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Thermal lag and principles of saturation pressure in sustainability

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Abstract

This research delves into exploring the concepts of measuring saturation pressure and the connection between pressure and temperature in turning a liquid into vapor. In this experiment, the goal is to grasp how saturation pressure is measured by studying how thermal insulation affects predictions of saturation pressure. The results indicate difficulties in making accurate predictions because of insufficient insulation emphasizing the importance of thorough insulation methods to counteract thermal lagging effects.

This experiment provides insights into how theory and experimentation interact in explaining the thermodynamic properties of substances with implications, across various scientific and engineering fields.

Keywords: Component; Heat; Mass; Transfer; linear; Aim; Volume; Energy; Fluid; Pressure

1. Introduction

This investigation explores the principles of thermodynamics, specifically studying how substances change phases from liquid to vapor. The experiments aim to understand how pressure, temperature, and phase transitions are interconnected, offering insights into the properties of the substances being studied.

We focus on measuring saturation pressure to grasp phase transitions in materials like water. By heating water in a container and observing changes in temperature and pressure this study aims to investigate how pressure variations impact the saturation point where a substance shifts between liquid and vapor states. Through data collection and analysis this experiment aims to create graphs showing saturation pressure plotted against saturation temperature shedding light on the balance between a substance's condensed and vapor forms.

Figures 1 reveals the schematics of the apparatus used in the experiment

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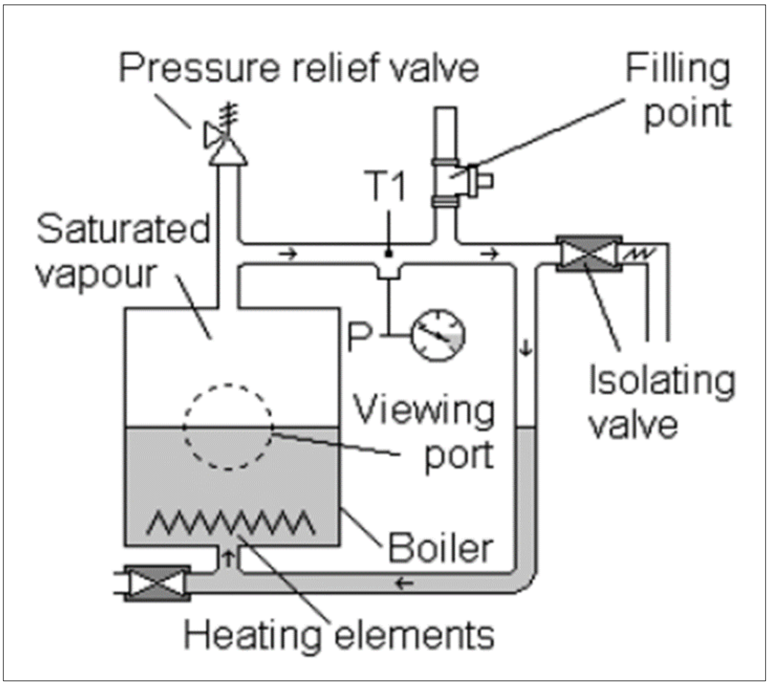

Figure 1 TH3 Apparatus [1]

This experiment is designed to uncover the intricacies of thermodynamics and phase changes offering valuable understandings into how substances act under different pressure and temperature scenarios. By merging concepts with hands-on trials these investigations play a role in progressing scientific understanding and have wide-ranging impacts across various disciplines spanning from engineering and environmental science to materials science and beyond.

1.1. Experimental assumptions

Experimental assumptions have been set to help simplify the experimental setup and analysis, allowing researchers to focus on specific aspects of the phenomena being studied. However, it's essential to recognize that while these assumptions facilitate understanding, they may not fully capture the complexities of real-world systems. Therefore, results should be interpreted with these limitations in mind, and further investigations may be necessary to validate findings and explore additional factors. See Table 1, for the experimental assumptions:

Table 1 Experimental Assumptions

Entry	Assumption
1	Closed system [1].
2	Constant volume [1].
3	Steady state [1].
4	Equilibrium between liquid and vapor phases [1].
5	Ideal behavior of water (for simplification) [1].
6	Negligible heat loss to the surroundings [1].
7	Negligible heat loss through the apparatus [1].
8	Uniform heating throughout the system [1].
9	Pressure and temperature measurements are accurate [1].
10	No phase change occurs during pressure and temperature measurement [1].
11	Barometric pressure: 101.325 kN/m^2 [6].

1.2. Theory of Saturation Pressure

In this experiment, the focus is on studying how saturation pressure is measured, which plays a role in understanding how substances change phases especially when transitioning between liquid and vapor states. The core idea revolves around finding a balance between a substance's form and its vapor phase. Saturation pressure indicates the pressure at which this balance occurs, marking the moment when a substance shifts between these two states at a temperature [2].

The saturation point, where phase change happens is typically shown graphically by plotting pressure against temperature. In this experiment water is the focus due to its well-known behavior during phase changes [2]. The saturation pressure of water changes with temperature and creating a graph that correlates saturation pressure with saturation temperature can reveal insights into water vapors' thermodynamic properties and their equilibrium with the liquid state [3].

This involves using a container to measure water saturation pressure. Initially, the container is filled with water. Heated until it boils. After that adjustments are made to keep steam flowing while recording resistance and pressure measurements at set intervals [3]. Through adjustments in pressure and careful temperature monitoring the experiment captures how saturation pressure changes dynamically under varying conditions [4].

The experiment delves into how fluctuations in conditions impact the accuracy of measurements. By observing how the system behaves during shifts from heating to cooling phases valuable insights are gained on the reliability and stability of the measurement process [3]. This comprehensive method not only clarifies the theoretical aspects of measuring saturation pressure but also offers practical perspectives on experimental approaches and factors affecting measurement precision. With data collection and analysis, it aims to enhance comprehension of saturation pressure measurement principles and their practical application, in thermodynamics and engineering realms [5].

The concept behind measuring saturation pressure is based on how temperature and pressure interact in a system with a pure substance. According to the laws of thermodynamics when the temperature of a substance goes up its vapor pressure—meaning the pressure from its vapor in balance with its phase—also increases [4]. Saturation pressure indicates the vapor pressure at a specific temperature offering important insights into the thermodynamic characteristics and phase changes of the material [4]. This connection is commonly explained using formulas rooted in thermodynamic principles, which help forecast saturation pressures across different temperatures. Testing these forecasts in real-world scenarios confirms the precision and trustworthiness of the fundamental theory enhancing our comprehension of phase shifts and thermodynamic activities, within diverse setups [5].

2. Material and methods

The general process for this experiment includes using sensors to measure temperatures. In the temperature readings were taken regularly from points in the system to track changes over time. This experiment followed an approach involving sensor calibration data collection at set intervals and analysing the data to spot patterns and differences, between measured and actual temperatures. Steps were likely taken to control factors affecting temperature readings like maintaining consistent environmental conditions during the experiments.

The experiment explored studying the fundamentals of measuring saturation pressure, an element in grasping how substances like water undergo phase transitions. By examining the balance between liquid and vapor phases of water across pressure and temperature scenarios this experiment seeks to clarify the connection between saturation pressure and temperature. By gathering and analysing data researchers gain valuable insights into the thermodynamic properties of water vapor paving the way for advancements in engineering and scientific domains.

The following steps were established to ensure the validity of the experiment:

- Ensure both valves on the apparatus are closed and fill the boiler halfway with water.
- Switch on the heater and allow the water to reach its boiling point.
- Adjust the heater power to maintain a steady flow of steam.
- Record the resistance (Rm1) and pressure (Pg) readings when they stabilize.
- Record thermometer output and pressure readings every 2 minutes until pressure reaches the maximum (e.g., 7 bar).
- Cooling Phase
    - Turn off the heater completely.
    - Record resistance (Rm1) and pressure (Pg) readings at 5-minute intervals until readings stabilize.

All recording of data must be done after the values have been stabilized by the measurement instruments. This will ensure accurate recordings are made, free from random and systematic errors to the best of the experimenter's ability.

3. Result and Discussion

The measurements were recorded when the pressure reached 7 Bar, Table 2 showcase the values record and calculated during the heating process:

Table 2 Experimental heating phase

Elapsed time (T) (minutes)	Measured output Rml (Ω)	Corrected output RC1 (Ω)	Absolute temperature (T_{abs}) (K)	Pressure P1 (kN/m²)	Absolute pressure (P_{abs}) (kN/m²)	Actual temperature (T_{act}) (K)	Thermal lag (K)
0	138.5	138.12	373.15	16	115	376.7	4.73
2	141.9	142.3	383.15	61	162	386.8	4.586
4	145.8	147.3	396.15	148	249	400.5	4.442
6	148.1	147.87	397.17	216	317	408.6	4.298
8	150.4	153.16	413.15	301	402	417	4.154
10	152.4	155.85	419.15	386	487	424	4.01
12	154.3	157.95	423.15	485	586	431	3.866
14	156.1	160.72	431.15	594	695	437.7	3.722
16	157.6	162.85	437.15	695	796	443.3	3.578

During the cooling process, the followed data was tabled in Table 3:

Table 3 Experimental cooling phase

Elapsed time (T) (minutes)	**Measured output Rml (Ω)**	**Corrected output Rc1(Ω)**	**Absolute temperature (T_{abs}) (K)**	**Pressure P1 (kN/m²)**	**Absolute pressure (P_{abs}) (kN/m²)**	**Actual temperature (T_{act}) (K)**	**Thermal Lag (K)**
5	153.5	157.22	423.15	426	527	427.2	4.37
10	150	152.5	410.15	273	374	414.4	4.01
15	146.2	147.3	397.15	153	254	401.1	3.65
20	143.7	144.75	389.15	93	194	392.4	3.29
25	140.7	141	380.15	41	142	382.9	2.93

The measured output at Rm1 (Ohms) must be corrected, because it fails to include the bridge circuit into account. This produces an additional column with the corrected values called RC1, which is then used to find Absolute Temperature T_{abs}. The Gauge pressure P1 is converted into absolute pressure P_{abs}, to find the actual temperature. Figure 2 below represents the measurements taken of the Absolute temperature and the actual temperature with respect to time during the heating process, extracted from Table 2.

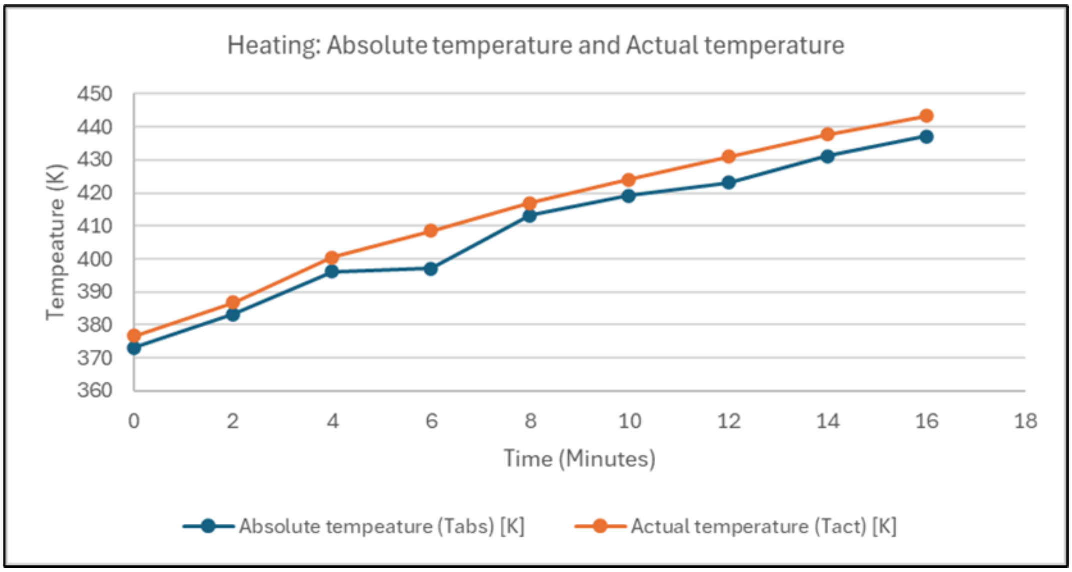

Figure 2 Abs Temp and Act Temp

Another graph can be produced from Table 3. This graph reveals the negative slopes of both the Absolute temperature and the actual temperature exhibited during the cooling process. The line-of-best-fit has been fitted on both temperature readings, producing the linear approximation equation of the lines.

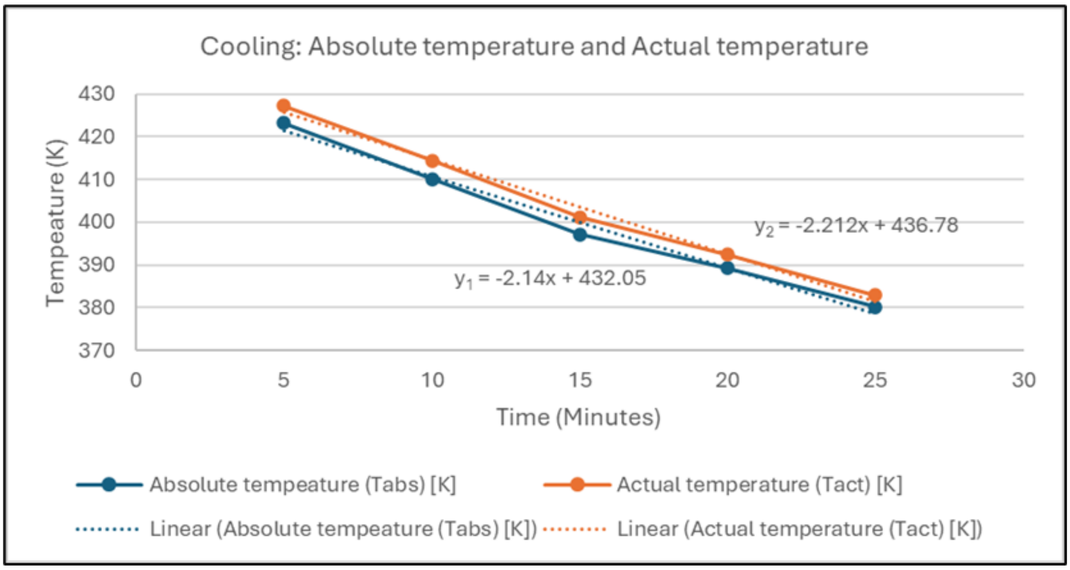

Figure 3 Abs Temp and Act Temp Cooling

In Figure 2 and Figure 3, it's clear that the T_{abs} (K) measurements and the actual temperature T_{act} (K) differ noticeably. T_{act} generally follows a straight line, as expected. While T_{abs} also seems to follow a straight line, there are fluctuations around the 5- to 10-minute marks likely due to errors from humans or machines. The big gap between the two graphs happens because of something defined as "Thermal Lagging." This means materials resist changes in temperature, so it takes time for the sensor to catch up to the actual temperature. Unfortunately, because the pipes aren't well insulated, we can't reduce this lag much. That's because the system changes temperature faster than the sensor can keep up. From Figure 3, the time lag can be estimated:

The equation of trendline for T_{abs} is given as:

$$Y\_1 = -2.14x1 + 432.05$$

The equation of trendline for T_{act} is given as:

$$Y\_2= -2.212x2 + 436.78$$

Assuming after a given time x (in minutes), the temperature is Y (K). To estimate the temperature lag, suppose the Tabs reaches temperature Y (K) in x minutes, while T_{act} reaches some temperature Y (K) in same x minutes. Thus, subtracting equations above for when x1 = x2.

$$Y\_2-Y\_1= -0.072x + 4.73$$

From this equation, time lag can be estimated by:

$$\text{Thermal Lag (K)} = -0.072\ t\ \text{(time in minutes)} + 4.73$$

Table 2 and Table 3 have been filled accordingly with all associated thermal lags values.

The results obtained from the experiment highlight the difficulties caused by lagging when trying to accurately predict saturation pressure. Despite efforts to make predictions the differences between the expected and actual pressures show how thermal lagging significantly affects the setup. We tried methods like placing the temperature sensor close to the water and introducing short delays before taking temperature readings, but these actions were not enough to overcome the major discrepancies caused by insufficient insulation in our experimental equipment. The lack of insulation in the pipes and container housing the water led to ongoing differences between predicted and actual values demonstrating how challenging it is to eliminate thermal lagging.

The consistent differences between predicted and actual values reveal how complex thermal dynamics are within our system. With attempts to reduce thermal lagging by placing sensors strategically and making time adjustments, inadequate insulation continued to have a significant impact on our experiments. Achieving predictions requires comprehensive insulation strategies that effectively address thermal lagging issues. This emphasizes the importance of considering not only sensor placement and timing but also broader environmental factors influencing heat transfer dynamics in our experimental setup.

The results from the experiment highlight how multifaceted thermal lagging is. Its significant impact on predictive accuracy, in experiments. Exploring methods like adjusting sensor placements and timing to reduce delays and the significant impact of insufficient insulation calls for a comprehensive approach to managing insulation. Ultimately dealing with delays is vital to maintaining the dependability and precision of experimental forecasts, in systems heavily influenced by heat transfer dynamics.

Referring to the experimental results previously acquired, we can look at this from a different perspective [7]. When referring to environmental sciences and sustainability, thermal lagging plays a critical role in energy efficiency and decreased overall costs of energy consumption. Whilst thermal lagging may be, somewhat of a constant battle to predict, regulate, and provide the right consistency at times, these challenges are a positive complement to sustainability challenges [7].

When implemented correctly, thermal lagging can reduce the amount of energy needed for heating and cooling, significantly decreasing overall economic and financial constraints [7, 8]. Adhering to lower greenhouse emissions, and providing protection in freezing conditions, where systems tend to freeze over, impacting hydro flow, vapour production, and system pressure, therefore a need to increase energy use for heating, causing variable consistency within the entirety of the system, adding to the energy burden [9]. Using Sustainability Practices, in this instance, can help us to achieve innovative solutions in solving these variables within the system [9].

4. Conclusion

This experiment provides insights into the intricacies of predicting and validating experiments in thermal dynamics. It highlights the challenge of lagging in accurately predicting saturation pressure emphasizing the need for thorough insulation measures to reduce discrepancies between theory and practice.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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