Notes for the First Year Lecture Course
Fluid Mechanics
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0.1 Objectives:

- **The course will introduce fluid mechanics and establish its relevance in chemical engineering.**
- **Develop the fundamental principles underlying the subject.**
- **Demonstrate how these are used for the design of simple unit operations.**

COURSE OUTCOMES

1. Knowledge of fundamental concepts in fluids, such as density, viscosity, pressure, stress/strain rate, etc.

2. Ability to apply mass, energy, and momentum balances to hydrostatic and fluid flow problems.

3. Ability to analyze laminar and turbulent frictional flow in pipes and piping networks.

4. "Ability to analyze fluid flow in chemical engineering equipment. including fluid drag on particles, solid separation systems and packed beds

5. Ability to set up the differential equations of fluid mechanics leading to the Navier-Stokes equations, and use them to solve fluid flow problems both analytically and numerically, as well as using existing CFD software packages. 6. Ability to analyze boundary layer flows.

7. Ability to solve problems involving Newtonian and non-Newtonian fluids..

8. Ability to analyze micron scale or smaller flows.

0.2 Consists of:

□□ **Lectures:**

14 Classes presenting the concepts, theory and application.

Worked examples will also be given to demonstrate how the theory is applied. You will be Asked to do some calculations - so bring a calculator.

Assessment:

Exam of 3 hours, worth 100% of the module credits.

This consists of 5 questions. Some extra work. His will involve a detailed report and further questions. The simplest strategy is to do the ab.]

Homework:

Example sheets: **These will be given for each section of the course. Doing these will *greatly* improve your exam mark. They are course work but do not have credits toward the module.**

Lecture notes: **Theses should be studied but explain only the basic outline of the necessary concepts and ideas.**

Books: **It is very important do some extra reading in this subject. To do the examples you will**

1. **Fluid Mechanics and its Applications Gupta and Gupta)**
   New Age international (P) Ltd, New Delhi, 5th Reprint

2. **Introduction to Fluid Mechanics,Fox and McDonald) ,ley, NY, 5th ed.**
3. Unit Operations in Chemical Engineering ,Cabe, Smith, Harriot)

   McGraw Hill, NY, 3th ed

Example classes:

There will be example classes each week. You may bring any problems/questions you have bout the course and example sheets to these classes.

Introduction

Fluid Mechanics in Chemical Engineering

Acknowledge of fluid mechanics is essential for the chemical engineer because the majority of chemical-processing operations are conducted either partly or totally in the fluid phase. Examples of such operations abound in the biochemical, chemical, energy, fermentation, materials, mining, petroleum, pharmaceuticals, polymer, and waste-processing industries.

There are two principal reasons for placing such an emphasis on fluids. First, at typical operating conditions, an enormous number of materials normally exist as gases or liquids, or can be transformed into such phases. Second, it is usually more efficient and cost-effective to work with fluids in contrast to solids. Even some operations with solids can be conducted in a quasi-fluid like manner; examples are the fluidized-bed catalytic refining of hydrocarbons, and the long-distance pipelining of coal particles using water as the agitating and transporting medium.

Although there is inevitably a significant amount of theoretical development, almost *all* the material in this course has some application to chemical processing and other important practical situations.

Throughout, we shall endeavor to present an understanding of the *physical* behavior involved; only then is it really possible to comprehend the accompanying theory and equations.

Lecture NO (1)
Units and Dimensions

1.1 Introduction

As any quantity can be expressed in whatever way you like it is sometimes easy to become confused as to what exactly or how much is being referred to. This is particularly true in the field of fluid mechanics.

Over the years many different ways have been used to express the various quantities involved. Even today different countries use different terminology as well as different units for the same thing .To avoid any confusion on this course we will always use the SI (metric) system - which you will already be familiar with. It is essential that all quantities are expressed in the same system or the wrong solutions will results.

1.2 System Unit

- International (SI)
- French System (CGS)
- British Gravitational (BG)
- English Engineer (EE)

System	**Mass**	**Length**	**Time**	**Force**
International (SI)	kg	m	s	N
French System	gm	cm	s	dyn
British Gravitational (BG)	Slug	ft	s	lb_f
English Engineer (EE)	lb_m	ft	s	pdl

1.2.1 The SI and CGS System of units

The SI system consists of six **primary** units, from which all quantities may be described. For convenience **Secondary** units are used in general practice which is made from combinations of these primary units.

1.2.2.1 Primary Units

The six **primary** units of the SI and CGS system are shown in the table below:

Quantity	Units	Symbols	Dimensions
Length	Meter, (SI)	M	L
	Centimeter (CGS)	Cm	
Mass	Kilogram, (SI)	Kg	M
	gram (CGS)	G	
Time	Second	S	T
Temperature	Kelvin	K	θ
Electric current	Ampere,	A	I
Light intensity	Candela	Cd	Cd

In fluid mechanics we are generally only interested in the top four units from this table.

Notice how the term 'Dimension 'of a unit has been introduced in this table. This is not a property of the individual units; rather it tells what the unit represents. For example a meter is a length which has a dimension L but also, an inch, a mile or a kilometer are all lengths so have dimension of L.(The above notation uses the MLT system of dimensions, there are other ways of writing dimensions – we will see more about this in the section of the course on dimensional analysis.)

1.3 Derived Units

There are many derived units all obtained from combination of the above primary units. Those most used are shown in the table below:

Quantity	SI Unit		Dimension
Velocity	m/s	ms^{-1}	LT^{-1}
Acceleration	m/s^2	ms^{-2}	LT^{-2}
Force	N	$kg\ ms^{-2}$	$M\ LT^{-2}$
Energy (or work)	Joule J, N m , $kg\ m^2/s^2$	$kg\ m^2s^{-2}$	$M\ L^2T^{-2}$
Power	Watt W , N m/s , $kg\ m^2/s^3$	Nms^{-1} $kg\ m^2s^{-3}$	$M\ L^2T^{-3}$
Pressure (or stress)	Pascal P, N/m2, kg/m/s2	Nm^{-2} $kg\ m^{-1}s^{-2}$	$ML^{-1}T^{-2}$
Density	kg/m^3	$kg\ m^{-3}$	$M\ L^{-3}$
Specific weight	N/m^3 , $kg/m^2/s^2$	$kg\ m^{-2}s^{-2}$	$M\ L^{-2}T^{-2}$
relative density	a ratio , no units		no dimension
Viscosity	N s/m^2 , kg/m s	N sm^{-2} ,$kg\ m^{-1}s^{-1}$	$M\ L^{-1}T^{-1}$
surface tension	N/m ,kg /s	Nm^{-1} , $kg\ s^{-2}$	$M\ T^{-2}$

Multiple Unit Preferences	
Tera (T) = 10^{12}	deci (d) = 10^{-1}
Giga (G) = 10^{9}	centi (c) = 10^{-2}
Mega (M) =10^{6}	milli (m) = 10^{-3}
Kilo (k) = 10^{3}	mirco (μ) = 10^{-6}
Hector (h) = 10^{2}	nano (n) = 10^{-9}
deka (da) = 10^{1}	pico (p) = 10^{-12},

The above units should be used at all times. Values in other units should NOT be used without first converting them into the appropriate SI unit. If you do not know what a particular unit means find out, else your guess will probably be wrong.

One very useful tip is to write down the units of any equation you are using. If at the end the units do not match you know you have made a mistake. For example is you have at the end of a calculation,

$$30 \text{ kg/m s} = 30 \text{ m}$$

You have certainly made a mistake - checking the units can often help find the mistake.

More on this subject will be seen later in the section on dimensional analysis and similarity.

1.4 Conversion of Units

A measured quantity can be expressed in terms of any units having the appropriate dimension. A particular velocity, for instance, maybe expressed in ft/s, miles/h, cm/yr, or any other ratio of a length unit to a time unit. The numerical value of the velocity naturally depends on the units chosen. The equivalence between two expressions of the same quantity may be defined in terms of a ratio:

$$\frac{1cm}{10mm} \text{ . (1 centimeter per 10 millimeters.) } \dots\dots\dots\dots\dots\dots \text{ (1.1)}$$

$$\frac{10mm}{1cm} \text{. (10 millimeters per centimeter.) } \dots\dots\dots\dots\dots\dots \text{ (1.2)}$$

$$\left[\frac{10mm}{1cm}\right]^2 = \frac{100mm^2}{1cm^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (1.3)}$$

Ratios of the form of Equations(1.1), (1.2), and (1.3) are known as **conversion factors.** To convert a quantity expressed in terms of one unit to its equivalent in terms of another unit, multiply the given quantity by the conversion factor (new unit/old unit). For example, to convert 36 mg to its equivalent in grams, write

$$36 \text{ mg} \times \frac{1\text{g}}{1000 \text{ mg}} = 0.036 \text{ g}$$

(Note how the old units cancel, leaving the desired unit.) An alternative way to write this equation is to use a vertical line instead of the multiplication symbol:

$$\frac{36 \text{ mg}}{\quad} \left| \frac{1 \text{ g}}{1000 \text{ mg}} \right. = 0.036 \text{ g}$$

Example

Convert an acceleration of 1 cm/s^2 to its equivalent in km/yr^2.

$$\boldsymbol{\frac{1\ cm}{s^2} \left| \frac{3600\ s^2}{1hr^2} \right| \frac{24^2 hr^2}{1^2\ day^2} \left| \frac{365^2\ day^2}{1^2\ yr^2} \right| \frac{1\ m}{10^2\ cm} \left| \frac{1\ km}{10^3\ m} \right. = \frac{(3600 \times 24 \times 1)^2}{10^2 \times 10^3} = 9.95 \times 10^9 \frac{km}{yr^2}}$$