Educational Administration: Theory and Practice
2024, 30(4), 7227-7234
ISSN: 2148-2403
https://kuey.net/

Research Article

Modeling And Analysis Of Spray Flash Evaporation Based On Droplet Analysis

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Citation: Sachin Komble et al (2024), Modeling And Analysis Of Spray Flash Evaporation Based On Droplet Analysis, *Educational Administration: Theory and Practice*, *3*(4), 7227-7234
Doi: 10.53555/kuey.v30i4.2541

ARTICLE INFO

ABSTRACT

The study delves into the comprehensive analysis and simulation of spray evaporation by examining droplet behaviors under three distinct experimental conditions. The investigation encompasses three categories: 1) Normal analysis employing a single nozzle, 2) Variation in nozzle diameter, and 3) Introduction of an obstacle positioned in front of the nozzle. Through meticulous droplet analysis within these categories, insights into the fundamental dynamics governing spray evaporation phenomena were uncovered.

In the normal analysis phase, a detailed assessment of droplet behavior was conducted utilizing a single nozzle setup. Subsequently, alterations in the nozzle diameter were implemented, and the resulting droplet dynamics were scrutinized. This alteration aimed to assess the impact of nozzle size on droplet behavior and subsequent evaporation characteristics.

The research employed advanced simulation techniques and analytical tools to comprehensively investigate droplet characteristics, such as size distribution, velocity, and evaporation rates (Temperature), under these varied experimental scenarios. The analysis of the obtained data provides valuable insights into the fundamental mechanisms governing spray evaporation dynamics and sheds light on the implications for practical applications in fields such as combustion, agricultural spraying, and industrial processes.

The findings from this study not only contribute to advancing the understanding of spray evaporation phenomena but also offer a basis for optimizing nozzle designs, controlling spray patterns, and enhancing the efficiency of various spraying applications. Ultimately, this research serves as a valuable resource for further exploration and innovation in the realm of spray technology.

Keywords — Droplet analysis, Nozzle spray, Evaporation**.**

I.INTRODUCTION

The study of spray evaporation holds paramount importance across numerous industries and scientific fields. In combustion engineering, comprehending droplet behavior during evaporation is pivotal for optimizing fuel injection systems, improving combustion efficiency in engines and heating systems, and reducing pollutant emissions. In agriculture, controlling droplet size and distribution during pesticide and fertilizer spraying is crucial for maximizing crop coverage while minimizing environmental impact. Furthermore, in industrial processes like spray drying and coating applications, manipulating droplet characteristics influences product quality and production efficiency.

Spray evaporation refers to the process by which liquid droplets disperse and transform into vapor when exposed to a gas or air at a different temperature, pressure, or humidity. This phenomenon is fundamental in various fields, including engineering, agriculture, industrial processes, and environmental science.

The insights gleaned from this research have profound implications for advancing various technological domains. They enable the refinement of nozzle designs, provide better control over droplet characteristics, and consequently enhance efficiency and efficacy in spray-based applications. Additionally, the understanding of how obstacles affect droplet dispersion and evaporation can offer insights into pollutant dispersion and mitigation strategies, impacting environmental studies and urban planning.

Spray evaporation, a fundamental process ubiquitous in various industries and technological applications, involves the dispersion and subsequent evaporation of liquid droplets. The dynamics governing droplet behavior during evaporation play a pivotal role in determining the efficiency, efficacy, and environmental impact of numerous engineering systems. Understanding and analyzing the intricate mechanisms underlying droplet behavior under different experimental conditions are paramount for optimizing spray-based technologies, enhancing combustion efficiency, and improving processes reliant on spray applications.

This research undertakes a comprehensive analysis of droplet behaviors under three distinct experimental categories to elucidate the complexities of spray evaporation dynamics. The investigation is structured around three primary categories: 1) Normal analysis utilizing a single nozzle setup, 2) Variations in nozzle diameter, and 3) Introduction of an obstacle in the trajectory of sprayed droplets.

Principles of Spray Evaporation:

1. Dispersal of Liquid Droplets: Spray evaporation initiates when a liquid substance, often in the form of droplets, is dispersed into a surrounding medium, typically air or gas. This dispersion can occur through mechanisms such as atomization, where larger liquid volumes break into smaller droplets due to forces like pressure, shear, or mechanical action.
2. Contact with a Different Medium: These dispersed liquid droplets encounter a medium with different thermodynamic conditions, such as temperature, pressure, or humidity, compared to the liquid phase. When the droplets come into contact with this medium, heat transfer and mass transfer mechanisms come into play, triggering evaporation.
3. Evaporation Process: As the liquid droplets are exposed to the surrounding medium, heat is transferred from the medium to the droplets. This increase in thermal energy elevates the kinetic energy of the droplets' molecules, causing them to overcome the intermolecular forces holding them together in the liquid phase.
4. Phase Change: As the kinetic energy surpasses the liquid's vapor pressure, molecules at the droplet's surface break away and transform into vapor, transitioning from the liquid phase to the gas phase. This phase change leads to the evaporation of liquid droplets into the surrounding gas or air, resulting in a mixture of vapor and gas.

Factors Influencing Spray Evaporation:
Several factors affect the process of spray evaporation:

1. Temperature Gradient: Differences in temperature between the liquid droplets and the surrounding medium play a crucial role. Higher temperature gradients usually accelerate the evaporation rate.
2. Droplet Size: Smaller droplets typically have a larger surface area-to-volume ratio, allowing for more efficient evaporation due to increased contact area with the surrounding medium.
3. Humidity Levels: Higher humidity in the surrounding air can reduce the rate of evaporation as the air is already saturated with moisture, making it harder for additional moisture to evaporate from the droplets.
4. Gas Flow Conditions: The movement, velocity, and turbulence of the gas or air surrounding the droplets influence the rate of evaporation. Increased airflow can promote quicker evaporation by facilitating the removal of vapor from the droplet surface.

Applications of Spray Evaporation:

1. Fuel Atomization and Combustion: Spray evaporation is vital in fuel injection systems for internal combustion engines, gas turbines, and heating systems, where efficient atomization and subsequent vaporization of fuel droplets are essential for optimal combustion efficiency.
2. Agricultural Spraying: In agriculture, spray evaporation plays a crucial role in the efficient application of pesticides, fertilizers, and herbicides. Proper droplet size and distribution facilitate effective coverage while minimizing environmental impact.
3. Pharmaceuticals and Cosmetics: Spray drying, a process that involves the transformation of liquid solutions into powders, relies on spray evaporation to remove moisture from droplets to obtain powdered products in pharmaceutical and cosmetic industries.
4. Industrial Processes: Spray evaporation is used in various industrial applications such as spray coating, cooling systems, inkjet printing, and food processing, where precise control over droplet characteristics influences product quality and production efficiency.

II. LITERATURE REVIEW

1) Experimental and mathematical study of the spray flash evaporation phenomena-

2017

Q. Chen, M. Kum Ja, Y. Li, K.J. Chua

In this paper an experimental setup has been developed to study the spray flash evaporation process of superheated water injected into a vacuum chamber. The effects of various parameters on the flash evaporation process have been investigated in this paper.

2) Modeling of spray flash evaporation based on droplet analysis

2017

Benan Cai, Xiaobing Tuo, Zichen Song, Yulong Zheng, Hongfang Gu, Haijun Wang

The model presented in this paper is verified by the experimental results. The model coincides well with the experimental results. The droplet motion, droplet size variation and temperature variation are taken into account in the present model. The model was validated against the experimental data sets from literature sources. The temperature variation against the traveled distance was obtained and analyzed. Four variables, namely, flow velocity, pressure attenuation ratio, droplet size and relative humidity, were investigated by means of this model.

3) Investigation on Spray Morphology, Droplet Dynamics, and Thermal Characteristics of Iso-Pentane Flashing Spray Basedon Open FOAM-

2022

Dong-Qing Zhu, Shu-Yan Chen, Hong-Jie Xing, Zhi-Fu Zhou , Jia-Feng Wang and Bin Chen

In this paper, a numerical study based on OpenFOAM was conducted to investigate the macro spray morphology and microdroplet behavior of iso-pentane two-phase flashing spray to simulate the accidental release due to leakage of a high-pressure hydrocarbon liquid in the form of a small hole. The effects of the initial injection pressure and temperature on iso-pentane flashing spray were examined and analyzed.

4) Experimental investigation on high-pressure high-temperature spray flash evaporation and the characteristic Jakob number-

2018

Can Ji, Lin Cheng, Naihua Wang, Zhigang Liu

In this paper, a series of high-pressure high-temperature spray flash evaporation experiments are carried out, the mechanism of spray flash evaporation is introduced, the variation of flash efficiency with initial temperature and evaporation pressure is discussed, and the role and influence of the characteristic Jakob number is investigated.

III.METHODOLOGY

In summary, the theoretical underpinnings encompassing droplet dynamics, vaporization kinetics, heat transfer, vapor diffusion, and the Jakob number form the theoretical foundation for understanding spray flash evaporation. The integration of these principles with computational tools empowers researchers to delve into the complex interactions and optimize the process for diverse applications.

Methodology:-

1. Understand a spray evaporation and droplet analysis.
2. Literature review.
3. Design a nozzle.
4. Experimental Setup:

A. Do a spray evaporation through a nozzle:-

1. Conduct experiments using a single nozzle setup under typical conditions.
2. Adjust parameters like flow rate, pressure, and liquid properties to observe droplet behaviors during evaporation.
3. Employ high-speed imaging techniques or particle tracking methods to capture and analyze droplet characteristics.

B. Variation in nozzle diameter:-

1. Conduct experiments using different nozzles with varying diameters.
2. Test different nozzles to study their impact on droplet behavior.

C. Obstacle Introduction:

1. Design and place an obstacle or barrier in the path of the sprayed droplets to simulate real-world scenarios.
2. Ensure the obstacle placement allows for controlled analysis of droplet dispersion and evaporation patterns.

5) Simulate all the results.
6) Data Analysis.
7) Results and Discussion.
8) Conclusion.

RESULTS:-

Three different scenarios:-

1) Simple analysis of evaporation system:-

Boundary Conditions-

1) Inlet

- Velocity- 2 m/s.
- Temperature- 300 k.

2) Outlet
- Pressure- 1 Pa.
- Temperature- 750 k.

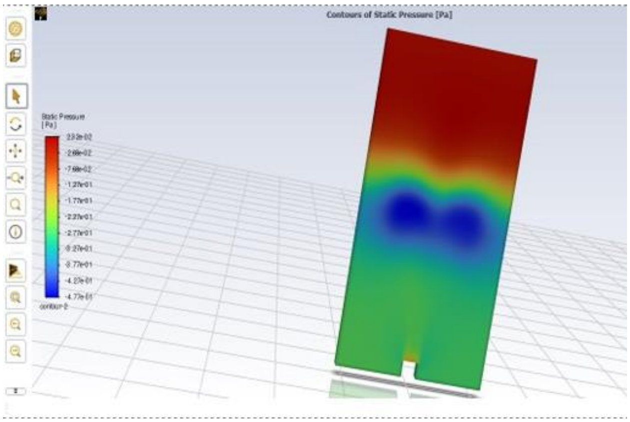

Fig 1. Contours of Static Pressure

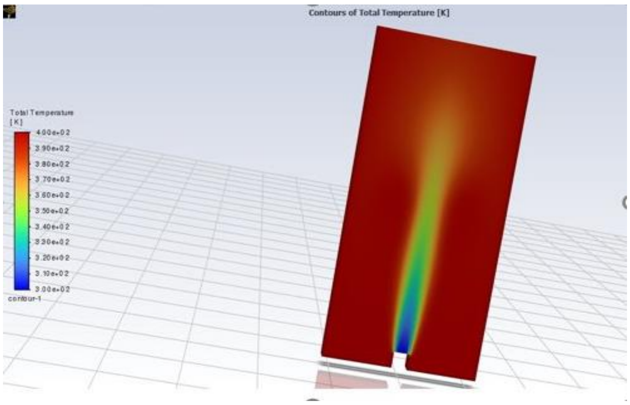

Fig 2. Contours of total Temperature

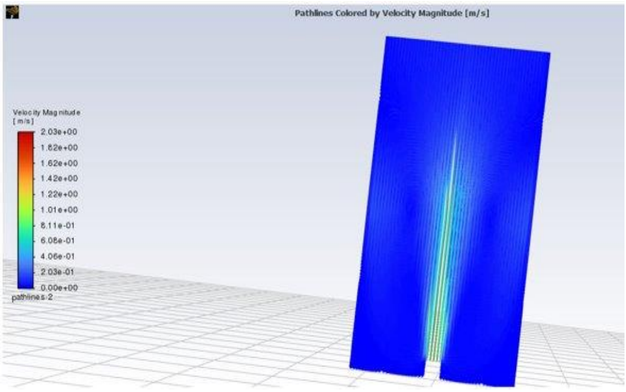

Fig 3. Velocity Pathlines

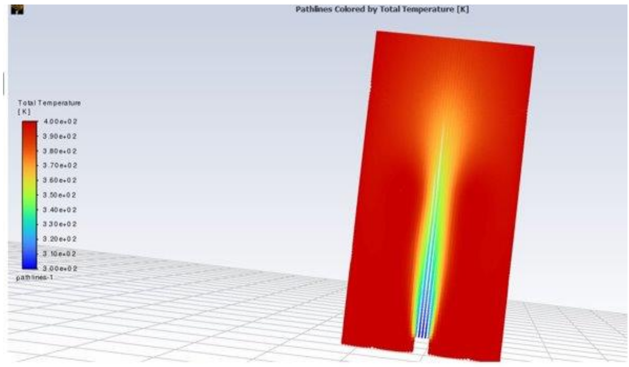

Fig 4. Temperature Pathlines

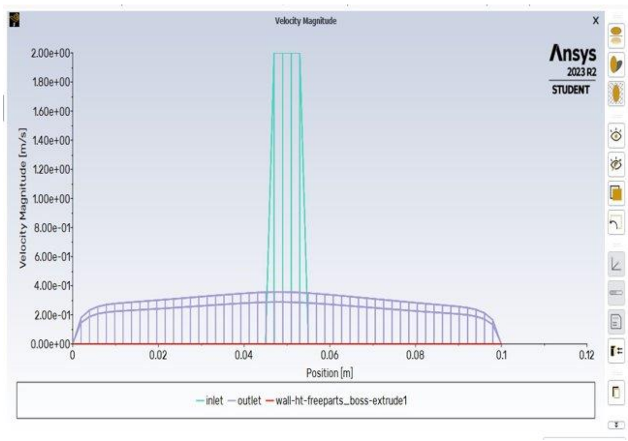

Fig 5. – Velocity Plot

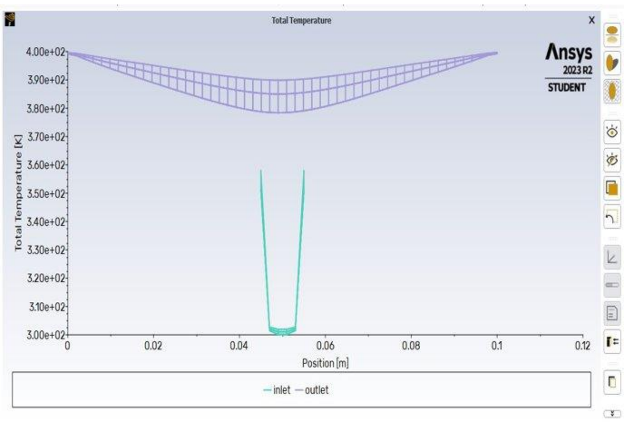

Fig 6. – Temperature Plot

2) Single Nozzle with Slot

Boundary Conditions –
Inlet – Velocity 2 m/s
Temperature – 300 K
Outlet – Pressure – 1 Pa
Temperature – 720K

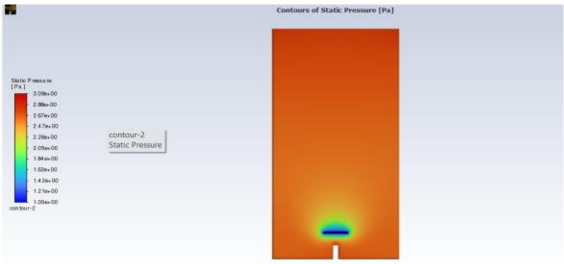

Fig 6. – Contours of Static Pressure

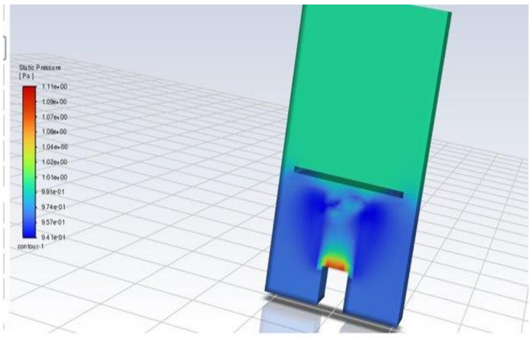

Fig 7. – Contours of Static Pressure 2

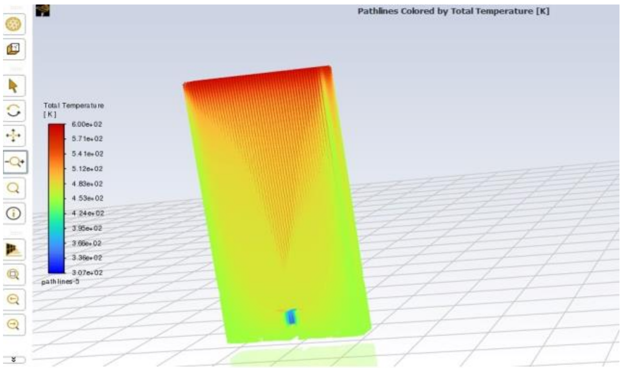

Fig 8. – Temperature Pathlines

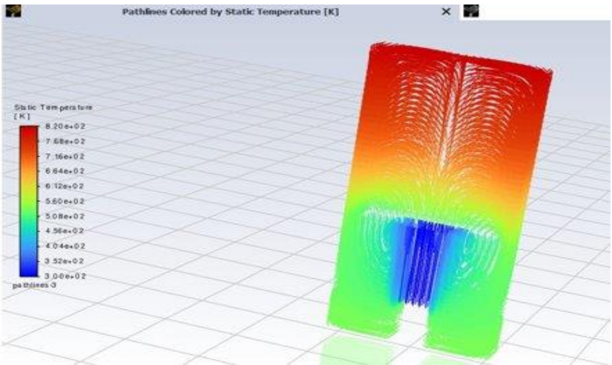

Fig 9. – Temperature Pathlines 2

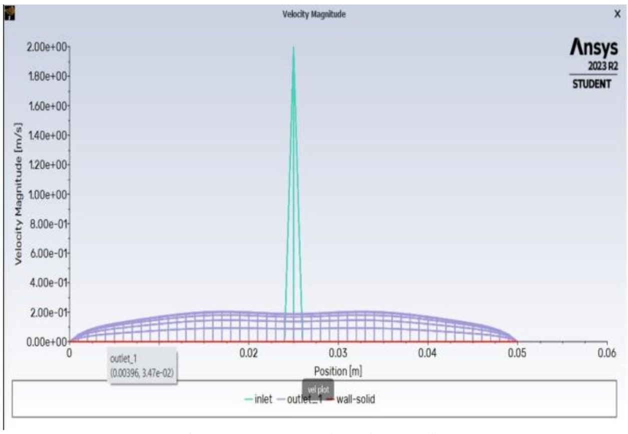

Fig 10. – Velocity Plot

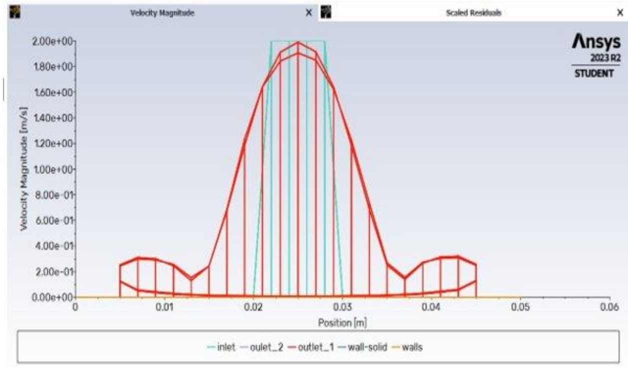

Fig 11. - Velocity Plot 2

3)Analysis with 3 Nozzles

Boundary Conditions

1) Inlet – Velocity – 5 m/s
   Temperature – 300 K
2) Outlet – Pressure – 1 Pa

Temperature – 720 K

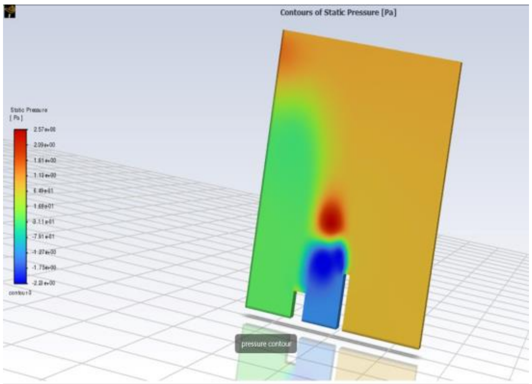

Fig 12 – Static Pressure Contours

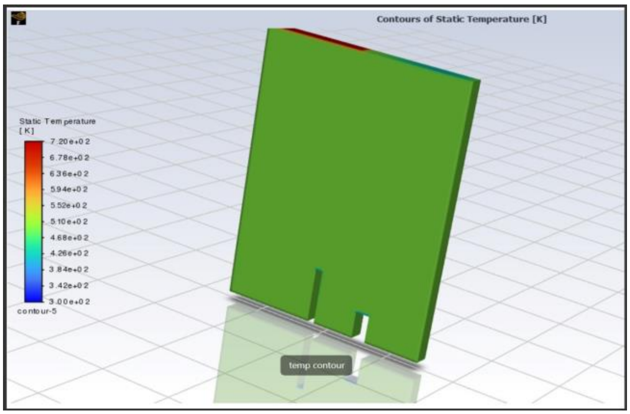

Fig 13. – Temperature Contours

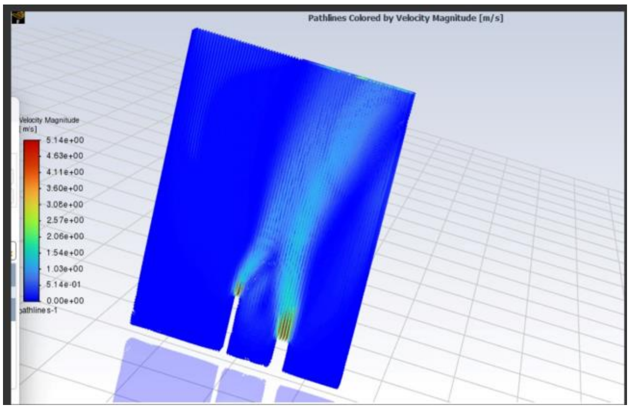

Fig 14. – Velocity Pathlines

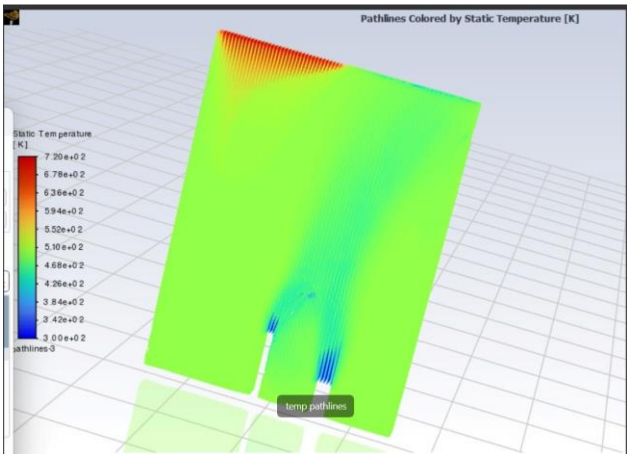

Fig 15 - Temperature Pathlines

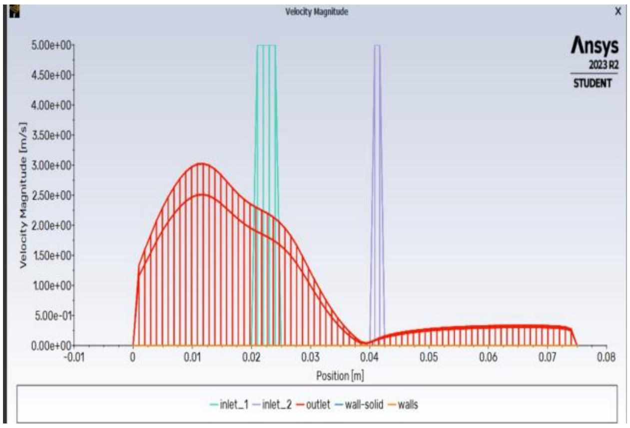

Fig 16 - Velocity Plot

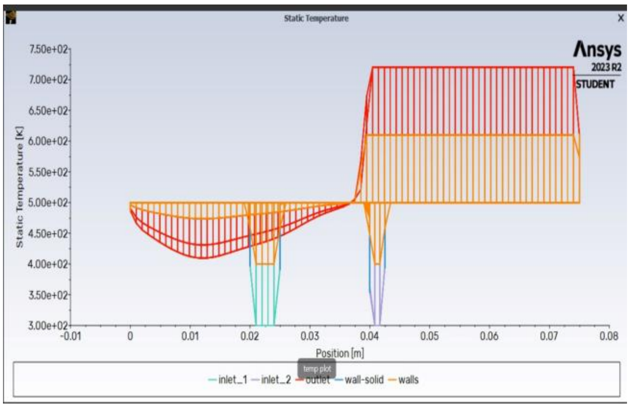

Fig 17 – Temperature Plot

IV.CONCLUSION

1) In the first scenario, with a straightforward inlet and outlet, we observed a change in pressure and temperature signifying evaporation taking place.
2) These obstacles disrupted the flow, resulting in regions of changed velocity and temperature, which may impact the overall evaporation efficiency.
3) Employing two different-sized nozzles, showcased variations in velocity and temperature dependent on the nozzle size.

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