EVERYDAY HEAT TRANSFER PROBLEMS

Sensitivities To Governing Variables

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INTRODUCTION

Everyday engineering problems in heat transfer can be very complicated and may require solutions using finite element or finite difference techniques in transient mode and in multiple dimensions. These engineering problems might cover conduction, convection and radiation energy transfer mechanisms. The thermophysical properties that govern a particular heat transfer problem can be challenging to discover, to say the least.

Some of the standard thermophysical properties needed to solve a heat transfer problem are density, specific heat at constant pressure, thermal conductivity, viscosity, volumetric thermal expansion coefficient, heat of vaporization, surface tension, emissivity, absorptivity, and transmissivity. These thermophysical properties can be strong functions of temperature, pressure, surface roughness, wavelength and other properties. in the region of interest.

Once a heat transfer problem's assumptions are made, equations set up and boundary conditions determined, one should investigate the sensitivities of desired outputs to all the governing independent variables. Since these sensitivities are mostly non-linear, one should analyze them in the region of interest. The results of such sensitivity analyses will provide important information as to which independent variables should be researched thoroughly, determined accurately, and focused on. The sensitivity analysis will also provide insight into uncertainty analysis for the dependent variable, (Reference S. J. Kline and F. A. McClintock [9]). If the dependent variable y is defined as a function of independent variables $x_1, x_2, x_3, \ldots x_n$ as follows:

$$y = f(x_1, x_2, x_3, \ldots x_n)$$

then the uncertainty U for the dependent variable can be written as:

$$U = [(\partial y/\partial x_1\, u_1)^2 + (\partial y/\partial x_2\, u_2)^2 + (\partial y/\partial x_3\, u_3)^2 + \ldots + (\partial y/\partial x_n\, u_n)^2]^{0.5}$$

where $\partial y/\partial x_1, \partial y/\partial x_2, \partial y/\partial x_3, \ldots, \partial y/\partial x_n$ are the sensitivities of the dependent variable to each independent variable and $u_1, u_2, u_3, \ldots, u_n$ are the uncertainties in each independent variable for a desired confidence limit.

In this book, I will provide sensitivity analyses to well-known everyday heat transfer problems, determining $\partial y/\partial x_1, \partial y/\partial x_2, \partial y/\partial x_3, \ldots, \partial y/\partial x_n$ for each case. The analysis for each problem will narrow the field of independent variables that should be focused on during the design process. Since most heat transfer problems are non-linear, the results presented here would be applicable only in the region of values assumed for independent variables. For the uncertainties of independent variables—for example, experimental measurements of thermophysical properties—the reader can find the appropriate uncertainty value for a desired confidence limit within existing literature on the topic.

Each chapter will analyze a different one-dimensional heat transfer problem. These problems will vary from determining the maximum allowable current in an open-air electrical wire to cooking a turkey in a convection oven. The equations and boundary conditions for each problem will be provided, but the focus will be on the sensitivity of the governing dependant variable on the changing independent variables. For the derivation of the fundamental heat transfer equations and for insight into the appropriate boundary conditions, the reader should refer to the heat transfer fundamentals books listed in the references.

Problems in Chapters 1 through 6 deal with steady-state and one-dimensional heat transfer mechanisms in rectangular coordinates. Chapters 7 through 10 deal with steady-state and one-dimensional heat transfer mechanisms in cylindrical coordinates. Unsteady-state problems in one-dimensional rectangular coordinates will be tackled in Chapters 11 through 14, cylindrical coordinates in Chapter 15, and spherical coordinates in Chapters 16 through 18.

The following six chapters are allocated to special heat transfer problems. Chapters 19 and 20 deal with momentum, mass and heat transfer analogies used to solve the problems. Chapter 21 analyzes a counterflow heat exchanger using the log mean temperature difference method. Chapters 22 and 23 solve heat transfer problems of ice formation and solidification with moving boundary conditions. Chapter 24 analyzes the problem of frictional heating of materials in contact with moving sources of heat.

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