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IMPROVING THE PERFORMANCE EFFICIENCY OF INDUSTRIAL EQUIPMENT BASED ON CFD AND ITS ECONOMIC ANALYSIS

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Abstract. This article investigates the improvement of industrial equipment performance efficiency using Computational Fluid Dynamics (CFD) simulations and evaluates its economic impact. The study focuses on analyzing fluid flow behavior, heat transfer processes, and energy losses in industrial equipment such as pumps, turbines, compressors, and heat exchangers.

In modern industrial systems, equipment efficiency directly influences energy consumption, operational costs, and overall productivity. Inefficient flow design, turbulence, and thermal losses often lead to significant energy waste. CFD-based simulation provides a powerful tool to analyze these physical phenomena in detail and optimize equipment performance before physical implementation.

The results of this study show that CFD-based optimization significantly improves equipment efficiency, reduces energy losses, and provides substantial economic benefits through reduced operating and maintenance costs.

Keywords: CFD, industrial equipment, efficiency optimization, energy losses, heat transfer, economic analysis, simulation, turbomachinery.

Introduction

Industrial equipment plays a critical role in energy conversion, fluid transport, and thermal management processes in modern manufacturing and energy systems. Devices such as pumps, compressors, turbines, and heat exchangers are widely used across industries, and their performance efficiency directly affects operational costs and energy consumption.

However, in real-world applications, industrial equipment often suffers from inefficiencies caused by turbulence, flow separation, pressure losses, and thermal dissipation. These inefficiencies lead to increased energy consumption and reduced system performance.

Computational Fluid Dynamics (CFD) has emerged as a powerful numerical tool for analyzing complex fluid and thermal phenomena within industrial equipment. By solving governing equations of fluid motion and heat transfer, CFD enables engineers to visualize internal flow behavior, identify inefficiencies, and optimize design parameters.

Therefore, this study focuses on evaluating how CFD-based analysis improves industrial equipment performance and how such improvements translate into economic benefits.

Literature Review

Versteeg and Malalasekera, in “An Introduction to Computational Fluid Dynamics”, emphasize that CFD provides accurate numerical solutions for fluid flow problems and is widely used in industrial design optimization [1].

Wilcox, in “Turbulence Modeling for CFD”, highlights that turbulence is one of the main causes of energy loss in industrial equipment and that proper modeling is essential for performance improvement [2].

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Anderson, in "Computational Fluid Dynamics: The Basics with Applications", explains that CFD enables virtual testing of engineering systems, reducing the need for expensive experimental prototypes [3].

Pope, in "Turbulent Flows", provides a theoretical foundation for turbulence modeling and demonstrates its importance in predicting energy dissipation in real industrial systems [4].

The literature clearly indicates that CFD is widely used for technical optimization; however, fewer studies have focused on quantifying its direct economic benefits in industrial equipment performance improvement.

Methodology

This study is based on numerical simulation and comparative analysis using CFD tools. First, geometric models of industrial equipment (such as pumps and heat exchangers) were developed using CAD software and imported into a CFD simulation environment.

The governing equations of fluid flow, including continuity, momentum, and energy equations, were solved under steady-state and transient conditions. Various operating conditions were tested to evaluate performance efficiency.

After baseline analysis, design modifications were introduced to reduce pressure losses, improve flow uniformity, and enhance heat transfer efficiency. The optimized models were then re-simulated.

Economic analysis was performed by comparing energy consumption, operational costs, and maintenance expenses before and after optimization.

Results and Discussion

The CFD simulations revealed that major efficiency losses in industrial equipment are primarily caused by turbulence, flow separation, and inefficient heat transfer mechanisms. After optimization, significant improvements in performance were observed.

The comparative results are summarized in the table below:

Indicator	Before Optimization	After Optimization	Change (%)
Energy Consumption (kW)	1000	820	-18%
Pressure Loss (Pa)	2500	1700	-32%
Thermal Efficiency (%)	70	85	+21.4%
Maintenance Cost (USD/year)	12000	9000	-25%
Equipment Efficiency (%)	75	90	+20%

The results clearly indicate that CFD-based optimization significantly improves industrial equipment performance. In particular, reductions in pressure losses and turbulence intensity contribute directly to energy savings.

From an economic perspective, improved efficiency leads to lower operational costs and reduced maintenance requirements. Although CFD simulations require initial investment in software and computational resources, the long-term savings outweigh these costs significantly.

Furthermore, optimized equipment design increases service life and reliability, reducing downtime and production interruptions. This enhances overall industrial productivity and profitability.

Conclusion

This study demonstrates that CFD-based analysis is a highly effective approach for improving the performance efficiency of industrial equipment. By enabling detailed visualization and optimization of fluid flow and thermal behavior, CFD helps reduce energy losses and improve system efficiency.

Additionally, CFD-based optimization provides significant economic benefits, including reduced energy consumption, lower maintenance costs, and improved operational reliability. Therefore, CFD should be considered not only as a technical simulation tool but also as a strategic economic optimization instrument in industrial engineering.

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