

AUTOMATION OPTIMIZATION OF A CASCADE UTILIZATION SYSTEM USING GEOTHERMAL WATER WITH MODERATE TEMPERATURE

Carmen Violeta IANCU^{1,#}, Mariana BEI², Ioana Maria BORZA³, Manuel Alexandru GITEA⁴, Andra Nicoleta LAZĂR⁵, Anamaria Melania ȘANDOR⁶, Isabel Andromeda DAVID⁷

^{1,2,3,4,5}University of Oradea, Faculty of Environmental Protection, Oradea, Magheru 26, 410087, Romania

⁶Special Technological High School No 1, Gheorghe Barițiu St. No 9, Oradea

⁷Student at the Food Engineering Department, University of Oradea, Faculty of Environmental Protection, 26 Gen. Magheru St., 410048, Oradea, Romania

Abstract

This paper presents detailed studies and analyses aimed at optimizing the automatic control system of a cascade utilization with thermal energy from moderate-temperature geothermal water. Ensuring the stable and efficient operation of the thermal installation requires the development of an automation program that continuously monitors, regulates, and coordinates all functional parameters. This technological approach is fundamental for the sustainable and economic exploitation of geothermal resources, reducing human intervention and minimizing the risk of operational errors.

Keywords: geothermal water; cascade utilization; automation loop, moderate temperature

Corresponding author: ciancu@uoradea.ro

INTRODUCTION

Geothermal energy represents the heat stored within the Earth, originating from the planet's internal structure and the physical processes occurring beneath its surface. Although this thermal energy exists in vast quantities, it is unevenly distributed and, in many cases, located at depths too great for practical industrial exploitation.

However, in certain regions the heat can accumulate near accessible zones, making these areas economically attractive for exploration and utilization.

Geothermalism encompasses all aspects related to the study, identification, exploitation, and efficient use of geothermal resources. According to Hochstein, a geothermal reservoir can be schematically defined as "convecting water in the Earth's upper crust that, within a confined space, transfers heat from a deep thermal source to an accumulation zone, which is generally the planet's surface." (Elena Zierler, 2008; J. W. Tester et al., 2006; Kailash N. et al., 2008; Marcel Roșca, 2007)

Thus, a geothermal reservoir consists of three essential components: a heat source, a storage reservoir, and a fluid that serves as the transport medium responsible for transferring thermal energy. Due to the complexity of the

issues involved, geothermal studies form an interdisciplinary domain that requires expertise from geology, drilling engineering, energy systems, agronomy, medicine, and other related fields. (Elena Zierler, 2008; J. W. Tester et al., 2006; Kailash N. et al., 2008; Marcel Roșca, 2007)

Current research interests in geothermal energy can be grouped into the following main areas:

- a) understanding the origin of geothermal energy as a manifestation of the Earth's internal heat;
- b) identifying geographic regions with geothermal potential;
- c) methods and technologies for exploiting geothermal reservoirs;
- d) direct and indirect applications of geothermal resources;
- e) economic and environmental considerations.

a) The origin of geothermal energy, as an expression of terrestrial thermal processes, must be examined from a multidisciplinary perspective. A significant contribution in this regard comes from the theory of global tectonics, which has revealed that the Earth's surface is divided into a mosaic of lithospheric plates whose nature and movement strongly

influence the distribution of the planet's thermal field. (Elena Zierler, 2008; J. W. Tester et al., 2006; Kailash N. et al., 2008; Marcel Roşca, 2007)

b) The identification of geographic zones with geothermal potential involves accurately determining those areas where geothermal resources can be effectively utilized. The geothermal resource base represents the total amount of geothermal energy stored in the Earth's crust beneath a given region (typically down to depths of about 10 km), relative to the local mean annual temperature. This resource base is classified into several categories: inaccessible resource base, accessible resource base, useful accessible resource base, and residual accessible resource base. From an economic perspective, geothermal resources are further classified into sub-economic resources, economic resources, undiscovered economic resources, and identified economic resources. (Elena Zierler, 2008; J. W. Tester et al., 2006; Kailash N. et al., 2008; Marcel Roşca, 2007)

c) The exploitation of geothermal deposits primarily concerns the development of production and reinjection wells, along with the drilling methods employed. This research area closely parallels the techniques used in drilling wells for oil and natural gas.

d) The utilization of geothermal deposits encompasses all ways in which geothermal energy can be harnessed for community and industrial purposes. Key applications include electricity generation, district heating systems, industrial processes, agricultural uses—particularly greenhouse heating, fish farming, and aquaculture—as well as balneology and various therapeutic applications.

e) Economic and ecological considerations focus on evaluating geothermal energy use in terms of cost-effectiveness and environmental impact. The recognition of geothermal energy as a viable alternative to fossil fuels has been strengthened by its technical and economic advantages, as well as by the fact that approximately 80 countries possess significant geothermal resources. (Elena Zierler, 2008)

The utilization of geothermal energy is generally based on extracting heat from geothermal reservoir waters and using it either directly as a thermal source or indirectly through conversion into electricity. Compared

to other energy sources, geothermal energy presents three defining characteristics:

1. It is, in principle, renewable, making it practically inexhaustible under appropriate management conditions;

2. It is a clean energy source, resulting in minimal environmental impact;

3. It represents an existing form of latent thermal energy that requires only to be accessed and harnessed.

Renewable energy represents the portion of natural energy resources that is continuously replenished and can be economically exploited under present or foreseeable conditions. Among renewable sources, hydropower has been used for many decades; however, its further expansion is increasingly limited due to ecological constraints and significant social impacts associated with large hydropower installations. Within the spectrum of renewable energies, geothermal energy occupies a distinct and important position. (Elena Zierler, 2008; J. W. Tester et al., 2006; Kailash N. et al., 2008)

Specialists classify geothermal energy utilization into two main categories: direct use and indirect use.

Direct use refers to the application of geothermal heat through direct transfer to the consumer or via an intermediate fluid. It includes four major subcategories:

1. Space heating and domestic hot water supply;

2. Agricultural applications (greenhouses, aquaculture, fish farming);

3. Balneology and therapeutic uses;

4. Industrial applications.

Indirect use involves converting the energy of geothermal fluids into electricity, either by driving turbines directly or by employing binary-cycle power plants. (J. W. Tester et al., 2006; Kailash N. et al., 2008; Marcel Roşca, 2007)

The range of possible applications is determined primarily by the temperature of the geothermal fluid. Lindal analyzed the main technological fields in which geothermal energy can be used efficiently both technically and economically according to fluid temperature. His findings were synthesized into a diagram known as the Lindal Diagram, illustrated in Figure 1. (Elena Zierler, 2008).

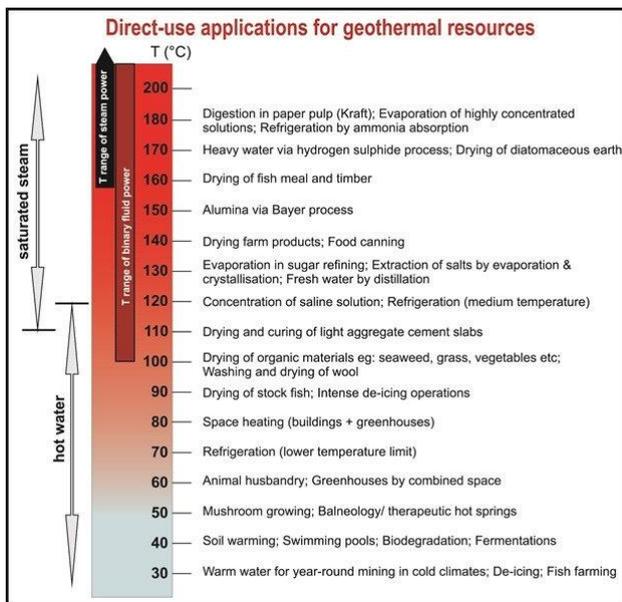


Figure 1. Linda Chart I

The utilization of geothermal energy in Romania currently takes place in 38 localities where geothermal resources have been identified, with 98 wells in operation—37 of which serve bathing and balneological purposes. The average temperature of the geothermal water is approximately 71 °C at intake and 28 °C at discharge. (Kailash N. et al., 2008; Marcel Roșca, 2007)

The total installed thermal capacity is 152 MWt, generating approximately 2,870 TJ per year. Direct uses of geothermal energy in Romania are distributed as follows: space heating - 37.4%, bathing and swimming including balneology - 30.4%, greenhouse heating - 23.1%, industrial applications - 7%, and fish farming and aquaculture - 2.1%, with an average capacity factor of 0.6%. (J. W. Tester et al., 2006)

One of the secondary beneficiaries considered in this study is a greenhouse complex that utilizes geothermal wastewater discharged from the geothermal power plant. (Elena Zierler, 2008) In the design phase, a crucial aspect is the evaluation of the energy or thermal balance across the greenhouse structure.

The study of system behavior always begins with a real, physical system created to solve various problems that arise in all areas of human activity. The ability of physical systems to address a particular type of problem depends on their intrinsic characteristics. In general, a physical system interacts with human activity as a tool designed to facilitate work, a function

achieved through the time-dependent modification of certain internal parameters.

Although any set of interacting physical bodies or real objects can be considered a physical system, this paper focuses on those systems intended to replace human observation, decision making, and action—known as automatic systems. These systems are designed, through the appropriate selection of their components, either to perform a predetermined sequence of events (in which case they are called automatic control systems) or to maintain prescribed values of one or several system variables that tend to change over time due to specific conditions such as disturbances. In this case, the systems are referred to as automatic regulation systems.

Since, in our case, the objective is to maintain certain parameters constant, the physical systems developed for this purpose are primarily automatic regulation systems. Therefore, throughout this work, the term physical system should be understood as referring to a physical automatic regulation system, unless explicitly stated otherwise.

The problem of regulating a real process may be described as follows: the variable or parameter that must be maintained at a desired value will, at a given moment during the process, take on a value different from that target value. This value is called the system response. The difference between the system response—i.e., the value measured by a sensor—and the reference value, which is the desired value of the parameter, is called the error. The appearance of this error is due to various disturbances that affect the real process. The main purpose of any regulation system is to reduce this error and keep it as close to zero as possible.

To achieve this, the error is transmitted to a physical system capable of acting on the real process in such a way as to decrease the error. This component is known as the controller (or regulator). The generic term controller may also include components that are not part of the controller in the strict sense but are essential elements of the regulation loop. These include the sensor, the comparison element, and the actuator.

The sensor retrieves the instantaneous value from the real process and converts it into a physical quantity that can be compared with another value of the same quantity, corresponding to the desired setpoint. This

comparison is performed by the comparison element, which provides the input to the actual controller. The controller then issues a command to an actuator, which adjusts the state of the physical system in order to keep the actual value as close as possible to the desired one.

MATERIAL AND METHOD

Solving the problem of automatic regulation involves the following steps:

1. Selecting appropriate sensors for acquiring the real variable from the process (the system response);
2. Selecting actuating elements capable of modifying the state and behavior of the system;
3. Describing the system components using mathematical equations;
4. Designing the actual controller based on these mathematical equations;

Analytical evaluation of the regulation design (possibly through simulation) and verification of the behavior of the real system.

A mathematical model of a real process consists of a set of equations that describe the relationships between various parameters characterizing the system. In general, these are differential equations with time as the independent variable, since regulation concerns the temporal evolution of the system parameters. A real process or system can be represented by multiple mathematical models, depending on which parameters are considered essential, which disturbances are taken into account, and how the evolution of the real process is interpreted.

Thus, for the same physical system, both simple and complex mathematical models may be formulated, depending on the level of detail incorporated into the model's structure. In practice, no mathematical model can fully describe a physical system; however, more complex models can approximate the real system with satisfactory accuracy. Due to the inherent limitations with which mathematical models approximate the real behavior of a physical system, if real-world tests of the designed regulation system fail to produce the expected results, it becomes necessary to revisit the choice of the mathematical model, seeking a more detailed and comprehensive representation of the real process.

STRUCTURAL HEAT BALANCE

In addressing climate control within a greenhouse, the heat balance and the thermal response of the crop, the indoor air, the roof structure, and the soil play a particularly important role. The greenhouse's hemispherical shape also affects the associated energy and mass transfer processes. (Crispin Allen, 1990; Curtis D. J., 1988; F. S. Blaga, 2009; Iancu Carmen, 2010)

The heat balance reflects the exchanges of heat and mass between the greenhouse and its surrounding environment. All parameters governing the physical processes inside the greenhouse are in energetic equilibrium with the external environment, and collectively they contribute to establishing the internal thermal balance. The principal heat exchange processes can be represented schematically as shown in Figure 2. (Crispin Allen, 1990; Danfoss, 1986; Iancu Carmen, 2010; T.-J. Yeh et al., 2009)

The energy balance in a greenhouse can be simplified expressed:

$$Q_{\text{tot}} = Q_{\text{gain}} - Q_{\text{loss}}$$

where: Q_{tot} = total amount of energy (net energy exchange) [W];

Q_{gain} = the amount of energy entering the greenhouse [W];

Q_{loss} = the amount of energy coming out of the greenhouse [W]

Determining the heating requirements of a greenhouse under various internal and external climatic conditions involves calculating all heat transfer processes included in the energy balance, as well as the climatic parameters that influence them. (Crispin Allen, 1990)

These processes depend on heat transfer coefficients, interior-exterior temperature and humidity differences, material properties, radiation, form factors, the characteristics of the plant canopy, and the specifications of heating and cooling systems. (Crispin Allen, 1990)

Some of these factors remain constant or nearly constant and can be calculated directly. Others vary with temperature and humidity and therefore must be evaluated under changing or so called dynamic conditions. Solar radiation and outdoor air temperature vary independently of the internal conditions of the greenhouse.

The amount of heat entering the greenhouse is:

$$Q_{\text{gain}} = Q_h + Q_l + Q_w$$

unde: Q_h = heat produced by the heating system [W];

Q_i = heat obtained from solar radiation [W];

Q_w = căldura datorată transpirației [W]

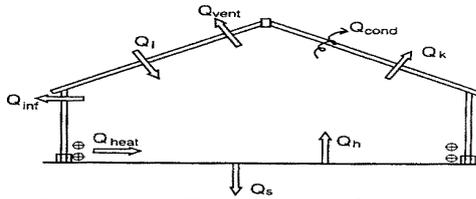


Figure 2. Energy transfer through the structure, greenhouse, condensation energy; energy of the heating system; infiltration energy; transmission through the roof; solar radiation; Evaporation; ventilation energy; Transmission through soil

MECHANISMS OF THERMAL ENERGY LOSS IN GREENHOUSE STRUCTURES

The amount of energy leaving the greenhouse can be estimated with the following equation::

$$Q_{\text{loss}} = Q_k = Q_s = Q_{\text{cond}} = Q_v = Q_{\text{inf}}$$

Q_k = heat lost by convection outwards [W];

Q_s = heat lost through conduction to the ground [W];

Q_{cond} = heat loss due to condensation [w];

Q_v = heat transfer due to ventilation [W];

Q_{inf} = heat transfer due to infiltration [W].

MECHANISMS OF OUTWARD CONVECTIVE HEAT LOSS

t represents the heat lost through the greenhouse envelope, from the interior air to the exterior environment, and can be quantified using the following equation:

$$Q_k = hxA_c(T_{\text{in}} - T_0)$$

where: T_0 = outside temperature [k];

h = overall heat exchange coefficient [w/m²k];

A_c = Area of the greenhouse shell [m²];

T_{in} = indoor air temperature [k].

In the equation above, the overall heat transfer coefficient incorporates the combined effects of convection, conduction, and thermal radiation. It does not account for air infiltration through cracks or openings around windows and doors of the greenhouse. (Ertuğrul Çam, 2007; F. S. Blaga, 2009; H. Silaghi et al., 2009; İlhan Kocaarslan, 2006; Michael Anderson et al., 2007; Szymon Ogonowski, 2010)

For practical calculations, the overall heat transfer coefficient can be determined using the following equation, in which w represents the wind speed [m/s]: $H = 2,8 + 1,2w$

Heat lost in the soil

The flow of heat to the ground is complicated to determine because it is associated with water circulation. In most cases, it is enough to consider the flow of heat to the ground using apparent thermal conductivity, which includes the effect of water flow. (Crispin Allen 1990, G. Ionescu, et al, 1983, H. Silaghi et al, 2009, Iancu Carmen, 2010)

In the calculations, it is considered that the earth is divided into 3 uniform layers in depth and the temperature in the center of each layer is T_1 , T_2 and T_b respectively. The temperature T_b at the lower layer is a boundary condition and the temperature at the soil surface is considered the indoor temperature of the greenhouse. (Crispin Allen 1990, H. Silaghi et al, 2009)

According to the energy balance equation, the heat flow in the soil during dt is expressed by dq/dt , and is adapted to the temperature exchange using mass properties:

$$\frac{dQ}{dt} = C_p \times \rho \times \frac{d\theta}{dt}$$

In heat transfer by conduction the energy balance can be written as:

$$C_p V_s \frac{dT_1}{dt} = K_s A_s \left(\frac{2(T_{\text{in}} - T_1)}{dz} + \frac{T_2 - T_1}{dz} \right)$$

$$C_p V_s \frac{dT_2}{dt} = K_s A_s \left(\frac{(T_1 - T_2)}{dz} + \frac{T_B - T_2}{dz} \right)$$

RESULTS AND DISCUSSIONS

To ensure the correct and efficient operation of the thermal energy system serving the greenhouse complex, an automation program must be developed to monitor and regulate its functional parameters. The main objective is to maintain the desired indoor temperature of the greenhouse, monitored by the TT6 temperature transducer. This measurement enables the correlation between the recorded parameters and the control actions applied to the actuating elements.

Figure 3 illustrates the automation loop, as well as the fault detection loop, associated with the thermal energy supply system for the greenhouse complex..

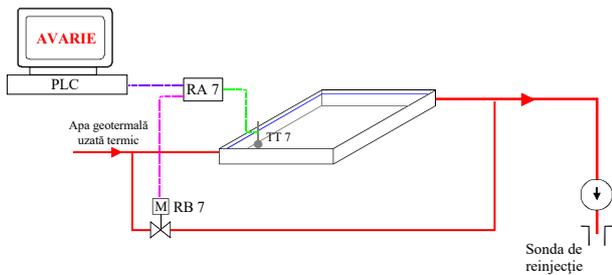


Figure 3. Automation and fault loops for the thermal energy supply installation for the greenhouse complex

A. AUTOMATION LOOP

The automation loop of the thermal energy supply installation for the greenhouse complex aims to achieve the condition: maintaining the temperature in the greenhouse within 18... 20°C. Geothermal water feeds the heating system from the ground surface and then passes into the ground heating system. The temperature inside the greenhouse must be maintained within 18... 20°C; This condition is achieved by regulating the geothermal water flow, obtained by opening/closing the RB6 tap, mounted on the geothermal water pipe that short-circuits the greenhouse.

If the temperature transducer TT6 located inside the greenhouse shows a temperature higher than the maximum permissible limit for this temperature, i.e. lt_6 ($lt_6=20^\circ\text{C}$), after the TTMP 2 delay time has elapsed ($ttmp\ 2=240\ \text{sec}$) since the last setting command was executed, and if the automatic valve controller on the geothermal water supply route meets the $ra_6 - 100\ \%$ inequality (the valve is not fully open), Open the RB6 valve with XRB6 value ($XRB_6=0,25\ \text{rot.}$) by the control given by the RA6 controller. if the tt_6 transducer shows a temperature lower than the minimum permissible limit for this temperature, i.e. lt_6 ($lt_6=18^\circ\text{C}$), after the TTMP 2 delay time has elapsed since the last setting command was executed, and if the automatic valve regulator on the geothermal water supply route satisfies the $RA_6-0\%$ condition (valve not closed), Close the RB6 valve with XRB6 value by the given command.

B. FAULT SIGNALLING AND SYSTEM RESPONSE IN THIS CAZ.

During operation, discrepancies may arise between the functional parameters of the installation and the prescribed operating conditions—discrepancies that the automation program is unable to correct on its own. In such situations, the operator is alerted to the

malfunction and must intervene to restore normal operating conditions. The fault-signalling system (Figure 3) and the corresponding system response represent a critical component of the automation program, as they prevent potential accidents and provide timely warnings regarding abnormal operation.

The most critical fault that may occur during operation is an increase in geothermal water pressure at the greenhouse inlet beyond the maximum permissible limit. If the TP6 pressure transducer, mounted on the geothermal water pipe at the entrance to the greenhouse, indicates a pressure higher than the maximum permissible value Lp_6 ($Lp_6=4\ \text{bar}$), for more than $ttmp\ av_2$ ($ttmp\ av_2=60\ \text{sec.}$) (situation caused by possible obstruction of the geothermal water circuit, especially in the area of the ground surface heating system or ground heating system), the system signals "FAILURE OF DEFECTIVE PIPES".

If the TT6 transducer shows a temperature lower than the minimum permissible limit for this temperature, i.e. lt_6 ($lt_6=18^\circ\text{C}$), after the TTMP2 delay time has elapsed since the last setting command was executed, and if the automatic valve controller on the geothermal water route corresponds to $RA_6=0\%$ equality (valve is closed), the system signals "FAILURE of faulty RB6 valve".

In order to determine the possible variations for the T_i parameter, several measurements were made, corresponding to a number of 20 experiments. It should be noted that each value was calculated as an average of 16 different measurements carried out on a case-by-case basis. In figure 4. a graphical representation of the results of the determinations made for parameter T1 is made.

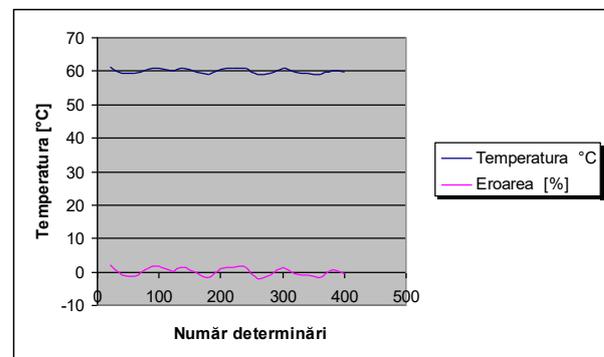


Figure 4. Graphical representation of the results of the determinations carried out for parameter LT6

In figure 5. a graphical representation of the results of the determinations made for parameter T3

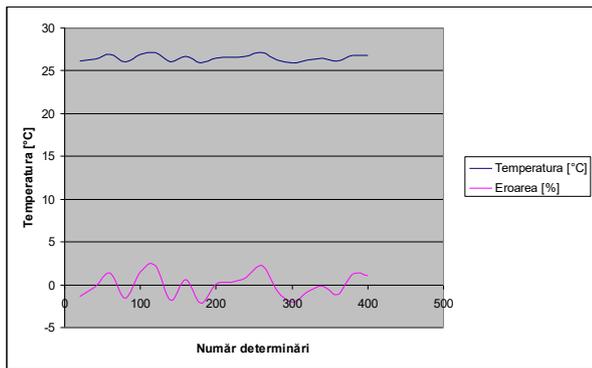


Figure 5. Graphical representation of the results of determinations made for parameter Ti

CONCLUSIONS

A central aspect in addressing climate control within a greenhouse is the evaluation of the heat balance and the thermal response of the crop, the internal air, the roof structure, and the soil. The geometric shape of the greenhouse, particularly its hemispherical configuration, also influences the associated energy and mass transfer processes. The heat balance is determined by the exchanges of heat and mass between the greenhouse and its surrounding environment. All parameters governing these physical processes are interrelated and collectively establish the energetic equilibrium between the greenhouse interior and the external environment.

The efficient operation of the thermal energy supply system for the greenhouse complex, it is necessary to implement an automation program capable of continuously monitoring and adjusting the installation's functional parameters. The central objective is to maintain the indoor temperature of the greenhouse—measured by the TT6 temperature transducer—within the prescribed limits. The data provided by this sensor enable the correlation between the monitored parameters and the control commands issued to the actuating elements.

To ensure the efficient operation of the thermal energy supply system for the greenhouse complex, an automation program must be developed to continuously monitor and adjust the functional parameters of the installation. The primary objective is to maintain the indoor temperature measured by the TT6 temperature transducer within the required limits. This measurement enables the synchronization of recorded parameters with the control actions applied to the actuating elements. In order to ensure the proper

functioning of the thermal energy installation for the greenhouse complex, it is necessary to develop an automation program to monitor and adjust its functional parameters. The aim is to maintain the temperature inside the greenhouse, measured using the TT6 temperature transducer. This allows a correlation between the measured parameters and the command of the execution elements. In order to determine the possible variations for the Ti parameter, several measurements were made, corresponding to a number of 20 experiments. It should be noted that each value was calculated as an average of 16 different measurements carried out on a case-by-case basis.

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