Analytical analysis on influence of dimensionless numbers in the thermal stratification of storage tank

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Abstract. An analytical analysis has been carried out to understand the influence of dimensionless numbers in the thermal stratification of solar domestic hot water storage (SDHW) tank. Thermal stratification is the phenomena to maintain cold water layer at the bottom of the storage tank and above the cold water maintaining of hot water layer. In between cold and hot water layer one barrier layer is considered, which is called a thermocline layer. From the thermocline layer the heat transfer exchanging starts in between hot and cold water layer. The thermocline layer thickness starts increasing, which is undesired and non-beneficial from maintaining of thermal stratification of the storage tank. This degradation of thermal stratification of the storage tank cannot be eliminated fully, but only it can be reduced down somehow. Hence this analytical study analysis is about to know the influence of dimensionless numbers like Reynold’s number, Nusselt number, Prandtl number on the thermal stratification of storage Tank.

Keywords. SDHW (Solar domestic Hot water), storage tank, stratification, charging, Reynold’s, Nusselt and Prandtl Number.

1. Introduction

SDHW Storage tank is used to store thermal energy, which obtained from the solar radiation and processed in the water. This thermal energy is charged into the storage tank. While being charging and storing for a particular duration is required to maintained a thermally stratified one in between cold and hot water. Expected hundred percent full stratified thermal storage tank is the desired one. But practically it is not possible to maintain a hundred percent thermally stratified storage tank due to the unavoidable interference of charging and discharging flow, continuous heat transfer in between hot and cold water, convection current etc. various experimental, analytical and CFD analysis are carried out by the various expert about the storage of thermal energy in the SDHW storage tank. The degradation of thermal stratification cannot be eliminated fully but can be reduced down and study analysis can be carried out to understand the stratification loss and impact of various factors [1-3]. The sensible heat storage, as well as latent heat storage of solar thermal energy in the water, can be done. In sensible heat storage it is not required to use phase change materials. In latent heat storage phase change materials like salt hydrates, either in the packed capsule form or by directly submerging in the water with direct interaction with water is very popularly used. Such uses of PCM in storage tank also studied and experiments also performed by the various experts and still, the studies are going on. In case of domestic storage tank PCM material is avoided or direct exposure with the water is avoided due to the human hygienic point of view. Study and analysis of storing of energy is one of the vast potential fields, especially in such case where the storing of thermal energy is from the solar light radiation. Solar energy and
light radiation are freely available in the atmosphere. The main limitation of solar energy is available during day time approximately 10 to 12 hours duration from morning at 6 o'clock to the evening at 6 o'clock. Out of that effective light radiation is achieved for mostly 8 to 10 hours [4-7]. Again during mid day hours, we get much sunlight with optimum temperature. Through out the year the temperature and radiation also vary from day to day, month to month and different place to different places of different countries during different seasons. Mostly in summer season the light intensity and radiation are much more. The main factor about to perform experiment and analysis with the solar thermal energy is due to freely availability in the atmosphere. The water is cheaply, easily available in the atmosphere. So the solar energy storage tank analysis is quite cost-effective analysis. Also, the specific heat of normal water is 4.187 KJ/Kg° K at an atmospheric temperature of 20 to 25°C. Fig. 1 illustrates the schematic diagram of SDHW storage tank and system with basis minimum equipment [8-10].

![Schematic diagram of solar domestic hot water (SDHW) storage system.](image)

2. Problem definition

The selected problem under study analysis is a model storage tank of dimensional geometry of diameter (D) 500 mm, height (H) 1000 mm, thickness (t) of 18 gauge (1.27 mm) of capacity almost 200 liters which is easily available in utensil shop, to provide continues hot water supply for a nuclear family of 04 persons. The selected material of the tank is stainless steel for domestic use. Considered the tank is insulated adiabatically with an insulation thickness of 50 mm. the charging, discharging, cold water inlet and makeup water lines dimetrical flow regulating valve and pipeline size (d) is 12 mm. The Fig.2 shows the schematic diagram of the Model storage tank understudy with geometrical dimensions.
3. Analytical Analysis

The analytical analysis carried out about the charging flow condition to understand the influence of flow for different values of dimensionless numbers and other parameters is temperature. The SDHW storage tank under analysis has been taken as an insulated adiabatic tank, with no heat flow through the walls of the tank. Here the minimum flow hot water temperature has been taken as 80°C for analysis and up to 100°C temperature has been taken under the condition for analysis and calculation. The calculations are taken on the assumption that hot water temperature is being available before to flow and store in the hot water storage tank, and once the below 80°C temperature is not available, then the flow stops automatically. Other requisite parameters like absolute viscosity (μ), the specific heat of water (cₚ), the thermal conductivity of water (k) has been taken out standard value from the heat transfer data book for different temperature requirement for the calculations and analysis.

To do flow analysis Reynold’s Number formula has been taken under condition, which is as,

$$Re = \frac{ρDv}{μ} \quad \text{(1)}$$

where, $Re$ = Reynold’s No.
$ρ$ = Density of water in kg/m³
$v$ = Velocity of water in m/sec.
$D$ = inlet diameter of the pipe in m.

The Nusselt No. also has been taken under consideration for analysis, which is as-

$$Nu = \frac{hD}{k} \quad \text{(2)}$$

where, $Nu$ = Nusselt No.
$h$ = convective heat transfer coefficient in W/m²K
$l$ = Diameter of inlet flow zone in m.
$k$ = Thermal conductivity of water in W/m K

The Prandtl's No. which also has been utilized in the analysis is as given below,

$$Pr = \frac{c_pμ}{k} \quad \text{(3)}$$
where $Pr = \text{Prandtl No.}$

$\mu = \text{Absolute viscosity of water in N-sec / m}^2$

$c_p = \text{Specific heat of the water in J / kg K}$

$k = \text{Thermal conductivity of water in W / m K}$

By utilizing the formulae, data and assuming inlet section size and other requisite parameters and calculations has been done and results in terms of graphs has been plotted and shown in the result section.

4. Results and discussions

The analytical analysis and the calculations are being presented here. For the different values of Reynold's No. starting from laminar zone Re value of 10 to turbulent region of Re value 5000 has been taken under consideration for calculation. With the assumed Re value the SDHW storage tank inlet velocity has been calculated. The same has been plotted in the graph and shown in Fig.3 for the inlet pipe size of 15 mm. There is a continuous rise in velocity with respect to increasing in the assumed Reynold’s No. Also, it has been shown in Fig. 4 for the inlet pipe size of 25 mm. The other dimensionless No. which is Nusselt No. with respect to convective heat transfer flow inlet into the SDHW storage tank by the tank inlet pipeline has been calculated and plotted. Fig. 5 shows the Nusselt No. v/s convective heat transfer flow (h). The calculated values of Prandtl No. for different temperature values have been plotted in the graph. Fig. 6 shows the Prandtl No. v/s tank inlet flow temperature. It has been observed that the decreases with the increase in the temperature and hence the graph also declines.

![Fig. 3: Reynold’s No. v/s SDHW storage tank inlet storage velocity (v in m/s) for pipe diameter of 15mm.](image-url)
5. Conclusions

From the analysis and calculations, a conclusion can be drawn that in case of flow and thermal analysis the dimensionless numbers play an essential role to understand the condition and influence in thermal disturbance due to influence of flow variation. With the increase in Reynold’s No., the inlet velocity increases proportionately. This increase in the inlet velocity affects the thermocline zone degradation and effects to maintain a steady-state condition in the hot water temperature. With the rise in Nusselt No., the convective heat transfer flow rate also increases. Hence it is advisable to maintain a lower Nusselt No in this case of SDHW storage tank system. As in this case, the maintaining of hot water temperature inside the tank is the prime motto to utilize the stored thermal heat energy to serve the requisite purpose. The Prandtl No. achieved from different considered hot water inlet temperature of SDHW storage tank. The thermal conductivity of water increases with the increase in water temperature. So it is also advisable to maintain a higher inlet hot water temperature into the storage tank and hence
lower Prandtl No. To maintain optimum thermal stratification into the SDHW storage tank, it is advisable to take lower values of dimensionless No. like (Re, Nu and Pr) for any such further calculation and analysis.

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