

# An Introduction to Fluid Mechanics and Transport Phenomena

# FLUID MECHANICS AND ITS APPLICATIONS

## Volume 86

---

*Series Editor:* R. MOREAU  
MADYLAM  
*Ecole Nationale Supérieure d'Hydraulique de Grenoble*  
*Boîte Postale 95*  
*38402 Saint Martin d'Hères Cedex, France*

### *Aims and Scope of the Series*

The purpose of this series is to focus on subjects in which fluid mechanics plays a fundamental role.

As well as the more traditional applications of aeronautics, hydraulics, heat and mass transfer etc., books will be published dealing with topics which are currently in a state of rapid development, such as turbulence, suspensions and multiphase fluids, super and hypersonic flows and numerical modeling techniques.

It is a widely held view that it is the interdisciplinary subjects that will receive intense scientific attention, bringing them to the forefront of technological advancement. Fluids have the ability to transport matter and its properties as well as to transmit force, therefore fluid mechanics is a subject that is particularly open to cross fertilization with other sciences and disciplines of engineering. The subject of fluid mechanics will be highly relevant in domains such as chemical, metallurgical, biological and ecological engineering. This series is particularly open to such new multidisciplinary domains.

The median level of presentation is the first year graduate student. Some texts are monographs defining the current state of a field; others are accessible to final year undergraduates; but essentially the emphasis is on readability and clarity.

G. Hauke

# An Introduction to Fluid Mechanics and Transport Phenomena

 Springer

G. Hauke  
Área de Mecánica de Fluidos  
Centro Politécnico Superior  
Universidad de Zaragoza  
C/Maria de Luna 3  
50018 Zaragoza  
Spain

ISBN-13: 978-1-4020-8536-9

e-ISBN-13: 978-1-4020-8537-6

Library of Congress Control Number: 2008932575

© 2008 Springer Science+Business Media, B.V.

No part of this work may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, microfilming, recording or otherwise, without written permission from the Publisher, with the exception of any material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work.

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

To my wife, my parents and my children

---

## Preface

This text is a brief introduction to fundamental concepts of transport phenomena within a fluid, namely momentum, heat and mass transfer. The emphasis of the text is placed upon a basic, systematic approach from the fluid mechanics point of view, in conjunction with a unified treatment of transport phenomena.

In order to make the book useful for students, there are numerous examples. Each chapter presents a collection of proposed problems, whose solutions can be found in the Problem Solutions Appendix. Also the Self Evaluation chapter gathers exercises from exams, so readers and students can test their understanding of the subject.

Most of the content can be taught in a course of 45 hours and has been employed in the course *Transport Phenomena* in Chemical Engineering at the Centro Politécnico Superior of the University of Zaragoza. The text is aimed at beginners in the subject of transport phenomena and fluid mechanics, emphasizing the foundations of the subject.

The text is divided into four parts: Fundamentals, Conservation Principles, Dimensional Analysis; Theory and Applications, and Transport Phenomena at Interfaces.

In the first part, Fundamentals, basic notions on the subject are introduced: definition of a fluid, preliminary hypothesis for its mathematical treatment, elementary kinematics, fluid forces, especially the concept of pressure, and fluid statics.

In the Conservation Principles part, the conservation equations that govern transport phenomena are presented and explained, both in integral and differential form. Emphasis is placed on practical applications of integral equations. Also, constitutive equations for transport by diffusion are contained in this part.

In the third part, Dimensional Analysis; Theory and Applications, the important tool of dimensional analysis and the laws of similitude are explained. Also the dimensionless numbers that govern transport phenomena are derived.

The last part, Transport Phenomena at Interfaces, explains how most transport processes originate at interfaces. Some aspects of the concept of boundary layer are presented and the usage of transport coefficients to solve practical problems is introduced. Finally the analogies between transport coefficients are explained.

There are a great number of people whose help in writing this book I would like to acknowledge. First my parents, for providing an intellectually challenging environment and awakening my early interest in engineering and fluid mechanics. Professor C. Dopazo, for his inspiring passion for fluid mechanics. My family, wife and children, for their love and support. C. Pérez-Caseiras for providing ideas to strengthen the text. Many colleagues and friends, who have accompanied me during these years, especially professors T.J.R. Hughes and E. Oñate, and friends Jorge, Antonio, Connie and Ed. Finally, I would like to acknowledge the encouragement of Nathalie Jacobs. Without them, this project would not have been possible.

Zaragoza,

*Guillermo Hauke*  
May 2008

---

# Contents

Nomenclature ..... XV

Introduction ..... 1

---

## Part I Fundamentals

---

<b>1</b>	<b>Basic Concepts in Fluid Mechanics</b> .....	5
1.1	The Concept of a Fluid .....	5
1.1.1	The Macroscopic Point of View .....	5
1.1.2	The Microscopic Point of View .....	8
1.2	The Fluid as a Continuum .....	8
1.3	Local Thermodynamic Equilibrium .....	10
	Problems .....	10
<b>2</b>	<b>Elementary Fluid Kinematics</b> .....	11
2.1	Description of a Fluid Field .....	11
2.1.1	Lagrangian Description .....	11
2.1.2	Eulerian Description .....	13
2.1.3	Arbitrary Lagrangian-Eulerian Description (ALE) .....	15
2.2	The Substantial or Material Derivative .....	15
2.3	Mechanisms of Transport Phenomena .....	19
2.4	Streamlines, Trajectories and Streaklines .....	20
2.4.1	Calculation of Streamlines .....	22
2.4.2	Calculation of Trajectories .....	24
2.4.3	Calculation of Streaklines .....	25
2.5	The Concept of Flux .....	26
	Problems .....	30



<b>3</b>	<b>Fluid Forces</b> .....	33
3.1	Introduction .....	33
3.2	Body Forces .....	34
3.3	Surface Forces .....	35
	3.3.1 The Stress Tensor .....	35
	3.3.2 The Concept of Pressure .....	40
3.4	Surface Tension .....	43
3.5	Summary .....	45
	Problems .....	45
<b>4</b>	<b>Fluid Statics</b> .....	47
4.1	The Fundamental Equation of Fluid Statics .....	47
4.2	Applications .....	48
	4.2.1 Hydrostatics .....	49
	4.2.2 Manometry .....	51
	4.2.3 Fluid Statics of an Isothermal Perfect Gas .....	51
	4.2.4 Forces over Submerged Surfaces .....	52
	Problems .....	62

---

## Part II Conservation Principles

---

<b>5</b>	<b>Transport Theorems</b> .....	69
5.1	Fluid Volume and Control Volume .....	69
5.2	Transport Theorems .....	70
	5.2.1 First Transport Theorem .....	72
	5.2.2 Second Transport Theorem .....	73
	5.2.3 Third Transport Theorem .....	73
<b>6</b>	<b>Integral Conservation Principles</b> .....	75
6.1	Mass Conservation .....	75
6.2	Momentum Equation .....	78
	6.2.1 Decomposition of the Stress Tensor .....	79
6.3	Angular Momentum Equation .....	82
6.4	Total Energy Conservation .....	85
	6.4.1 Body Force Stemming from a Potential .....	87
6.5	Other Energy Equations .....	89
	6.5.1 Mechanical Energy Equation .....	89
	6.5.2 Internal Energy Equation .....	95
	6.5.3 Energy Transfer Between Mechanical and Internal Energy .....	96
6.6	Conservation of Chemical Species Equation .....	96
	6.6.1 Introductory Definitions .....	96
	6.6.2 Derivation of the Conservation Equations .....	98
	6.6.3 Chemical Species Equations for Molar Concentrations ..	102

6.6.4 Equations with Respect to the Molar Average Velocity . 103

6.7 Equation of Volume Conservation for Liquids . . . . . 103

6.8 Outline . . . . . 105

6.9 Initial and Boundary Conditions . . . . . 107

    6.9.1 Initial Conditions . . . . . 107

    6.9.2 Boundary Conditions . . . . . 107

    Problems . . . . . 111

**7 Constitutive Equations . . . . . 119**

    7.1 Introduction . . . . . 119

    7.2 Momentum Transport by Diffusion . . . . . 120

    7.3 Heat Transport by Diffusion . . . . . 129

    7.4 Mass Transport by Binary Diffusion . . . . . 132

    7.5 Transport Phenomena by Diffusion . . . . . 136

    7.6 Molecular Interpretation of Diffusion Transport . . . . . 137

    Problems . . . . . 139

**8 Differential Conservation Principles . . . . . 141**

    8.1 Derivation of the Differential Conservation Equations . . . . . 141

    8.2 Continuity Equation . . . . . 142

        8.2.1 Particular case: incompressible fluid . . . . . 143

    8.3 Momentum Equation . . . . . 143

        8.3.1 Particular case: Newtonian liquid with constant viscosity 143

    8.4 Energy Equations . . . . . 144

        8.4.1 Total Energy Equation . . . . . 144

        8.4.2 Mechanical Energy Equation . . . . . 145

        8.4.3 Internal Energy Equation . . . . . 146

        8.4.4 Enthalpy Equation . . . . . 148

    8.5 Entropy Equation . . . . . 149

    8.6 Conservation of Chemical Species . . . . . 149

        8.6.1 Particular case: constant density and constant  
                molecular diffusivity . . . . . 150

    8.7 Summary . . . . . 151

    Problems . . . . . 152

---

**Part III Dimensional Analysis. Theory and Applications**

---

**9 Dimensional Analysis . . . . . 157**

    9.1 Introduction . . . . . 157

    9.2 Dimensional Homogeneity Principle . . . . . 158

    9.3 Buckingham's *II* Theorem . . . . . 160

        9.3.1 Application Process of the *II* Theorem . . . . . 160

    9.4 Applications of Dimensional Analysis . . . . . 163

        9.4.1 Simplification of Physical Equations . . . . . 163

9.4.2	Experimental Economy .....	164
9.4.3	Experimentation with Scaled Models. Similarity .....	165
	Problems .....	169
<b>10</b>	<b>Dimensionless Equations and Numbers .....</b>	<b>173</b>
10.1	Nondimensionalization Process .....	173
10.1.1	Continuity Equation .....	174
10.1.2	Momentum Equation .....	175
10.1.3	Temperature Equation .....	176
10.1.4	Conservation of Chemical Species Equation .....	177
10.2	Other Important Dimensionless Numbers .....	178
10.3	Physical Interpretation of the Dimensionless Numbers .....	178
	Problems .....	181

---

**Part IV Transport Phenomena at Interfaces**

---

<b>11</b>	<b>Introduction to the Boundary Layer .....</b>	<b>187</b>
11.1	Concept of Boundary Layer .....	187
11.2	Laminar versus Turbulent Boundary Layer .....	188
11.3	The Prandtl Theory .....	188
11.3.1	Estimation of the Boundary Layer Thicknesses for Laminar Flow .....	189
11.3.2	Relative Boundary Layer Thicknesses .....	192
11.4	Incompressible Boundary Layer Equations .....	193
11.4.1	Continuity Equation .....	193
11.4.2	$x$ -Momentum Equation .....	194
11.4.3	$y$ -Momentum Equation .....	194
11.4.4	Temperature and Concentration Equations .....	195
11.4.5	Boundary Layer Equations: Summary .....	196
11.5	Measures of the Boundary Layer Thickness .....	197
	Problems .....	197
<b>12</b>	<b>Momentum, Heat and Mass Transport .....</b>	<b>199</b>
12.1	The Concept of Transport Coefficient .....	199
12.2	Momentum Transport .....	201
12.2.1	Basic Momentum Transport Coefficients .....	207
12.3	Heat Transport .....	207
12.3.1	Heat Transfer by Forced Convection .....	209
12.3.2	Heat Transfer by Natural Convection .....	212
12.3.3	Basic Heat Transport Coefficients .....	215
12.4	Mass Transport .....	216
12.4.1	Mass Transport by Forced Convection .....	218
12.4.2	Mass Transport by Natural Convection .....	219
12.4.3	Mass Transfer across Fluid/Fluid Interfaces .....	220

12.4.4 Basic Mass Transport Coefficients . . . . . 223  
 12.5 Analogies . . . . . 223  
     12.5.1 Reynolds Analogy . . . . . 224  
     12.5.2 Chilton-Colburn Analogy . . . . . 226  
 Problems . . . . . 228

**Part V Self Evaluation**

**13 Self Evaluation Exercises** . . . . . 233  
 Problems . . . . . 233

**Part VI Appendices**

**A Collection of Formulae** . . . . . 243  
 A.1 Integral Equations for a Control Volume . . . . . 243  
     A.1.1 Mass Conservation Equation . . . . . 243  
     A.1.2 Chemical Species Conservation Equation . . . . . 243  
     A.1.3 Momentum Equation . . . . . 243  
     A.1.4 Angular Momentum Equation . . . . . 243  
     A.1.5 Mechanical Energy Equation . . . . . 244  
     A.1.6 Total Energy Equation . . . . . 244  
     A.1.7 Internal Energy Equation . . . . . 244  
 A.2 Relevant Dimensionless Numbers . . . . . 245  
 A.3 Transport Coefficient Analogies . . . . . 246  
     A.3.1 Analogy of Reynolds . . . . . 246  
     A.3.2 Analogy of Chilton-Colburn . . . . . 246

**B Classification of Fluid Flow** . . . . . 247  
 B.1 Stationary (steady) / non-stationary (transient, periodic) . . . . 247  
 B.2 Compressible / incompressible . . . . . 248  
 B.3 One-dimensional / Two-dimensional / Three-dimensional . . . . 248  
 B.4 Viscous / Ideal . . . . . 249  
 B.5 Isothermal / Adiabatic . . . . . 249  
 B.6 Rotational / Irrotational . . . . . 249  
 B.7 Laminar / Turbulent . . . . . 249

**C Substance Properties** . . . . . 251  
 C.1 Properties of water . . . . . 251  
 C.2 Properties of dry air at atmospheric pressure . . . . . 251

<b>D</b>	<b>A Brief Introduction to Vectors, Tensors and Differential Operators</b> .....	253
	D.1 Indicial Notation .....	253
	D.2 Elementary Vector Algebra .....	256
	D.3 Basic Differential Operators .....	257
	Problems .....	261
<b>E</b>	<b>Useful Tools of Calculus</b> .....	263
	E.1 Taylor Expansion Series .....	263
	E.2 Gauss or Divergence Theorem .....	263
<b>F</b>	<b>Coordinate Systems</b> .....	265
	F.1 Cartesian Coordinates .....	265
	F.2 Cylindrical Coordinates .....	265
	F.3 Spherical Coordinates .....	266
<b>G</b>	<b>Reference Systems</b> .....	267
	G.1 Definitions .....	267
	G.2 Velocity Triangle .....	267
	G.3 Conservation Equations for Non-Inertial Systems of Reference .....	269
	Problems .....	269
<b>H</b>	<b>Equations of State</b> .....	271
	H.1 Introduction .....	271
	H.2 Simple Compressible Substance .....	272
	H.3 Mixtures of Independent Substances .....	274
<b>I</b>	<b>Multicomponent Reacting Systems</b> .....	277
	I.1 Mass Conservation .....	277
	I.2 Momentum Equation .....	277
	I.3 Total Energy Conservation .....	278
	I.3.1 Mechanical Energy Equation .....	279
	I.3.2 Internal Energy Equation .....	279
	I.4 Conservation of Chemical Species .....	280
	I.5 Generalized Fourier's and Fick's laws .....	280
	I.5.1 Heat Transport .....	280
	I.5.2 Mass Transport .....	281
	I.6 Chemical Production .....	282
	<b>Problem Solutions</b> .....	283
	<b>References</b> .....	291
	<b>Index</b> .....	293

---

## Nomenclature

Roman Symbols		Units	Dimensions
$A$	area	$\text{m}^2$	$\text{L}^2$
$c$	mixture molar concentration	$\text{mol}/\text{m}^3$	$\text{NL}^{-3}$
$c_A$	molar concentration of species $A$	$\text{mol}/\text{m}^3$	$\text{NL}^{-3}$
$c_v$	specific heat at constant volume	$\text{J}/(\text{kg K})$	$\text{L}^2\text{T}^{-2}\Theta^{-1}$
$c_p$	specific heat at constant pressure	$\text{J}/(\text{kg K})$	$\text{L}^2\text{T}^{-2}\Theta^{-1}$
$C_D$	drag coefficient	—	—
$C_f$	friction coefficient	—	—
$D$	length, diameter	$\text{m}$	$\text{L}$
$D_{AB}, D_A$	molecular mass diffusivity	$\text{m}^2/\text{s}$	$\text{L}^2\text{T}^{-1}$
$D_v$	power dissipated by viscous dissipation	$\text{W}$	$\text{ML}^2\text{T}^{-3}$
$\text{Da}_I$	Damköhler number	—	—
$e$	specific internal energy	$\text{J}/\text{kg}$	$\text{L}^2\text{T}^{-2}$
$e_{\text{tot}}$	specific total energy	$\text{J}/\text{kg}$	$\text{L}^2\text{T}^{-2}$
$\text{Ec}$	Eckert number	—	—
$\text{Eu}$	Euler number	—	—
$f_m$	body force per unit mass	$\text{N}/\text{kg}$	$\text{LT}^{-2}$
$f_s$	stress at surface	$\text{Pa}$	$\text{ML}^{-1}\text{T}^{-2}$
$f_v$	body force per unit volume	$\text{N}/\text{m}^3$	$\text{ML}^{-2}\text{T}^{-2}$

$F, \mathbf{F}$	force	N	$\text{MLT}^{-2}$
$\mathbf{F}_s$	surface force	N	$\text{MLT}^{-2}$
$\mathbf{F}_v$	body force	N	$\text{MLT}^{-2}$
Fr	Froude number	—	—
$\mathbf{g}$	gravity acceleration	$\text{m/s}^2$	$\text{LT}^{-2}$
Gr	Grashof number	—	—
$h$	length, depth	m	L
	heat transport coefficient	$\text{W}/(\text{m}^2 \text{K})$	$\text{MT}^{-3}\Theta$
$h_m$	mass transport coefficient	m/s	$\text{LT}^{-1}$
$H$	length	m	L
$\mathbf{H}$	angular momentum	N m	$\text{ML}^2\text{T}^{-2}$
$I$	surface moment of inertia	$\text{m}^4$	$\text{L}^4$
	moment of inertia	$\text{kg m}^2$	$\text{ML}^2$
$\mathbf{I}$	identity tensor / matrix	—	—
$\dot{j}_A$	mass flux of species $A$	$\text{kg}/(\text{m}^2 \text{s})$	$\text{ML}^{-2}\text{T}^{-2}$
$\dot{j}'_A$	molar flux of species $A$	$\text{mol}/(\text{m}^2 \text{s})$	$\text{NL}^{-2}\text{T}^{-1}$
$\dot{j}_A^m$	mass flux of species $A$ w.r.t the molar mean velocity	$\text{kg}/(\text{m}^2 \text{s})$	$\text{ML}^{-2}\text{T}$
$\dot{j}_A^{m'}$	molar flux of species $A$ w.r.t the molar mean velocity	$\text{mol}/(\text{m}^2 \text{s})$	$\text{NL}^{-2}\text{T}^{-1}$
$J_A$	mass flux of species $A$	kg/s	$\text{MT}^{-1}$
Kn	Knudsen number	—	—
$L$	length, depth	m	L
Le	Lewis number	—	—
$m$	mass	kg	M
$\dot{m}$	mass flux	kg/s	$\text{M/T}$
$M, \mathbf{M}$	moment	N m	$\text{ML}^2/\text{T}^2$
$M$	molar mass of mixture	kg/kmol	$\text{MN}^{-1}$
$M_A$	molar mass of species $A$	kg/kmol	$\text{MN}^{-1}$
Ma	Mach number	—	—

$n_{\text{esp}}$	number of chemical species in the mixture	—	—
$\mathbf{n}$	normal vector	—	—
Nu	Nusselt number	—	—
$p$	pressure	Pa	$\text{ML}^{-1}\text{T}^{-2}$
$\mathbf{P}$	momentum	N	$\text{MLT}^{-1}$
Pe	Péclet number	—	—
$\text{Pe}_{\text{II}}$	Péclet II number	—	—
Pr	Prandtl number	—	—
$\mathbf{q}$	heat flux vector	$\text{W}/\text{m}^2$	$\text{MT}^{-3}$
$Q$	volumetric flux	$\text{m}^3/\text{s}$	$\text{L}^3\text{T}^{-1}$
$\dot{Q}$	heat per unit time	W	$\text{ML}^2\text{T}^{-3}$
$r, R$	radius	m	L
$\mathbf{r}$	position vector	m	L
Ra	Rayleigh number	—	—
Re	Reynolds number	—	—
$S$	surface	$\text{m}^2$	$\text{L}^2$
S	Strouhal number	—	—
$S_c(t)$	control volume surface	$\text{m}^2$	$\text{L}^2$
$S_f(t)$	fluid volume surface	$\text{m}^2$	$\text{L}^2$
$\mathbf{S}$	deformation rate	$\text{s}^{-1}$	$\text{T}^{-1}$
Sc	Schmidt number	—	—
Sh	Sherwood number	—	—
St	Stanton number	—	—
$t$	time	s	T
$T$	temperature	$^{\circ}\text{C}$ or K	$\Theta$
$\mathbf{u}$	velocity field	m/s	$\text{LT}^{-1}$
$U$	potential energy	J/kg	$\text{L}^2/\text{T}^2$
$\mathbf{v}$	mass average velocity	m/s	$\text{LT}^{-1}$
$\mathbf{v}_A$	velocity of species $A$	m/s	$\text{LT}^{-1}$



XVIII Nomenclature

$v^c$	control volume velocity	m/s	$\text{LT}^{-1}$
$v^m$	molar average velocity	m/s	$\text{LT}^{-1}$
$V$	volume	$\text{m}^3$	$\text{L}^3$
	velocity	m/s	$\text{LT}^{-1}$
$V_c(t)$	control volume	$\text{m}^3$	$\text{L}^3$
$V_f(t)$	fluid volume	$\text{m}^3$	$\text{L}^3$
$\mathbf{x}$	Cartesian coordinates	m	L
	position vector	m	L
$X_A$	molar fraction of species $A$	—	—
$Y_A$	mass fraction of species $A$	—	—
$\dot{W}$	power	W	$\text{ML}^2\text{T}^{-3}$
We	Weber number	—	—

---

**Greek Symbols**

---

$\alpha$	thermal diffusivity	$\text{m}^2/\text{s}$	$\text{L}^2\text{T}^{-1}$
$\delta$	viscous boundary layer thickness	m	L
$\delta_T$	thermal boundary layer thickness	m	L
$\delta_c$	concentration boundary layer thickness	m	L
$\eta_a$	apparent viscosity	Pa s or kg/(m s)	$\text{ML}^{-1}\text{T}^{-1}$
$\theta$	angle	rad	—
$\kappa$	thermal conductivity	W/(m K)	$\text{MLT}^{-3}\Theta^{-1}$
$\lambda$	second viscosity coefficient	Pa s	$\text{ML}^{-1}\text{T}^{-1}$
	friction factor for pipes	—	—
	mean-free path	m	L
$\mu$	dynamic viscosity	Pa s or kg/(m s)	$\text{ML}^{-1}\text{T}^{-1}$
$\nu$	kinematic viscosity	$\text{m}^2/\text{s}$	$\text{L}^2\text{T}^{-1}$
$\rho$	fluid density	$\text{kg}/\text{m}^3$	$\text{ML}^{-3}$
$\rho_A$	mass concentration of species $A$	$\text{kg}/\text{m}^3$	$\text{ML}^{-3}$

$\sigma$	surface tension	N/m	$MT^{-2}$
	normal stress	Pa	$ML^{-1}T^{-2}$
$\boldsymbol{\tau}, \tau$	stress tensor, stress component	Pa	$ML^{-1}T^{-2}$
$\tau'$	shear stress	Pa	$ML^{-1}T^{-2}$
$\boldsymbol{\tau}'$	viscous stress tensor	Pa	$ML^{-1}T^{-2}$
$\phi_v$	viscous dissipation function	$W/m^3$	$ML^{-1}T^{-3}$
$\omega$	angular velocity	rad/s	$T^{-1}$
$\dot{\omega}_A$	chemical generation of species $A$	$kg/(m^3 s)$	$ML^{-3}T^{-1}$
$\dot{\omega}'_A$	molar chemical generation of species $A$	$mol/(m^3 s)$	$NL^{-3}T^{-1}$

---

---

# Introduction

Most chemical processes, and the chemical and physical operations involved, imply a transport of momentum, heat and mass.

For example, let us consider a chemical reactor. The chemical compounds need to be transported into the reactor. Once in the reactor, the chemical concentrations will evolve according to the mass transport laws. In order to speed up mixing, agitation may be used to add velocity, vorticity, and turbulence to the fluid. Therefore, we are acting upon the velocity of the fluid, transferring momentum. Finally, by adding heat to the reactor, the temperature gradients generate energy transport from the heat source to the fluid particles, a process that is called heat transfer. As a consequence, in most chemical processes we can encounter mass, momentum and heat transport phenomena.

In general, the exchange of momentum, mass and energy are interrelated and appear together. For instance, mass and heat transfer are faster in the presence of agitation.

Furthermore, the laws and models that describe the transport of properties within a fluid are very similar. This is demonstrated by the existence of analogies between the three kinds of transport phenomena. Therefore, a unified study of all transport processes facilitates the learning process and deepens a relational understanding.

Finally, the chemical operations between solids, liquids and gases typically take place inside fluids (mainly liquids).

In brief, given that fluids are present in most chemical processes, it is vital for the chemical engineer to thoroughly understand fluid mechanics and transport phenomena.