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A Comprehensive Analysis of Parallel Heat Pipe System with Evolution of its Properties

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Abstract- Genetic Algorithm (GA) based heat exchanger analysis employs evolutionary optimization techniques to enhance the performance and efficiency of heat exchangers. By mimicking natural selection processes, GA iteratively searches for optimal design parameters such as geometry, material properties, and flow configurations. This method efficiently navigates the complex solution space, identifying designs that maximize heat transfer and minimize costs. GA's flexibility and robustness make it an effective tool for tackling the multifaceted challenges in heat exchanger design, leading to improved thermal performance and economic benefits.

Keywords- Heat pipe Multi-channel, Two-phase heat transfer, Modelling.

I. INTRODUCTION

A heat pipe is a two-phase heat transfer device with a very high effective thermal conductivity. It is a vacuum tight device consisting of an envelope, a working fluid, and a wick structure. The heat input vaporizes the liquid working fluid inside the wick in the evaporator section.

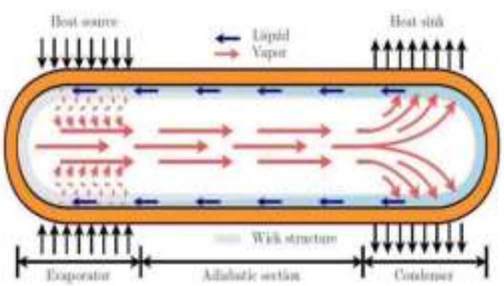

Fig 1 Basic working of a heat pipe

The saturated vapor, carrying the latent heat of vaporization, flows towards the colder condenser section. In the condenser, the vapor condenses and gives up its latent heat. The condensed liquid returns to the evaporator through the wick structure by capillary action. The phase change processes and two- phase flow circulation continues as long as the temperature gradient between the evaporator and condenserare maintained.

II. ROLE OF CFD IN ANALYSIS

CFD provides a qualitative analysis of the flow in fluids. Sometimes, however, it can also perform quantitative analysis of the fluid flow. To do this, it uses algorithms and numerical methods to solve problems regarding the fluid flow. The interaction of solids with their surrounding fluid, both liquid and gas can be simulated with the help of CFD. The boundary conditions can be determined with the help of it. With progress in research, even complex scenarios like turbulent flow can be simulated and various parameters of the fluid flow can be determined with the help of more accurate software. Navier - Stoke´s equation is the basis for most of the CFD modelling problems. These equations describe the flow of a single-phase fluid. Research led to development of more complex equations that take into account more and more of reallife parameters that affect the fluid flow. CFD utilizes partial differential equations (PDE) for mathematical modelling, discretization and solution in numerical methods and several software tools processing before and after analysis. The computer simulations are performed in a virtual flow laboratory ‘by trained scientists and engineers. The triumph of simulation over experimentation is that it is much faster and cheaper. Parallel and multi - purpose simulations can be conducted simultaneously. The simulations are most accurate when the flow to be evaluated is a laminar one instead of a turbulent flow. Similarly, it is much more difficult to simulate multi - phase flows than to simulate single phase flows. The accuracy improves manifold if the fluid is chemically inert instead of being a reactive flow. Working Principle of CFD - Firstly, a mathematical model of the physical problem is constructed with the help of equations. Care is taken so that the equations satisfy the conservation of momentum, energy and mass.

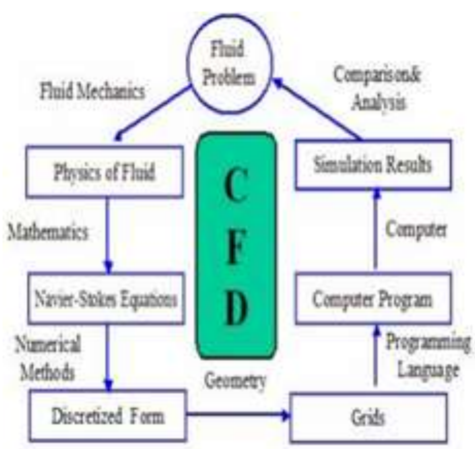

Fig.2 Process of Computational Fluid Dynamics

Some of the properties are determined empirically. Even then some assumptions have to be made to simplify the problem. Usually, it is considered that the fluid is flowing with a steady flow rate. Secondly, numerical methods are applied to these equations. This is called discretization and it employs methods like Finite element method, finite volume method, finite difference method etc. These equations are solved simultaneously for very small volumes of the fluid known as mesh. This involves iterations and re - iterations using a computer until and unless a convergence is reached. Thirdly, after processing, parameters like drag friction, torque, heat transfer, pressure loss can be determined. In the real life, CFD has been used to design aerodynamic shapes, the shape and flow.

Construction of Heat Pipe

A general heat pipe consists of a sealed hollow tube, which is made from a thermo-conductive metal such as copper or aluminum. The pipe contains a small quantity of "working fluid" (such as water, ethanol or mercury) with the remaining of the pipe being filled with vapor phase of the working fluid. On the internal side of the tube's side-walls a wick structure exerts a capillary force on the liquid phase of the working fluid. This is typically a sintered metal powder (sintering is a method for making objects from powder, by heating the material until its particles adhere to each other) or a series of grooves etched in the tube's inner surface. The basic idea of the wick is to soak up the coolant. Heat pipes contain no moving parts and require no maintenance and are completely noiseless. In theory, it is possible that gasses may diffuse through the pipe's walls over time, thus reducing this effectiveness. The vast majority of heat pipes use either ammonia or water as working fluid. Extreme applications may call for different materials, such as liquid helium (for low temperature applications) or mercury (for extreme high temperature applications). The advantage of heat pipe is their great efficiency in transferring heat. They are actually a better heat conductor than a mass of solid copper. As mentioned previously there is liquid vapor equilibrium inside the heat pipe. When thermal energy is supplied to the evaporator, this equilibrium breaks down as the working fluid evaporates. The generated vapor is at a higher pressure than the section through the vapor space provided. Vapor condenses giving away its latent heat of vaporization to the heat sink. The capillary pressure created in the menisci of the wick, pumps the condensed fluid back to the evaporator section. The cycle repeats and the thermal energy is continuously transported from the evaporator to condenser in the form of latent heat of vaporization. When the thermal energy is applied to the evaporator, the liquid recedes into the pores of the wick and thus the menisci at the liquid-vapor interface are highly curved.

III. PROPOSED METHODOLOGY

Genetic Algorithm (GA) based heat exchanger analysis is a computational optimization technique that applies the principles of natural evolution to solve complex engineering problems.

In the context of heat exchangers, GAs are used to optimize various design parameters to achieve improved thermal performance and cost-efficiency. Here's a detailed description of the process:

1. Initialization
The GA starts with a randomly generated population of potential solutions. Each solution, known as a chromosome, represents a specific design configuration of the heat exchanger. The parameters encoded in the chromosome can include dimensions, flow rates, material properties, and other design variables.

2. Fitness Evaluation
Each chromosome is evaluated to determine its fitness, which reflects how well it meets the optimization criteria. The fitness function typically includes objectives such as maximizing heat transfer efficiency, minimizing pressure drops, reducing material costs, and ensuring operational reliability.

3. Selection
Based on their fitness scores, the best-performing chromosomes are selected to form a new population. Selection methods, such as roulette wheel selection, tournament selection, or rank-based selection, ensure that higher fitness solutions have a greater chance of being chosen.

4. Crossover
To create new chromosomes (offspring), pairs of selected chromosomes undergo crossover (recombination). This process involves exchanging segments of their parameter sets to produce offspring that inherit characteristics from both parents. Crossover increases the diversity of the population and helps explore new areas of the solution space.

5. Mutation
To maintain genetic diversity and avoid premature convergence, some chromosomes undergo mutation. This involves randomly altering one or more parameters in a chromosome. Mutation ensures that the GA can explore a broader range of potential solutions and escape local optima.

6. Iteration
The new population of chromosomes is evaluated for fitness, and the selection, crossover, and mutation processes are repeated over many generations. With each iteration, the population evolves towards better solutions.

7. Convergence
The algorithm continues iterating until a stopping criterion is met, such as a maximum number of generations or a satisfactory fitness level. The best chromosome in the final population represents the optimized heat exchanger design.

8. Advantages of GA-Based Analysis
Robustness: GAs can handle complex, non-linear, and multi-modal optimization problems effectively.
Flexibility: They can optimize multiple conflicting objectives simultaneously.

9. Global Search Capability
GAs are less likely to get trapped in local optima compared to traditional optimization methods.

Applications
Thermal Efficiency Optimization
Enhancing the heat transfer rate and reducing thermal resistance.

Cost Minimization
Reducing material and manufacturing costs while maintaining performance.

Design Innovation
Exploring unconventional design configurations that may not be considered using traditional methods.

In summary, GA-based heat exchanger analysis provides a powerful tool for optimizing design parameters, leading to more efficient, cost-effective, and innovative heat exchanger solutions.

IV. RESULT AND SIMULATION

The Condenser Evaporator (2P-MA) block can operate as either a condenser or an evaporator. In the condenser case, heat flows from the refrigerant to the moist air.

This causes the refrigerant to condense from a superheated vapor to a two-phase mixture to a subcooled liquid, resulting in up to three fluid zones along the length of the condenser tubes. In the evaporator case, heat flows from the moist air to the refrigerant. If the moist air is sufficiently wet, water vapor condenses on the surface and is removed from the rest of the moist air flow.

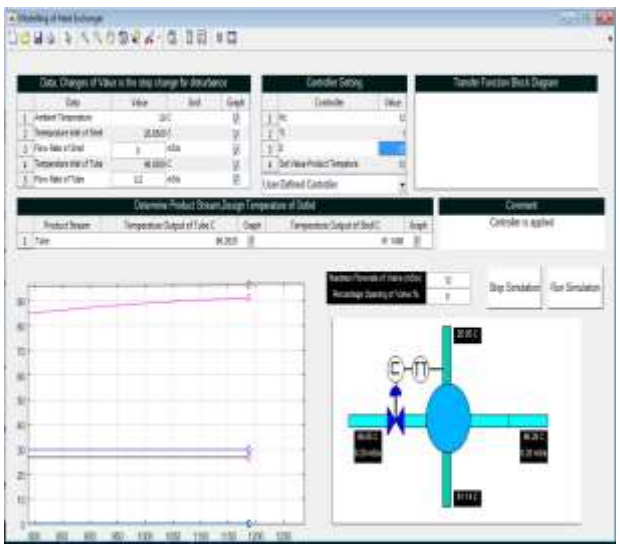

Fig. 3 Customize controller

Fig. 4 Best performance using Ga and PID

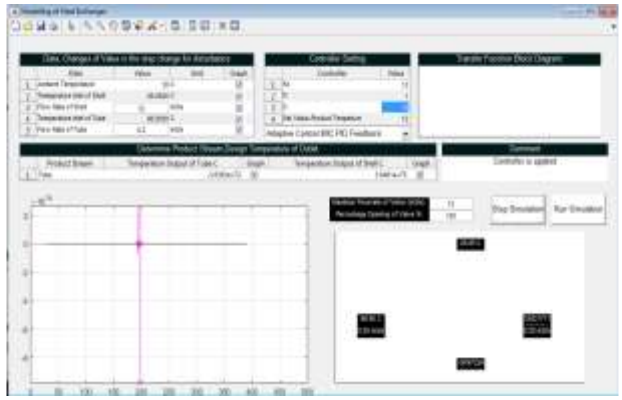

Fig. 5 Only PID based Controller Performance

V. CONCLUSION

In conclusion, the application of Genetic Algorithms (GA) in heat exchanger analysis offers an efficient and robust method for optimizing design parameters to enhance thermal performance and cost-effectiveness. By leveraging the evolutionary principles of selection, crossover, and mutation, GA can explore a wide solution space and identify optimal configurations that traditional methods might overlook. This approach not only improves heat transfer efficiency but also reduces operational costs and material usage, making it a valuable tool in the design and optimization of heat exchangers. The adaptability and effectiveness of GA highlight its potential for broader applications in thermal systems and other engineering optimization problems.

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