GEC 223 COURSE COMPACT

Course

Course code: GEC. 223

Course title followed by the credit unit: FLUID MECHANICS I (2 UNITS)

Course status if it’s either – GENERAL COURSE (compulsory)

Course Duration

Two hours per week for 15 weeks (30 hours)

Lecturer Data

1. Name of the lecturer: Engr. Aliyu Samuel Jacob.
   Qualifications obtained: M. Eng. (Thermo-Fluid. Power Plant & Auto. Option.)
   Department: Mechanical Engineering.
   Faculty: College of Science and Engineering
   E-mail: aliyu.samuel@lmu.edu.ng
   Office Location: New college Building, Wing C, First floor, Room 128.
   (Engr. Aliyu Samuel Jacob).
   Consultation Hours: 24/7 (Days and time).

2. Name of the lecturer: Engr. Sojobi, Adebayo O.
   Qualifications obtained: MSc., B.Sc.
   Department: Civil Engineering
   Faculty: Engineering
   College: Science and Engineering
   E-mail: sojobi.adebayo@lmu.edu.ng
   Office Location: B006, Ground Floor, New College Building
   Consultation Hours: Wednesday:4-6 pm

Course Content:

Properties of fluids. Fluid statics. Density, pressure, surface tension, viscosity, compressibility, etc. Basic conservation laws, friction effects and losses in laminar and turbulent flows in ducts and pipes, dimensional analysis and dynamic similitude; principles of construction and operation of selected hydraulic machinery; hydropower systems. The students should undertake laboratory practical in-line with the topics taught.

Course Description:- Introduces students to:

- Introduction
- Fluid Properties
  - Fluids vs. Solids
  - Viscosity
  - Newtonian Fluids
  - Properties of Fluids
- Statics
Hydrostatic pressure
Manometry / pressure measurement
Hydrostatic forces on submerged surfaces

- Dynamics
  - The continuity equation.
  - The Bernoulli Equation.
  - Applications of the Bernoulli equation.
  - The momentum equation.
  - Application of the momentum equation.

- Real Fluids
  - Boundary layer.
  - Laminar flow in pipes.

- Introduction to dimensional analysis
  - Dimensional analysis
  - Similarity

Course Justification:
- The course will introduce fluid mechanics and establish its relevance in engineering applications.
- Develop the fundamental principles underlying the subject.
- Demonstrate how these are used for the design of simple hydraulic components.
- With the wealth of sound, practical and theoretical knowledge, students can fit into organisations handling fluids (e.g. water resources) projects, hydropower stations, etc. In addition, students can be change agents pioneering such projects in their sphere of influence.

Course objectives
At the end of this course, students would be able to:

(i) Understand basic theories and laws governing fluid in motion and at rest
(ii) Understand frictional effects and losses in pipe and duct flow
(iii) Understand the practical uses of dimensional analysis in hydraulic projects
(iv) Familiarize with principles of construction and operation of selected hydraulic machinery
(v) Appreciate the use, operations of hydropower systems, governing equations

Course Requirement

To gain maximally from this course, students should be familiar with the various uses of fluids; students are also expected to be sound in simple calculations

Method of Grading- An example below
<table>
<thead>
<tr>
<th>S/N</th>
<th>Grading</th>
<th>Score (%)</th>
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<tbody>
<tr>
<td>1.</td>
<td>Tests</td>
<td>10</td>
</tr>
<tr>
<td>2.</td>
<td>Assignments</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Practical (laboratory work)</td>
<td>10</td>
</tr>
<tr>
<td>4.</td>
<td>Final Examination</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Total</td>
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</tr>
</tbody>
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Course Delivery Strategies

1. *Interactive class discussions complimented by lecture notes. Students are also given take-home assignments which further buttresses the course objectives.*
2. *The use of the public address system for audibility during lecture delivery.*
4. *Teaching aids with practical illustrations.*

**LECTURE CONTENT**

**Week 1: Topic for the week**

*Introduction to fluid mechanics and fluid properties and causes of viscosity in fluids.*

- **Objectives (list the objectives)**
  - At the end of the lecture for this week:
    - Students should by the way of introduction know what is fluid mechanics and why we study fluid mechanics.
    - Students should know the type of flow forces responsible to fluid flow.
    - Students should understand the common areas of flow application.

- **Description**
  - **First hour:** Definition of fluid mechanics and the separating line between the fluid and solids.
  - **Second hour:** Introduction of fluids and non-fluids

- **Study Question:** This section entails study question for the week lecture.
  1. A plate having an area of 0.6 $m^2$ is sliding dawn an inclined plane at 300 to the horizontal with a velocity of 0.36 $m/s$. There is a cushion of fluid 1.8mm thick between the plane and the plate. Find the viscosity of the fluid if the weight of the plate is 280N.

- **Reading List - Books and materials students can read. Illustration below:**
  - *Douglas, John. F. Solution of problems in Fluid Mechanics: (Vol.1 &2, Part One and Part Two).*
  - Dr Andrew Sleigh. *An Introduction to Fluid Mechanics.*
Week 2: Topic for the week

*Fluid statics, pressure and its measurement by manometer*

- **Objectives (list the objectives)**
  - The students at the end of the lectures for the week should be able to:
    1. State and prove the Pascal law for a static fluid
    2. Know the definition and importance of Piezometric head, velocity measurement using Pitot, etc.
    3. Determine the pressure at a desired point in a fluid by employing a single – tube, U-tube (Upright or inverted) or a differential manometer

- **Description**
  - **First hour:** Introducing the students to “the state of rest of fluids”
  - **Second hour:** Developing the Pascal’s pressure law at a point; which state that “the pressure at a point in a static fluid is equal in all directions in space”

- **Study Question:** This section entails study question for the week lecture.
  
  A hydraulic jack consists of a handle cum lever of 30 cm and an assembly of given dimensions. In order that a load of 20 kN be supported by the jack, what should be the force exalted on the handle? The distance between the fulcrum of the lever and the point where the plunger is connected is 25 mm

- **Reading List**
  - K.L. Kumar, Engineering Fluid Mechanics.

Week 3: Topic for the week

*Uniform flow, flow rate and Bernoulli’s equation*

- **Objectives (list the objectives)**
  - The students at the end of the lectures for the week should be able to:
    1. Establish the steady flow energy equation and obtain the Bernoulli’s equation from it.
    2. Know what is meant by Fluid dynamics.
    3. Should, therefore, state and apply the accepted laws of motion and formulate the equations governing the fluid in motion.

- **Description**
  - **First hour:** Introduction to statement of laws for a system as it affect motion i.e, Newton’s first, second and third laws of motion.
  - **Second hour:** Introduction to types of fluid flow.

- **Study Question:** This section entails study question for the week lecture.
  1. Air flows steadily through a horizontal nozzle. At the nozzle inlet, the velocity is 6m/s and the pressure is 100 kN/m². If the inlet area is 0.1 m² and the contraction ratio is 5, determine,
     a. The velocity and the pressure at the exit
     b. The discharge and mass flow rate through the nozzle.
  2. In a fluid, the velocity field is given by;
     \[ V = (3x + 2y)\mathbf{i} + (2z + 3x^2)\mathbf{j} + (2t - 3z)\mathbf{k}, \]
     Determine:
     The velocity components, u, v, w at any point in the flow field,
Reading List - Books and materials students can read.
- K.L. Kumar, Engineering Fluid Mechanics.

Week 4: Topic for the week

Applications of Bernoulli’s equation

Objectives (list the objectives)
The students at the end of the lectures for the week should be able to:
1. Work with the energy equation expressed in terms of heads, and use it to determine the turbine power output and pumping power requirements.
2. That the liquid, under assumption, is ideal and incompressible
3. That the flow, under assumption, is steady and continuous.
4. That the flow, under assumption, is along the streamline, i.e, it is one dimensional.
5. The velocity is uniform over the sections and is equal to the mean velocity.
6. The only forces acting on the fluid are the gravity forces and the pressure forces.

Description
- First hour: Derivation of the Bernoulli equation, which state that “in an ideal incompressible fluid when the flow is steady and continuous, the sum of pressure energy, kinetic energy, and potential (or datum) energy is constant along a streamline”
- Second hour: Application of Bernoulli equation to fluid discharge scenarios.

Study Question: This section entails study question for the week lecture.
1. A large tank open to the atmosphere is filled with water to a height of 5 m from the outlet tap. A tap near the bottom of the tank is now opened, and water flows out from the smooth and rounded outlet. Determine the water velocity at the outlet.
2. A piezometer and a Pitot tube are tapped into a horizontal water pipe to measure static and stagnation (static + dynamic) pressures. For the indicated water column heights, determine the velocity at the center of the pipe.

Reading List - Books and materials students can read. Illustration below:
- K.L. Kumar, Engineering Fluid Mechanics.

Week 5: Topic for the week

Real fluid- laminar and turbulent flow

Objectives (list the objectives)
The students at the end of the lectures for the week should be able to:
1. Know that Newtonian fluids are classified as Laminar and turbulent fluids.
2. Know the characteristics of these fluids.
3. Know the effect of Reynolds number.
4. Describe the conditions under which the flow is laminar or turbulent.
5. Solve simple laminar flow problems.

- **Description**
  - **First hour:** Introducing types of laminar flow and their characteristics.
  - **Second hour:** Laminar Flow through a round pipe.

- **Study Question:** This section entails study question for the week lecture.
  1. A lubricating oil flows in a 10 cm diameter pipe at 1 m/s. Determine whether the flow is laminar or turbulent. For the lubricating oil, \( \mu = 0.1 \text{N-s/m}^2 \) and \( \rho = 930 \text{ kg/m}^3 \). Calculate also the transition velocity.
  2. A 20 cm diameter pipe 30 km long transport oil from a tanker to the fuel station underground tank at 0.01 m\(^3\)/s. Calculate the power required to maintain the flow. Take \( \mu = 0.1 \text{Nm/s}^2 \), \( \rho = 900 \text{ kg/m}^3 \) for the oil.

- **Reading List - Books and materials students can read.**
  - K.L. Kumar, Engineering Fluid Mechanics.

**Week 6:** Topic for the week

*Pressure loss due to friction in pipeline*

- **Objectives (list the objectives)**
  The students at the end of the lectures for the week should be able to:-
  1. Understanding the different velocity and flow rate measurement techniques and learn their advantages and disadvantages.
  2. Calculate loss of energy (or Head) in pipes.
  3. Calculate change in pressure with gradual change of section.

- **Description**
  - **First hour:** Introduction of major and minor energy losses in pipes.
  - **Second hour:** Type of Pipes that causes energy losses.

- **Study Question:** This section entails study question for the week lecture.
  1. In a pipe of 300 mm diameter and 800 m length an oil of specific gravity of 0.8 is flowing at the rate of 0.45 m\(^3\)/s. Find:
    - i) Head loss due to friction,
    - ii) Power required to maintain the flow.
    Take kinematic viscosity of oil as 0.3 stoke.
  2. Water is to be supplied to the inhabitants of a college campus through a supply main. The following data is given is given:
    - Distance of the reservoir from the campus = 3000 m.
    - Number of inhabitants = 4000
    - Consumption of water per day of each inhabitant = 180 litres.
    - Loss of head due to friction = 18 m.
Co-efficient of friction for the pipe, \( f = 0.007 \).

If the half of the day supply is pumped in eight hours, determine the size of the supply main.

- **Reading List - Books and materials students can read.**
  - K.L. Kumar, Engineering Fluid Mechanics.

**Week 7: Topic for the week**

*Pressure loss during laminar flow in a pipe*

- **Objectives (list the objectives)**
  - The students at the end of the lectures for the week should be able to:-
    1. Know that a flow is more likely to be laminar if the velocity \( U \) is low; the diameter \( d \) is small; the density \( \rho \) is low, and the viscosity \( \mu \) is high.
    2. Know what is meant by the upper and lower critical Reynolds number.

- **Description**
  - First hour: Introducing the basic laminar flow process of flow in pipes.
  - Second hour: Characteristics of fluid flow in pipes and the related equations.

- **Study Question: This section entails study question for the week lecture.**
  1. An oil having a viscosity of 0.0098 kg/s/m² and a specific gravity of 1.59 flows through a horizontal pipe of 5 cm diameter with a pressure drop of 0.06 kg/cm² per meter length of the pipe. Determine: a) the rate of flow in kilograms per minute, b) the shear stress at the pipe wall, c) the total drag for 100 m length of pipe, d) the power required for the 100 m length of the pipe to maintain the flow.

- **Reading List - Books and materials students can read. Illustration below:**
  - Dr Andrew Sleigh. An Introduction to Fluid Mechanics.
  - K.L. Kumar, Engineering Fluid Mechanics.

**Week 8: Topic for the week.**

*Boundary layers*

- **Objectives (list the objectives)**
  - The students at the end of the lectures for the week should be able to:-
    1. Introducing the student to stratification of fluid flow phenomena.
    2. Know causes of stratification of flows in horizontal pipes.
3. Know the velocity profile and the variation of shear stress with radial distance for turbulent flow in a pipe.
4. Establish the boundary layer equations for two-dimensional incompressible flow.

➢ Description

- First hour: Introduction and definitions of boundary layer and characteristics.
- Second hour: Estimate of boundary layer thickness, Displacement thickness, Momentum thickness, Boundary layer equation and Drag on flat plate.

➢ Study Question: This section entails study question for the week lecture.
1. A uniform free stream of air at 10m/s flows over a flat plate. Calculate the drag coefficient and the drag for the plate, 0.5 m long and 2 m wide (take \( p = 1.2 \text{ kg/m}^3 \), \( \mu = 18 \times 10^{-6} \text{ N-s/m}^2 \))
2. Calculate the drag and the power required to tow a smooth, flat plate 2 m wide 20 m long through still water (dynamic viscosity, \( \mu_s = 0.001 \text{ N-s/m}^2 \)) at 10 m/s. What would be the drag and power required if the plate was half as long?

➢ Reading List - Books and materials students can read.
- Dr Andrew Sleigh. An Introduction to Fluid Mechanics.
- K.L. Kumar, Engineering Fluid Mechanics.

Week 9: Topic for the week.
Boundary layers in pipe and effect of surface roughness

➢ Objectives:

At the end of the lecture for this week:

i. Students should be aware of the effects of boundary layer and surface roughness in pipe flow
ii. Students should understand the characteristics of boundary layers and methods of measurements
iii. Students should understand the equations governing boundary layers in pipe flow and practical applications in real life

➢ Description:

- First Hour: Definition of boundary layer, characteristics of boundary layers, boundary layer thickness and methods of measurements,
- Second Hour: Equations governing boundary layers in pipes

➢ Study Questions:

1. A lubricating oil of viscosity 1 poise and specific gravity 0.9 is pumped through a 30mm diameter pipe. If the pressure drop per metre length of pipe is 20KN/m2,
determine:
  i. The mass flow rate in kg/min
  ii. The shear stress at the pipe wall
  iii. The Reynolds number of flow
  iv. The power required per 50m length of the pipe to maintain the flow
2. The velocity distribution in the boundary layer is given by

\[
\frac{u}{U} = \left(\frac{y}{\delta}\right)^{1/7}
\]

Calculate the following:
  i. Displacement thickness
  ii. Momentum thickness
  iii. Shape factor
  iv. Energy thickness
  v. Energy loss due to boundary layer if at a particular section, the boundary layer thickness is 25mm and the free stream velocity is 15m/s.

➢ Reading List

Week 10: Topic for the week.
  Hydropower Systems I

➢ Objectives:

At the end of the lecture for this week:
  i. Students should know the components and arrangements of hydropower systems
  ii. Students should know factors that affect the location of hydropower systems
  iii. Students should know the cost considerations and controls for hydropower systems
  iv. Students should know the classification of hydropower plants
  v. Students should understand the design, construction and working of an impulse turbine (pelton wheel)

➢ Description:
   First Hour: Components and arrangements of a hydropower system, factors affecting the location of hydropower systems, cost considerations and controls for hydropower systems, classification of hydropower plants
   Second Hour: design, construction and working of an impulse turbine (pelton wheel)

➢ Study Questions:

1. The following data relate to a pelton wheel:
   Head______________72m
   Speed of wheel____________240rpm
   Shaft power of wheel_______115KW
Speed ratio_______________0.45
\(C_v\)_______________________0.98
Overall efficiency___________0.85

Design the Pelton wheel

2. A pelton wheel running at 480 r.p.m. and operating under an available head of 420m is required to develop 4800KW. There are two equal jets and the bucket deflection angle is 165°. The overall efficiency is 85% when the water is discharged from the wheel in a direction parallel to the axis of rotation. The coefficient of velocity of nozzle is 0.97 and the blade speed ratio is 0.46. The relative velocity of water at exit from the bucket is 0.86 times the relative velocity at inlet. Calculate the following:

i. Cross-sectional area of each jet
ii. Bucket pitch circle diameter, and
iii. Hydraulic efficiency of the turbine

➢ Reading List

Week 11: Hydropower Systems II

➢ Objectives:

At the end of the lecture for this week:

i. Students should know the components and arrangements of Francis systems
ii. Students should understand the design, operation, construction and workings of a Francis turbine
iii. Students should understand the equations governing Francis turbine
iv. Students should know the advantages and disadvantages of Francis turbine compared to pelton wheel
v. Students should know the cavitation effects on turbines and how it can be avoided

➢ Description:
   First Hour: Components and arrangements of Francis turbine; design, operation, construction and workings of Francis turbine;
   Second Hour: Equations governing the operations of Francis turbine; advantages and disadvantages of Francis turbine compared to Pelton turbine; cavitation effects on turbines and how it can be avoided

➢ Study Questions:
1. An inward flow reaction turbine has external and internal diameters as 1.08m and 0.54m. The turbine is running at 200rpm. The width of the turbine at inlet is 240mm and velocity of flow through the runner is constant and is equal to 2.16m/s. The guide blades make an angle of $10^0$ to the tangent of the wheel and discharge at the outlet of the turbine is radial. Draw the inlet and outlet velocity triangles and determine:
   i. The absolute velocity of water at inlet of the runner
   ii. The velocity of whirl at inlet
   iii. The relative velocity at inlet
   iv. The runner blade angles
   v. Width of runner at outlet
   vi. Weight of water flowing through the runner per second
   vii. Head at inlet of the turbine
   viii. Power developed
   ix. Hydraulic efficiency of the turbine
   x. Specific speed of the turbine if the centre-line of the spiral casing inlet of the turbine is 2.5m above the tail water level.

2. Discuss the various classifications of hydropower plants

➢ Reading List

Week 12: Topic for the week.
   Dimensions, Units and Dimensional Analysis

➢ Objectives:
   At the end of the lecture for this week:
   i. Students should know the derive various dimensions from the primary dimensional units
   ii. Students should know the uses, advantages and limitations of dimensional analysis
   iii. Students should understand the common methods of dimensional analysis

➢ Description:
    First Hour: Primary and secondary dimensions; uses, advantages and limitations of dimensional analysis; dimensional homogeneity and applications
    Second Hour: methods of dimensional analysis

➢ Study Questions:
i. Show that the power \( P \) developed in a water turbine can be expressed as:

\[
P = \rho N^2 D^5 \phi \left( \frac{D}{B} \right) \frac{\mu \rho D^2 N}{\nu \sqrt{gH}}
\]

Where \( \rho \) = mass density of the fluid
\( N \) = Speed in r.p.m.
\( D \) = Diameter of the runner
\( B \) = Width of the runner
\( \mu \) = Coefficient of dynamic viscosity

Under what conditions can it be used to determine the characteristic of a similar machine

ii. Discuss the advantages and limitations of dimensional analysis

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**Reading List**


**Week 13:** Topic for the week.
Similitude and Model Analysis

**Objectives:**

At the end of the lecture for this week:

i. Students should know the types of models, their advantages and disadvantages

Students should know the types of similitude and similarity laws guiding model analysis

ii. Analysis

iii. Students should understand the applications of model analysis

Primary and secondary dimensions; uses, advantages and limitations of dimensional analysis; dimensional homogeneity and applications; methods of dimensional analysis

**Description:**

- **First Hour:** Types of models, their advantages and disadvantages; types of similarity: geometric, kinematic and dynamic;
- **Second Hour:** similarity laws: Reynolds, Froude, Euler, Weber and Mach model laws and applications

**Study Questions:**
1. The characteristics of a spillway are to be studied by means of a geometrically similar model constructed to the scale ratio of 1:10.
   i. If the maximum rate of flow in the prototype is 28.3 cumecs, what will be the corresponding flow in the model?
   ii. If the measured velocity in the model at a point on the spillway is 2.4 m/s, what will be the corresponding velocity in the prototype?
   iii. If the hydraulic jump at the foot of the model is 50 m, what will be the height of jump in prototype?
   iv. If the energy dissipated per second in the model is 3.5 m, what will be the height of jump in prototype?

2. In a hydroelectric generating plant there are four similar turbines of total output 220000 KW. Each turbine is 90% efficient and runs at 100 r.p.m. under a head of 65 m. It is proposed to test the model of the above turbine in a flume where discharge is 0.4 m$^3$/s under a head of 4 m. Determine the size (scale ratio) of the model. Also calculate the model speed and power results expected from the model.

3. Discuss scale effects in engineering models

➢ Reading List

Week 14: Topic for the week.
Revision

➢ Objective:
   i. To revise all the topics taught

➢ Description:
   • First Hour: Revise topics taught in class from fluid properties to boundary layer
   • Second Hour: Revise topics taught in class from boundary layers in pipes to similitude and model analysis with study questions 1-5.

➢ Study Questions:
   1. What is the critical criterion for determining if a flow is laminar or turbulent?
   2. Derive Hagen-Poiseuille equation
   3. Discuss classifications of hydropower plants
   4. A reaction turbine works at 450 r.p.m. under a head of 120 m. Its diameter at inlet is 1.2 m and the flow area is 0.4 m$^2$. The angles made by absolute and relative velocities at inlet are 200 and 600 respectively with the tangential velocity. Determine:
i. The volume flow rate
ii. The power developed
iii. The hydraulic efficiency

5. A ship 300m long moves in sea water, whose density is 1030kg/m$^3$. A 1:100 model of the ship is to be tested in a wind tunnel. The velocity of air in the wind tunnel around the model is 30m/s and the resistance of the model is 60N. Determine the velocity of ship in sea-water and also the resistance of the ship in sea-water. The density of air is given as 1.24kg/m$^3$. Take the kinematic viscosity of sea-water and air as 0.012 stokes and 0.018 stokes respectively.

➢ Reading List

**Week 15**: Topic for the week.
Examination

➢ **Objective:**

i. To examine the students on all that has been taught during the semester.

➢ **Description:**

*Classroom-based examination*

➢ **Reading List**