23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

DESIGN AND CONSTRUCTION OF A SYSTEM FOR CONTROLLING THE INLET TEMPERATURE IN SOLAR COLLECTOR TESTING

Crisciele Ferreira dos Santos
criscieleferreira@gmail.com

Arno Krenzinger
arno.krenzinger@ufrgs.br

Tiago Francisco Manea
tiagomanea@gmail.com
Federal University of Rio Grande do Sul (UFRGS),Post Graduated Program of Mechanical Engineering (PROMEC), Sarmento Leite, St., 425 - 2º Floor CEP: 90.050-170 - Porto Alegre, RS - Brazil

Gian Roberto Tirello
Regional Integrated University (URI), Undergraduate of Mechanical Engineering, RS 331, n°345, District Demoliner CEP 99700-000-Erechim, RS - Brazil
giantirello@hotmail.com

Abstract. *Solar collectors are devices that convert solar energy into thermal energy. These devices are widely used in water heating for domestic use. To determine the efficiency of the collectors tests are required, where the temperature at the inlet and outlet of the collector must be measured, as well as other parameters. For the analysis, it should be used the ABNT NBR15747-2 that has two test methods: stationary and quasi-dynamic. During the test the water temperature in the collector entry should be kept constant, i.e., with less fluctuation possible. The stability of the water inlet temperature is of capital importance during the test, since it significantly affects the thermal energy converted by the solar collector. The objective of this paper is to describe how the system for controlling the water temperature for the collector inlet was developed. To achieve temperature stability, a temperature control system was prepared with two electric heaters that are controlled by a PID controller, flow meter and Pt100 sensors for temperature measurement. The test of the controller was carried out for different temperatures and the temperature control system comply with the need of provision on the inlet temperature stability to the collector under test.*

Keywords: *solar energy, temperature control, PID control*

1. INTRODUCTION

The increasing energy consumption in Brazil and the appeal to reduce the use of nonrenewable sources instigate the use of alternative energy to product electricity or reduce the energy consumption. Solar energy is a suitable choice in that way, since in Brazil there is a good incidence of sunlight throughout the year. This type of energy can be use to produce electricity through the use of photovoltaic panels or can be use in form of thermal energy for heating domestic water using solar collectors.

The solar collectors should have a good efficiency in conversion of solar energy into thermal energy. Duffie and Beckman (1991) said that the basic method of measuring collector performance is to expose the operating collector to solar radiation and measure the fluid inlet and outlet temperatures and the fluid flow rate. So to evaluate the efficiency of these collectors it is necessary to conduct tests where the temperature at the inlet and outlet of the collector should be measured, as well as other parameters such as the solar radiation that reaches the plane of the collector, wind speed, ambient temperature, among others.

There are some standards establishing how to determine the collector thermal performance. A standard that could be use to test solar collectors is the ABNT NBR15747-2 that provides two tests methods: the steady-state and quasi-dynamic tests, and calculation procedures for determining the thermal performance of glazed liquid heating solar collectors. In both methods, the parameters for the test must fluctuate over a predetermined range.

The stability of the water inlet temperature is of capital importance during the test since it significantly affects the thermal energy converted by the solar collector. This work presents the mounting of a temperature controller used to smooth the fluctuation of inlet temperature. The aim of this paper is to describe how the system was developed to control the water temperature in the collector inlet and the results of the controller performance.

2. SOLAR COLLECTORS

The most of solar collectors used in Brazil are flat plate and tubes. The framing is showed at Fig. 1 and is formed by a metal plate with absorber tubes attached to it through which the working fluid flows. This plate is located inside a solid housing, isolated in its back and sides to avoid thermal losses and at its upper face is placed a transparent cover which may be of glass with low reflectance, to minimize the reflection of solar radiation.

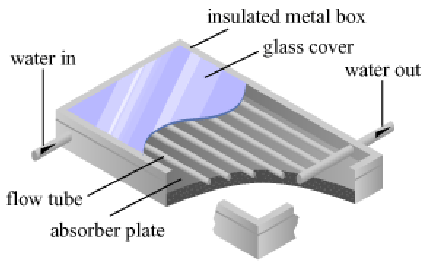

Figure 1: Flat plate collector solar details. Source: www.solartribune.com

The collector with evacuated tubes generally consists of two concentric tubes of glass as can be seen in Fig. 2, where (1) is the inner glass tube, (2) is the selective surface, (3) is the vacuum jacket, (4) is the cover glass tube, (5) is the retainer, (6) is the getter and (7) is the flashed getter film.

The set of tubes can be connected to a thermal isolated distribution manifold, or can be connected directly to the storage tank. Normally the selective surface is used in the absorber to minimize radiation losses since this type of collector works at higher temperatures. The vacuum inside the tube is made so as to avoid heat losses by convection.

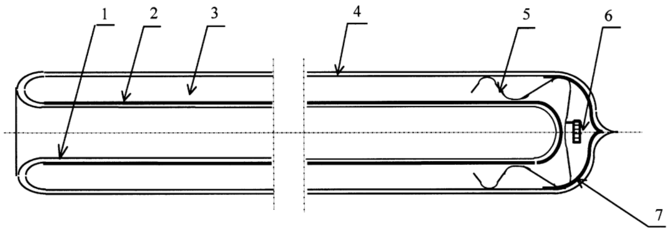

Figure 2. Detail of concentric evacuated tube. *Source:* Zhiqiang (2005).

The heat transfer may occur by direct transfer (water-in-glass) when the water fills the tubes. This type is most utilized due to its simplicity and low manufacturing costs (Morrison *et al.*, 2004). Another way of heat transfer is though heat pipes. The heat pipe is a cooper tube with a working fluid inside that is put within the glass tube as shown in Fig. 3. In this configuration the water does not touch the glass tube. The water enters in contact only with the heat pipe condenser. When the fluid inside the copper tube heats and change from liquid to vapor, the vapor goes upstream to the condenser of the cooper tube and transfer heat to the water and then condense and goes down.

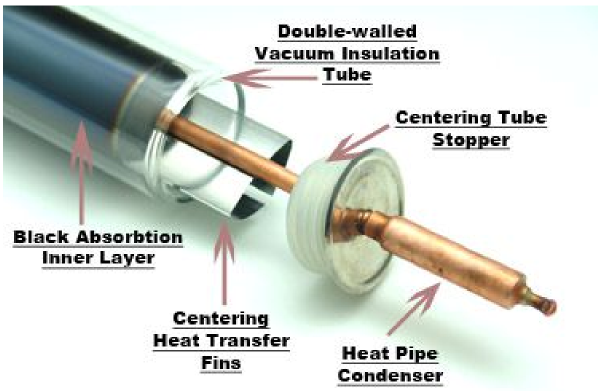

Figure 3. Solar collector with heat pipe. Source: www.solartubs.com

3. EXPERIMENTAL PROCEDURE

3.1 Test and European Stardard

The ABNT NBR15747-2 based on European Standard EN 12975:2006 can be used for testing solar collectors. The NBR15747-2 has two test methods: stationary and quasi-dynamic. The stationary method requires that all the important variables for the thermal characterization of the collector remain constant throughout the test. In practice variation of these parameters is limited because it is known that it is very difficult to maintain completely constants variables. The quasi-dynamic method comes from the stationary method, but some fixes are added that allow a greater variation of the important parameters for the test. In Table 1 it is possible to observe some parameters generally used in the tests, as well as acceptable range of values throughout the test.

Table 1. Acceptable range values to Stationary and Quasi-dynamic tests.

Variable	Stationary Method		Quasi-dynamic Method	
	Value	Deviation	Value	Deviation
Global Solar Radiation (W/m²)	>700	±50	-	-
Angle of Incidence of Radiation (°)	<20	-	-	-
Diffuse Fraction (%)	<30	-	-	-
Room Temperature (K)	-	±1.5	-	-
Inlet Temperature (K)	-	0.1	-	1
Wind Speed, u (m/s)	2<u<4	-	1<u<4	-
Flow Mass (kg/m²·s)	0.02	±1%	0.02	±1%

The test needs to be done at four different temperatures within the collector´s temperature range of operating. The major difficulty in these tests is to keep the fluid inlet temperature within the required variation range.

The time for the stationary test can last for about two hours to the stationary method and for the transient test a minimum of three hours is required. The water which is inside the tank gradually increases its temperature. Thus, if the tank is not big enough the test may have its inlet temperature modified in the case of returning the heated water to the same tank.

3.2 PID Control

According to Ogata (1985) an automatic controller compares the actual value of the process output with the desired value, determines the deviation, and produces a control signal that reduces the difference to a zero or very small value. The manner in which the automatic controller produces the current signal is called control action, an example of control action is the proportional integral derivative (PID) control.

The PID has three installments for process control. The proportionate share is a proportional correction to the process error, i.e., as the error between the actual and the desired value (set-point) grows correction increases. The integral portion is proportional to the product correction of error and time, i.e., for small errors that have been there for a long time a more intense correction is required. The derivative portion refers to the proportional correction to the error rate of change, so when the error is changing very fast this rate should be reduced to avoid oscillations. The behavior of the PID algorithm is conform Aström (1995) show in Eq. (1).

$$MV(t) = Kp \times [E(t) + Ki \times \int E(t)dt + Kd \times dE(t)/dt] \quad (1)$$

where Kp, Ki and Kd are the gains of proportional portions, integral and derivative, which define the intensity of each parameter, and E refers to the error between the set point and process variable, MV refers to the control variable.

In this work it was used a NOVUS PID controller. This controller can be used in manual or automatic mode. In the manual mode the PID parameters should be set by the user. In the automatic mode the controller made a tune (called Auto Tune) that consists of applying a test in the process to obtain the parameters Pb, Ir and Dt. This internal calculation performed by the controller is suitable for most cases, but some cases require manual correction to improve control performance. Table 2 shows some guidelines of how proceed if the behave of the process is unsatisfied.

3.3 Bench of Temperature Controll

The stability of the water inlet temperature is of utmost importance during the test, by significantly affect the thermal energy converted. In view of this it was set up a bench for temperature control, to maintain the temperature of water entering the tank and thus allow the tests within the norm.

Table 2. Guidelines to manual adjust of PID parameter.

Parameter	Problem verified	Solution
Proportional Band	Slow response	Reduce
	Large fluctuation	Increase
Integrate rate	Slow response	Increase
	Large fluctuation	Reduce
Derivative time	Slow Response or Instability	Reduce
	Large fluctuation	Increase

The bench consists of a 100 liters tank, a pump, two resistances of 3500 Watts, four pt100 temperature gauges and an electromagnetic flow meter. The mass flow was controlled by a globe valve. The schematic figure of the bench is presented in Fig. 4. The PID controller is connected to the resistances with a solid state relay. The controller emits a sign to the relay that permits the passage of current to turn on the resistances so that controls the on-off of the resistances. Figure 5 shows the schematic electric circuit for the PID controller where R1 and R2 refer to the resistances.

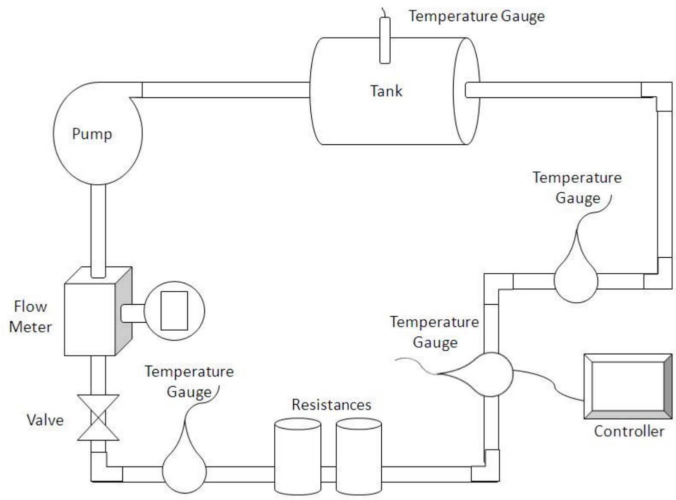

Figure 4. Bench for control temperature.

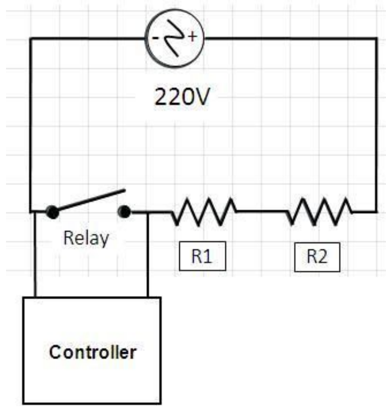

Figure 5. Schematic electric circuit for the PID controller.

4. RESULTS AND DISCUSSION

The test of the bench to control the temperature was done by maintaining the mass flow constant at 3 l/min. The Auto Tune was used to obtain the parameters for the PID control. The Auto Tune was done for 30°C and for 35°C. The values for the parameters can be seen in Tab. 3. The tests were performed for PID parameter shown in the Tab. 3.

Table 3. Parameters for 30°C and 35°C.

Parameters	30°C	35°C
Proportional Band	0.7	0.7
Integrate Rate	0.8	1.04
Derivative Time	14	11

The test starts to an established set point. The controller turns the resistance on and off to promote the heat required to increases the temperature as set in the controller. Pass time the temperature inside the tank rises as shown in Fig. 6 and Fig. 7. As the temperature inside the tank approaches the temperature of set point the fluctuation of outlet temperature diminishes. The Figure 6 shows the behavior of the temperature through time for a set point of 35°C with parameters set for 30°C. Figure 7 shows the behavior of the temperature through time for a set point of 35°C with parameters set for 35°C. Tests were carried for set point of 35°C, 40°C and 48°C using parameters for PID control for 35°C and for the parameters for 30°C the set points were 35°C, 40°C and 50°C.

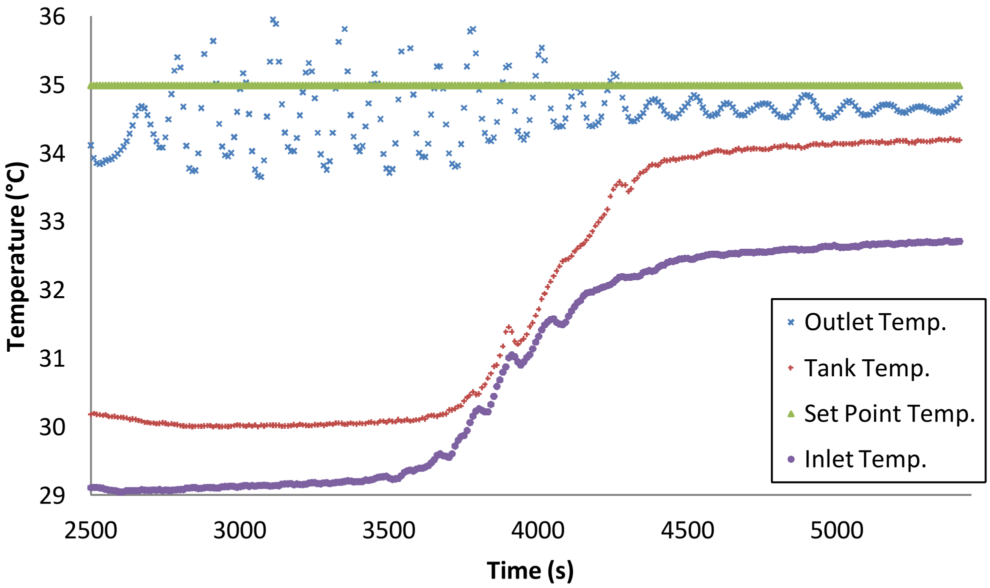

Figure 6. Behavior of temperature for a set point of 35°C and parameters PID for 30°C.

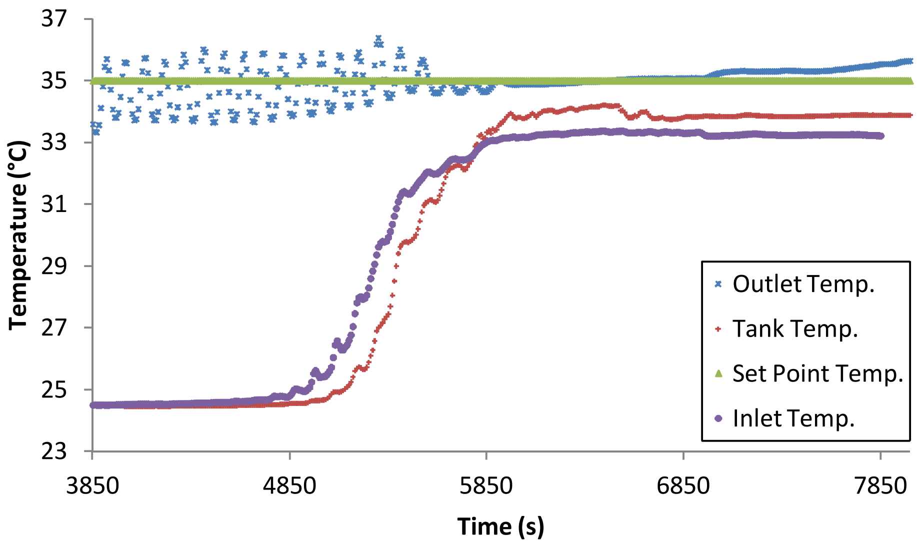

Figure 7. Behavior of temperature for a set point of 35°C and parameters PID for 35°C.

To analyze the fluctuation that occurs in the control process it was found for each frequency of wave the maximum and minimum point to determine the amplitude. For this data the average inlet temperature (the inlet temperature refers to the temperature of the water before the electric heaters) was found and the difference with the set point was taken. The results can be seen at Fig. 8 and Fig. 9, where the amplitude is the difference between the higher and lower value at a determinate range, and the ΔT is the difference between the set point and the average of the inlet temperature for the range established.

The results showed that for both parameters sets, if one look for fluctuation with amplitude lower than 0.5°C, the maximum temperature rise that could be introduced by the controller heater is about 2.5°C. Because it is possible to damp the amplitude of the fluctuation even more using an intermediate integrating tank, 0.5°C of amplitude can be considered satisfactory.

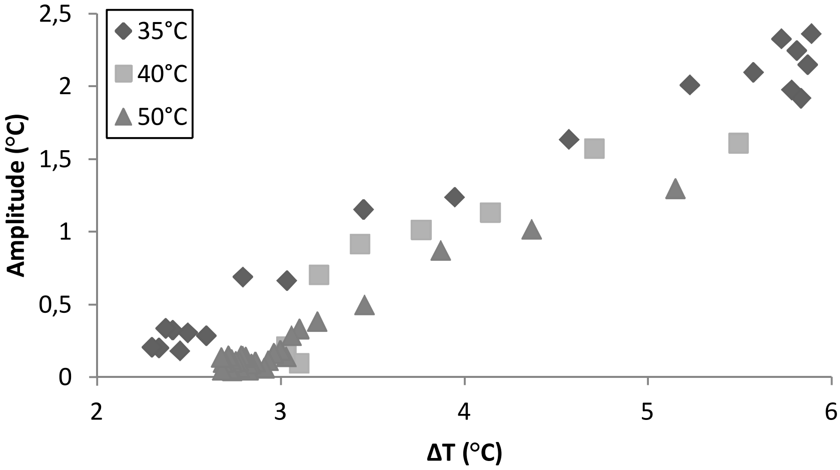

Figure 8.Results for PID parameters set for 35°C.

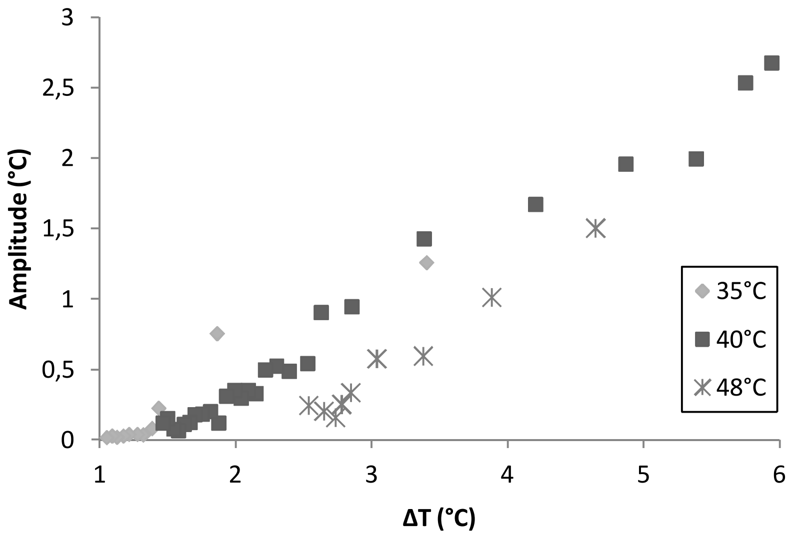

Figure 9. Results for PID parameters set for 30°C.

5. CONCLUSION

A bench controller temperature was mounted and tests were performed to analyze the behavior of the PID controller and whether it can be used to assure the requirement in ABNT NBR 15747-2 related to the inlet temperature. As seen in the norm, the fluctuation to the inlet temperature should be of 0.1°C to stationary method and of 1°C to quasi-dynamic method.

The results shown in tests revealed that if looking for fluctuations with amplitude lower than 0.5°C the maximum temperature rise that could be introduced by the controller is about 2.5°C, so the controller can be used for a range of difference in inlet temperature and the set point temperature around 2.5°C. To achieve the required in the norm by the stationary method an intermediate integrating tank can be use to damp the remnants fluctuations.

6. REFERENCES

ABNT. Brazilian Association of Technical Standards. NBR 15747-2 – *Thermal Solar Systems and its Components – Sollar Collectors Part 2 – Test Methods*, Rio de Janeiro, 2009.

Aström, K. J. and Hägglund, T. "PID Controllers: Theory, Design and Tuning." Instrument Society of America- ISA, 1995.

CEN. European Committee for Standardization. EN 12975-2 – *Thermal Solar Systems and Components – Solar Collectors*. Bruxelas, 2006.

Duffie, J. A., Beckman, W. A., 1991. Solar Engineering of Thermal Processes, John Wiley & Sons, United States, 2nd edition.

Morrison, G. L.; Budihardjo, I.; Behnia, M., 2004. "*Water-in-glass Evacuated Tube Solar Water Heaters.*" Solar Energy, v. 76, p. 135–140.

Ogata, K.,1985. *Modern control engineering.* Prentice-Hall of Brazil, Rio de Janeiro.

PID Basic Control. Technical Article – Introduction to PID Control. NOVUS Electronics Products. 2003.

SOLARTUBS. Official Site of Companie. 25 Apr. 2015 <http://www.solartubs.com>.

Zhiqiang, Y., 2005. "Development of solar thermal systems in China." Solar Energy Materials & Solar Cells, v. 86, p. 427–442.

TRIBUNE. Site Solar Tribune. 10 May 2015 <http://www.solartribune.com>.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.