounted on the water supply tank or directly on the supply pipes of fish tanks are used for water heating. After consulting an extensive bibliography on the current state of development of heat pump installations, we reviewed the most efficient models in terms of thermal performance coefficient (COP).

## Chapter 5. Current state of development of heat pump installations

In this chapter, a review was made of the types of heat pumps that currently exist on the market, their technical characteristics but also about the state of theoretical and practical research worldwide.

After studying an extensive bibliography of the research stage of heat pump development, it was concluded that Yujin Nam, Ryozo Ooka, Suckho Hwang developed a numerical model to estimate the heat exchange rate of a water pump installation based on water. underground. In addition, they propose a method for estimating soil properties and the comparison between the experimental results and the numerical analysis of the above-mentioned model was made in the conditions of an experiment in 2004. To use these heat pump systems it is necessary to accurately predict heat extraction and heat exchanger flows. Most of these models are based on a thermal conduction in cylindrical coordinates, in which the effect of water flow is incorporated in the effective thermal conductivity.

Models that are not sufficiently represented may be inaccurate in their estimates over longer periods of time. Moreover, most of the proposed models use a cylindrical heat exchanger, under the concept of an equivalent diameter, and do not take into account the exact shape of the heat exchanger.

D. Vanhoudt, D. Geysen, B. Claessens, F. Leemans, L. Jespers and J. Van Bael performed a laboratory test to quantify the performance of a heat pump in a controlled and active manner. This test made it possible to operate the heat pump in real conditions. They observed that in a week with moderate heat in the hot season, the heat pump has a higher COP than in the cold season, and the combination with a wind-powered heat pump provides better results than the combination with a heat pump.

Zhiwei Lian, Seong-rzong Park and Henian Qi compared and analyzed the annual energy consumption of a water loop heat pump system and a conventional air conditioning system, when they are applied in several cities in China.The results of this research showed that the water loop heat pump system has an obvious effect of economy when an electric boiler is used.
According to the calculation in the paper, the maximum energy saving rate can reach 19.29%, and the most appropriate ratio between the cooling load and the heating load for the water loop heat pump is about 4.8%.Given its other advantages, water loop heat pumps can be applied in buildings where the ratio of cooling load to thermal load is not more than 4.2%.

K.J. Chua, S.K. Cabbage, W.M. Zang reviewed the progress of the heat pumps. They concluded that heat pumps are widely used to improve ambient heating from sustainable energy sources such as air, water, soil and waste heat. They can be used for heating and cooling residential and commercial spaces, for cooling and heating water, and in many industrial processes. With an abundant amount of heat available from various natural sources and heat generated by various industrial processes, the heat pump has become an indispensable technology that can help maintain a cleaner environment. D.S.Kim, I. Moretti, H. Hubert, M Monsberger developed a database for heat pumps, and the study focused in particular on the influence of heat exchangers on heat pump performance. The database comprises 475 data sets for 69 heat pumps, with five different working agents. Analyzes have shown that the influence of an individual component can be separated from the others, and the results can be expressed as a semi-empirical equation. It was found that the compressors were responsible for a maximum deviation of 20% in the COP, and the two-phase heat exchangers caused a maximum deviation of 15-20% at the heat pumps studied.

## Chapter 6. Experimental study of the water heating / cooling installation from a recirculating aquaculture system with heat pump

This chapter describes the composition of the water heating / cooling system from a recirculating aquaculture system with heat pump, heat pump, cold source vehicle pump (groundwater), hot / cold water vehicle pump, exchanger plate heat exchanger, buffer vessel, self-cleaning filter, 3-way solenoid valves, various fittings and measuring equipment, automation system consisting of outdoor, indoor, flow, return, vaporizer, condenser, overload protection, compressor overheat protection, control submersible pump, recirculation pumps, flow temperature limiter, hour / day temperature control - cold / hot and compressor working hours counter, a submersible pump and recirculation pumps). Also in this chapter was made the description of the technical-functional characteristics of the water heating / cooling installation from a recirculating aquaculture system with heat pump. An explicit description of the working methodology was made, a description of the recirculating aquaculture system on which the experimental determinations were performed was made and we reviewed the equipment used for the experimental determinations. Experimental determinations were performed on the heat pump installation, for the water heating and cooling regime at different water change rates.

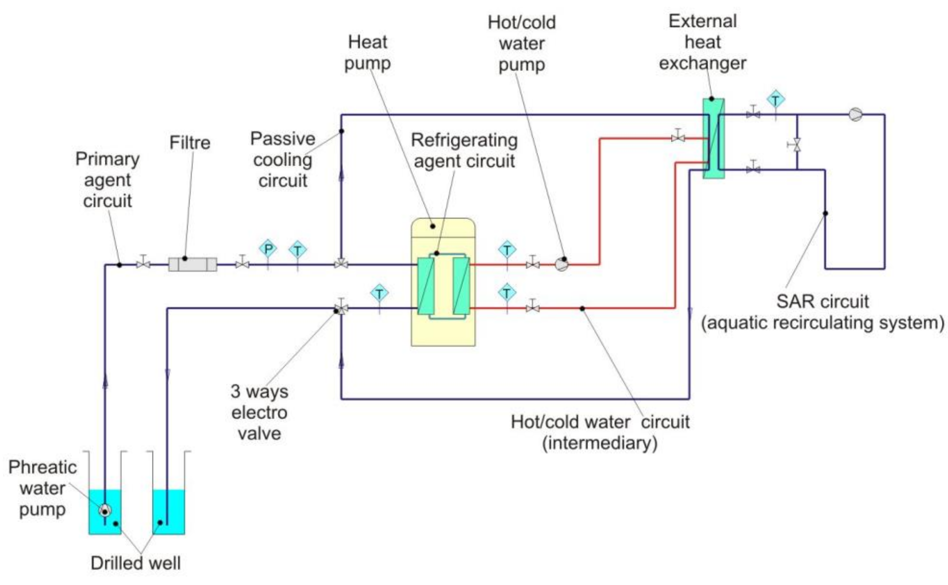


**Figure 1. Operating diagram of the water heating / cooling system with heat pump**

With the CoolPack program, the refrigeration cycle of the heat pump was studied and a brief description of the working refrigerants was made. Thermodynamic diagrams were used to estimate the sizes of working refrigerants, which allowed the study of the thermodynamic cycles of refrigeration installations or heat pumps.

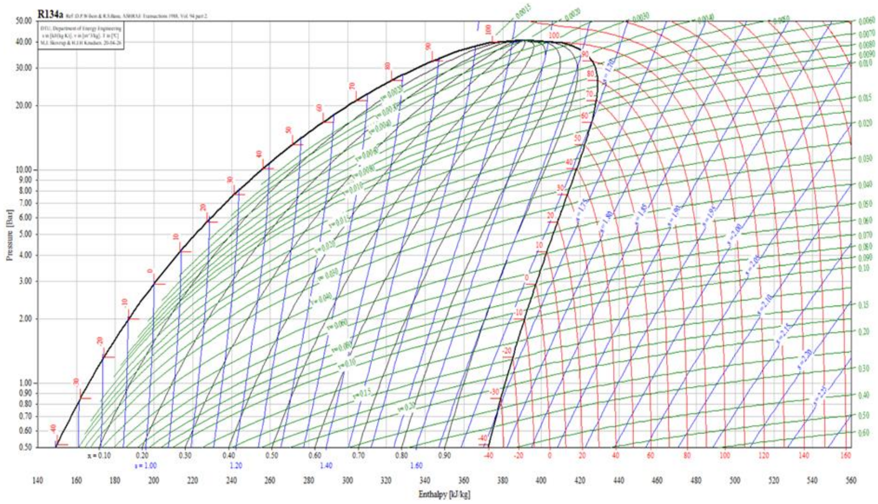


**Figure 2. Lgp-h diagram for R407C**

The cycle was studied in the working agent diagram for the data measured on the heat pump installation.

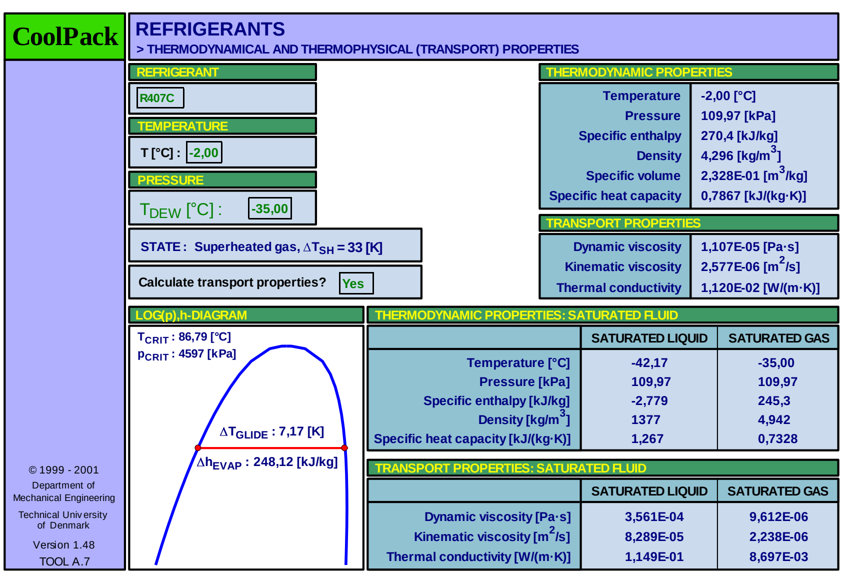


**Figure 3. Transport characteristics of the R407C freon**

The thermal performance coefficient obtained after the simulation with the CoolPack program is different from the one determined experimentally on the installation in operation. The difference can be explained by the irreversible losses that occur in the actual installation. Simulations using the CoolPack program can be used in the future to optimize the operating parameters of heat pump systems.

In this paper it was demonstrated that the energy required for the operation of a recirculating aquaculture system for fish farming is of two categories: *Electrical energy* required to operate various technological equipment and *Caloric energy* required for heating / cooling the water in the system and the hall.

Electricity is needed to operate various technological equipment such as some types of mechanical filters, aeration pumps and UV sterilization installation.

The electricity consumption per 1 $m^3$ of water of these equipments varies widely depending on the type, use, quantity and quality of feed administered to the fish material (fish species bred in the recirculating aquaculture system) as well as the degree of use of its, the density of popular but also other factors.

The pumping unit has the role of ensuring the circulation of water in the system. Power consumption depends on pump type, efficiency, pump height and hydraulic resistance of the system. For the circulation of one $m^3$ of water at a pumping height of one meter of water column, 4.6 - 6 Wh / $m^3$ of electricity is generally consumed.

The radial, rotary, “drum” type mechanical filters, most often used for mechanical filtration in recirculating aquaculture systems, use energy to perform the rotational movement of the drum and to operate the washing pump of the filter material.

The unit energy consumption depends on the size of the holes of the filter material and on the intensity of its washing, being in the range 3.7 - 4.5 Wh / $m^3$.

The role of aeration pumps is to introduce air into the water in the recirculating aquaculture system to increase the oxygen concentration in the water. The amount of oxygen that fish need depends mainly on the species, age and density of the population, as well as other factors such as water temperature and pH, ammonium concentration, nitrites and nitrates, etc. The average energy consumption for the aeration process is 3-6Wh / $m^3$.

Ultraviolet disinfection is the ability on the penetration of UV light to destroy all forms of bacteria, viruses and other small organisms present in the culture water.

In order to obtain a maximum disinfection capacity with UV rays, an energy consumption of approximately 5 Wh / $m^3$ is taken into account.

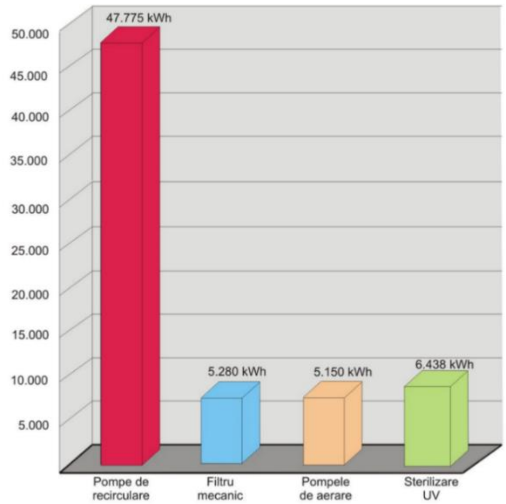


**Figure 4. Chart of annual electricity consumption for treating and water from a recirculating aquaculture system**

## Chapter 7. Simulation of the thermal system of the heat pump installation in a recirculating aquaculture system

With KULI software, the thermal system of the installation with heat pump was designed in a recirculating aquaculture system. The design of a thermal network is increasingly important in the development of various static or mobile applications. The exclusive design and testing on test stands or at the site of the thermal network is a very time consuming activity and is also very expensive at the same time, often being almost impossible to achieve. Therefore, tools are needed that can analytically simulate the performance of thermal networks in real operating conditions and at the same time give confidence in the results obtained.

This program uses components to simulate different types of heat exchangers, fans, pumps, compressors, etc., integrating them into complex thermal networks. These complex thermal networks simulate the real situations in the operation of different applications. These systems can simulate operating conditions (flow rates, temperatures, pressures, speeds, etc.) independent of the experimental data used in creating the components. The system also allows dimensional extrapolation, so that the need to design, execute and test any other new solution is eliminated in order to evaluate its hydraulic and thermal performance. In the first stage of the simulation, the system components were defined. The components were chosen depending on the type of hot fluid we want to cool but also depending on the type of construction solution chosen.

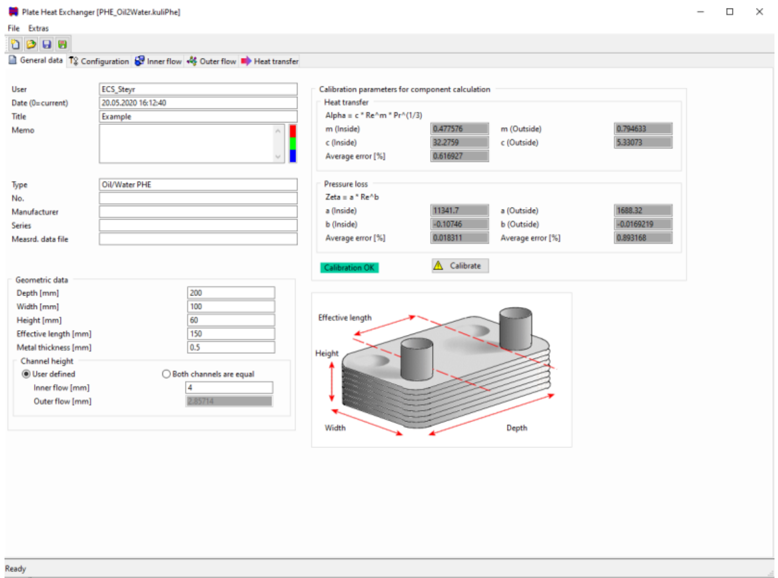


**Figure 5. Geometric information of a Kuli component for brazed plate heat exchanger (BPHE)**

The next step was to enter the data for the hot fluid part, it was necessary to enter the type of fluid, the pressure at which the data and the pressure drop data were determined according to the fluid flow and the inlet and outlet temperatures.

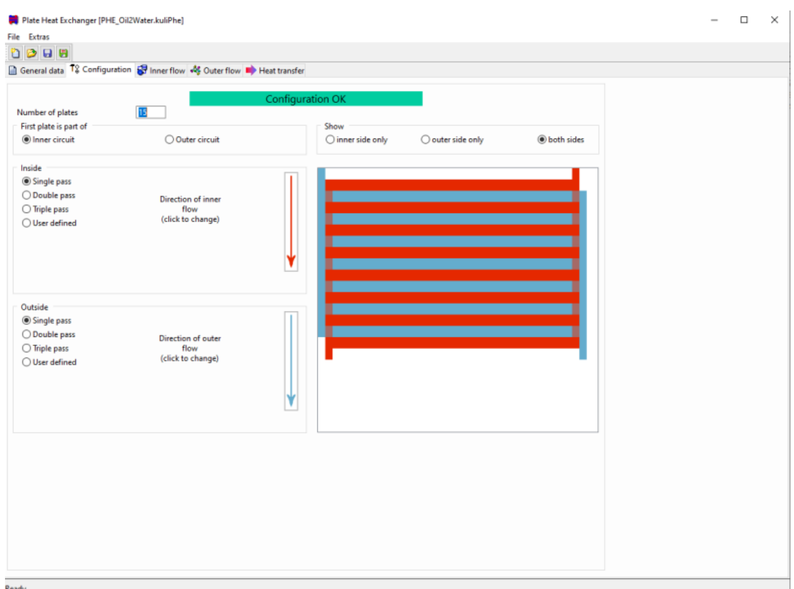


**Figure 6. Setting the flow type**

The fluid type (which may be different from that defined in the component) and the circuit type (closed or open) were chosen. In the closed circuits the initial parameters of the desired heat flux were set and the outlet temperature for this flow was obtained, while in the open circuit the inlet temperature was set as the initial parameter and the achieved heat flux was obtained. Also at this stage the desired flow rates, inlet temperatures or desired heat flux were defined. Having all the parameters, the calculation of the results was launched. The results were evaluated from Kuli Lab and presented in tabular form.

In the KULI program we made the thermal network of the recirculating aquaculture system together with the heat pump. This was achieved by introducing elements that simulate the thermal mass of the water present in the secondary system, the mass of water in the fish basins.

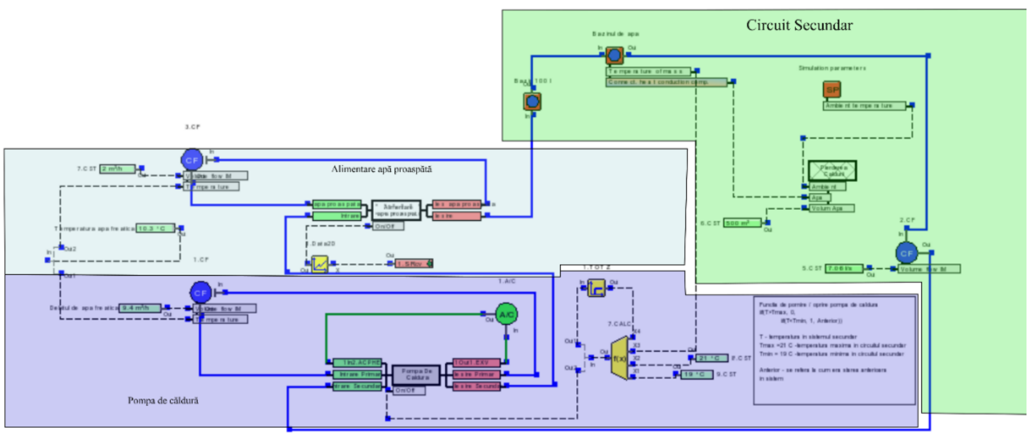


**Figure 7. Thermal network of the recirculating aquaculture system**

This thermal network simulates the heat pump and the groundwater extraction system, the secondary circuit system and the fresh water supply system. In total, a number of 4 simulations were performed for different configurations of the heating system. The simulations analyze the thermal dynamics of the system for 96 hours of operation starting with the power supply of the installation.

The first simulation analyzes the thermal evolution of the installation in the presence of a buffer tank of 1000 l and a configuration in which the water is refreshed once every 24 hours with a volume of 40% of capacity. The second simulation analyzes the thermal evolution of the installation with the positioning of the 1000 l basin after the fish basins The third simulation analyzes the thermal evolution of the installation with the change of the position of the refresh water.

The fourth simulation analyzes the thermal evolution of the installation without the 1000 l buffer tank. All these configurations have a very close thermal evolution, their difference is given only by the operating time of the heat pump. As shown above, the first configuration has the lowest energy consumption, followed by the third and fourth configurations. The most inefficient configuration being the second simulation.

## Chapter 8. Conclusions and personal contributions

This paper "**Studies and research on energy efficiency of heat pumps in a recirculating aquaculture system"** is based on theoretical and practical knowledge gained in about 10 years of experience of the author in research and development in agriculture and food industry.

Recirculating aquaculture systems have an energy-consuming technology, the energy consumed by the entire recirculating aquaculture system is of two types, namely electricity needed to operate various technological equipment and heat energy needed to heat and cool the water in the system and the hall where it is located.

In order to reduce the energy consumption related to filtration, aeration and disinfection with UV radiation (which together represent only about 15% of the total consumption), it is possible to intervene to a limited extent, by using the most efficient and efficient equipment. raised.

The most significant share of the total energy consumption of a recirculating aquaculture system (approx. 42%) is the energy consumed for water circulation in the system. This weight increases with the increase of the system and with the increase of the recirculation intensity, ie of the total volume of water circulated.

Energy consumption for water circulation can be significantly reduced by developing systems that require a pumping height as low as possible, avoiding unnecessary pumping and by judiciously designing hydraulic networks.

In this way, by reducing the pumping to approximately 4 mca, a reduction of the energy consumption of the pumps is obtained by approximately 43%, which in the case of the analyzed system represents approximately 18% of the total consumption.

Thermal energy costs ($E_{IA}$ and $E_{IH}$) account for a significant share of total energy consumption, approximately 43%. The reduction of these consumptions can be achieved by diminishing the heat losses by isolating as efficiently as possible the constructions and the external water networks (if it is the case).

An efficient way to reduce heat consumption is to use alternative energy sources, such as heat pumps, which use environmental energy to produce heat. By using for heating and cooling water from a recirculating aquaculture system a heat pump, water-water type with a COP = 5.4, 1 kWh thermal energy is obtained 2.2 times cheaper compared to the use of methane gas and 5.4 times cheaper than using electricity at current rates. Reducing thermal energy costs by 81% results in a reduction in the total energy costs of operating a recirculating aquaculture system by approximately 35%.

Using the CoolPack program, after a brief description of the refrigerants, the refrigeration cycle of the heat pump was studied. The cycle was studied in the R407C freon diagram for the data measured on the heat pump installation. The COP obtained after the simulation with the CoolPack program is different from the one determined experimentally on the installation in operation.

Simulations using the CoolPack program are used to optimize the operating parameters of heat pump systems. We performed in the Kuli program a number of 4 simulations for different configurations of the thermal system. The simulations analyze the thermal dynamics of the system for 96 hours of operation starting with the power supply of the installation. The first simulation analyzes the thermal evolution of the installation in the presence of a buffer pool of 1000 l and a configuration in which the water is refreshed once every 24 hours with a volume of 40% of capacity. The second simulation analyzes the thermal evolution of the installation with the positioning of the 1000 l basin after the fish basins The third simulation analyzes the thermal evolution of the installation with the change of the position of the refresh water The fourth simulation analyzes the thermal evolution of the installation without the 1000 l buffer tank.

All these configurations have a very close thermal evolution, their difference is given only by the operating time of the heat pump. As shown above, the first configuration has the lowest energy consumption, followed by the third and fourth configurations. The most inefficient configuration being the second simulation. From the above it can be concluded that the position and existence of the 1000 l buffer tank is important in reducing the energy consumption of the studied thermal system. Due to the fact that simulation 2 is the most inefficient, it indicates that the position of the 1000 l buffer tank is more important than its existence.

Also, the position in the system of the fresh water supply is important, the optimal being between the heat pump and the buffer tank of 1000 l. In this configuration the resevoir tank has the greatest influence on the energy consumption of the system. Thermal simulations are very important, they allow us to make virtual changes to the heating system without incurring additional costs. Moreover, they allow the study of the dynamics of the thermal system over time which in reality is costly and time consuming, and is not always possible. In the future, we want an exergetic analysis of the operation of heat pumps, which would highlight the advantages over conventional heating systems.

The following personal contributions and results can be listed:

• consultation of an extensive bibliography in the field of recirculating aquaculture systems for fish farming

• study of the current state of development of heat pump installations worldwide and nationally.

• performing experimental determinations on a heat pump installation in a recirculating aquaculture system to establish electricity consumption at different rates of water change in the system at different temperatures for both heating and water cooling regime.

• study with the help of the CoolPack program of the theoretical cycle of the heat pump for the heating regime.

• comparison in CoolPack of the theoretical cycle of the heat pump with the real one during operation.

• the realization in the Kuli program of a number of 4 simulations in which different configurations of the thermal system of the heating system with heat pump of some basins from a recirculating aquaculture system were tried, resulting in a number of 46 tables present in annex A (Only a few selective values were entered in the appendix).

• demonstration in the Kuli program of the influence of the position of the fresh water supply buffer tank on the energy consumption of the entire system.

• determination by calculation of the total energy consumption of a recirculating aquaculture system, which shows that the total percentage of energy consumed (42%) is the energy consumed for water circulation in the system. This weight increases with the increase of the system and with the increase of the recirculation intensity, ie of the total volume of water circulated in the system. This energy consumption can be reduced by developing systems that require a pumping height as low as possible, avoiding unnecessary pumping and by judiciously designing hydraulic networks.

Of note are the works published in:

- *Experimental Heat Transfer indexed ISI*

  Marțian Vlad, Septimiu Albețel, **Laza** (**David) Evelin-Anda**, Nagi Mihai *"Heat transfer and hydraulic performance models for a family of aluminum plate heat exchanger with transversal offset strip fins" Experimental Heat Transfer* ID UEHT-2016-0076.R2
- *8th International Conference on Thermal Equipment, Renewable Energy and Rural Development, TE-RE-RD 2019 revistă indexată ISI*

  **Laza (David) E.A**., Dumitrescu L., Boboc M., Moiceanu G*.,"Greenhouse Heating by ussing an installation of biogaz gazeification"*

  Septimiu Albetel, Alexandru Rus, **Evelin David (Laza)**, Vlad Martian "The Amplitude Influence on the Thermal and Hydraulic Performances for a Wavy Air Fin in a Compact Heat Exchanger used in Agriculture Applications"

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15. Septimiu Albetel, Alexandru Rus, **Evelin David (Laza)**, Vlad Martian "The Amplitude Influence on the Thermal and Hydraulic Performances for a Wavy Air Fin in a Compact Heat Exchanger used in Agriculture Applications"
16. **David E-A**, Pop A., Andrei Sorin - Theoretical considerations regarding improving energy consumption of a recirculating aquaculture system of superintensive fish growing / Consideraţii teoretice privind îmbunătăţirea consumului energetic al unui sistem acvacol recirculant de creştere superintensivă a peştilor, ISB INMA TEH' 2014, International Symposium, 30 octombrie – 1 noiembrie Bucureşti, ISSN 2344-4118.
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