

# IN-LINE WATER HEATING SYSTEM FOR INDUSTRIAL APPLICATION

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**Abstract:** Due to the increase of electricity prices in South Africa and the World, there exists the need for energy efficient water heating systems. The authors of this paper conducted a literature study on existing water heating systems. The study shows that there is a possibility of designing more efficient water heating system at lower cost. An in-line water heating system for industrial applications was designed and tested. Before the system was designed a Finite Element Method analysis of the system was carried out to predict the systems' pressure and temperature. During a physical model test the energy consumption was measured and compared to a conventional storage water heating system. The designed in-line water heating system is shown to be more energy efficient than the conventional storage water heating system. It also had a variety of advantages such as: size, adaptability to a variety of locations, and robustness.

**Keywords:** Energy consumption, temperature controller, water heating system.

## 1. INTRODUCTION

Tankless electric water heaters have become more popular in industrial use due to their advantages over conventional water heating systems. Tankless electric water heaters are not harmful to the environment and require less space for installation, since there is no water tank.

A consumer can receive hot water instantaneously at any time. Tankless water heating systems are more durable than the conventional water heating tanks. The absence of the water tank significantly simplifies maintenance (no rust, corrosion, flooding or bursting of a tank, etc.). The disadvantages of electrical water heating systems are: electronic failure, and trouble shooting.

Almost one third of electricity bills in the industrial sector are towards hot water energy consumption. There are therefore always room for improvement in the water heating field, which will save money, water and preserve the environment.

After exploring alternative methods of increasing the efficiency of water heating systems [1-4], a design of an in-line water heating system was performed. Literature study shows that some of the water heating system manufactures do not consider temperature controllers in their products [5-6]. There is therefore the possibility of pressure and temperature build up in the system which can end up with significant power losses. The main focus of this paper is to design an energy efficient instantaneous water heating system including controller. The project is also oriented on minimizing the cost of the system, and avoiding any complexity in manufacturing. The designed in-line water heating system includes affordable components available in the market in South Africa.

## 2. CONCEPTUAL DESIGN

In-line electric water heaters usually consist of two coils. The first is the water carry coil. It carries the cold water into the system, heats it and then warm water is sent through the same coil as output to the user. The second coil is better known as the heating coil. With a swirling motion it is twisted around the carrier and heats the water as it passes through. The water unit system consists of different types of sensors to ensure correct and efficient operation. When the hot water faucet is turned open, two sensors are activated: the pressure and temperature sensors. The pressure and temperature of the incoming cold water are measured and the data is sent to a microprocessor for calculations. The microprocessor compares the calculated values with the pre-programmed data, and adjusts the heating coil as needed [7-8]. Figure 1 shows the conceptual design of the in-line water heating system.

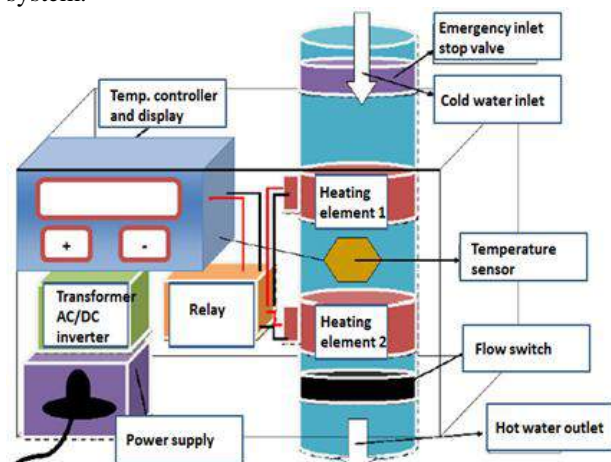


Figure 1: Conceptual design of the in-line water heating system

The components are as follows: temperature controller, transformer or AC/DC inverter, relay, heating elements, emergency input valve, temperature sensor, flow switch, outside enclosure containing all the components, outlet valve, power input inlet, and heating pipe. The system is designed to provide reliable operation with maximum efficiency at minimal cost.

Cold water fills the pipe which can be copper or galvanize pipe. The flow switch detects the water flow in the system and turns on the heating elements. The temperature sensor sends a signal to the temperature controller which in turn correlates the received temperature with the pre-programmed temperature. The controller also sends a signal to the relay that conveys the essential power to the heating elements. The heating elements heat the pipe with the power reviewed from the relay. The heated water reaches the outlet. As soon as the inlet faucet is turned off the flow sensor opens and the system turns off.

### 3. DETAILED DESIGN

The detailed design of the system is shown in figures 2 and 3.

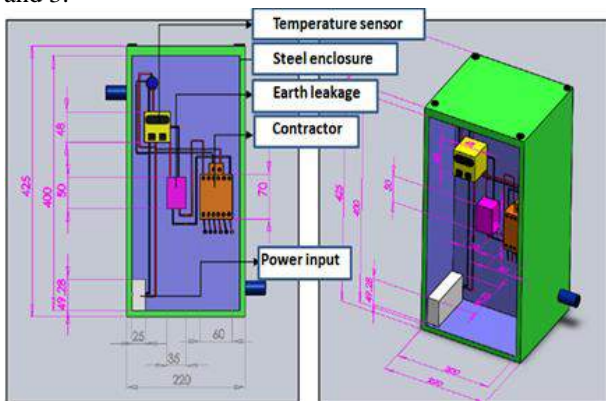


Figure 2: Designed in-line water heating system with all necessary components

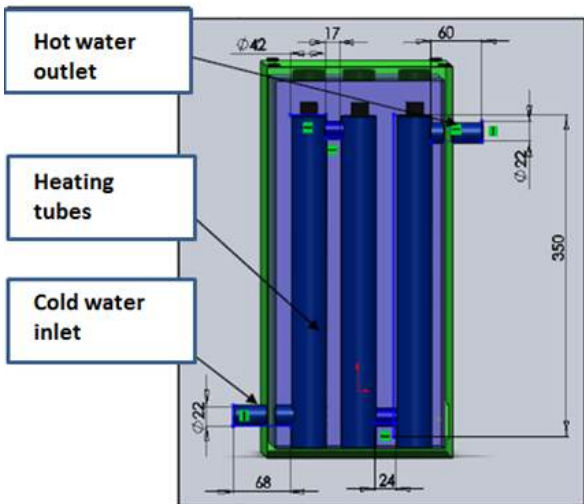


Figure 3: Water circulating component of the system

The design consists of a 230 VAC PID controller, power inlet at 230 VAC, electromechanical relay, contractor, three 4 kW screw type stainless steel geyser elements, a PT 100 temperature sensor, cold water inlet with pressure reducing valve, and a warm water outlet faucet with a flow switch mounted inside the outlet pipe.

The main task of the project is to provide the system with optimal control in order to increase efficiency of the system. The temperature controller can either increase or decrease efficiency of the system depending on how it is used. On/off control would be the most uncomplicated mode to select, but the water heating system should be energy efficient and more advanced than existing water heaters. The PID control option is selected for the project. The reason for this is because PID control takes present, future and past errors in consideration to assure efficient working of the system. PID control improves the speed of the response, suppress disturbances and reduce oscillations. Control accuracy is dependent on the signal from the temperature sensor. PT 100 (platinum resistant thermometer) temperature probe was implemented in the design. In most heating water systems a basic geyser thermostat is used. However, the temperature controller is not adjusted to the thermostat input. The PT 100 temperature probe is another critical integration. The output of the system is dependable on the temperature sensor. The PT 100 ranges from -199.99 °C to 500 °C. The probe sends a temperature input to the temperature controller. If the process value reaches the set value (in a particular case 40 °C) the heating unit should switch off. The temperature probe is located in the second heating tube. This is done in order to make the process less flexible and the output more stable. The measured hot water output was adjusted by a couple of degrees Celsius for the measurement to be accurate.

CN-40 temperature controller was used to display both the process and set values of the system. The output of the system is dependable on the programmed settings of the controller. Most of the settings on the controller are pre-programmed. The controller receives 220 V and data from the PT 100 sensor and the in-line Flow/Pump flow switch. The Flow/Pump flow switch is the critical component which makes the heating system an in-line or instantaneous system. The switch enables the system to switch on as soon as enough water passes through the normally open switch. The pressure allows the switch to close, which in return activates the controller and energizes the contractor. When the contractor is de-energized the heating elements switch off. Each of the three stainless steel heating elements is mounted in a stainless steel heating tube.

The heating elements are connected to the contractor as well as to the earth connection in the casing. This is required by safety standard for electrical products. The CN-40 temperature controller, flow switch, contractor, and heating element are shown in figure 4.

To calculate the efficiency of the in-line water heating system, the Watts hour have to be measured and

compared to existing systems. A kWh counter was integrated for this purpose. An identical unit was also connected to a conventional geyser in order to be able to make a comparison. The counter has a green light if zero or minimal energy is drawn, a flashing red light during normal load operation and a green/red flashing when a fault occurs. The counter is shown in figure 5 a).

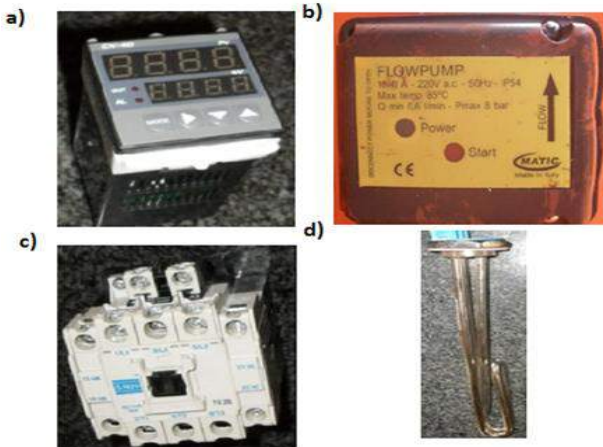


Figure 4: In-line water system components: a) CN-40 temperature controller, b) Flow/pump switch, c) contractor, d) heating element

Earth leakage connector can also be seen as one of the main safety devices in the heating system. The earth leakage will trip for several reasons. If any of the electrical wiring or devices receives water damage the earth leakage will trip. The earth leakage connector is shown in figure 5 b).

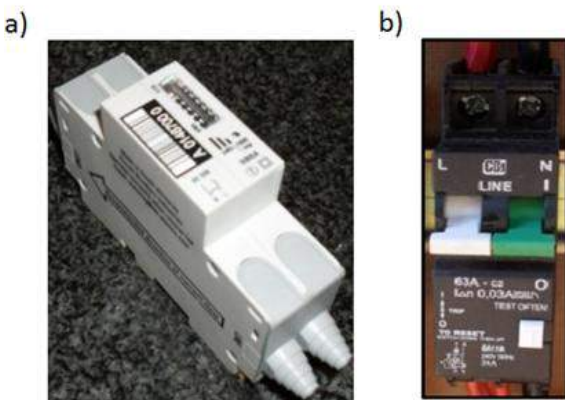


Figure 5: a) single-phase kWh counter, b) earth leakage connector

All the individual units come together in a 600 mm x 400 mm x 200 mm steel enclosure. The enclosure is waterproof and will protect the electrical units from dust and water particles. Both plumbing and electrical devices are mounted inside the enclosure. The controller is mounted in the door, with the display facing outwards for easy accessibility. This enclosure is smaller than

conventional water heating systems presented in the market.

The completed system is shown in figure 6.

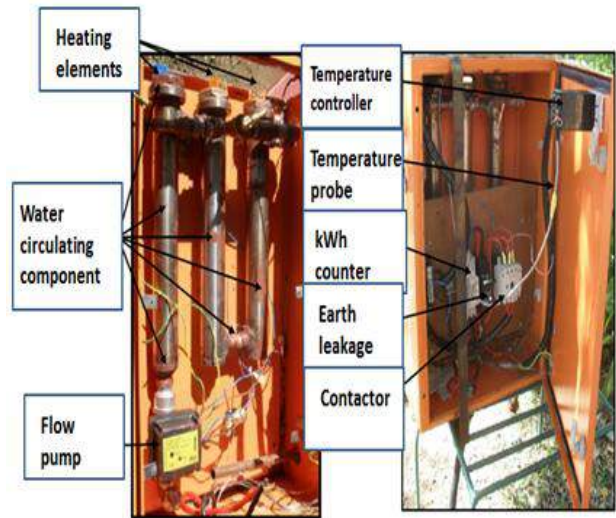


Figure 6: Completed in-line water heating system

#### 4. SIMULATIONS AND PRACTICAL RESULTS

The system was simulated for a variation of inputs in order to predict system behaviour before testing. From the flow lines in figure 7 a) is clearly visible how the 20 °C input cold water heats up with three separate 4 kW heating element in each heating tube to obtain an average output value of 34 °C when the water flows at 0.1333 kg/s (8 l/min).

Figure 7 d) shows the temperature simulation results where input flow rate of the water has been reduced, while figure 7 c) shows the result for an increase in flow rate. By reducing the speed of the water flow inside of the heating tubes a more suitable and stable output can be achieved.

Figure 7 b) shows the simulation results in terms of pressure for a cold water input value of 20 °C at flow rate of 0.1333 kg/s. The results show a decrease in pressure during the flow in each heating tube. If the faucet at the outlet is turned off the pressure in the system will increase.

The practical tests were performed in the laboratory. Two systems: 1) conventional and 2) in-line water heating systems were tested and the results were compared. The conventional geyser used power of 10.5 kW and two and half hours to heat 150 litres of water from 15 °C to 60 °C. This means that the geyser takes 70 Wh to heat a single litre of water. The in-line water heating unit consumed the same amount of energy of half of the time, but provided more than twice as much hot water.

The instantaneous geyser takes 24.9 Wh to heat a single litre of water. This is 36.9 Wh per litre difference compared to the conventional geyser. Figure 8 shows

conventional geyser versus the in-line water heating systems energy consumptions.

From figure 8 it is visible that in both systems kWh rating is directly growing to the time for which the system is running. With a high current rating the in-line water heating systems takes only seconds to reach the process value, while the conventional heating system takes hours.

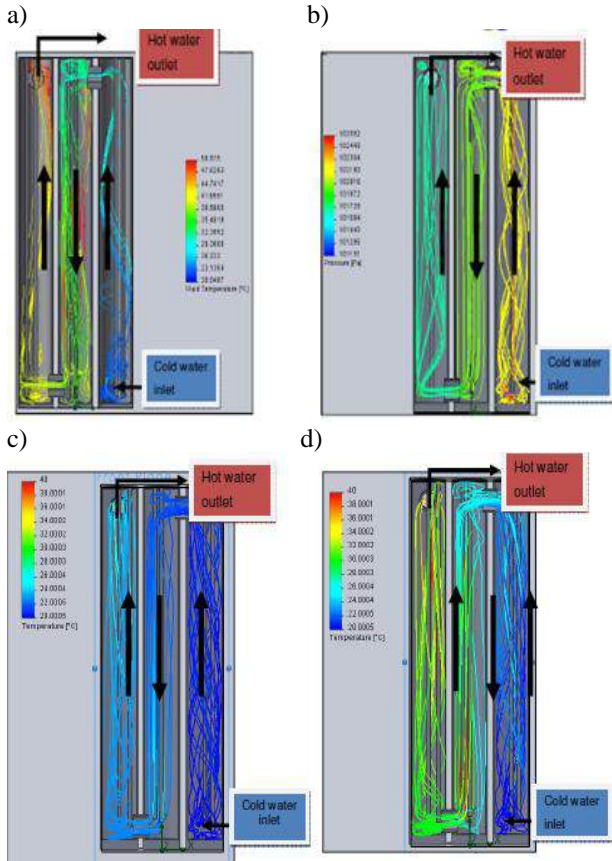


Figure 7: In-line water system simulation: a) temperature analysis for 12 kW at 0.1333 kg/s, b) pressure analysis for 12 kW at 0.1333 kg/s, c) temperature analysis for 12 kW at 0.66 kg/s. d) temperature analysis for 12 kW at 0.233 kg/s

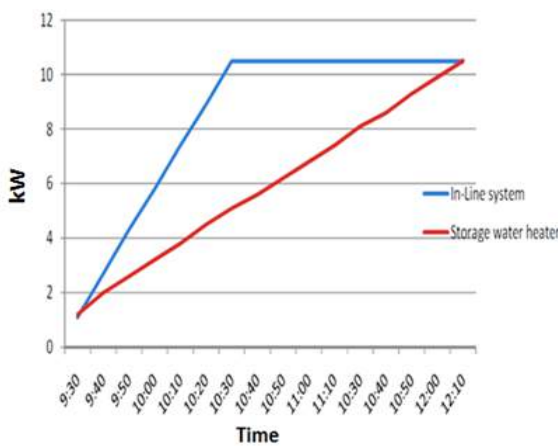


Figure 8: Energy consumption of a conventional and in-line water heating systems

Figure 9 shows the in-line temperature measurements over the energy consumed every ten minutes the system is running. During the first twenty minutes the temperature shows a fluctuation, thereafter the process temperature shows increase up until 45 °C. For the last twenty minutes the process stabilizes at 45 °C.

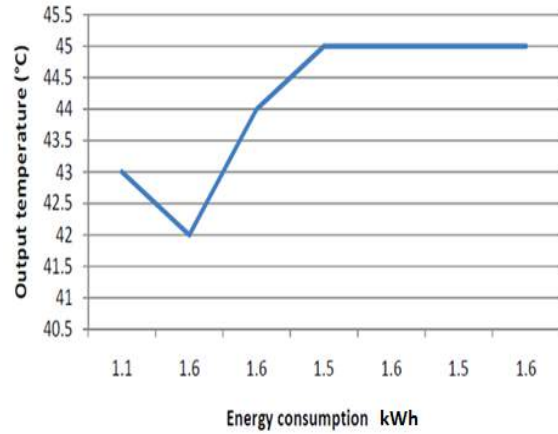


Figure 9: Energy consumption with output temperature of the in-line water heating systems

## 5. CONCLUSIONS

Energy savings in industry are becoming a problem in South Africa. The authors of the paper conducted a literature study to find possible ways to minimize the energy consumption in industry by maximizing efficiency of electro-technical processes. One of these processes was water heating.

An efficient in-line water heating system with a controller is designed and tested. The energy consumption was measured and compared to a conventional storage water heating system. After a variety of tests and measurements the in-line water heating system appeared to be more energy efficient. The system can supply hot water within 35 seconds from turn on at a flow rate of 7 litres per minute. Ideally in any hot water system the flow rate should be unlimited, but in comparison to existing water heaters in-line water system performed better.

Apart from unlimited hot water supply the in-line heating has a number of advantages such as: size, adaptability to a variety of locations, and robustness. The system is a right solution for industries where instantaneous flow of hot water is required.

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