Performance Analysis of Shell and Tube Heat Exchanger by Using Nano Fluid Medium

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Abstract
Heat exchangers play a crucial role in thermal systems by regulating the operating temperature of working fluids. Among the various types used in industry, shell and tube heat exchangers are the most common. In this study, a performance analysis of a shell and tube heat exchanger was carried out using CFD tools, based on boundary conditions obtained from an industrial setting. To enhance system efficiency, the conventional cooling fluid—liquid ammonia—was replaced with a CuO based nanofluid and analyzed. Subsequently, the shell and tube configuration was replaced with a U-tube heat exchanger, and the analysis was repeated under the same boundary conditions. A comparative study of the results revealed that the use of CuO significantly improves thermal efficiency.

Keywords: Heat exchangers – CFD analysis – performance optimization – Nano fluids.

1. Introduction

Heat exchangers are extensively used across various thermal and thermally related industries to maintain desired temperatures within systems. Heat transfer in these systems occurs in several forms, with convection—also known as convective heat transfer—being one of the most prevalent. This form of heat transfer is fundamental to the operation of all types of heat exchangers. Among them, shell and tube heat exchangers are widely favored due to their simple construction and low maintenance requirements. These heat exchangers typically operate in either parallel flow or counter flow modes.

In this project, a shell and tube heat exchanger is selected for performance analysis. The geometric modeling of the heat exchanger is carried out using SolidWorks software, which will also be used for future CFD (Computational Fluid Dynamics) simulations, thanks to its integrated design and analysis capabilities. The simulation data will be sourced from a nearby dairy factory, where heat exchangers are employed to regulate process temperatures. Initially, a CFD analysis will be performed on the existing setup, and the results will be recorded. Subsequently, the working fluid will be changed from ammonia to a Copper(II) oxide (CuO) nanofluid in an effort to enhance heat transfer from gas to liquid. The new CFD results will then be documented and compared with the baseline data.

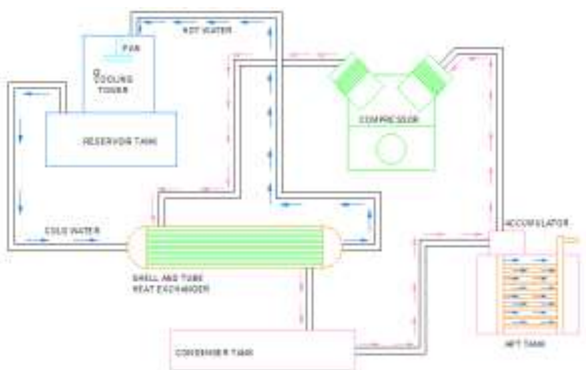
2. Methodology

Methodology forms the foundation of any project, as it outlines the defined starting point, workflow, and end goals. Effective planning and systematic execution are essential for the successful completion of the work. The methodology adopted for this project is detailed below.

Flow chart of work progress.

3. Problem Definition

Heat exchangers are essential heat transfer devices, widely used in the food industry to preserve products and maintain a consistent temperature at specific stages of fluid transport. The following describes the layout of a typical heat transfer system in a food processing facility. In this system, cold water from a reservoir enters the shell and tube heat exchanger. Simultaneously, a compressor draws ammonia from an accumulator and circulates it through a network of pipes under constant pressure. As the ammonia is compressed, it gains thermal energy and flows through the pipes toward the heat exchanger. Inside the heat exchanger, the cold water comes into thermal contact with the heated ammonia, resulting in heat transfer. Consequently, the water heats up and is directed back to the reservoir through pipelines, performing various thermal tasks along its path. Meanwhile, the ammonia, having transferred its heat, cools down and condenses. The condensed ammonia is collected in a condenser tank, now in liquid form, and is pumped back into the accumulator to begin the cycle again. However, the heat transfer occurring within the exchanger is observed to be inefficient. Not all of the condensed ammonia reaches the collection tank; some remains at the bottom of the shell. Over time, this residual ammonia can lead to corrosion within the shell, potentially resulting in system failure.



Thermal system of the industry.

4. Objective

In response to the identified problem, the primary objective of this project is to enhance the condensation rate and increase the quantity of liquid ammonia collected in the tank. It has also been observed that the use of suitable working fluids can significantly improve the heat transfer rate, thereby boosting the overall efficiency of the system. With this understanding, the project focuses on optimizing heat transfer performance in a shell and tube heat exchanger by varying both the coolant fluid and the geometry of the exchanger. Computational Fluid Dynamics (CFD) is employed to analyze the heat transfer rate, temperature distribution between the shell and tubes, and the inlet and outlet conditions of the working fluids.

Geometry Specification

Shell Details

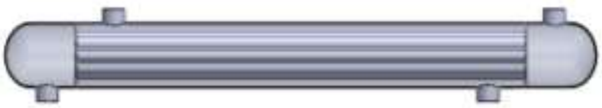
Outer diameter = 142mm
Inner diameter = 136mm
Length of the HE = 1500mm
No. of baffles = 5
Distance between baffles = 300mm
Baffle opening = 25% (except first and last)

Tube Details

Outer diameter = 23mm
Inner diameter = 20mm
Length = 1200mm
No. of tubes = 9

Materials Details

Shell = Stainless Steel
Tubes = Copper
Baffles = Copper



Shell and Tube type Heat Exchanger _ existing type

U-Tube type Heat Exchanger _ proposed type

Material Specification

Material Properties of NH_4 _ Existing fluid

Property	Values
Boiling Point	-28°F
Weight per gallon of liquid at -28°F	5.69 pounds
Weight per gallon of liquid at	5.15 pounds

Property	**Values**
60°F	
Specific gravity of the liquid (water=1)	0.619
Specific gravity of the gas (air=1)	0.588
Flammable limits in air	16-25%
Ignition temperature	1204°F
Vapor pressure at 0°F	16 psi
Vapor pressure at 68°F	110 psi
Vapor pressure at 100°F	198 psi
One cubic foot of liquid at 60°F expands to	850 cubic foot of gas

Material Properties of CuO _ Proposed fluid

Property	**Minimum Value (S.I.)**	**Maximum Value (S.I.)**	**Units (S.I.)**
Density	6.31	6.32	g/cm^3
Energy Content	-1990	-840	MJ/kg
Glass Temperature			K
Latent Heat of Fusion	200	260	kJ/kg
Maximum Service Temperature	350	1130	K
Melting Point	1600	2419	°C
Minimum Service Temperature	0		K
Specific Heat	531	540	J/kg.K
Thermal Conductivity	69	76	W/m.K
Thermal Expansion	4	8.1	10-6/K
Breakdown Potential	0.45	7.2	MV/m

CFD Analysis

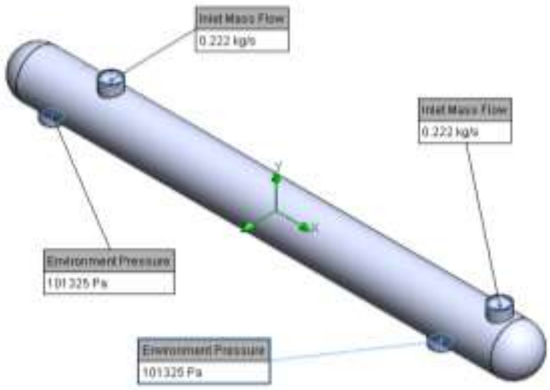
The CFD analysis was conducted under the following four steps.

- Pre-processing

- Analyze and CFD process
- Solution
- Post-processing

The pre-processing stage involves importing and cleaning the model, generating the mesh, applying boundary conditions, and assigning material properties. The solution stage includes configuring solver settings, defining output parameters, and running the simulations. Finally, in the post-processing stage, results are extracted from the saved simulation data in the form of contour plots and tabulated values. A detailed explanation of the post-processing procedures will be provided in the following chapter. Following are the pre-processing data used in this work.

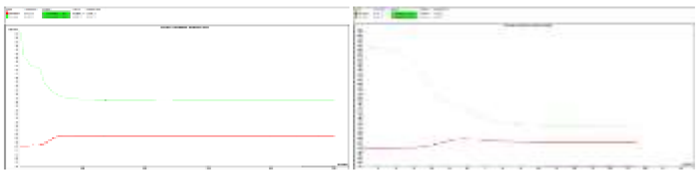
- Inlet mass flow = 0.222 Kg/Sec (Hot and Cold)
- Inlet Hot fluid temperature = 55ºC
- Inlet Cold fluid temperature = 25º C
- Outlet conditions = Environmental temperatures and pressure (Hot and Cold)



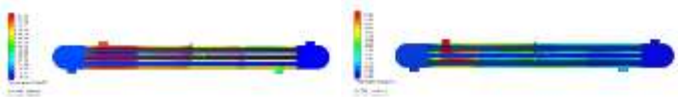
Boundary Conditions of the Heat exchanger used for CFD analysis

4. Results and Discussions

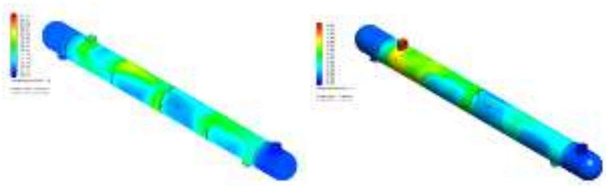
The following are the outputs of the solved problem. This is termed as the post-processing in the CAE analysis. Here the outputs are displayed as coloured contours and graphs and tabulated readings.



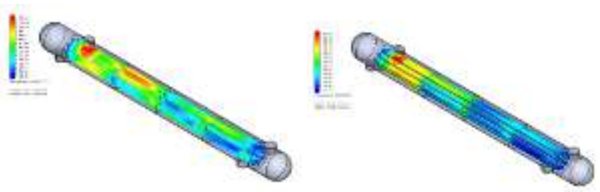
Convergence plot for Straight tube Heat exchanger _ existing and proposed fluid conditions



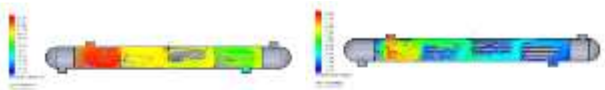
Temperature plot on tubes for Straight tube Heat exchanger _ existing and proposed fluid conditions



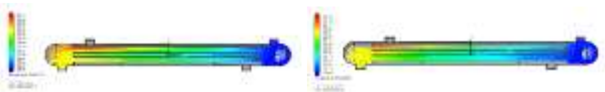
Surface temperature of shell for Straight tube Heat exchanger _ existing and proposed fluid conditions



Surface temperature of tubes for Straight tube Heat exchanger _ existing and proposed fluid conditions



Fluid flow inside shell for Straight tube Heat exchanger _ existing and proposed fluid conditions



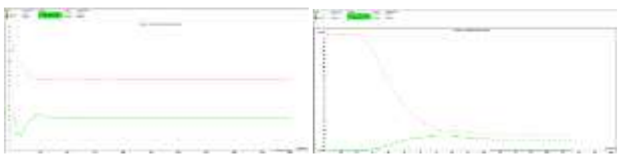
Fluid flow inside tubes for Straight tube Heat exchanger _ existing and proposed fluid conditions

Temperature results for Straight tube Heat exchanger _ Existing and fluid conditions

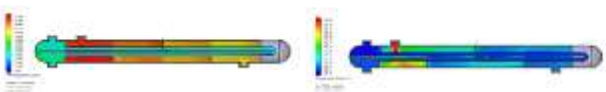
Parameter	**Average value**	**Minimum Value**	**Maximum Value**
NH_4 Outlet Temperature [°C]	27.22	27.21	27.24
H_2O Outlet Temperature [°C]	36.28	36.25	36.32

Temperature results for Straight tube Heat exchanger _ Proposed fluid conditions

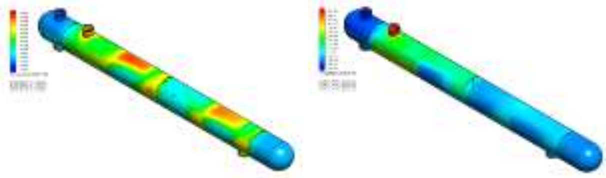
Parameter	***Average value***	***Minimum Value***	***Maximum Value***
CuO Outlet Temperature [°C]	26.76	26.73	26.82
H_2O Outlet Temperature [°C]	31.52	31.46	31.68



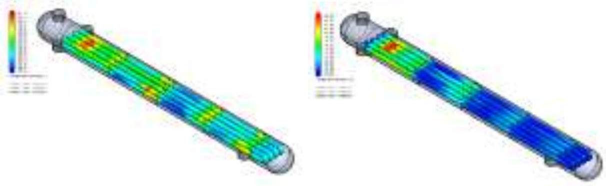
Convergence plot for U- tube Heat exchanger _ existing and proposed fluid conditions



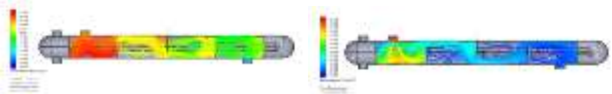
Temperature plot on tubes for U- tube Heat exchanger _ existing and proposed fluid conditions



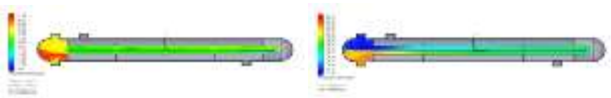
Surface temperature of shell for U- tube Heat exchanger _ existing and proposed fluid conditions



Surface temperature of tubes for U- tube Heat exchanger _ existing and proposed fluid conditions



Fluid flow inside shell for U- tube Heat exchanger _ existing and proposed fluid conditions



Fluid flow inside tubes for U- tube Heat exchanger _ existing and proposed fluid conditions

Temperature results for U- tube Heat exchanger _ Existing and fluid conditions

Parameter	***Average value***	***Minimum Value***	***Maximum Value***
NH_4 Outlet Temperature [°C]	38.56	38.55	38.57
H_2O Outlet Temperature [°C]	23.15	23.11	23.19

Temperature results for U- tube Heat exchanger _ Proposed fluid conditions

Parameter	***Average value***	***Minimum Value***	***Maximum Value***
CuO Outlet Temperature [°C]	29.22	29.20	29.23
H_2O Outlet Temperature [°C]	27.72	27.70	27.80

The colored contour plots and tabulated results indicate that the straight tube heat exchanger using the proposed fluid (CuO) exhibits improved thermal performance. Both the degree of heating and the degree of cooling of the fluids are enhanced under the proposed conditions compared to the existing setup. In the case of the U-tube heat exchanger, the thermal performance with the existing fluid was found to be less effective than that of the straight tube heat exchanger with the same fluid. However, when the proposed CuO fluid was used in the U-tube configuration, the results showed significantly better performance across key thermal parameters—such as the degree of heating and cooling—surpassing all other three cases analyzed.

5. Conclusion

In this project, a performance analysis was carried out to compare a shell and tube heat exchanger with a U-tube heat exchanger using CFD tools. Initially, 3D models of both heat exchangers were created in Solid Works, based on dimensional data collected from an industrial setup. These models were then imported into the Solid Works Flow Simulation package for CFD analysis. Pre-processing was completed using industry-sourced input parameters, and simulations were run accordingly. Post-processing tools were used to extract results, which were saved as contour plots and tabulated values for detailed analysis. From the results, it was observed that the shell and tube heat exchanger using ammonia as the working fluid produced a hot fluid outlet temperature of approximately 36°C and a cold fluid outlet of around 27°C. When titanium dioxide (CuO) nanofluid was used instead, the hot fluid outlet dropped to around 31°C and the cold fluid outlet to 26°C.

This indicates that CuO improves cooling performance by about 5°C on the hot fluid side. Although the heating of the cold water was slightly lower with CuO compared to ammonia, this was not considered critical, as the cold water is subsequently sent to a cooling tower and has no specific external function. In the case of the U-tube heat exchanger, the hot fluid outlet temperature was approximately 29°C when using CuO, compared to about 38°C with ammonia. This represents a cooling improvement of 9°C with CuO.Overall, the analysis shows that CuO nanofluid enhances cooling efficiency in both straight and U-tube heat exchangers. Among the two, the U-tube configuration demonstrated superior performance. Based on these findings, the use of CuO in a U-tube heat exchanger is recommended as the more effective operating condition for improved thermal performance.

6. References

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