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Control methodologies based on geothermal recirculating aquaculture system

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A B S T R A C T

One of the most common uses of geothermal heat is in RAS (recirculation aquaculture systems) where the water temperature is accurately controlled for optimum growing conditions for sustainable and intensive rearing of marine and freshwater fish. This paper presents a design for RAS rearing tank and plate type heat exchanger to be used with geothermal energy as a source of heating water. A well at Umm Huweitat on the Red Sea is used as a source of geothermal energy. The heat losses from the RAS tank are calculated using Geo Heat Center Software. Then a plate type heat exchanger is designed using the epsilon–NTU (number of transfer units) analysis method. For optimal growth and abundance of production, a different techniques of control system are applied to control the water temperature. The total system is built in MATLAB/SIMULINK to study the overall performance of control unit. Finally, a comparison between PI, Fuzzy-PID, and Fuzzy Logic Control has been done.

1. Introduction

Geothermal energy is energy derived from the natural heat of the earth. The earth's temperature varies widely, and geothermal energy is usable for a wide range of temperatures from room temperature to well over 300 °C. Geothermal energy can be used for both electricity generation and direct uses depending on the temperature and chemistry of the resources [1–5]. Currently, direct uses are on commercial level and are replacing fossil fuels in uses of low heat applications such as district heating, processing of agricultural products, therapeutic uses as well as in aquaculture [6,7].

Catching fish from the wild may not yield enough product to meet consumer demand and simultaneously keep the natural ecosystem in balance. The Food and Agriculture Organization of the United Nations estimates that by 2030, about 40 million tons of seafood will be necessary to keep up with demand. Catfish is one type of fish that is quite popular in Egypt and readily available, either in the village or town [8,9].

The Health benefits of catfish are rich in omega-3 fatty acid content, but increasing consumption of all types of fish and seafood is recommended to derive the best health benefits, Catfish are excellent sources of protein that are low in fat, Catfish is high in Vitamin D, Farm-raised catfish contains low levels of omega-3 fatty acids and a much higher proportion of omega-6 fatty acids, The protein in fish is of high quality, containing an abundance of essential amino acids, and is very digestible for people of all ages, Catfish is also generally lower in fat and calories than beef, poultry or pork, It is also contains of minerals such as iron, zinc and calcium.

The use of artificial intelligence has become more common in industrial and manufacturing process control systems in recent years. The advantages of AI systems include: (1) the rapid transfer of expert knowledge throughout an industry, especially those young industries that do not have enough available experts; (2) a reduction in labor costs due to automation of all primary functions; (3) improved process stability and efficiency; and (4) improved understanding of the process through the development and testing of the rules. Their usefulness in aquaculture has been advocated due to all of these reasons [10].

This paper simulates a RAS (Recirculation Aquaculture System) with a specific design of fish tank and plate type heat exchanger. The Fuzzy logic controller is proposed to control the RAS temperature using the MATLAB/SIMULINK simulation program.

2. RAS (Recirculating aquaculture system)

RAS represent a new and unique way to farm fish. Instead of the traditional method of growing fish outdoors in open ponds and raceways, this system rears fish at high densities, in indoor tanks with a "controlled" environment. Attempts to advance these systems to commercial scale food fish production have increased dramatically in the last decade [11].

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The renewed interest in recirculating systems is due to their perceived advantages: the possibility to be placed near the fish markets, high product quality, shorter production cycles due to high food conversion factors and a constant monitoring of the farm environment in order to improve rearing conditions [12]. The functional parts of a RAS include a growing tank, sump of particulate removal device, biofilter, aeration subsystem, water circulation pump, and water heating system depending on the water temperature and fish species selected. Ozone and ultraviolet sterilization may be advantageous to reduce organic and bacteria loads [13]. The required RAS components are indicated in Fig. 1.

3. System design methodology

This section discusses the system components design of geothermal system, load design, Heat Exchanger, and fuzzy logic control as given below.

3.1. Geothermal system design

Geothermal water flows from the well at 70 °C and average flow rates of 0.12 L/s. The geothermal water passes through one side of the heat exchanger, and flows into the reinjection well. On the secondary side of the heat exchangers, fresh water is circulated through the heat exchanger and to the rearing tank system so that there is no actual contact or mixing between the geothermal water and rearing tank. The hot water enters the rearing tank with 50 °C which is mixed with the cold water to obtain the desired water temperature in the tank.

3.2. Geo-heat center software inputs

The Geo-Heat Center software was developed for using in conjunction with geothermal direct use systems. The software includes several tools among them is the “HEATOOLS” which allows the calculation of the steady state heat loss from an indoor pond (or pool) in the evaporative, convective and radiant modes [14]. In this case, the calculations assume that the pond (or pool) is located in an enclosed building such that evaporative and convective losses are driven only by natural convection of the air. The inputs to this software are the geothermal fluid temperature, the pond water temperature, the air temperature inside the building, the pond surface area, and the air relative humidity inside the structure housing the pond.

3.3. Heat exchanger design

Heat exchangers are devices that are used to transfer heat between two or more fluid streams at different temperatures. They can be classified as either direct contact or indirect contact type where the media are separated by a solid wall so that they never mix. Due to the absence of a wall, direct contact heat exchangers could achieve closer approach temperatures, and the heat transfer is often accomplished with mass transfer. The indirect contact heat exchangers is focused where a plate wall separates the hot and cold fluid streams, and the heat flow between them takes place across this interface. Plate heat exchangers and shell-and-tube heat exchangers are examples of indirect contact type exchangers [15].

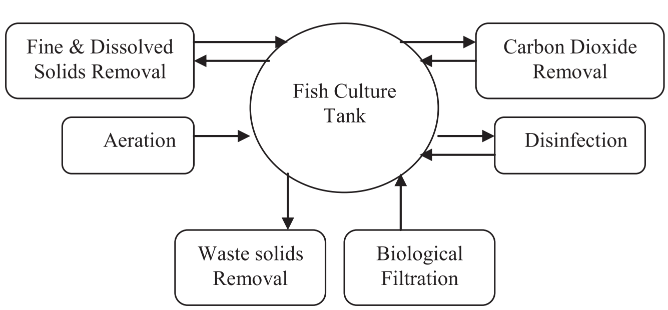

Fig. 1. Recirculating aquaculture system components.

A plate heat exchanger is a compact one which provides many advantages and unique application features. These include flexible thermal sizing, easy cleaning for sustaining hygienic conditions, achievement of close approach temperatures due to their pure counter-flow operation, and enhanced heat transfer performance [16].

Most geothermal fluids, because of their elevated temperature, contain a variety of dissolved chemicals. These chemicals are frequently corrosive toward standard materials of construction. As a result, it is advisable in most cases to isolate the geothermal fluid from the process to which heat is being transferred.

The task of heat transfer from the geothermal fluid to a closed process loop is most often handled by a plate heat exchanger. The two most common types used in geothermal applications are: bolted and brazed [17].

To design or predict the performance of a heat exchanger, it is essential to determine the heat lost to the surrounding atmosphere for the analyzed configuration. The heat power emitted from hot fluid (Q_h), and the heat power absorbed by cold fluid (Q_c) can be calculated as follows (neglecting potential and kinetic energy changes) [18];

$$Q_h = \dot{m}_h(h_{hi} - h_{ho}) = \dot{m}_h C_h(T_{hi} - T_{ho}) \quad (1)$$

$$Q_c = \dot{m}c(h_{ci} - h_{co}) = \dot{m}_c C_c(T_{ci} - T_{co}) \quad (2)$$

Where m_h, m_c are mass flow rate of hot and cold fluid, respectively, h_{hi}, h_{ho} are inlet and outlet enthalpies of hot fluid, respectively, h_{ci}, h_{co} are inlet and outlet enthalpies of cold fluid, respectively, T_{hi}, T_{ho} are inlet and outlet temperatures of hot fluid, respectively, T_{ci}, T_{co} are inlet and outlet temperatures of cold fluid, respectively, and C_h, C_c are specific heats of hot and cold fluid, respectively.

From energy conservation, $Q_c = Q_h = Q$, and the heat transfer rate Q is related to the overall heat transfer coefficient U, and the LMTD (log mean temperature difference) by means of:

$$Q_c = U\ A\ \text{LMTD}\ C_f \quad (3)$$

The LMTD is derived as:

$$\text{LMTD} = \frac{\Delta t_1 - \Delta t_2}{\ln\left(\frac{\Delta t_1}{\Delta t_2}\right)} \quad (4)$$

$$\Delta t_1 = T_{ho} - T_{ci} \quad (5)$$

$$\Delta t_2 = T_{hi} - T_{co} \quad (6)$$

where U is the overall heat transfer coefficient, A is the total surface area for heat exchange, and C_f is a correction factor.

The epsilon–NTU method is one of the heat exchanger analysis methods. The effectiveness/NTU (number of transfer units) method was developed to simplify a number of heat exchanger design problems. The heat exchanger effectiveness (ε) is defined as the ratio of the actual heat transfer rate to the maximum possible heat transfer rate if there were infinite surface area. The heat exchanger effectiveness depends upon whether the hot fluid or cold fluid is a minimum fluid. That is the fluid which has the smaller capacity