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Hot Water Management of DHW Storage Tank: Supply Features

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Abstract

The current study is directed to analyze the mixing nature of cold and hot water inside storage tank, and the corresponding effects on the total usable and delivered energy to consumers. The analyses are done for two different supply features bottom and side supply of cold water. An experimental rig consisting of hot water reservoir, cold water reservoir, water pump, flow meter, hot water storage tank (HWST), and a PC with Lab-View data acquisition system, was constructed to collect the necessary data for analyses. Four different flow rates ranging from 1.9 to 10 L/min have been taken under consideration. The results were in a good agreement with the published expectations. As it is well known, low flow rates save more energy in both bottom and side cold water supply (CWS). The comparison between the two supply features showed that the side CWS has higher amount of usable hot water than the bottom CWS at the same flow rate. Side CWS also minimizes the turbulent mixing within the HWST which by its turn supply higher energy for consumers. The bottom supply feature which is easier for assembly, has a bad effect on the total usable hot water and the total amount of energy delivered to the customers. A special mechanism to distribute the water as a uniform layer from the bottom of the tank is currently under investigations.

Keywords: Water Management, Hot Water, Cold Water, Mixing Process, Storage Tanks, Usable Energy, Energy Losses..

1. Introduction

World these days is suffering from the shortage in water and energy. Hot water is a precious commodity in most homes and businesses. Companies working with the manufacturing of HWSTs are working a lot to minimize losses of energy in their designs. Many HWST features are available in markets, which may look the same in shape but differ significantly in their heat transfer and flow patterns.

Many Researches have been performed to save energy by insulation, which reduces the heat losses from the HWST and the accompanied piping system [5, 10, and 11]. Special heat exchangers were proposed by Industrial Technology to recover the energy wasted during usage. Approximately 80% to 90% of all hot water energy flows down the drain, carrying with it up to 955 kilowatt-hours (kWh) of energy [8]. In an attempt to reduce the wasted energy, Barta [5] investigated mathematically the optimal insulation thickness. To reduce the heat losses from the plumbing attachments, Jing Song et al. [11] investigated the effects of plumbing attachments on heat losses from solar domestic hot water storage tanks. In purpose to verify the estimated energy savings for hot water systems, J. Wiehagen and J.L. Sikora [4] have studied the performance comparison of residential hot water systems, in their study a laboratory test experiment was conducted to measure the energy performance of two different types of water heaters; electric storage tank and demand (tankless) heaters for different plumbing distribution systems. Results of simulation showed an increase in overall system efficiency for the demand water heater with a parallel piping distribution system over the storage tank water heater with copper piping.

These studies have been dealing with heat losses reduction, heat recovery from wasted hot water, for maximizing the hot water usage. None of the available published researches investigated what happens inside the storage tank.

As creating new resources of water and clean energy is a hard task, efforts are directed towered conservation and managing the available resources. Actually conservation of resources can be defined as more efficient or effective use of resources [3]. The efficient or effective use of resources requires spreading wide educational programs through people of how to use effectively the available resources. It is extremely important to investigate and analyze what happens while energy and water are consumed, how and why these resources are wasted.

This study is a part of a project aimed to investigate how to use effectively the available hot water resources. The project investigates deeply the hot water temperature variations within the HWST, for different supply features of the HWST.

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2. Experimental Test Apparatus

To analyze and investigate the nature of hot water temperature changes within the HWST, data on the variation of the hot water temperature should be collected under the different variable conditions; to achieve these data an experimental rig has been constructed (Figure 1). This experimental rig consist of Hot water reservoir: even though the water in the storage tank is usually heated by solar energy or electrical energy, heating the water by solar or electrical energy needs time, to eliminate the time required to heat the water a hot water reservoir has been used. It supplies the storage tank by constant temperature hot water about 62 ^{o}C immediately when required.

•Cold water reservoir: supplies the hot water storage tank by cold water when required; it also gives the opportunity to control the CWS temperature.

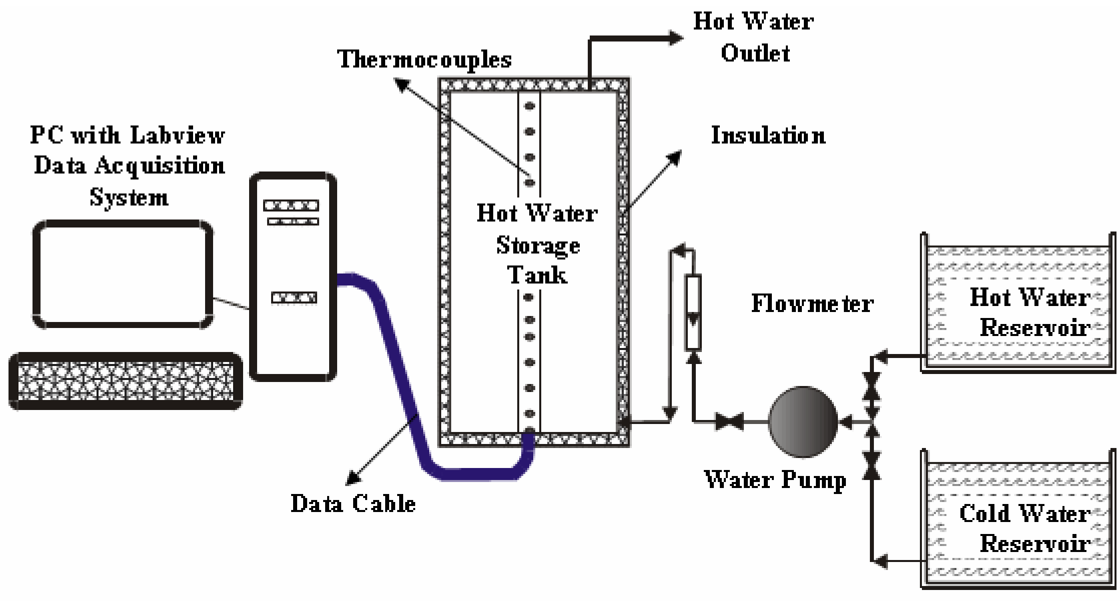

Figure 1. Schematic Diagram for the Experimental Rig

- Water pump: in order to achieve the required flow rate a water pump is used to pump hot or cold water into the storage tank, it gives the head required to overcome the losses within the piping system.
- Flow meter: Used to measure the cold water flow rate entering the hot water storage tank.
- Hot water storage tank: where hot water and cold water are mixed at the specified conditions, it is a cylindrical tank, contains a set of thermocouples to measure the temperature change within the storage tank (see table 1).

Table 1. Dimensions of the Hot Water Storage Tank.

Hot Water Storage Tank	
Height	*78 cm*
Internal diameter	*42 cm*
Number of thermocouples	*15*
Distance between thermocouples	*5 cm*
Insulation thickness	*4 cm*
Tank total capacity	*0.108 m^3*

- •Data Acquisition System: (Lab-View software) consist of data cable, data acquisition card, and personal computer, it is used to collect automatically the temperatures from the storage tank at different times and store it in a separate excel file.

In the experiments done hot water is filled into the HWST from the hot water reservoir, circulated until having a uniform temperature of 62 ^{o}C inside the tank, then the cold water from the cold water reservoir is pumped at a specific flow rate into the HWST from a side or bottom opening, the cold water is allowed to be mixed with the hot water, the temperature changes as a result of the mixing process is recorded for analyses purposes.

3. Analyses

Many hot water storage tanks are available in the markets, each has different feature as shown in figure2, some have side cold water supply others have bottom cold water supply. Manufacturers spend a lot of money to insulate the hot water tanks to minimize the heat losses, which is of a great importance in energy conservation. Nevertheless they give less attention to what happen inside the hot water storage tank during usage. The mixing nature and heat transfer mechanism associated with the different used flow rates affects the available amount of hot water to a large extend. In this work attention had been given to understand the variation of temperature for bottom and side flow CWS within the HWST, four different continuous flow rates were used from 1.9 to 10 L/min.

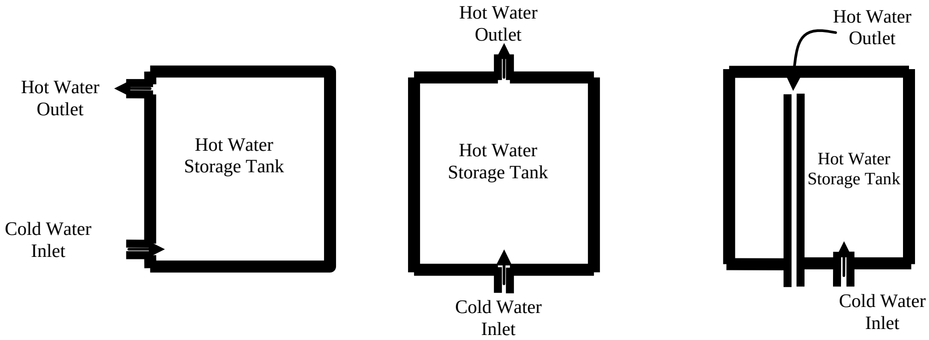

Figure 2. Features of Hot Water Storage Tanks in Markets.

For side supply of cold water, four different flow rates were used 1.9, 3.5, 5.4, and 10 L/min. Figure 3. shows the side supply cooling curves for 15 thermocouples located vertically inside the HWST (see figure1), for cold water flow rate of 1.9 L/min, the total time consumed to fill the tank with its 108 litters was 3410 sec, to cool down all thermocouples to the cold water inlet temperature it took about 5200 sec due to heat transfer between the cold water and hot water in their mixing process. A non-uniform behavior is observed in the temperature of thermocouples 1 and 2 as a result of the turbulent mixing at the relative levels, this turbulent mixing dominates the mixing heat transfer at this region. Almost all of the other thermocouples are cooled in a uniform way, as the convection heat transfer dominates in the relative region.

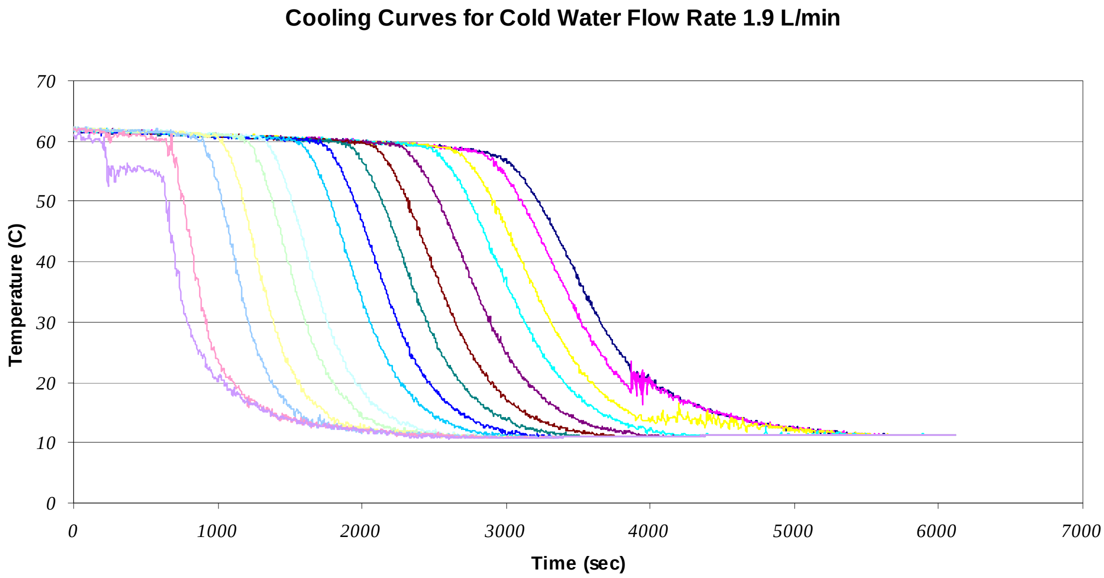

Figure 3 Cooling Curves For Cold Water Flow Rate of 1.9 L/min (side supply).

Figure 4 shows the side supply cooling curves for a cold water flow rate of 10 L/min. It is clear that a large turbulent region and non-uniform cooling curves are existed as a result of the high flow rate entering the HWST. As observed almost all of the cooling curves include a notable oscillation in temperature, this indicates the higher motion of the cold water inside the tank through the mixing process. Also it indicates that at higher flow rates a non-uniform temperature may be obtained from the HWST.

For bottom supply of cold water, again four different flow rates were taken; these are 3, 6, 8, and 9 L/min. Figure 5 shows the cooling curves within the HWST for cold water flow rate of 3 L/min, as it can be observed from figure 5 the first three thermocouples were cooled together, which means that the corresponding flow rate 3 L/min had made a turbulent flow within the first 15 cm of the HWST. The rest of the thermocouples were cooled in a uniform way. Small oscillations were observed in the temperature at the different levels within the tank, this shows that there is a simple turbulence in the flow within the tank. Figure 6 show the cooling curves within the HWST for cold water flow rate of 9 L/min. It is clear that turbulent mixing is dominant, and almost all the tank gets to have the same low temperature after a short period of time. This means that a short amount of hot water can be used in such a case and the rest of the hot water comes to be with a low temperature which can not be used as hot water.

In general, the heat transfer mechanisms within the entire tank can be divided into two parts, one of which depends on the direct contact between the hot and cold water, and heat then is transferred as a result of convection, the other is resulted from the high flow rate in

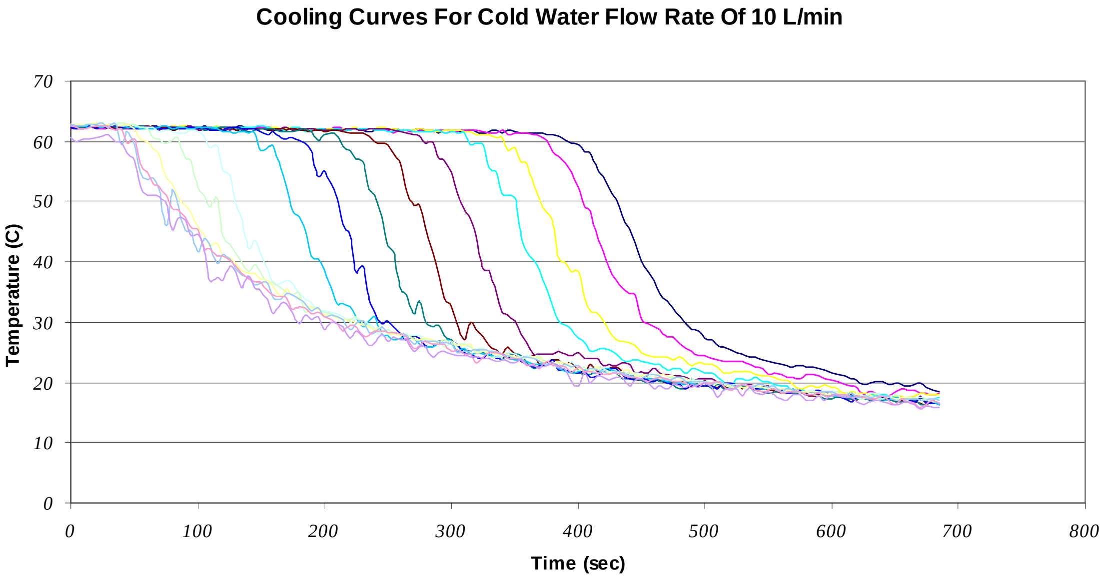

Figure 4 Cooling Curves For Cold Water Flow Rate of 10 L/min (side supply).

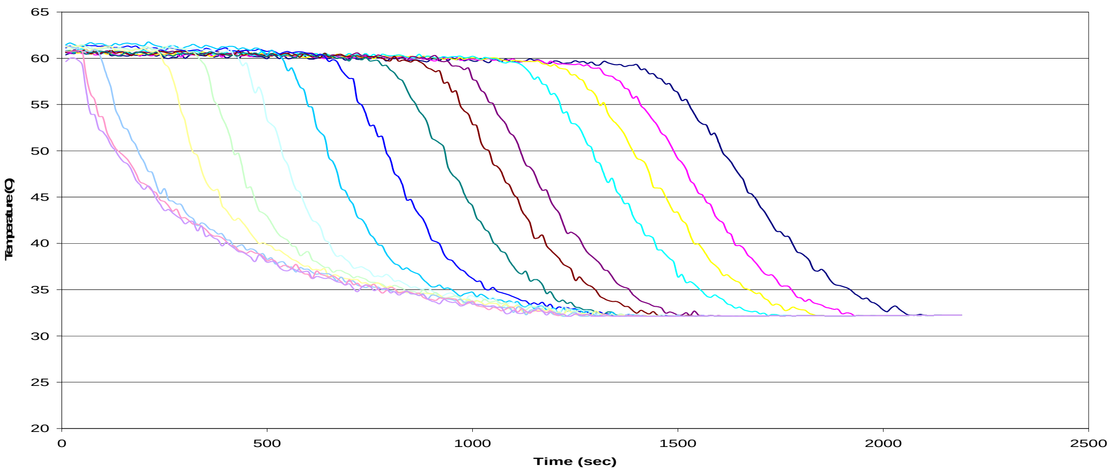

Figure 5 Cooling Curves For Cold Water Flow Rate of 3 L/min (bottom supply).

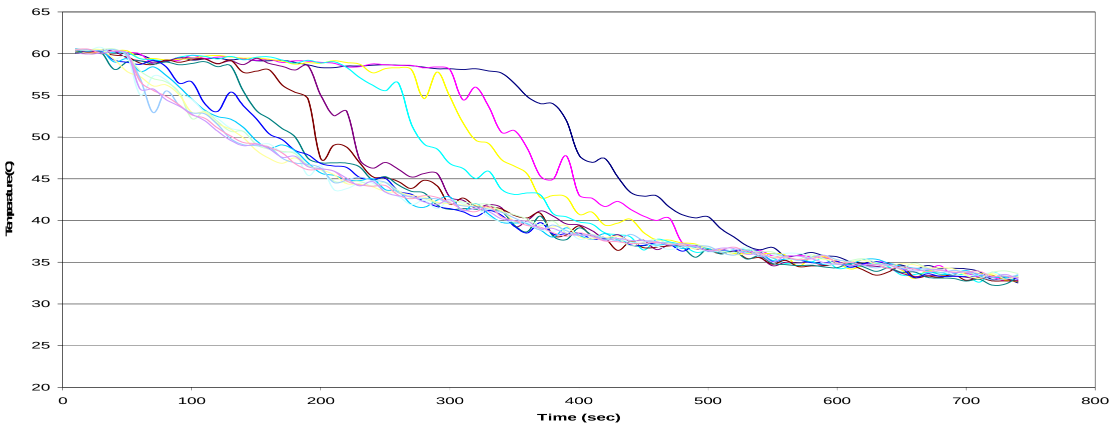

Figure 6 Cooling Curves For Cold Water Flow Rate of 9 L/min (bottom supply).

the relative levels within the tank, this create turbulent mixing of the cold and hot water inside the tank which by its turn accelerates the heat transfer between the cold and hot water layers, and drop significantly the temperature of the hot water that is supplied to consumers.

The total usable hot water available versus the cold water flow rate was drawn for both cases of bottom and side CWS features as indicated by figure 7. It has been observed that in the side CWS and for the flow rates between 1.9 to 10 L/min, a range between 110 to 75 L/min were achieved, where as for the bottom CWS feature and for a cold water flow rates between 3 to 9 L/min, a range between 90 to 55 L/min were achieved. The large drop in the amount of usable hot water is related to the high turbulent mixing in the case of bottom CWS. Thus the use of bottom CWS in the HWST waste a large amount of the usable hot water as a result of turbulent mixing.

In figure 8, the total delivered energy to the customer was analyzed for both features. It has been found that the energy supplied to the customers ranges from 27000kJ to 19000 kJ, in the side CWS. Whereas, total delivered energy ranges from 21000 kJ to 15000 kJ in the bottom CWS. This result indicates that bottom supply of cold water does not only reduce the amount of the usable hot water, but also reduces the total energy supplied to the consumers, keeping most of the collected energy within the HWST unsuitable for use.

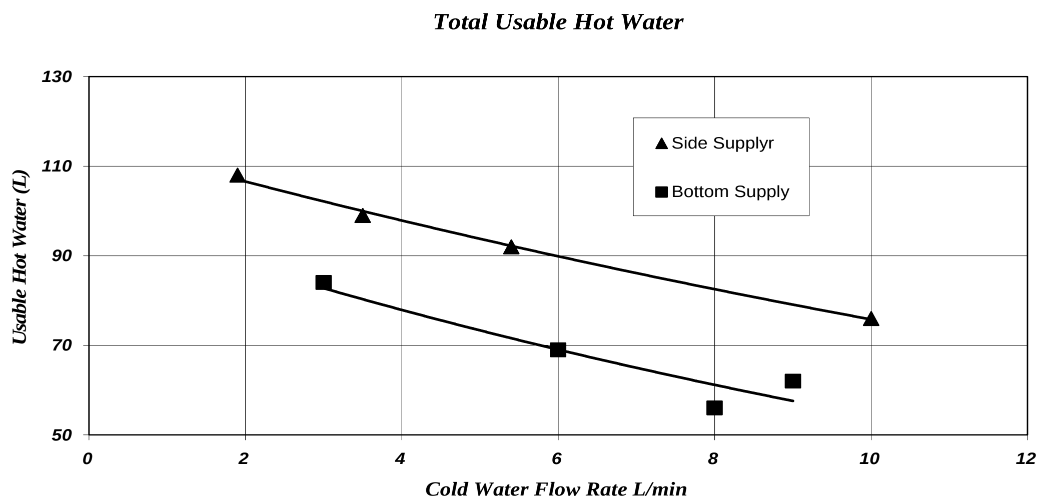

Figure 7 Total Usable Hot Water versus Cold Water Flow Rate for Bottom and Side Supply of Cold Water.

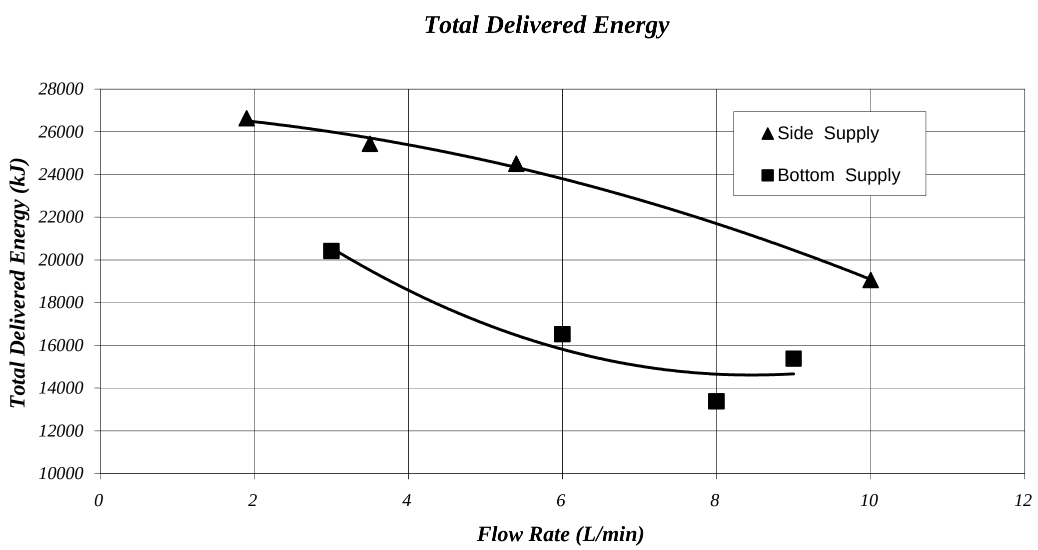

Figure 8 Total Delivered Energy For Bottom and Side Cold Water Supply.

Furthermore, the time required to cool each thermocouple (node as shown in Figure 1) in the HWST was drawn in figure 9. It has been found that for small flow rates the time needed to cool the nodes increases by going from bottom to top of the HWST, whereas, for high flow rates less time was required (as expected [14]).

Figure 9, indicates that for low flow rates the convection heat transfer is dominant and thus more time will be required to cool the higher levels as the temperature of the higher nodes gets closer to each other thus minimizes the heat transfer rate. At the higher flow rates turbulent mixing heat transfer will dominate which by its turn will reduce the time required to cool the different thermocouple within the HWST.

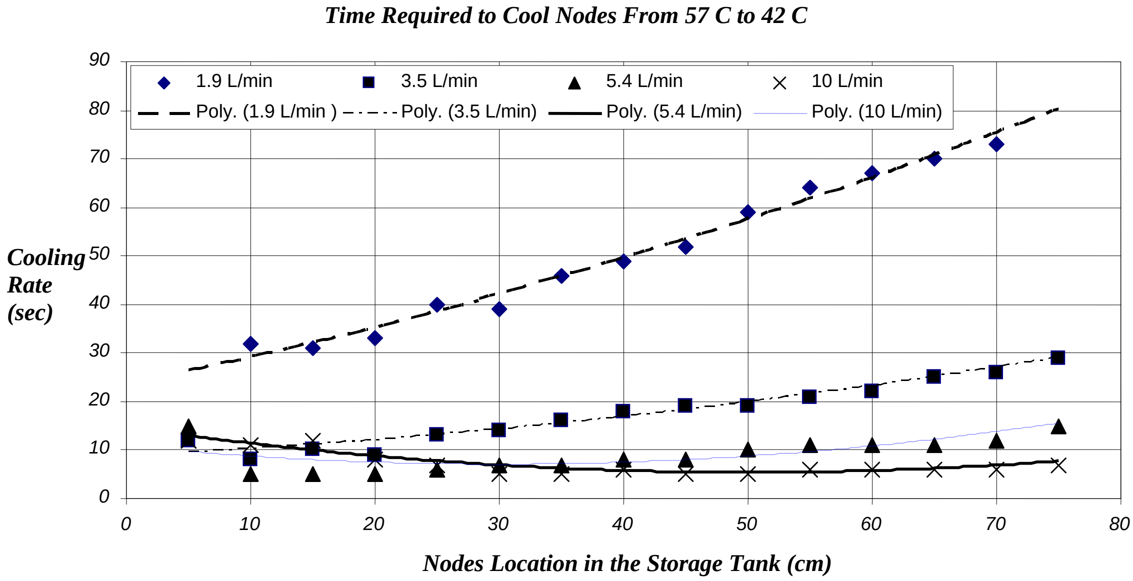

Figure 9 Time Required for Cooling Nodes From 57 ^oC to 42 ^oC.

4. Conclusion

Energy conservation is defined as more efficient or effective use of energy. As fossil fuel costs rise and environmental concerns grow, more efficient energy conservation and utilization technologies become cost effective. However, technologies alone can not produce sufficient results without continuing management efforts. This study is directed toward analyzing the heat transfer between the cold and hot water inside the storage tank for both bottom and side CWS features. Experiments Results show that low flow rates save more energy for consumption in both cases. The comparison between the two supply features suggests the use of side CWS which gives higher amount of usable hot water than bottom CWS at the same flow rates. Side CWS also minimize the turbulent mixing within the HWST which by its turn supply higher energy for consumers. For small flow rates convection heat transfer is the dominant mechanism where the turbulent mixing heat transfer dominates at high flow rates. It is clear that the bottom supply feature has a bad effect on the total usable hot water, and there is a need to stop the turbulent mixing in the HWST. A special mechanism to distribute the water as a horizontal uniform layer from the bottom of the tank is currently under investigations.

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