Transport Phenomena (UG) - Web course

COURSE OUTLINE

Transport Phenomena is the subject which deals with the movement of different physical quantities such as momentum, energy and mass in any chemical or mechanical process and combines the basic principles (conservation laws) and laws of various types of transport. Transport Phenomena can be classified into three types:

- **Momentum transport** deals with the transport of momentum in fluids and is also known as fluid dynamics. Solution of equation of motion provides information about the velocity distribution in the system.
- **Energy transport** deals with the transport of different forms of energy in a system and is also commonly known as heat transfer. Solution of basic equation of thermal energy provides the information about the temperature distribution in the system.
- **Mass transport** deals with the transport of various chemical species in a system. The solution of convective diffusion equation provides the information about the concentration distribution in the system.

Although all these fields are developed separately throughout the history of science and technology, it is important to study these transport phenomena together due to following reasons.

- These transport phenomena occur frequently and most of the time simultaneously in industrial problems.
- All type of transport phenomena can be explained by similar transport and conversion laws. Physical properties which are used to describe transport laws like kinematic viscosity, thermal diffusivity or mass diffusivity play similar role.
- The mathematical requirements for solving problems related to transport phenomena are more or less similar.

Transport phenomena occurring in any system can be studied at different levels. We can study transport at macroscopic level where the transport equations are developed by balancing of physical quantities as input and output streams in a control volume which may provide a fair idea about overall performance of systems. But it cannot provide information at local level. Whereas, the transport phenomena at microscopic level, where the transport equations are developed by balancing physical quantities for a small control volume and then allowing the control volume to approach zero results in transport equations which are valid at each point in the fluid. Theses equations may be solved by using appropriate assumptions and boundary conditions. Microscopic level of study of system gives the chance to study the systems in much more details and provides more accurate description of the transport phenomena occurring in the system. If required, these equations may be integrated for the whole system for better understanding of the overall performance of the system.

Third level of study of transport phenomena is at molecular level. Here, the transport phenomena are described in terms of molecular structure and intermolecular forces. Study of transport phenomena at this level may be important for theoretical physicist/ chemist because it link the basic characteristic of material or molecules of material to transport properties like viscosity or thermal conductivity but it may not have as much importance for a technologist who is working on actual engineering problems where it may not be possible to integrate the simulations from molecular level to full system. This course basically deals with the second microscopic description of transport phenomena. In chemical engineering the first, macroscopic, approach is normally take up at first in a course commonly called fluid mechanics followed by a course in heat transfer and later one or two courses in mass transfer. Subsequently in many colleges the course on transport phenomena is taught at third year or fourth year and that too may be as an elective course. Here at IIT Delhi, we have been teaching the course transport phenomena to our first year students with great success. This is a core course for Chemical

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Engineering, Biochemical Engineering and Biotechnology as well as for students of Engineering Physics. This course is the followed by courses in fluid mechanics, heat transfer and mass transfer courses. The feedback from our students has clearly shown that this approach may be better. Though, the way this course is presented here, it may be taught at any time in an undergraduate chemical engineering program. The course may also be helpful to students of other disciplines.

This web course is inspired by the book 'Transport Phenomena' by Bird, Stewart and Lightfoot and should not be in any case considered as replacement for this wonderful book. Most of the problems and reading material given as tutorial problems(TP) at the end of each module are prescribed from this book only. It is strongly advised that the lectures in this course should be read in combination with this book. The actual lectures notes were first prepared by two of my Ph.D. students Manish Jain and Dinesh Attarde as they sat in my transport phenomena classes for two years in 2011-12 and 2012-13 when this course was offered to IIT Delhi students as CHL 110. After several rounds of corrections, additions, and editing, the web course is now ready. I would like to acknowledge all the hard work done by Manish and Dinesh. Also, I would like to thank AnantGovidRajan, one of my B.Tech. student, who provided some help in editing the lecture notes. I would also like to thank NPTEL for providing me the opportunity to prepare this web course.

COURSE DETAIL

Since transport phenomena deals with scalar, vectors and 2nd order tensor quantities, the primarily knowledge of these quantities are required. Therefore, initial few lectures are devoted to understand the basic mathematics involved in vector and tensor analysis. Later, momentum transfer, heat transfer and mass transfer are studied separately. However, throughout the course the similarities between these processes are emphasized. The objective of this course is to give basic knowledge of transport phenomena one by one. The basic laws of transport phenomena like the Newton's law of viscosity or the Fourier's law of heat conduction or the Fick's law of diffusion are taken up at appropriate places. Basic axioms of conservations namely conservation of momentum, energy and mass are used for deriving simple shell balances and then the basic equations of transport phenomena are derived. Since this is a course meant for undergraduate students, solutions of some simple engineering problems which can be solved analytically are studied.

- Introduction to transport phenomena
- Vector and tensor calculus
- Mechanisms of momentum transport
- Shell momentum balances
- 1-D problems on velocity distribution in laminar flow
- Equations of change for isothermal systems
- Applications of equations of change to solve 1-D problems on velocity distribution in laminar flow
- Transport phenomena in polymeric liquids
- Mechanisms of energy transport
- Shell energy balances
- 1-D problems on temperature distribution in solids and in laminar flow
- Equations of change for non-isothermal systems
- Applications of equations of change to solve 1-D problems on temperature distribution in solids and in laminar flow
- Mechanisms of mass transport
- Shell mass balances
- Applications of shell mass balances to solve 1-D problems on concentration distributions in solids and in laminar flow
- Equations of change for multi-component systems
- 1-D problems on concentration distributions in solids and in laminar flow
- Methods of solution of momentum, heat and mass transfer problems with more than one independent variable

Modules	Lecture No.	Topics
	01	Vector and tensor analysis part 1

Module 1	02	Vector and tensor analysis part 2
	03	Vector and tensor analysis part 3
	04	Vector and tensor analysis part 4
	05	Vector and tensor analysis part 5
	06	Coordinate systems and time derivative.
Module 2	07	Introduction to momentum transport
	08	Introduction to momentum transport, Axiom 1 mass is conversed
	09	Axiom 2 momentum is conversed
	10	Solution of momentum transport problems by shell momentum balance part1
	11	Solution of momentum transport problems by shell momentum balance part2
	12	Solution of momentum transport problems by shell momentum balance part3
	13	Solution of momentum transport problems by shell momentum balance part4
	14	Solution of momentum transport problems by shell momentum balance part5
	15	Derivation of equation of motion part 1
	16	Derivation of equation of motion part 2
	17	Solution of momentum transport problem by using Navier stokes equation part1
	18	Solution of momentum transport problem by using Navier stokes equation part2

	19	Solution of momentum transport problem by using Navier stokes equation part3	
	20	Introduction to Non-Newtonian fluids	
	21	Momentum transport problem for power law and Bingham fluid	
	22	Tube Flow Problem For Bingham Fluid	
	23	Coutte flow for Non-Newtonian fluid	
		Appendix 1	
Module 3	24	Introduction to Energy transport, Axiom 4 energy is Conversed	
	25	Solution of heat transport problems by shell energy balance part1	
	26	Solution of heat transport problems by shell energy balance part2	
	27	Solution of heat transport problems by shell energy balance part3	
	28	Derivation of equation of energy part1	
	29	Derivation of equation of energy part2	
	30	Derivation of equation of energy part3	
	31	Derivation of equation of energy part4	
	32	solution of heat transport problems by equation of thermal energy part1	
	33	Solution of heat transport problems by equation of thermal energy part2	
		Appendix 2	
	34	Introduction to mass transport part 1	

Module 4	35	Introduction to mass transport part 2
	36	Mass transport in binary systems, special cases
	37	Solution of mass transport problems for binary systems part1
	38	Solution of mass transport problems for binary systems part2
	39	Solution of mass transport problems for binary systems part3
	40	Solution of mass transport problems for binary systems part4
		Appendix 3