Osama Mohammed Elmardi

Solutions to Problems in Heat Transfer

Transient Conduction or Unsteady Conduction

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Dedication

In the name of Allah, the merciful, the compassionate

All praise is due to Allah and blessings and peace is upon his messenger and servant, **Mohammed**, and upon his family and companions and whoever follows his guidance until the day of resurrection.

To the memory of my mother **Khadra Dirar Taha**, my father **Mohammed Elmardi Suleiman**, and my dear aunt **Zaafaran Dirar Taha** who they taught me the greatest value of hard work and encouraged me in all my endeavors.

To my first wife **Nawal Abbas** and my beautiful three daughters **Roa, Rawan** and **Aya** whose love, patience and silence are my shelter whenever it gets hard.

To my second wife **Limya Abdullah** whose love and supplication to Allah were and will always be the momentum that boosts me through the thorny road of research.

To Professor **Mahmoud Yassin Osman** for reviewing and modifying the manuscript before printing process.

This book is dedicated mainly to undergraduate and postgraduate students, especially mechanical and production engineering students where most of the applications are of mechanical engineering nature.

To Mr. **Osama Mahmoud** of Daniya Center for publishing and printing services whose patience in editing and re – editing the manuscript of this book was the momentum that pushed me in completing successfully the present book.

To my friend Professor **Elhassan Mohammed Elhassan Ishag**, Faculty of Medicine, University of Gezira, Medani, Sudan.

To my friend **Mohammed Ahmed Sambo**, Faculty of Engineering and Technology, Nile Valley University, Atbara, Sudan.

To my homeland, Sudan, hoping to contribute in its development and superiority.

Finally, may Allah accept this humble work and I hope that it will be beneficial to its readers

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I am also indebted to published texts in thermodynamics and heat and mass transfer which have been contributed to the author's thinking. Members of Mechanical Engineering Department at Faculty of Engineering and Technology, Nile Valley University, Atbara – Sudan, and Sudan University of Science & Technology, Khartoum – Sudan have served to sharpen and refine the treatment of my topics. The author is extremely grateful to them for constructive criticisms and valuable proposals.

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Special appreciation is due to the British Council's Library for its quick response in ordering the requested bibliography, books, reviews and papers.

Preface

During my long experience in teaching several engineering subjects I noticed that many students find it difficult to learn from classical textbooks which are written as theoretical literature. They tend to read them as one might read a novel and fail to appreciate what is being set out in each section. The result is that the student ends his reading with a glorious feeling of knowing it all and with, in fact, no understanding of the subject whatsoever. To avoid this undesirable end a modern presentation has been adopted for this book. The subject has been presented in the form of solution of comprehensive examples in a step by step form. The example itself should contain three major parts, the first part is concerned with the definition of terms, the second part deals with a systematic derivation of equations to terminate the problem to its final stage, the third part is pertinent to the ability and skill in solving problems in a logical manner.

This book aims to give students of engineering a thorough grounding in the subject of heat transfer. The book is comprehensive in its coverage without sacrificing the necessary theoretical details.

The book is designed as a complete course test in heat transfer for degree courses in mechanical and production engineering and combined studies courses in which heat transfer and related topics are an important part of the curriculum. Students on technician diploma and certificate courses in engineering will also find the book suitable although the content is deeper than they might require.

The entire book has been thoroughly revised and a large number of solved examples and additional unsolved problems have been added. This book contains comprehensive treatment of the subject matter in simple and direct language.

The book comprises eight chapters. All chapters are saturated with much needed text supported and by simple and self-explanatory examples.

Chapter one includes general introduction to transient conduction or unsteady conduction, definition of its fundamental terms, derivation of equations and a wide spectrum of solved examples.

In chapter two the time constant and the response of temperature measuring devices were introduced and discussed thoroughly. This chapter was supported by different solved examples.

Chapter three discusses the importance of transient heat conduction in solids with finite conduction and convective resistances. At the end of this chapter a wide range of solved examples were added. These examples were solved using Heisler charts.

In chapter four transient heat conduction in semi – infinite solids were introduced and explained through the solution of different examples using Gaussian error function in the form of tables and graphs.

Chapter five deals with the periodic variation of surface temperature where the periodic type of heat flow was explained in a neat and regular manner. At the end of this chapter a wide range of solved examples was introduced.

Chapter six concerns with temperature distribution in transient conduction. In using such distribution, the one dimensional transient heat conduction problems could be solved easily as explained in examples.

In chapter seven additional examples in lumped capacitance system or negligible internal resistance theory were solved in a systematic manner, so as to enable the students to understand and digest the subject properly.

Chapter eight which is the last chapter of this book contains unsolved theoretical questions and further problems in lumped capacitance system. How these problems are solved will depend on the full understanding of the previous chapters and the facilities available (e.g. computer, calculator, etc.). In engineering, success depends on the reliability of the results achieved, not on the method of achieving them.

I would like to express my appreciation of the assistance which I have received from my colleagues in the teaching profession. I am particularly indebted to Professor Mahmoud Yassin Osman for his advice on the preparation of this textbook.

When author, printer and publisher have all done their best, some errors may still remain. For these I apologies and I will be glad to receive any correction or constructive criticism.

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Chapter One

Introduction

From the study of thermodynamics, you have learned that energy can be transferred by interactions of a system with its surroundings. These interactions are called work and heat. However, thermodynamics deals with the end states of the process during which an interaction occurs and provides no information concerning the nature of the interaction or the time rate at which it occurs. The objective of this textbook is to extend thermodynamic analysis through the study of transient conduction heat transfer and through the development of relations to calculate different variables of lumped capacitance theory.

In our treatment of conduction in previous studies we have gradually considered more complicated conditions. We began with the simple case of one dimensional, steady state conduction with no internal generation, and we subsequently considered more realistic situations involving multidimensional and generation effects. However, we have not yet considered situations for which conditions change with time.

We now recognize that many heat transfer problems are time dependent. Such unsteady, or transient problems typically arise when the boundary conditions of a system are changed. For example, if the surface temperature of a system is altered, the temperature at each point in the system will also begin to change. The changes will continue to occur until a steady state temperature distribution is reached. Consider a hot metal billet that is removed from a furnace and exposed to a cool air stream. Energy is transferred by convection and radiation from its surface to the surroundings. Energy transfer by conduction also occurs from the interior of the metal to the surface, and the temperature at each point in the billet decreases until a steady state condition is reached. The final properties of the metal will depend significantly on the time – temperature history that results from heat transfer. Controlling the heat transfer is one key to fabricating new materials with enhanced properties.