CHAPTER 1
INTRODUCTION

1.1 Background

Global energy demand continues to rise due to population growth and industrial expansion. Much of this demand is still met by fossil fuels such as coal, oil, and natural gas, which are finite and produce harmful emissions that contribute to environmental degradation [2]. This situation highlights the need for cleaner and more sustainable energy sources, particularly renewable energy.

Solar energy is one of the most promising renewable resources because it is abundant and environmentally friendly. Solar thermal systems, for example, convert solar radiation into useful thermal energy. However, their performance is strongly dependent on sunlight availability, leading to reduced effectiveness during nighttime or cloudy conditions [2]. To overcome this limitation, Thermal Energy Storage (TES) systems are used to store excess heat when solar radiation is high and release it when needed.

Phase Change Materials (PCMs) are among the most effective TES technologies because they can store large amounts of thermal energy through melting and solidification at nearly constant temperatures [2]. Kapilan et al. [6] emphasized the suitability of PCMs for solar heating applications. Paraffin wax is widely chosen due to its stability, non-toxicity, non-corrosive nature, and relatively low cost [2]. However, its low thermal conductivity slows the heat absorption and release process, reducing overall system efficiency [2] [6].

Various methods, such as the use of fins, metal foams, and nanoparticles have been proposed to enhance heat transfer in PCM systems. While these techniques can improve performance, they often increase system weight, cost, and complexity, and may raise concerns regarding long-term stability [2][6]. Therefore, simpler and more practical enhancement methods are still required.

One promising alternative is the use of dimple structures on the PCM container surface. Dimples disrupt the boundary layer and create small vortices that enhance convective heat transfer. Previous studies support this approach, Apeta and Borse [3] observed improvements of 18% in heat transfer coefficient and 22% in

Nusselt number, Oluyale et al. [4] reported up to a 91.8% increase in Nusselt number with minimal pressure drop, and Hasnain et al. [5] found heat transfer enhancement factors between 1,16 and 2,32.

Despite these encouraging results, research specifically examining how dimple geometry affects heat transfer in cylindrical PCM containers especially through three-dimensional CFD simulations remains limited. CFD is a reliable tool for studying PCM behavior, as it provides detailed insight into temperature distribution and heat flow during phase change [6].

Therefore, this study investigates the influence of dimple geometry variations on convective heat transfer in a cylindrical paraffin wax PCM container using three-dimensional CFD simulations at different Reynolds numbers. The objective is to determine the optimal dimple configuration that can enhanced the thermal performance of TES units in solar thermal systems.

1.2 Problem Formulations

This research conducts a numerical analysis of a paraffin-based thermal energy storage system, where paraffin is used as the phase change material (PCM) and surface dimples are introduced to improve external convective heat transfer. The geometric influence of the dimples modifies surface interaction with the airflow, thereby affecting the overall thermal performance.

1.3 Aim

The aim of this study is to investigate the effect of dimpled surface geometry with varying geometry correlate to Reynolds numbers on the convective heat transfer performance of a cylindrical Phase Change Material (PCM) container, in order to determine their influence on the temperature distribution and convective heat transfer coefficient improvement under cross-flow conditions.

1.4 Benefits

1. To provide three-dimensional CFD numerical data as a scientific reference for subsequent researchers in exploring surface modification approaches on cylindrical Phase Change Material (PCM) containers within thermal energy storage systems.

2. To establish a validated CFD simulation framework using ANSYS Fluent that can be further extended and applied to various dimple geometries, PCM materials, or alternative container configurations in subsequent thermal engineering investigations.

1.5 Problem Scopes

The simulations conducted in this final project are developed using Autodesk Inventor and ANSYS Fluent. The scope and limitations of this study are defined as follows:

1. Container and dimple geometry are simplified
2. The simulations are conducted in ANSYS fluent for two configurations: a baseline model and a modified model equipped with teardrop dimples
3. The dimensions of the container use the specified height and diameter. The diameter and depth of the dimple are also specified.
4. This research is utilized numerically using Ansys fluent 2021 R2 software.
5. The Phase Change Material (PCM) employed in this study is paraffin wax.
6. The simulations are performed under transient conditions.
7. The simulations are performed under turbulent flow conditions.
8. The analysis is limited to the charging process, focusing solely on the melting phase of the PCM.

1.6 Report Outline

This final project consists of five chapters. The first chapter describes the background, problem formulation, purpose, outcome, problem scope, and report outline. The second chapter provides an overview of the literature that becomes a reference in the final project. The third chapter describes the research methodology. The fourth chapter contains the results and discussion. The last chapter is the conclusion of the final project.