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Research Article

Development of a Constant Temperature Hot and Cold-Water Supply System (CT50WS) for Laboratory Application

Isa I. Isa, Yinka S. Sanusi*, Samaila Umaru, Talib O. Ahmadu

Mechanical Engineering Department, Engineering Faculty, Ahmadu Bello University, PMB 1045 Zaria Kaduna, Nigeria

Corresponding Author: yssanusi@abu.edu.ng

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Abstract

Over 95% of Nigeria undergraduate students enrolled in public universities. Public universities in Nigeria are however poorly funded and lack adequate facilities. The recent rise in the foreign currency against the Nigerian Naira has further increase the cost of purchasing and maintaining foreign equipment. In this work, a constant temperature hot and cold-water supply system (CT50WS) for laboratory application was developed. This is to explore the production of equipment locally. The developed system was tested on a load and no-load conditions. A shell and tube heat exchanger were used to simulate the load on the component. The system was designed to heat and cool 50 liters of water independently. Results of the tests carried out on the constructed CT50WS on no load condition showed that the actual rate of heat loss from the hot water system is 34.4W. The actual rate of heat gain from the cold-water tank is 16.03W, far lower than the designed heat gain rate of 74.9 W (10%) heat gain rate. When tested on-load condition, the CT50WS was able to continuously supply 100 litre/hr of hot and cold water at a temperature of 50 and 18°C respectively to the heat exchanger. The open market cost of a similar foreign equipment is about 25 times the cost of CT50WS. Its acceptability will further open opportunities in local production of teaching and research equipment, thereby serving as source of job creation and saving the scarce foreign currencies.

Nomenclature and units

Q_h	The heat energy required	$\Delta T_{ins.}$	The temperature difference due to insulation	T_{amb}	The ambient temperature
V	The volume occupied by the substance	L_t	The length of the tank	T_f	The final temperature
ρ	The density of the substance	k	The thermal coefficient	P	The Power required to pump the water
C_p	The Specific heat capacity	μ	Viscosity of the fluid	Q	The flowrate
ΔT	The temperature difference	Re	Reynolds number	H	The total head
P_h	The power required	U	The overall heat transfer coefficient	COP	Coefficient of performance in refrigeration
t	The time taken	f	Friction factor	H_s	The static head
$Q_{loss/gain}$	The heat energy lost or gained	L	Length of pipe	H_D	The dynamic head

1.0 Introduction

The total number of universities in Nigeria are 174. There are 43 Federal Universities, 52 State Universities and 79 private universities (Funmilola, 2020). The private universities however, account for less than 6% of student's population according to Nigeria Universities Commission (Adedigba, 2018). Nigerian governments (Federal and states) allocate as low as seven per cent to the education sector (Ojomoyela, 2018). This resulted in poor funding of the public universities. Academic Staff of Union of Universities (Vanguard, 2018) had embarked on several nationwide strikes to protest inadequate funding of public universities. The inadequate funding has resulted in infrastructural decay, obsolete equipment in the laboratory and workshop, out dated books and journals in the library among other issues. In school of engineering especially mechanical, instructional laboratories is an essential part of engineering education (Feisel & Rosa, 2005). Thermal sciences which is a branch of mechanical engineering involves the study of power generation, energy conversion and transmission, the flow of liquids and gases, and the transfer of thermal energy (by means of conduction, convection and radiation). Therefore, equipment that can transfer both hot and cold water for heating and cooling is essential in thermal laboratories. These equipment are available by major equipment producing companies. For instance, ARMFIELD produces a heat exchanger service unit HT30XC that can be used as a service equipment to several heat exchangers. The HT30XC hot water system has a 75°C maximum thermostat setting. The cold water is supplied directly from the main water supply without any additional process. The system requires a supply of water at 300 litres/ hour at 1.25 bar gauge, while the temperature should be below 20°C (Armfield). TECQUIPMENT produces a heat exchanger service module TD360. The cold water is supplied directly from the main water supply without any additional process. The system requires a supply of water at the flowrate of 300 litres / hour and at a pressure range of 1 to 3 bar (Tecquipment). PA Hilton produces a heat exchanger service unit H102. The H102 has a 3kW immersion heater and the hot water system has 80°C maximum thermostat setting. The cold water is supplied directly from the main water supply without any additional process. Both hot and cold water are supplied at the rate of 14.4 litres/ hour to 180 litres/ hour. The system requires a supply of water at 180 litres/ hour at 20m head (Hilton). Due to infrastructural decay in the public universities, most of the laboratories does not have constant water supply system. Therefore the use of these equipment from the major equipment manufacturers will be challenging. Besides, these equipment are expensive for a country that is bedeviled with scarce foreign currency. In 2017 a contractor made an offer to supply heat exchanger service module code named (TD360) for $ 11,680.25 (Tech-Ed Systems Inc, 2017). The equipment transportation cost and other auxiliary costs will further increase the equipment landing cost. Therefore, there is need to develop hot and cold water supply system that address the challenges of main water supply requirement and specifications. This equipment when produced locally will be cheaper and give institutions independence from foreign equipment. The effect of foreign exchange will be minimal since most parts would be locally sourced. Maintenance would also be much convenient with locally sourced parts. The equipment would be cheaper since other costs such as shipping and custom duty would be avoided.

Several cold water supply systems have been developed using vapour compression cycle (Atrsaw et. al (2020), (Bhagyesh, et. al (2018)), absorption cycle (Ahmadu, (2019)), (Osman & Abdalla, (2016)) and thermoelectric module (Wiriyasart, et. al (2019)), (Fayazahamed, et. al (2018)), (Hommalee et. al (2018)). Balogun (2020) developed a temperature controlled water heated bath for science laboratories. Solar water heater development has also been well documented (Omer El Kassri (2019)), (Ebubechuku Jude (2020)), (Ambarita (2018)). Okiy S & Oreku B.U, (2018) developed an adaptable hot and cold water dispenser with inbuilt inverter where a Peltier device serves the cold and hot chamber simultaneously. Similarly, Ashish Ramprasad and Subhrajyoti Abnerjee (2015) developed water dispenser system that utilizes a heat pump to heat water from 31 to 42ºC in 90 minutes, and cools water from 31 to 24 in 90 minutes simultaneously.

In this work, a constant temperature hot and cold water supply system for laboratory application was developed. The developed system was tested on a load and no load conditions. A shell and tube heat exchanger was used to simulate the load on the component.

2.0 Design Considerations

Water supply: A tank was considered to compensate for the unavailability of a constant water supply system.

Piping and pumping system: The piping mainly consists of flexible braided hoses because they contain gaskets and are easy to tighten without the need of other materials and equipment such as gum, thread tape, or wrench, common available flexible braided hoses in the market have a diameter of 12.7mm. Therefore the piping system diameter to be adopted is 12.7mm.

Operating temperature: The heating system is required to heat water to a maximum temperature of 80 ºC, while the cooling system is required to be able to cool water to a minimum temperature of of 5 ºC.

Insulation: The heat loss from the equipment should be limited to 10% to minimize environmental interference and also allow the heating and cooling system to function with high efficiency and produce the desired result.

2.1 Design Theory

The amount of heat energy added/rejected from the water in the tank during heating/cooling operation was computed from:

$$\mathbf{Q_h = (V \times \rho) \times C_p \times \Delta T} \quad \textbf{(1)}$$

Where, Q_h is the heat energy, V is the tank volume, C_p is the specific heat capacity of water, ΔT is the temperature difference. The power rating of the heating element is:

$$P_h = \frac{Q_h}{t} \quad (2)$$

Where, t is time in seconds.

- **Tank insulation**

The allowable heat loss/gain from the ambient during heating/cooling operation is 10%. The amount of heat loss/gain is:

$$Q_{loss/gain} = 10\% \times P_h \quad (3)$$

$$\mathbf{Q_{loss/gain} = U \times A \times \Delta T_{ins.}} \quad \textbf{(4)}$$

$$Q_{loss/gain} = \left(\frac{2\pi Lk}{\ln(D_2/D_1)}\right) \times (T_f - T_{amb}) \quad (5)$$

- **Pumping System**

The pump power required was calculated from eq. (6).

$$P = Q \times H \times \rho \times g \quad (6)$$

$$H = H_s + H_D \quad (7)$$

$$\mathbf{H_D = f\frac{L}{D}\frac{v^2}{2g}} \quad \textbf{(8)}$$

$$f = \frac{0.316}{Re^{1/4}} \quad (9)$$

$$Re = \frac{4\rho Q}{\mu\pi D} \quad (10)$$

- **Design evaluation**

Hot water supply system

$$\mathbf{Efficiency = \frac{Heat\ gained}{Power\ input}}$$

(11)

Cold water supply system

$$\mathbf{COP = \frac{Refigeration\ Effect}{Work\ Done}} \quad \textbf{(12)}$$

Insulation

$$\mathbf{Percentage\ of\ heat\ loss/gain = \frac{Heat\ loss/gain\ rate}{Power\ input_{ins}}}$$

(13)

3.0 Description of the Experimental Setup

Figure 1 shows the schematic diagram of the hot and cold-water supply system presented in this work. The system is a service equipment that can be used to supply either or both hot and cold water to other laboratory equipment that is referred here as load. The load can be double pipe heat exchanger, shell and tube heat exchanger, conduction apparatus etc. The system consists of hot (25) and cold (16) water tanks. Water is allowed to enter the Hot and cold-water tanks via water inlet hoses (2 and 13). The tank exits were connected to pumps (21 and 24) for continuous flow of water. The pumps were further connected to the flow meters (7 and 9) through the gate valves (1 and 15) in order to regulate the flow of water through the load. Water exits the hot and cold-water supply system at (8 and 14). The system also has the following components: switches (5 and 11) to turn on the entire hot or cold-water system, pump switches (6 and 10) to start/stop the water pumps, digital thermostats (4 and 12) to preset the water temperature and water level indicators (22 and 23) to display the water level in the tanks. The compressor (20), condenser (19) and refrigerant pipe (18) were connected as shown in the cold-water system.

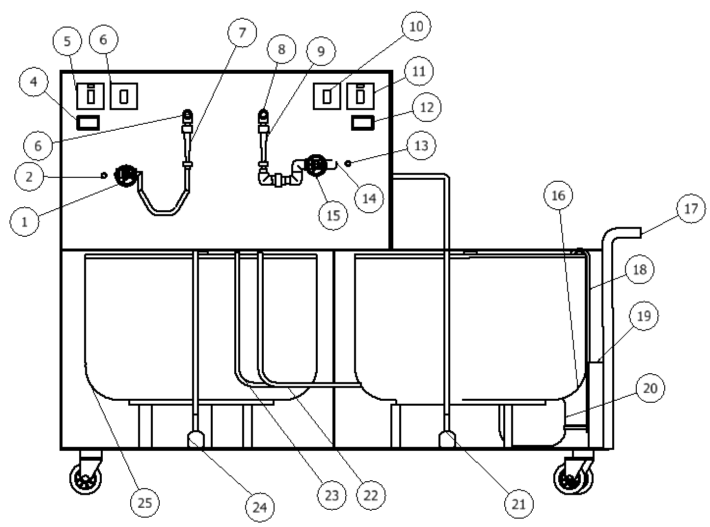

Figure 1: Schematic diagram of a constant temperature hot and cold water supply system.

3.1 Material Selection

Stainless steel was selected for the water tank due to its anti-corrosion tendency. The insulators used in the hot water tank and cold-water tank are glass wool and armaflex respectively. Galvanized iron pipes and high temperature resistant flexible hoses were used in the hot water system while PVC pipes and flexible hoses were used in the cold-water system. Figure 2 shows the major components that were designed and selected/fabricated to form the hot and cold-water system presented in this work.

Figure 2: Major components of the equipment.

4.0 Results and Discussion

The construction of a constant temperature hot and cold-water supply system for laboratory application was carried out. The equipment was codenamed CT50WS and is presented in Figure 3. The frame was designed and constructed to withstand the 100kg of water for both hot and cold in addition to the weight of the system. All the components for the hot water system were made of materials that can resist temperatures above boiling point while the components for the cold part of the system were made of materials that can withstand low temperatures. The system was designed to heat and cool 50 liters of water independently. After the system reaches the desired temperature, the water is pumped to independent equipment that will be used for experiments. The thermostat was used to maintain the preset temperature throughout the experiment. The equipment was tested under no-load and on-load conditions. On no load condition, both the hot and cold-water system were turned on such that the hot water part raise the water temperature from room temperature to a temperature of 80ºC. While the cold-water part cools the water from room temperature to temperature of 5ºC. The water heating system is recommended to heat to a maximum temperature of 80ºC while, the cooling system is recommmended to cool to a minimum temperature of of 5 º similar to the teperature recommendations from similar equipment in the market. The system was not connected to any external equipment (i.e. not water supply from the hot/cold water system) during the no-load condition. The thermostat incorporated in the system was used to maintain a presest temperature.

Figure 3: Constant Temperature Hot and Cold Water Supply System, CT50WS.

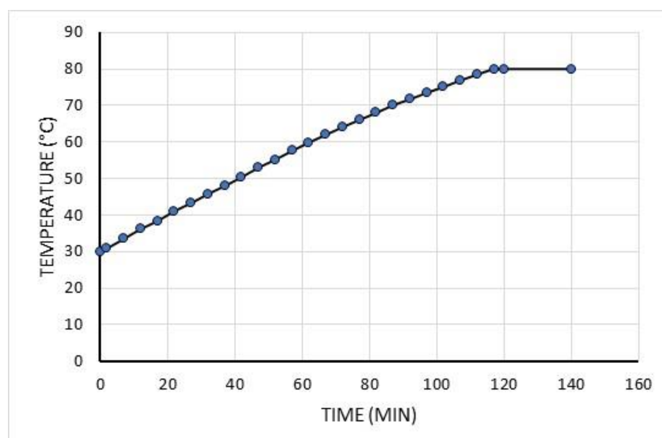

Figure 4: Temperature of water in the hot water tank during heating operation.

Figure 4 shows that it took about 2 hours for the hot water system to heat water from 30°C to 80°C. While it took about an hour for the temperature to be raised by 30º (from 30ºC to 60ºC), it took another hour to for the temperature to be raised by 20º (from 60ºC to 80 ºC). This is due to higher heat loss at higher temperature difference between the hot water and the ambient temperature. The hot water system was allowed to maintain the temperature of 80ºC for about an hour with the aid of thermostat control.

Thereafter, the hot water system was switched off and allowed to cool naturally as shown in Figure 5. It can be seen that the water temperature drops from 80ºC to 36.5°C in 74 hours. As expected, the rate of heat loss was initially high due to high temperature difference between the hot water and the environment. The actual heat loss from the hot water system was obtained as 34.4W that represent 2.3% of the heating rate. The actual heat loss rate is lower than the designed heat loss rate of 10%. This is due to increased thickness of insulation used. Material with a greater thickness was acquired due to its market availability.

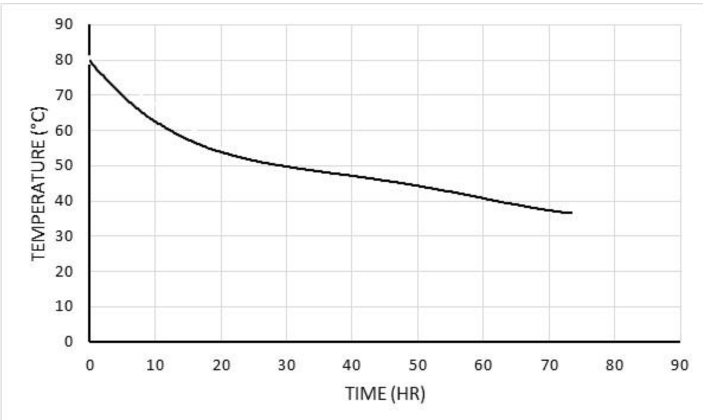

Figure 5: Temperature of water in the hot water tank during ambient cooling operation.

In the cold water supply system, it took about 100 minutes for the temperature of water to be lowered from 25ºC to 5°C (20º temperature difference) as shown in figure 6. The coefficient of performance of the cooling system was computed to be 1.04. This is lower than 3.17 reported in the work of Atrsaw et al. (2020). Other researchers have also reported varying COP such as 0.57 by Bhagyesh et al. (2018), 1.07 and 1.098 reported by, Jayesh & Neeraj (2014). Further analysis shows that different COP was observed for different temperature ranges as shown in Figure 7. The low COP observed at low water temperature range was due to freezing on the evaporator coil as the water temperature drops below 10ºC. This suggest that the cooling system works better when cold water supply is required at temperature of 10ºC or more.

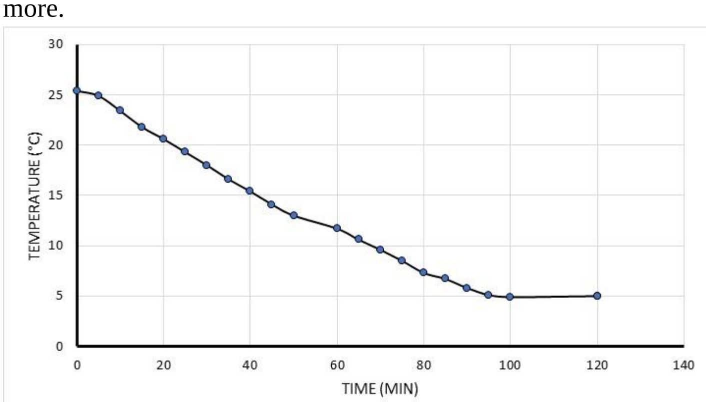

Figure 6: Temperature of water in the cold water tank during cooling operation.

It took about 72 hours for the cold-water temperature to rise from 5ºC to 24.7°C due to gain from the ambient without any cooling operation as shown in figure 8. The actual rate of heat gain is 16.03W, lower than designed heat gain rate of 70 W (10%). The heat gain rate is less than the design heat gain rate due the increased thickness of insulation used as well as due to change in ambient temperature especially during the night.

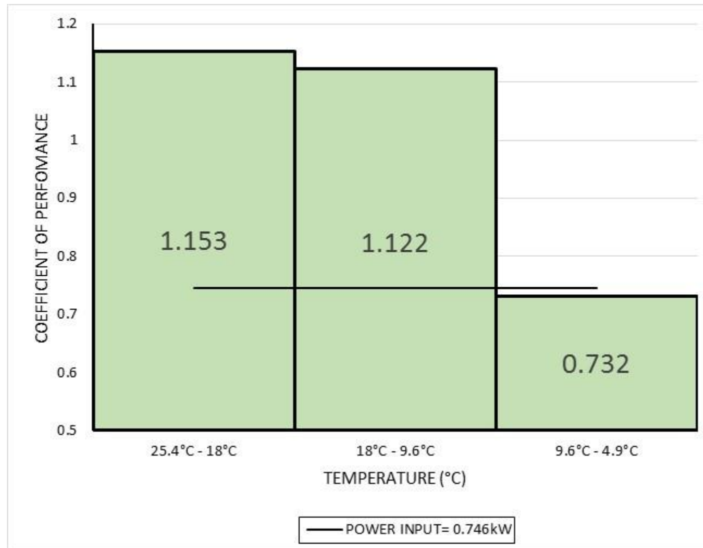

Figure 7: Coefficient of performance (COP) of the refrigeration unit.

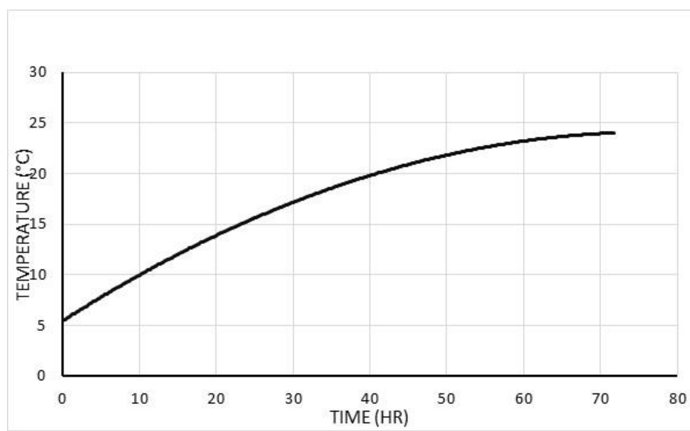

Figure 8: Temperature of water in the cold-water tank during ambient heating operation.

4.1 On-load test of CT50WS

Further tests were conducted under a load condition such that the constructed hot and cold water supply system CT50WS was connected to a shell and tube heat exchanger as shown in figure

9. This is to observe the variation of the hot and cold water temperature in the tank.

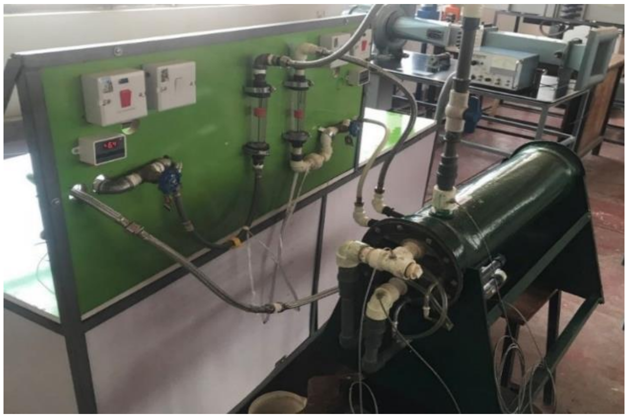

Figure 9: Experimental set up of CT50WS and Shell and Tube Heat Exchanger under load test condition.

The shell inlet was connected to the outlet of the cold-water tank, while the shell outlet was connected to the inlet of the cold-water tank. Such that cold water continues to flow through the shell and returns back to the cold water tank. Similarly, the inlet of the tube was connected to the outlet of the hot water tank, while the outlet of the tube was connected to the inlet of the hot water tank. The temperature in the hot water tank was preset at 50ºC and that of the cold water tank was preset at 18ºC. Hot water and cold water were allowed to flow through the shell and tube side of the shell and tube heat exchanger at the rate of 100 litre/h for one hour.

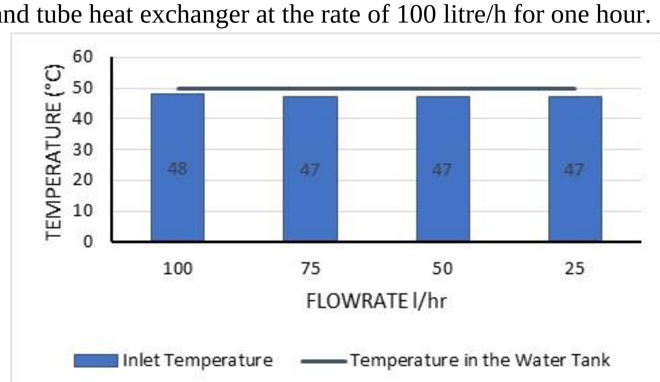

Figure 10: The hot water temperature at the inlet of the heat exchanger.

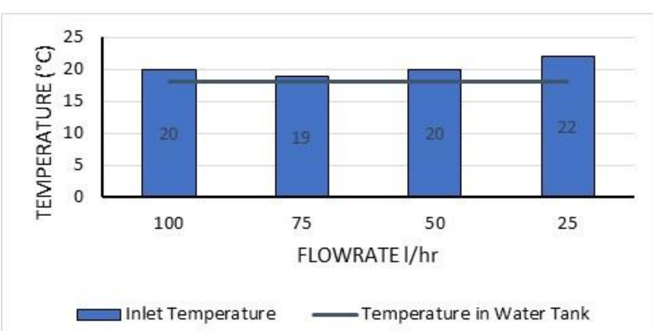

Figure 11: The cold water temperature at the inlet of the heat exchanger.

From figure 10, it can be seen that when the preset temperature is 50ºC, the temperature of the water at the inlet of the heat exchanger is 48ºC. This difference could be due to heat loss in the piping between the tank and heat exchanger and also due to the time lag in heating the colder water that returns from the heat exchanger to the hot water tank. Similarly, the cold water tank temperature was preset at 18ºC while, the temperature at the inlet of the heat exchanger is 20ºC as shown in figure 11. The observed temperature difference is due to the heat gained in the piping between the cold water tank and the heat exchanger and the time lag in cooling the hotter water that returns from the heat exchanger to the cold water tank. The flow rates of the hot and cold water were simultaneously decreased as shown in figures 10 and 11. A marginal increase in the cold water temperature was observed with no significant change in the hot water temperature at the inlet of the heat exchanger. Additional changes in the water temperature at the inlet of the heat exchanger at lower flow rate is due to the increased residence time of the water in the piping that leads to more heat loss/gain. This suggests that the equipment should be used at elevated water flow rate to reduce temperature drop between the tank and equipment inlet.

4.2 Cost Comparison of CT50WS and Service Module TD360

The total cost spent in the fabrication of the hot and cold water supply system (CT50WS) was estimated at 191, 608 naira. This cost comprises of the cost of materials and labor. The equipment does not need municipal water supply. The tanks can be filled manually at the start of the experiment or when needed. A similar equipment that has been identified for comparison is code named TD360. TD360 is also a heat exchanger service module. The system requires a supply of water at a flow rate of 300 liters / hour, pressure range of 1 to 3 bar and temperature range of 5°C to 20°C from the municipal water system. The system lacks a refrigeration system because the TD360 cold water supply system relies on the temperature of the main supply water to the system. A contractor made an offer to a state government to procure the TD360 heat exchanger service module for $ 11,680.25, which is about 4.8 million naira (at the official rate of 411 naira/dollar). This cost is about 25 times the locally constructed equipment at the cost of 191,608 Nigerian naira. Furthermore, the rise of foreign currency against the Nigerian currency makes all foreign products expensive. The cost of shipping the equipment back and forth for maintenance or repair will further add to the operating expenses. This implies that exploring local production of this equipment will enhance its availability and affordability to numerous universities and other higher institution of learning. Its acceptability will further open opportunities in local production of teaching and research equipment, thereby serving as source of job creation and saving the scarce foreign currencies.

5.0 Conclusion

In this work, a constant temperature hot and cold water supply system (CT50WS) has been designed and constructed for laboratory application. The developed system was tested on a no-load and on a load conditions. A shell and tube heat exchanger was used to simulate the load on the service equipment (CT50WS). From operational test of the equipment, The water heating system is recommended to heat to a maximum temperature of 80 ºC while, the cooling system is recommmended to cool to a temperature of of 10ºC to conform to market standard so that it can be used on other equipment with minimal modifications. The actual rate of heat loss from the hot water system was obtained as 34.4W that represent 2.3% of the heating rate as compared to the designed heat loss rate of 10%. The actual rate of heat gain from the cold water tank is 16.03W far lower than designed heat gain rate of 70 W (10%) heat gain rate. The CT50WS was further tested on-load condition by connecting it to a shell tube heat exchanger. When the rate of hot and cold water supply to the heat exchanger is set as 100liter/hr, the temperature of the hot water at the inlet of the heat exchanger is 48ºC as compared to the preset temperature of 50ºC. Similarly, the cold water temperature at the inlet of the heat exchanger is 20ºC as compared to preset temperature of 18ºC. The difference in the temperature is due to heat losses in the piping due to the prevailing room temperature. The equipment is recommended to be used at elevated water flow rate (i.e. 50 litre / hr or more) to reduce temperature drop between the tank and equipment inlet. The total cost in the fabrication of the hot and cold water supply system (CT50WS) was estimated as 191, 608 naira. The cost of a similar foreign equipment is about 25 times the cost of CT50WS. This implies that exploring local production of this equipment will enhance its availability and affordability to numerous universities and other higher institution of learning in Nigeria. Its acceptability will further open opportunities in local production of teaching and research equipment, thereby serving as source of job creation and saving the scarce foreign currencies.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

References

Adedigba, A. (2018, July 10). *Private universities account for less than 6% of Nigerian students population*. Retrieved from Premium times: https://www.premiumtimesng.com/news/more-news/275650-private-universities-account-for-less-than-6-of-nigerian-students-population-nuc.html

Ahmadu, T. (2019). Experimental Evaluation of a 3kW Absorption Chiller prototype . *Nigerian Journal of Technology*, 334-341.

Ambarita, H. (2018). *IOPscience.* Retrieved from IOP Conference Series: Materials Science and Engineering: https://iopscience.iop.org/article/10.1088/1757-899X/420/1/012013

Armfield. (n.d.). *HT30XC Computer Controlled Heat Exchanger Service Module.* Retrieved October 2021, from armfield.

Ashish Ramprasad, S. B. (2015, October). *Scopus Indexed Journals.* Retrieved from IAEME Publication: https://iaeme.com/Home/issue/IJMET?Volume=6&Issue=10

Atrsaw, Jejaw, Aschale, G., Bekele, A., & Chandraprabu, V. (2020). Experimental Test of Locally Fabricated Public Water Cooler. *International Journal of Recent Technology and Engineering (IJRTE)*.

Balogun, A., Edem, I., Isitua, C., & Fayemi, D. (2020). Development of a Temperature Controlled Water Heated Bath for Science Laboratories in Nigeria with Locally Available Materials. *Nigerian Journal of Engineering Science Research (NIJESR)*, 01-11.

Bhagyesh, T., Avinash, B., & Rahul, J. (2018). Design & Fabrication of Vapour Compression Refrigeration System Test Rig. *International Journal of Science and Research (IJSR)*, 1414-1418.

Fayazahamed, R., CyrilJain, S., Alagarasan, K., Balachandran, A., & Balasubramani, P. (2018). Design, Analysis and fabrication of Thermoelectric Cooling and Heating System for Water Dispenser. *IJARIIE*.

Feisel, L. D., & Rosa, A. J. (2005). The Role of the Laboratory in Undergraduate Engineering Education. *Journal of Engineering Education*, 121.

Funmilola, B. (2020, August 30). *List of universities in Nigeria Approved by NUC (2020)*. Retrieved from Campusbiz Journal: https://campusbiz.com.ng/list-of-universities-in-nigeria/

Hilton, P. (n.d.). *Heat Exchanger Service Unit.* Retrieved October 2021, from PA Hilton: https://www.p-a-hilton.co.uk/products/heat-transfer/heat-exchanger-service-unit

Hommalee, C., Wiriyasart, S., & Naphon, P. (2018, December 1). Development of cold-hot water dispenser with thermoelectric module systems. *Heat Trans. Asian Res.*

Jayesh, S. A., & Neeraj, K. C. (2014). Design and performance Analysis of Water Chiller. *Journal of Engineering Research and Applications*, 19-25.

Ojomoyela, R. (2018, October 21). *Educational funding: Babalola slams FG for flouting UNESCO's recommendation*. Retrieved from Vanguard: https://www.vanguardngr.com/2018/10/educational-funding-babalola-slams-fg-for-flouting-unescos-recommendation/

Okiy, S., & Oreko, B. U. (2018). Design and Development of Adaptable Hot and Cold Water Dispenser with Inbuilt Inverter for Rural Communities in Nigeria. *American Journal of Engineering Research (AJER)*, 34-41.

Omer, E. K. (2019). *Solar Water Heater Design.*

Osman, E., & Abdalla, K. (2016). Design and Construction of an Absorbtion Cooling System Driven by Solar Energy. *7th Annual Conference for Postgraduate Studies and Scientific Research Basic Sciences and Engineering Studies.* Khartoum.

Tech-Ed Systems Inc. (2017, August). *Group 38224 - Materials and Equipment for Educational Technology and Occupational Training (Statewide).* Retrieved June 21, 2021, from Office of General Services: https://online.ogs.ny.gov/purchase/spg/pdfdocs/3822423077PL_TechEd.pdf

Tecquipment. (n.d.). *Thermodynamics: Heat Exchanger Service Module.* Retrieved OCTOBER 2021, from Tecequipment: https://www.tecquipment.com/assets/documents/datasheets/TD360-Heat-Exchangers-Module-Datasheet.pdf

Uwah, E. J. (2020, December). Design and construction of portable solar water heater.

Vanguard. (2018, November 05). *ASUU strike comprehensive, indefinite* . Retrieved from Vanguard: https://www.vanguardngr.com/2018/11/asuu-strike-comprehensive-indefinite-president/

Wiriyasart, S., Hommalee, C., Prurapark, R., Srichat, A., & Naphon, P. (2019). Thermal efficiency enchancement of thermoelectric module system for cold-hot water dispenser; Phase II. *Elsevier*.