Academic Guru Publication House

Advances in Thermal Engineering : Emerging research and opportunities

Volume 1
Year: 2021

A review on thermal fluid management

Arun Prakash J[1*], P.Jayapradha[2]

[1]*Assistant Professor, Department of Aeronautical Engineering, Hindusthan Institute of Technology, Coimbatore*

2 Assistant Professor, Department of Mechanical Engineering, Karpagam Academy of Higher Education, Coimbatore

Abstract

Thermal fluid management is a critical area in industries that require constant monitoring. If the systems are not managed properly then it will result in catastrophic failures including significant breakdown, replacement, downtime and costs. Though many systems are incorporated to manage the systems ranging from sensors to automatic cut-offs many problems still persist. The non-monetary complications that arise due to the mismanagement of these systems will put lives and livelihoods at risk. The operation of these Thermal fluid heating systems is generally a closed loop but still, the continuous circulation of these thermal fluids/heat transfer fluid operates in a closed loop with the thermal fluid (also referred to as heat transfer fluid) in constant circulation. This constant circulation will also act as heat transfer agents and also their fluid properties tend to change. A special set of control loops are commonly used to monitor these systems. Systems tend to operate mostly in the liquid state and at times there are systems that operate in the vapor state also. Safety, flexibility and efficiency are the key factors when it comes to the management of these systems.

Keywords: Thermal Fluid, Fluid Proprty, Flexibility, Vapour State.

Introduction

The thermal fluid (also called heat transfer fluid) in closed-loop heating systems is always circulating. This on-demand heat supply is maintained by steady circulation at the supply temperature. Individual users may be managed, and the temperature of the thermal fluid can be adjusted independently for each user by means of auxiliary control loops. Although vapour phase fluids are available for some specialised

* ISBN No. 978-81-955340-8-1

applications that benefit more from latent heat than simple heat, in most systems the thermal fluid or heat transfer fluid remains in a liquid form all the way through the loop.

Types of Heat Transfer Fluids

It is usual practice to heat a building using thermal oil, water, or a water-glycol combination. There are benefits and drawbacks to using each of these heat transfer fluids, and they change with the system's operating temperature and desired level of performance. To make the best decision for any given use case, familiarity with the various fluid options is essential.

1. **Hot water and water-glycol**: When considering thermophysical qualities, water is the greatest heat transport medium conceivable, but it also has a few limitations. To start, it can be caustic, it can pick up pollutants, it boils at 212 degrees Fahrenheit, and it freezes at 32 degrees Fahrenheit. The freezing point may be lowered by adding glycol to a water solution, and the boiling point raised, although the heat capacity will be diminished somewhat.
2. **Thermal oil**: When compared to water-based solutions, thermal oils can withstand hotter conditions without boiling or significantly raising system pressure. Oil-based systems may be used at temperatures up to 800 degrees Fahrenheit with some synthetic oils. Long-term cost reductions are realised since a qualified boiler operator is not normally required for oil-based heating systems that are approved under ASME Section VIII. Because of their lack of corrosiveness, thermal oils also don't require special treatment to avoid the buildup of hard water deposits.

Advantages of Thermal Fluid Heating Systems

Compared to conventional boilers, thermal oil heating systems provide a number of benefits. Among these benefits are:

1. **Achieving High Temperatures at Low Pressures**

A wider temperature range and a hotter maximum are available from thermal fluid systems. Thermal oil allows these systems to run at temperatures between 0 and 750 degrees Fahrenheit, but steam limits them to a maximum of 350 degrees Fahrenheit before operating pressures rise over 425 pounds per square inch. Water-glycol thermal fluid systems may achieve temperatures between 32 and 350° F at pressures somewhat lower than those required by steam, providing even greater versatility than conventional systems.

As useful as the temperature range is, the low pressure is perhaps more so. The maximum system pressure is merely what is produced by the centrifugal circulation pumps, which is sufficient for most hot oils running at temperatures below 600 °F. Vapor pressures of less than 100 PSIG are sufficient for use of high-temperature synthetics up to 750° F. To maintain a steam temperature of 750 degrees Fahrenheit, the system pressure must be more than 3,200 pounds per square inch (PSIG).

2. Minimal Maintenance

Maintenance for thermal fluid heating systems is minimal outside of routine flashpoint checks. If properly maintained and checked on a regular basis, the circuits are simple and the fluid seldom needs adjusting or replenishing. In contrast to conventional boilers, thermal fluid systems need no upkeep such as blowdown, re-tubing, steam trap maintenance or water treatments.

3. No Attendant Needed

Because of rising concerns about the safety of employees in close proximity to boilers, more and more industries, states, and municipalities are passing laws mandating the permanent presence of an engineer in all boiler rooms. During peak production times, many facilities throughout the country are required to have a trained staff in the boiler room. Most boilers that use fire as a steam source need this.

With a thermal fluid heater and unfired steam generator, a facility may operate with just a roving attendant. This benefit may be conditional on meeting requisites in a certain jurisdiction.

4. Outdoor Installation

Due to the nature of the thermal fluid system's output, it is possible to place it in otherwise inaccessible areas, whether inside or out. The safety of the whole plant may be maximised by separating the heater and major system components from the rest of the building's vital production areas.

Even though there are some extra steps involved, installing a thermal fluid system in an outdoor setting is simple. The proper size of a circulation pump and motor involves taking into account cold start provisions. It's possible that other things, like pouring slabs or protecting exposed pipes and equipment, will need to be done as well.

Conduction

A substance's ability to conduct heat depends on how well it is in touch with another material. A temperature differential between the two sides of a material is the driving factor in conduction. Putting one end of a metal rod in a fire will cause the whole rod to heat up because the heat will travel down the metal's surface and out the other end. Heat exchangers and equipment insulation are two popular methods used in the area of thermal and fluid sciences to determine the amount of heat lost or gained owing to conduction. Heat flow through a wall or roof, however, is much simpler to picture. To determine how much heat is transferred by conduction through a uniform material, use the following formula.(Boettner, 2017):

$$Q_{cond,flat\ plate} = \frac{k * A * (T_{hot} - T_{cold})}{t}$$

$$where\ Q_{cond,flat\ plate} = quantity\ of\ heat\ transfered\ through\ flat\ surface\ \left[\frac{Btu}{hr}\right]$$

$$k = thermal\ conductivity\ of\ material\ \left[\frac{Btu}{hr * ft * °\mathrm{F}}\right]$$

$$T_{hot} - T_{cold} = temperature\ difference\ [°\mathrm{F}]$$

$$t = thickness\ of\ material\ [ft];\ A = area\ of\ heat\ transferl\ [ft^2]$$

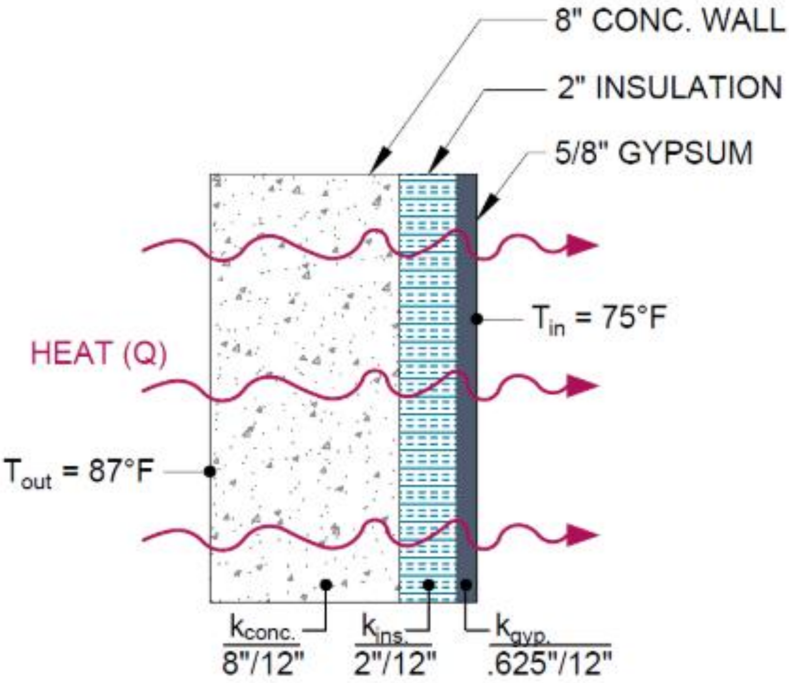

Figure 1: Conduction through a building wall

Design Analyses of Fluid-Thermal Systems using Excel

Excel's user interface provides a wealth of in-built functions and other analytical tools that enable us to perform a wide range of operations on the stored data. It also has a plethora of options for customising the look of the workspace and generating a variety of reports from the core data.

The modelling framework utilised in this book for thermofluid studies is developed around Excel due to its user-friendliness, extensive in-built functionality, iterative tools and graphical representations. Not all of Excel's capabilities and built-in functions are covered here, but the ones that are relevant to creating analytical models for thermofluid studies are. Rather than the customary method of the formulaic location reference, the chapter emphasises the use of cell-labelling. This chapter also shows how to solve nonlinear equations using Goal Seek and circular computations in Excel, and how to solve linear systems with Excel's matrix functions. Excel's trendline function, used for fitting curves to tabular data, is shown in the section on the program's graphical capabilities that follows.(El-Awad, n.d.).

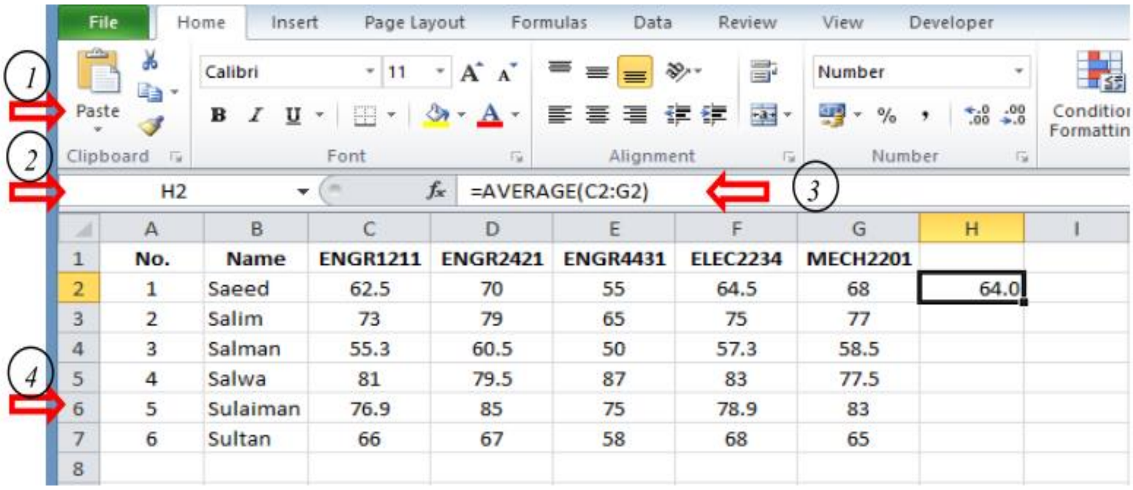

Figure 2: The main elements of Excel's user-interface

Design sensitivity analysis of steady fluid-thermal systems

Finding the maximum of an objective function while adhering to a number of constraints is the goal of numerical optimization methods. Nonlinear aeroacoustics, magnetoplasma dynamic applications, casting process simulations and automobile design optimization are all areas where zeroth-order approaches are impractical due to the high cost of assessing the objective function and constraints. Gradient-based design optimization approaches are often used for difficult issues. These methods rely on the gradients of the objective function and limitations on the dependent variable, with regard to the independent shape-design factors. It is possible to calculate these gradients, also known as sensitivity gradients, using finite differencing. But if it is not well managed, this process may lead to erroneous gradient estimates and a high computing cost.

The ideal approach for analytically evaluating these derivatives entails an extra layer of DSA simulation. The computing cost of these approaches is far lower than that of the main analysis, but they nevertheless provide precise design sensitivities. Two such techniques, the direct differentiation approach and the adjoint method, are introduced briefly here. For transitory systems, we will describe how to evaluate sensitivity using a generalised response function.

Within the bounds of a set of design requirements, the objective of an optimization problem is to achieve the minimum cost function. It is possible to express these restrictions and cost functions in terms of a generic response function, denoted by F.

$$F(\mathbf{d}) = G(\mathbf{U}(\mathbf{d}), \mathbf{d}).$$

Literature Review

(Mueller, 2006) includes the modelling, simulation, economic analysis and optimization of thermal systems to apply the concepts of thermodynamics, fluid mechanics and heat transport. Activities and objectives for student learning that are specific to the course are described. Many potential course materials and digital resources are also included.

(Javvadi et al., 2020) Such creativity is essential in the development of new In 1990, Akachi was the first to develop a pulsating heat pipe. An efficient method of transferring heat, the pulsating heat pipe is a relatively new invention. Despite extensive theoretical and experimental studies, researchers still lack a full understanding of its complicated operating mechanism, which involves a coupling effect between hydrodynamics and thermodynamics. The thermo-hydrodynamic properties of this apparatus are briefly discussed in this study. The working fluid volume, tube cross-section, and internal diameter will be discussed briefly. The thermal behaviour is also determined by the number of device rotations and the thermo-physical parameters of the working fluid.

(Tu & Zeng, 2020) While one-dimensional (1D) fluid system simulation techniques offer greater computational efficiency but inadequate calculation accuracy, traditional 3D computational fluid dynamics (CFD) methods can depict the system's internal flow and heat transfer performance in depth with complicated mesh models and very poor calculation efficiency. This research provides a strategy for implementing effective and precise simulation to address this issue. To determine the P-Q characteristic curve for each pipeline component, 1D fluid system analysis models are set up. These 1D models are also used to assess the thermal insulation effectiveness of the system pipes and the homogeneity of air flow into each section of the aeroplane cabin. Using the subsystem P-Q characteristics as boundary conditions, a 3D CFD model is developed to analyse the mix manifold's air distribution performance.

(El-Awad, n.d.) The basics of thermodynamics, fluid mechanics and heat-transfer may be effectively introduced to engineering students by the time-honored technique of employing hand-calculations with property tables and charts. However, for a number of reasons, computer-aided approaches are necessary for applying these concepts to design assessments of fluid-thermal systems. Nonlinear equations and the interdependence of fluid characteristics with the imposed system stresses, pressures, and temperatures are two major causes for the requirement for iterative solutions.

(El-Awad & Al-Saidi, 2022) Microsoft Excel, with its built-in Solver and VBA, is a great tool for doing fluid-thermal system design studies in the classroom. This study uses the double-pipe heat exchanger as an example of a popular form of such a system to demonstrate this capacity. In order to get the optimal standard-pipe size for the system, a user-defined function (UDF) is developed in Visual Basic for Applications while Solver does the optimisation study.

(Salari et al., 2021) The photovoltaic thermal system (PVTS) is one of the most well-known hybrid solar technologies because of its ability to generate both electricity and heat energy. The thermal energy is the heat that is taken in by the PV module and then sent on to the thermal collector and then the heat transfer fluid. Increases in acquired thermal and electrical powers, as well as improvements in PV thermal management, may be achieved with the use of an appropriate heat transfer fluid. The use of nanofluids, which have advantageous thermophysical characteristics, has emerged as a tried and true method for boosting PVTS performance during the last decade.

(Balagangadhar & Roy, 2001) The aerospace and automotive industries have shown a strong interest in studying how to optimise the design of fluid-thermal systems. Changing channels for internal and exterior flows while still meeting the governing equations is the focus of this area of study. Among the many optimization methods now in use, the analytical sensitivity analyses-based optimization is widely regarded as the most effective design instrument for difficult multi-dimensional practical issues. This document details how we added sensitivity analysis to the CFD code's list of possible analyses (DSA).

Conclusion

Recent developments in high-performance computing, fluid-thermal system simulation, and industrial process modelling have presented engineers with novel requirements, possibilities, and problems. It is clear that today's industry calls for engineers to build better products with higher performance, in less time, and at lower costs, as seen by the rising focus on the design and optimization of engineering systems.

In order to achieve this objective, it is necessary to create virtual environments for digital simulations of the actual world that take into account the limits of several disciplines. Numerous studies have shown how using CFD and DSA in engineering design may improve the process significantly. But its potential is hampered by the absence of a computational technique to aid in the design synthesis of connected large-scale multi-physics domain solutions. The new technique is likely to have an effect on CFD-based design environments, as it will provide a realistic method of optimising massive CFD problems, therefore advancing the state of the art in the field. Using a massage passing interface, the authors are creating a parallel CFD design optimization environment that can evaluate several functions simultaneously. As the price of computers continues to drop, parallel processing is poised to become the standard for CFD-enabled design software. In addition to facilitating more efficient use of resources, this will hasten the discovery of new information and push the limits of engineering further.

References

Balagangadhar, D., & Roy, S. (2001). Design sensitivity analysis and optimization of steady fluid-thermal systems. *Computer Methods in Applied Mechanics and Engineering*, *190*(42), 5465–5479. https://doi.org/10.1016/S0045-7825(01)00224-9

Boettner, D. D. (2017). Thermal Fluid Systems. In *The Chemical Engineer*.

El-Awad, M. M. (n.d.). Design Analyses of Fluid-Thermal Systems using Excel. *Academia.Edu*. https://www.academia.edu/download/65676602/Book2c.pdf

El-Awad, M. M., & Al-Saidi, M. S. (2022). Excel as an Educational Platform for Design Analyses of Fluid-Thermal Systems. *World Journal of Engineering and Technology*, *10*(02), 434–443. https://doi.org/10.4236/wjet.2022.102025

Javvadi, V. S., Panitapu, B., Gangam, R., & Kulkarni, H. (2020). A review on Mechanism of fluid flow and Transfer of Heat in Closed Loop Pulsating Heat Pipe. *E3S Web of Conferences*, *184*, 1–6. https://doi.org/10.1051/e3sconf/202018401056

Mueller, D. (2006). A new design of thermal-fluid systems elective: Description, observations, and experiences. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--579

Salari, A., Taheri, A., Farzanehnia, A., Passandideh-fard, M., & Sardarabadi, M. (2021). An updated review of the performance of nanofluid-based photovoltaic thermal systems from energy, exergy, economic, and environmental (4E) approaches. *Journal of Cleaner Production*, *282*, 124318. https://doi.org/10.1016/j.jclepro.2020.124318

Tu, Y., & Zeng, Y. (2020). One-dimensional and three-dimensional computational thermal fluid hybrid analysis-aided air distribution pipeline system design. *Engineering Applications of Computational Fluid Mechanics*, *14*(1), 436–446. https://doi.org/10.1080/19942060.2020.1717996