IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, April 2026
Impact Factor: 8.2

Temperature – Level Relationship in a Process Tank: Experimental Analysis & Study

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Abstract: *An accurate level measurement in presence of temperature is main requirement in industrial process tanks for ensuring operational safety, efficiency, and control. However, temperature plays a catalytic role in any process and variations in it significantly influence liquid properties such as volume and density, thereby affecting level measurements. This study presents a detailed analysis of the relationship between temperature and liquid level in a process tank through both theoretical modelling and experimental observation performed on my Project Model. The results indicate that as temperature increases, liquid expansion leads to a rise in level, while simultaneous density reduction introduces errors in pressure-based measurement systems. This study highlights the necessity of incorporating temperature compensation techniques in industrial instrumentation to improve accuracy and reliability for the measuring devices and local readings.*

Keywords: Temperature, RTD, L Type Brass Level Indicator, Liquid Level, Thermal Expansion, Density Variation, Process Tank, Instrumentation

I. INTRODUCTION

Process tank is an equipment which is used to carry out a process in the industry. This plays a role in the sequence of the product recipe in a manufacturing industry. The task of monitoring and controlling the liquid level in these tanks is essential to maintain process efficiency, preventing overflow, and ensure safety.

In real industrial environments, temperature variations are unavoidable due to variable external climatic conditions throughout the year, heat transfer processes, or chemical reactions occurring within the tank. The change in the temperature can be minimized but can't be neglected. These temperature changes affect the physical properties of liquids, particularly volume and density. The relation of the temperature is with the atom's movement in the liquid. The excitation and rapid position changing in the particles (atoms) increases the liquid level and hence impacts the efficiency of the process. As temperature increases, liquids generally expand, leading to an increase in volume and consequently the liquid level. At the same time, density decreases, which directly impacts hydrostatic pressure-based measurement systems. This density change should not be there as we are using Differential Pressure based level measurement.

Despite its importance, the interaction between temperature and level measurement is often neglected in basic system design which at the end impacts the production and efficiency. This research aims to investigate this relationship in detail, quantify the level variation with temperature, and evaluate its impact on measurement accuracy.

THEORETICAL BACKGROUND

1 Thermal Expansion of Liquids

In this section, substance changes in volume in response to temperature variations. In my case, the substance or process fluid used is water. When an increment in temperature is identified, that leads to an increase in molecular kinetic energy, causing molecules to move farther apart and resulting in volumetric expansion. This nature is quantified by the coefficient of volumetric expansion which relates that the fractional change in volume to the change in temperature in presence of pressure.

DOI: 10.48175/IJARSCT-32319

For a process tank, the change in liquid volume directly affects the liquid level, considering tank geometry remains constant. For a tank having uniform cylindrical cross-sectional area, the increment in volume translates proportionally into rise in liquid height. Water, in particular, shows anomalous behaviour between 0°C and 4°C, where it contracts upon heating before expanding at higher temperatures.

For liquids, this behaviour is significant and can be expressed mathematically as:

$$V = V_0 (1 + \beta \Delta T)$$

where V_0 is the initial volume, β is the volumetric expansion coefficient, and ΔT is the change in temperature.

Around this range (for clarity):

Between 0 to 4°C**: β** is **negative** (water contracts when heated)

At 4°C**: β = 0** (no expansion/contraction)

Above 4°C**:** β becomes **positive** and increases with temperature

Key takeaway from this section:

Water behaves uniquely at the below temperatures:

It shrinks when heated from 0°C to 4°C

It expands normally above 4°C

For a cylindrical tank with constant cross-sectional area A:

$$V = A \times h$$

In my case, it is a cylindrical tank so Volume= $\pi r^2 h$

Additionally, temperature variations can influence measurement accuracy in level sensing systems, such as float, capacitive, or ultrasonic sensors, due to changes in fluid density and dielectric properties.

In closed or pressurized tanks, thermal expansion also leads to pressure buildup, further affecting system dynamics.

2 Density Variation with Temperature

Density is defined as mass per unit volume and is inversely related to temperature. As temperature increases, intermolecular spacing increases, resulting in a decrease in density. Density variation with temperature is critical factor that influences the temperature – level relationship in process tank. For small temperature ranges, the change in density can be related to the volumetric expansion coefficient (β).

The change in density affects *hydrostatic pressure* measurements:

$$P = \rho g h$$

A decrease in density leads to a decrease in pressure, even if the actual liquid level increases. This creates a discrepancy between actual and measured values.

In the case of water, density exhibits anomalous behaviour under influence of temperature variation. Water reaches its maximum density at approximately 4°C, and any deviation from this temperature—either heating or cooling will result in a decrease in density.

Density variation also plays an important role in hydrostatic level measurement techniques, where pressure at the base of the tank is used to infer liquid height. Therefore, accurate modelling and correction for density changes are essential for reliable level measurement.

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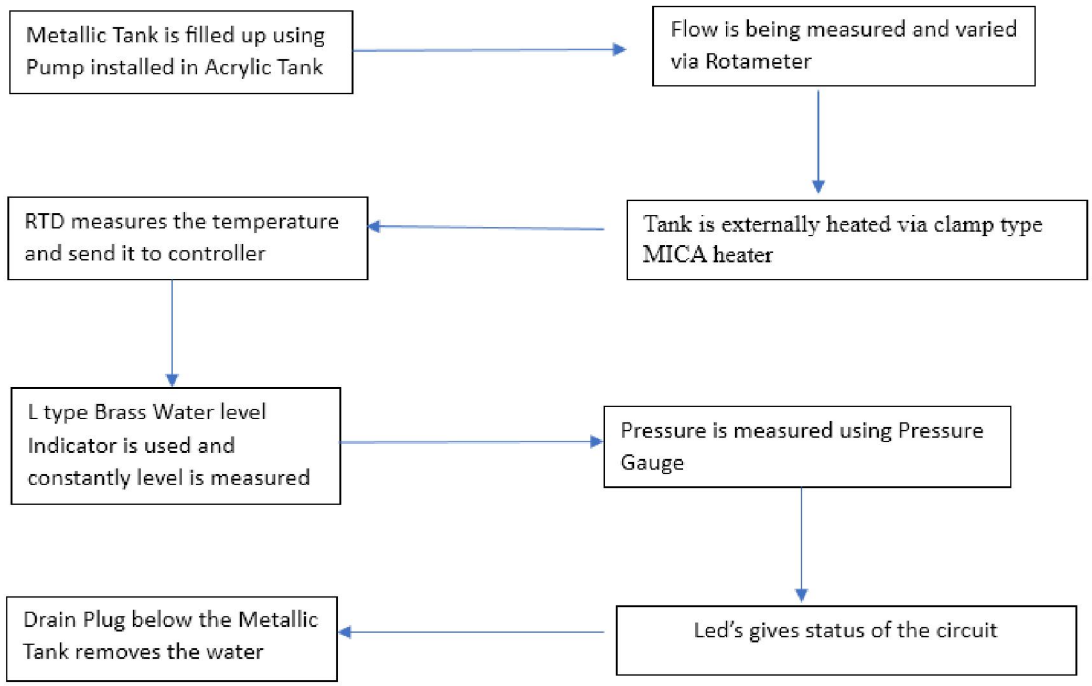
Flow chart



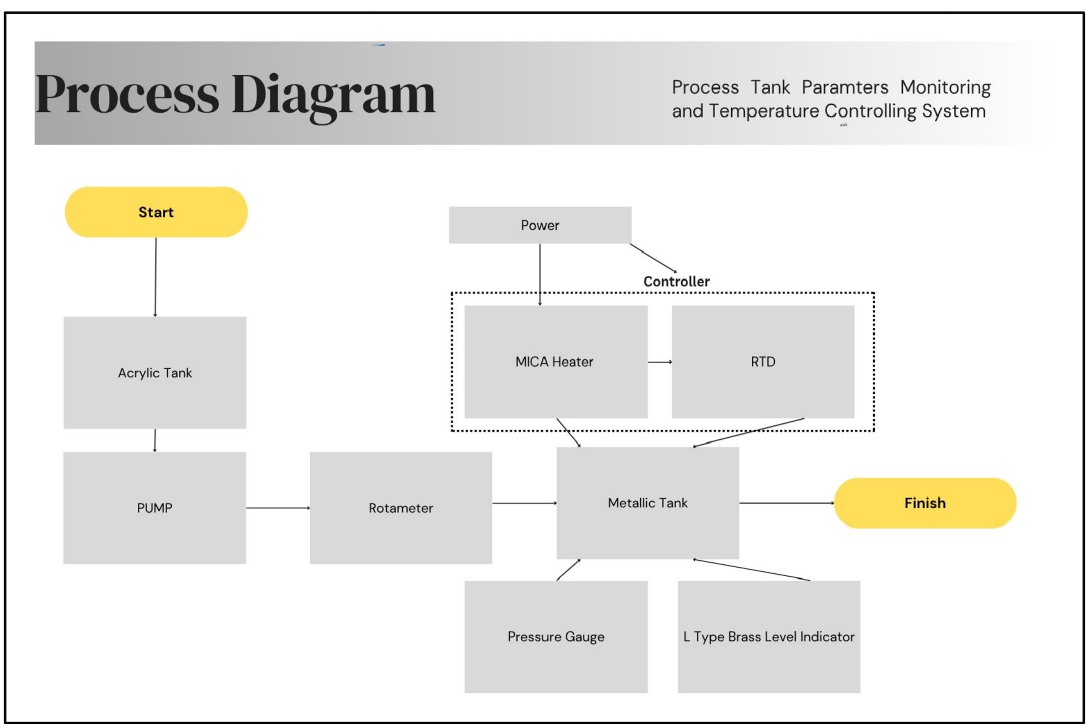


Figure 1: Process Diagram of the Model

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II. METHODOLOGY

1 Experimental Setup

My working model is used to experiment this relationship in practical life. The setup mainly consists of Mild Steel Tank, MICA Heater (Clamp type), Resistance Temperature Detector (RTD), L Type Brass Level Indicator. The tank is filled with water with known initial level, leaving sufficient space above the liquid level for the thermal expansion.

To Heat the water, MICA heater (Clamp Type) is used which is controlled by the controller placed in the back panel for reading value and control the process variable.

2 Experimental Procedure

The tank was filled to a known initial level at room temperature.
Initial temperature and level were recorded.
Heat was applied gradually to increase the temperature in steps.
At noted temperature interval, the liquid level was measured and recorded.
Repetitive readings were taken to ensure accuracy and consistency.

3 Variables

Independent Variable: Temperature in °C
Dependent Variable: Liquid Level in cm
Controlled Variables: Tank dimensions, liquid type, ambient conditions

III RESULTS AND DISCUSSION

Table 1: Experimental Data of Temperature and Level

Temperature (°C)	Liquid Level (cm)
25	15
35	15.4
45	15.9
55	16.5
65	17.1

1 Graphical Analysis

A graphical representation of Temperature versus Liquid Level is shown below that depicts a clear positive trend. The relationship is approximately linear within the observed temperature range.

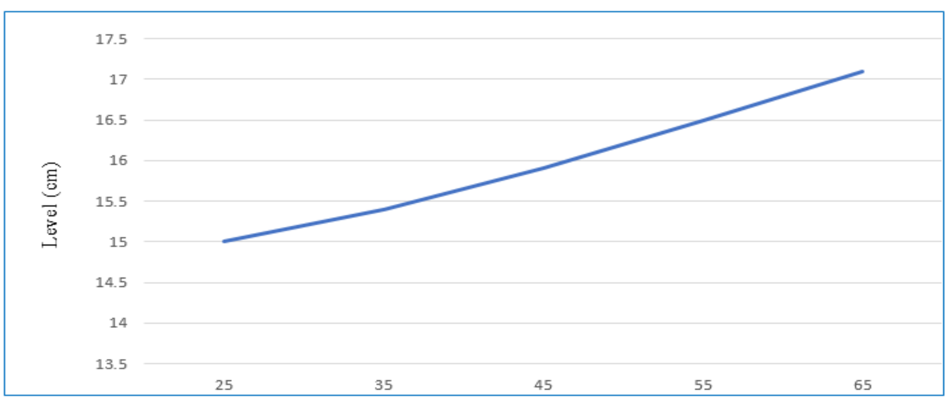

Figure 2: Graph of Temperature vs Liquid Level Readings

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The slope of the graph represents the expansion rate of the liquid (water). The near-linear behaviour indicates that the volumetric expansion coefficient remains approximately constant within the experimental range.

2 Discussion of Results

The experimental results align closely with theoretical predictions. As temperature increases, the liquid expands, resulting in a rise in level. However, in real industrial applications, the measurement of level may not reflect this increase accurately due to density changes affecting pressure-based instruments.

At higher temperatures, deviations from linearity may occur due to:

- Non-uniform heating
- Increased evaporation
- Material expansion effects

The effect of density variation was also evident, particularly in hydrostatic considerations, where the change in fluid density could influence the actual level interpretation. Overall, the results highlight the importance of consideration for temperature effects in level measurement systems. Incorporating these proper calibration and compensation techniques can significantly improve accuracy and reliability in practical industrial applications.

3 Error Analysis

In the process of research, error analysis is essential to evaluate the accuracy and reliability of the experimental results obtained for the relationship in a process tank.

Instrumental Errors are the primary source of uncertainty. Temperature sensor (RTD) may have calibration limitations, response delays and finite resolutions leading to slight inaccuracies in recorded temperature. Similarly for level measurement, Parallax based error interferes while noting observations.

Heat Transfer losses to surroundings also contribute significantly to error. Due to this non uniform temperature distribution within the fluid is observed.

Human and observational errors also occur during the manual readings, particularly when using visual scales. As water is used which is transparent which adds the effort of focused eyesight for the readers to note the level.

IV. INDUSTRIAL APPLICATIONS

The findings of this study are applicable in various industrial sectors:

- Chemical storage and reaction vessels
- Oil and fuel storage tanks
- Boiler systems
- Food processing units

Accurate level measurement in these systems is essential for safety, efficiency, and cost control.

V. FUTURE SCOPE AND FURTHER ADVANCEMENTS

Every Project has a scope of advancement which allows the better usage in the future. So for my project, the advancements that can be done are listed below:

- Integration of Smart Sensors and IoT
- Use of AI and Predictive Analytics
- Development of Compensation Algorithms
- Hybrid Measurement Techniques
- Closed Loop Control System Implementation

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VI. CONCLUSION

This study determines that temperature has a significant and dominating role in influencing liquid level in process tanks. Thermal expansion causes an increase in liquid level, while density variation affects measurement accuracy, particularly in pressure-based systems. Additionally, constantly the pressure build up in this tank allows the system to be in control and minimize the uncertainty in the process. The combined effect can lead to systematic errors if not properly addressed. Therefore, temperature compensation techniques should be integrated into level measurement systems to ensure reliable operation in industrial environments. Furthermore, the variation in the readings will lead to the disturbance in the control action of the controller.

Also, the pressure builds up when the temperature is increasing along with the level rise. This relationship states that the parameters are dependent on each other.

By this experimental analysis, we get the clear idea of the designing of the tank and connections that are to be included. Because the increment in the connections leads to the number of ways by which the leakages can occur in the system. So this factor is kept in the mind for further advancements in the system.

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