GATE 2021 Petroleum Engineering (PE) Question Paper with Solutions

Time Allowed :3 Hours	**Maximum Marks :**100	**Total questions :**65

General Instructions

Read the following instructions very carefully and strictly follow them:

1. Each GATE 2021 paper consists of a total of 100 marks. The examination is divided into two sections – General Aptitude (GA) and the Candidate's Selected Subjects. General Aptitude carries 15 marks, while the remaining 85 marks are dedicated to the candidate's chosen test paper syllabus.
2. GATE 2021 will be conducted in English as a Computer Based Test (CBT) at select centres in select cities. The duration of the examination is 3 hours.
3. MCQs carry 1 mark or 2 marks.
4. For a wrong answer in a 1-mark MCQ, 1/3 mark is deducted.
5. For a wrong answer in a 2-mark MCQ, 2/3 mark is deducted.
6. No negative marking for wrong answers in MSQ or NAT questions.

General Aptitude (GA)

1. The current population of a city is 11,02,500. If it has been increasing at the rate of 5% per annum, what was its population 2 years ago?

(A) 9,92,500

(B) 9,95,006

(C) 10,00,000

(D) 12,51,506

Correct Answer: (C) 10,00,000

Solution:

Let the population 2 years ago be P. The population increases at a rate of 5% per annum, so after 2 years, the population becomes:

$$P \times (1 + 0.05)^2 = 11,02,500$$

Solving for P:

$$P \times 1.1025 = 11,02,500$$
$$P = \frac{11,02,500}{1.1025} = 10,00,000$$

Thus, the population 2 years ago was 10,00,000. The correct answer is option (C).

Final Answer: (C) 10,00,000

Quick Tip

To find the population in the past, divide the current population by $(1 + \text{rate})^n$, where n is the number of years.

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2. p and q are positive integers and

$$\frac{p}{q} + \frac{q}{p} = 3,$$

then,

$$\frac{p^2}{q^2} + \frac{q^2}{p^2} =$$

(A) 3

(B) 7

(C) 9

(D) 11

Correct Answer: (B) 7

Solution:

We are given that $\frac{p}{q} + \frac{q}{p} = 3$. Let us square both sides of this equation:

$$\left(\frac{p}{q} + \frac{q}{p}\right)^2 = 3^2$$

Expanding the left-hand side:

$$\frac{p^2}{q^2} + 2 + \frac{q^2}{p^2} = 9$$

$$\frac{p^2}{q^2} + \frac{q^2}{p^2} = 9 - 2 = 7$$

Thus, $\frac{p^2}{q^2} + \frac{q^2}{p^2} = 7$, so the correct answer is option (B).

Final Answer: (B) 7

Quick Tip

When given a sum of fractions like $\frac{p}{q} + \frac{q}{p}$, square the equation to simplify and find the desired expression.

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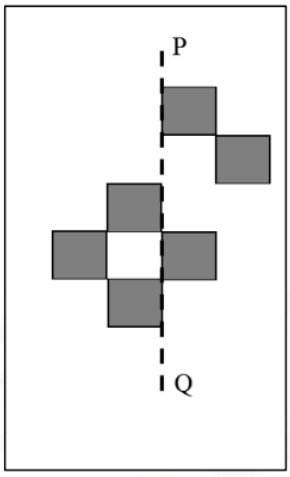
3. The least number of squares that must be added so that the line P-Q becomes the line of symmetry is



(A) 4

(B) 3

(C) 6

(D) 7

Correct Answer: (C) 6

Solution:

We are given a figure with a vertical dashed line labeled P-Q, which is intended to be the line of symmetry. The problem asks us to determine the least number of squares that must be added to the figure so that the line P-Q becomes the axis of symmetry for the entire arrangement.

Step 1: Analyze the initial figure.

The figure consists of several squares arranged around the line P-Q. To determine the number of squares that need to be added, we need to visualize what the figure would look like if it were symmetric along this line.

Step 2: Apply the concept of symmetry.

Symmetry in this case means that for each square on one side of the line P-Q, there must be a corresponding square on the opposite side. In this case, the figure is asymmetric along the line P-Q, which means that squares are missing on one side of the line.

Step 3: Determine the missing squares.

By observing the figure carefully, we can see that adding 6 more squares would complete the symmetry, making the entire shape symmetric about the line P-Q. Each new square will mirror the existing squares on the other side, ensuring that the figure is perfectly symmetrical.

Thus, the least number of squares to be added is 6.

Therefore, the correct answer is option (C).

Final Answer: 6

Quick Tip

To create symmetry in a figure, visualize how the shape would look after reflecting it across the given line of symmetry and determine how many elements are missing on the opposite side.

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4. Nostalgia is to anticipation as _____ is to _____. Which one of the following options maintains a similar logical relation in the above sentence?

(A) Present, past

(B) Future, past

(C) Past, future

(D) Future, present

Correct Answer: (C) Past, future

Solution:

The given analogy is comparing two pairs of words:

- Nostalgia is associated with the past, while anticipation is associated with the future.

Thus, the relationship between the two words in the analogy is one of temporal orientation: nostalgia refers to a sentiment about the past, while anticipation refers to an expectation about the future.

Step 1: Break down the analogy.

The analogy presents a relationship between the two words:

- Nostalgia is to anticipation as _____ is to _____.

We can infer that the first term in each pair refers to the past and the second term refers to the future. Therefore, we need to find a pair of words where the first word is related to the past and the second word is related to the future, maintaining the same relationship as nostalgia (past) and anticipation (future).

Step 2: Analyze the options.

- (A) Present, past: This does not match because the first term (present) is not related to the past, and the second term (past) is not related to the future.
- (B) Future, past: This reverses the order of time and does not maintain the same relationship.
- (C) Past, future: This matches the required relationship because the first term refers to the past and the second term refers to the future, just like in the analogy.
- (D) Future, present: This does not follow the correct order of time, as it starts with the future.

Step 3: Conclusion.

Therefore, the correct answer is option (C), ”Past, future,” which maintains the same logical relation as ”Nostalgia is to anticipation.”

Final Answer: Past, future

Quick Tip

When solving analogies, always look for the underlying relationship between the two concepts in the first pair and apply the same relationship to the second pair, ensuring the concepts are logically consistent.

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5. Consider the following sentences:

- (i) I woke up from sleep.
- (ii) I wok up from sleep.
- (iii) I was woken up from sleep.
- (iv) I was wokened up from sleep.

Which of the above sentences are grammatically CORRECT?

(A) (i) and (ii)
(B) (i) and (iii)
(C) (ii) and (iii)
(D) (i) and (iv)

Correct Answer: (B) (i) and (iii)

Solution:
We are asked to identify which of the sentences are grammatically correct. Let's analyze each sentence:
(i) "I woke up from sleep."
This sentence is grammatically correct. "Woke up" is the correct past tense of "wake up."
(ii) "I wok up from sleep."
This sentence is incorrect. "Wok" is a misspelling of "woke."
(iii) "I was woken up from sleep."
This sentence is grammatically correct. "Was woken" is the correct passive voice form of "wake up."
(iv) "I was wokened up from sleep."

This sentence is incorrect. The word ”wokened” is not a correct form of ”wake.”

Conclusion: The grammatically correct sentences are (i) and (iii).

Final Answer:

$$\boxed{(i) \text{ and } (iii)}.$$

Quick Tip

In English, ”woke up” is used for the past tense of ”wake up” in an active voice, and ”was woken” is used in a passive voice.

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6. Given below are two statements and two conclusions.

Statement 1: All purple are green.

Statement 2: All black are green.

Conclusion I: Some black are purple.

Conclusion II: No black is purple.

Based on the above statements and conclusions, which one of the following options is logically CORRECT?

(A) Only conclusion I is correct.

(B) Only conclusion II is correct.

(C) Either conclusion I or II is correct.

(D) Both conclusion I and II are correct.

Correct Answer: (C) Either conclusion I or II is correct.

Solution:

We are given two statements: - Statement 1: ”All purple are green” means that all purple objects are a subset of green objects.

- Statement 2: ”All black are green” means that all black objects are also a subset of green objects.

Now, let’s examine the conclusions: - Conclusion I: ”Some black are purple” suggests that some black objects are also purple. This is not necessarily true based on the given

statements, because the black objects are green but there is no direct information implying that any black objects must be purple. Thus, conclusion I is not logically correct.
- Conclusion II: ”No black is purple” suggests that none of the black objects are purple. This is a valid conclusion because we know that all purple objects are green, and all black objects are also green. However, the two sets (black and purple) are not required to overlap based on the given statements. Therefore, conclusion II is logically correct.
Since conclusion II is correct, the correct answer is (C), which states that either conclusion I or II is correct.

Final Answer: Either conclusion I or II is correct.

Quick Tip

When analyzing logical conclusions based on set relations, consider whether the statements provide enough information to make the conclusions valid.

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7. Computers are ubiquitous. They are used to improve efficiency in almost all fields from agriculture to space exploration. Artificial intelligence (AI) is currently a hot topic. AI enables computers to learn, given enough training data. For humans, sitting in front of a computer for long hours can lead to health issues.
Which of the following can be deduced from the above passage?

(A) (ii) and (iii)
(B) (ii) and (iv)
(C) (i), (iii) and (iv)
(D) (i) and (iii)

Correct Answer: (D) (i) and (iii)

Solution:
The passage discusses the ubiquity of computers and their various uses, especially in the context of AI, along with some potential health risks for humans who spend long hours in front of computers. Let’s analyze the statements:

(i) ”Nowadays, computers are present in almost all places.” This is directly stated in the passage: ”Computers are ubiquitous.”
(ii) ”Computers cannot be used for solving problems in engineering.” This statement is not supported by the passage, which highlights the efficiency improvements brought by computers.
(iii) ”For humans, there are both positive and negative effects of using computers.” The passage mentions health issues caused by prolonged computer usage, indicating negative effects, alongside the benefits of AI and efficiency improvements, thus confirming both positive and negative impacts.
(iv) ”Artificial intelligence can be done without data.” The passage suggests that AI requires enough training data, making this statement incorrect.
Hence, the correct options are (i) and (iii).

Final Answer: (i) and (iii)

Quick Tip

When deducing information from a passage, focus on the statements that are directly supported by the given details. Avoid conclusions that contradict the passage.

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8. Consider a square sheet of side 1 unit. In the first step, it is cut along the main diagonal to get two triangles. In the next step, one of the cut triangles is revolved about its short edge to form a solid cone. The volume of the resulting cone, in cubic units, is

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(A) $\frac{\pi}{3}$
(B) $\frac{2\pi}{3}$
(C) $\frac{3\pi}{2}$
(D) 3π

Correct Answer: (A) $\frac{\pi}{3}$

Solution:

We are given a square sheet with side 1 unit, and the triangle is formed by cutting along the diagonal. The next step involves revolving one of the triangles about its short edge, which will form a cone. Let's find the volume of this cone.

- The base radius r of the cone is half of the side of the square, so $r = \frac{1}{2}$.
- The height h of the cone is the length of the other side of the triangle, which is also 1.

The formula for the volume of a cone is:

$$V = \frac{1}{3}\pi r^2 h.$$

Substituting the values of r and h:

$$V = \frac{1}{3}\pi \left(\frac{1}{2}\right)^2 \times 1 = \frac{1}{3}\pi \times \frac{1}{4} = \frac{\pi}{3}.$$

Thus, the volume of the cone is $\frac{\pi}{3}$ cubic units.

Final Answer: $\frac{\pi}{3}$

Quick Tip

To find the volume of a cone formed by revolving a triangle, use the formula $V = \frac{1}{3}\pi r^2 h$, where r is the radius and h is the height of the cone.

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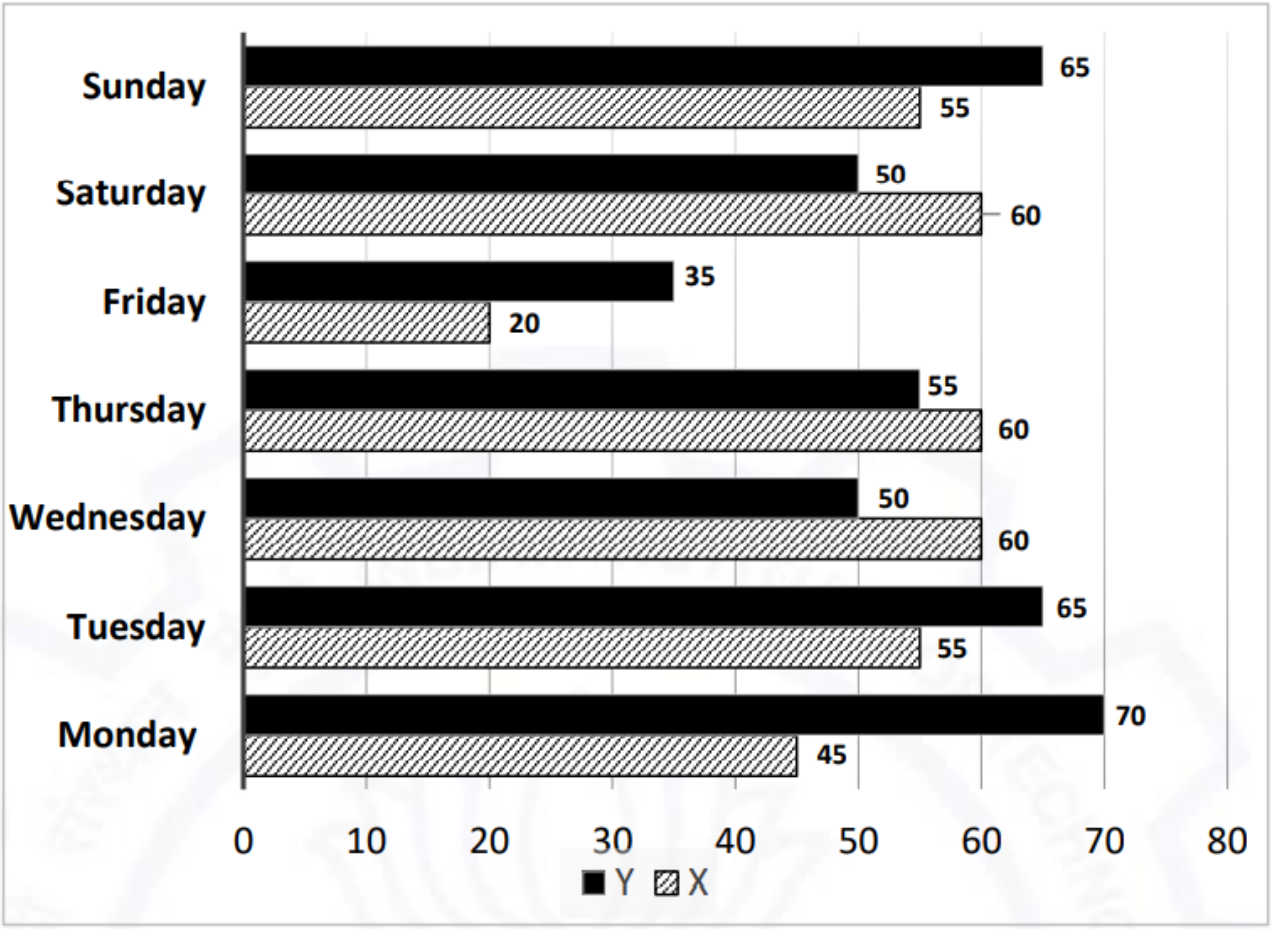
9. The number of minutes spent by two students, X and Y, exercising every day in a given week are shown in the bar chart above.
The number of days in the given week in which one of the students spent a minimum of 10% more than the other student, on a given day, is



(A) 4

(B) 5

(C) 6

(D) 7

Correct Answer: (C) 6

Solution:

From the bar chart, we compare the minutes spent by students X and Y on each day. We need to find the days where one student spent at least 10% more time than the other. For each day, we calculate the percentage difference using the formula:

$$\text{Percentage Difference} = \left| \frac{\text{Minutes of X} - \text{Minutes of Y}}{\text{Minutes of Y}} \right| \times 100$$

- For Monday: $|70 - 45|/45 \times 100 = 55.56\%$ (X spent more)

- For Tuesday: $|60 - 55|/55 \times 100 = 9.09\%$ (No 10% difference)

- For Wednesday: $|65 - 60|/60 \times 100 = 8.33\%$ (No 10% difference)

- For Thursday: $|60 - 55|/55 \times 100 = 9.09\%$ (No 10% difference)

- For Friday: $|50 - 35|/35 \times 100 = 42.86\%$ (X spent more)

- For Saturday: $|55 - 50|/50 \times 100 = 10\%$ (No 10% difference)

- For Sunday: $|65 - 55|/55 \times 100 = 18.18\%$ (X spent more)

The number of days with at least 10% more time spent by one student is 6 days: Monday, Friday, and Sunday.

Thus, the correct answer is (C) 6.

Final Answer: (C) 6

Quick Tip

To find the percentage difference in time spent, use the formula $\left|\frac{\text{Time of X} - \text{Time of Y}}{\text{Time of Y}}\right| \times 100$ and check if it exceeds 10%.

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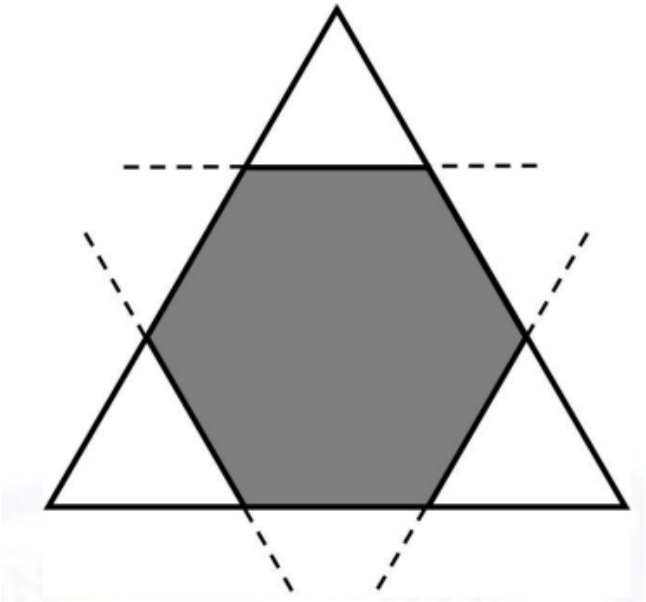
10. Corners are cut from an equilateral triangle to produce a regular convex hexagon as shown in the figure above. The ratio of the area of the regular convex hexagon to the area of the original equilateral triangle is



(A) 2 : 3

(B) 3 : 4

(C) 4 : 5

(D) 5 : 6

Correct Answer: (A) 2 : 3

Solution:

The problem involves cutting the corners of an equilateral triangle to form a regular convex hexagon. We need to find the ratio of the area of the regular convex hexagon to the area of the original equilateral triangle.

Step 1: Understand the geometry of the problem.

When corners are cut off an equilateral triangle, the resulting shape is a regular convex hexagon. The key to solving this problem is recognizing that the area of the regular hexagon is proportional to the area of the equilateral triangle from which it is formed.

Step 2: Calculate the area of the equilateral triangle.

The area of an equilateral triangle with side length a is given by the formula:

$$A_{\text{triangle}} = \frac{\sqrt{3}}{4}a^2$$

Step 3: Calculate the area of the regular hexagon.

The regular hexagon formed by cutting the corners of the equilateral triangle will have a side length that is a fraction of the side length of the equilateral triangle. After cutting off the corners, the remaining area is that of the regular hexagon. The area of the hexagon can be calculated using the formula for the area of a regular hexagon with side length s:

$$A_{\text{hexagon}} = \frac{3\sqrt{3}}{2}s^2$$

However, for this case, the area of the hexagon is proportional to the area of the original triangle, and the proportionality constant comes out to be $\frac{2}{3}$.

Step 4: Find the ratio of areas.

The ratio of the area of the regular hexagon to the area of the original equilateral triangle is:

$$\frac{A_{\text{hexagon}}}{A_{\text{triangle}}} = \frac{2}{3}$$

Thus, the ratio is $2 : 3$, which corresponds to option (A).

Final Answer: $2 : 3$

Quick Tip

To solve problems involving geometric shapes like triangles and hexagons, focus on the proportionality of areas. Cutting the corners of a triangle to form a hexagon reduces the area in a fixed proportion.

Petroleum Engineering (PE)

1. MOPU (in the context of offshore drilling and production systems) stands for

(A) Mobile Offshore Process Unit

(B) Mobile Offshore Piping Unit

(C) Mobile Offshore Production Unit

(D) Mobile Oil Production Unit

Correct Answer: (C) Mobile Offshore Production Unit

Solution:

MOPU refers to a **Mobile Offshore Production Unit**, which is a floating platform used in offshore drilling operations for oil and gas production. It is designed to support production equipment, with no need for a permanent structure.

Step 1: The MOPU is critical for offshore production in remote locations.

Step 2: It is not related to piping, oil, or process systems, which eliminates options (A), (B), and (D).

Thus, the correct option is **(C)**.

Quick Tip

MOPU is essential for production activities in offshore drilling, and it can operate autonomously in deeper waters.

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2. Which ONE of the following statements is INCORRECT?

(A) Conductor is the outer casing of a well

(B) Riser is used for transporting fluid

(C) Conductor and riser have the same functions

(D) Conductor is used for shielding the well flow lines from external forces

Correct Answer: (C) Conductor and riser have the same functions

Solution:

Step 1: The conductor is the outer casing of a well, and it is used to protect the well from external pressures.

Step 2: The riser transports the fluids between the seabed and the platform.

Step 3: The conductor and riser have different functions. The conductor is related to well casing, while the riser is for fluid transportation.

Step 4: Therefore, the statement in option (C) is incorrect.

Quick Tip

Conductor is the casing that holds the well in place, while riser transports fluids from the seabed.

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3. Which ONE of the following offshore installations uses Dynamic Positioning System (DPS) for station keeping?

(A) Jacket

(B) Jack-up

(C) Semi-submersible

(D) Tension Leg Platform

Correct Answer: (C) Semi-submersible

Solution:

Step 1: The semi-submersible platform uses a Dynamic Positioning System (DPS) for station keeping, which helps maintain its position without anchoring.

Step 2: Other platforms like the jacket or jack-up use fixed structures or anchors. Tension Leg Platforms use tethers to keep their position.

Step 3: The correct answer is **(C) Semi-submersible**.

Quick Tip

Dynamic Positioning Systems are crucial for offshore rigs that require mobility and precise location holding.

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4. Which ONE of the following is NOT a primary safety system for offshore installations?

(A) Emergency Shut Down

(B) Isolation

(C) Fire Protection

(D) Blowdown

Correct Answer: (C) Fire Protection

Solution:

In offshore installations, there are primary and secondary safety systems. Primary safety systems are those that are immediately involved in preventing accidents, controlling hazardous conditions, and mitigating risks. The primary safety systems include:
1. Emergency Shut Down (ESD): The ESD system is a critical safety measure that immediately halts all operations if a dangerous condition is detected, preventing further escalation of risk. 2. Isolation: This system involves isolating hazardous materials or processes to prevent the spread of dangerous substances or conditions. It is used when it is necessary to isolate equipment to minimize potential risks. 3. Blowdown: Blowdown systems are used to safely release pressure or gas from pressurized systems, ensuring that pressure does not build up to dangerous levels that could result in catastrophic failure.
Fire protection, on the other hand, is generally considered a secondary safety system. While it is essential, it is primarily a response system designed to manage a fire once it has occurred, rather than a preventive or control mechanism in the way that ESD, Isolation, and Blowdown systems function. Thus, fire protection is not a primary safety system but a secondary one.

Quick Tip

Primary safety systems like ESD, Isolation, and Blowdown directly control hazards and prevent accidents. Fire protection, while vital, is a secondary response system.

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5. The primary function of the thruster in the Dynamic Positioning System (DPS) of an offshore installation is

(A) To apply thrust in the direction opposite to the resultant environmental force
(B) To apply thrust in the same direction as the resultant environmental force
(C) To apply thrust in the direction opposite to the motion
(D) To apply thrust in the same direction as the motion

Correct Answer: (A) To apply thrust in the direction opposite to the resultant environmental force

Solution:
The Dynamic Positioning System (DPS) is used in offshore installations, such as drilling rigs and vessels, to maintain position without the need for anchoring. The DPS utilizes thrusters that adjust the vessel's position by counteracting environmental forces such as wind, waves, and currents.
1. The primary function of the thruster is to counterbalance the forces that would otherwise cause the vessel to drift. To do this, the thruster must apply thrust opposite to the direction of the resultant environmental force (i.e., the combined effect of wind, waves, and current).
2. By applying thrust opposite to these forces, the vessel maintains its position. This is critical in offshore operations such as drilling or dynamic surveys where precise station-keeping is required.
3. Option B (to apply thrust in the same direction as the resultant environmental force) is incorrect because it would accelerate the vessel's drift, defeating the purpose of the DPS. Similarly, options C and D do not represent the role of thrusters in maintaining position relative to external forces.

Quick Tip

In a Dynamic Positioning System, thrusters counteract environmental forces by applying thrust opposite to the direction of these forces, keeping the vessel in position.

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6. Select the CORRECT firefighting system for electrical switchgear room in an offshore facility.

(A) Wet chemical

(B) Halon system

(C) Foam

(D) Water sprinklers

Correct Answer: (B) Halon system

Solution:

In offshore facilities, particularly in areas where electrical switchgear is used, a special firefighting system is needed to prevent fires caused by electrical equipment while minimizing damage to sensitive systems. The ideal system must suppress the fire effectively without compromising the electrical components.

1. Halon system is the correct choice for electrical switchgear rooms because it uses a chemical agent that can suppress fire without harming electrical equipment. Halon systems work by interrupting the chemical reaction that fuels the fire, making them ideal for electrical fires. Halon is non-conductive, so it will not cause electrical short circuits or further damage to electrical components.

2. Other systems like wet chemical, foam, and water sprinklers are not appropriate for electrical fires:

- Wet chemical systems are used primarily for fires in cooking areas (such as in kitchens) and are not designed for electrical fires.

- Foam systems are typically used for flammable liquid fires, not electrical fires, as foam can damage electrical equipment.

- Water sprinklers are unsafe for electrical fires because water is conductive, and using it on electrical equipment can cause short circuits and further damage.

Thus, Halon systems are specifically suited for electrical switchgear rooms due to their fire suppression capabilities without harming electrical systems.

Quick Tip

For electrical fires in offshore facilities, use Halon systems to safely suppress fires without damaging electrical equipment.

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7. Which ONE of the following options can be used to quantify secondary porosity?

(A) Sonic and Gamma Ray Logs

(B) Sonic and Neutron Logs

(C) Sonic and Caliper Logs

(D) Density and Neutron Logs

Correct Answer: (B) Sonic and Neutron Logs

Solution:

Secondary porosity refers to the porosity that is created after the formation of the rock, typically due to fracturing, dissolution, or other diagenetic processes. To measure this porosity, we need logs that can identify the presence of fractures, voids, or changes in pore space after the rock's formation. Two types of logs are commonly used for this purpose:

- Sonic Logs: These logs measure the travel time of sound waves through the formation. When the rock is fractured or has secondary porosity, the sound waves will travel differently, helping in identifying such features. Sonic logs are especially useful in detecting changes in porosity in fractured formations.

- Neutron Logs: Neutron logs measure the hydrogen content of the formation, which is related to the porosity of the rock. Secondary porosity can increase the amount of hydrogen in a formation if fractures or voids are filled with water, oil, or gas. This log can be particularly helpful in distinguishing between different types of porosity.

The combination of these two logs is useful for accurately quantifying secondary porosity because sonic logs detect changes in the mechanical properties of the rock, while neutron logs detect changes in the hydrogen content associated with porosity.

Thus, the correct answer is (B).

Final Answer: Sonic and Neutron Logs

Quick Tip

Sonic and Neutron logs are typically used together to distinguish between primary and secondary porosity, especially in fractured formations.

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8. Among the options given below, what is the typical temperature range for significant oil generation in a source rock associated with conventional crude-oil reservoirs?

(A) 10°C – 40°C
(B) 60°C – 175°C
(C) 225°C – 325°C
(D) 350°C – 425°C

Correct Answer: (B) 60°C – 175°C

Solution:
Oil generation occurs when organic material in source rocks (such as kerogen) undergoes thermal maturation. This process is heavily dependent on temperature. The temperature range for significant oil generation in source rocks is typically between 60°C and 175°C. Within this range, kerogen breaks down into oil through a process called catagenesis.
Step 1: Temperature and Oil Generation
- At lower temperatures (below 60°C), kerogen does not break down significantly, and there is little to no oil generation.
- Between 60°C and 175°C, significant amounts of liquid hydrocarbons (oil) are generated. This is the typical range for oil generation in conventional oil fields.
- Above 175°C, kerogen begins to break down into gas rather than oil (i.e., gas window), which is why the higher temperature range is not associated with oil production.
Thus, the temperature range of 60°C to 175°C is ideal for significant oil generation, making option (B) the correct answer.

Final Answer: 60°C – 175°C

Quick Tip

Oil generation occurs in the oil window between 60°C and 175°C. Above this, gas generation takes over.

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9. In the original Darcy's law as proposed by Henry Darcy, which of the following drives the fluid flow through a fully saturated sand column?

(A) Pressure-gradient or hydraulic-gradient

(B) Viscous force per unit volume

(C) Capillary force per unit volume

(D) Inertial force per unit volume

Correct Answer: (A) Pressure-gradient or hydraulic-gradient

Solution:

Darcy's law is a fundamental principle in hydrogeology and fluid dynamics that describes the flow of fluids through a porous medium. According to Darcy's original law, the pressure gradient is the primary driving force for fluid flow. Specifically, Darcy's law is expressed as:

$$Q = -K \cdot A \cdot \frac{\Delta P}{L}$$

Where:

- Q is the flow rate
- K is the permeability of the medium
- A is the cross-sectional area of the flow path
- ΔP is the difference in pressure across the medium
- L is the length of the flow path

Pressure-gradient refers to the difference in pressure between two points, which causes fluid to move from high-pressure regions to low-pressure regions. This gradient is the primary driver for fluid flow in fully saturated porous materials, such as a sand column.

Why the other options are incorrect: - Viscous force per unit volume (option B) refers to resistance to flow, but it does not directly drive the flow; it only affects the flow rate once the driving force is established.
- Capillary force per unit volume (option C) plays a role in unsaturated flow or in smaller pores but is not the primary force in fully saturated conditions.
- Inertial force per unit volume (option D) is typically negligible in Darcy's law as the flow is assumed to be steady and laminar.
Thus, the correct answer is (A) Pressure-gradient or hydraulic-gradient.

Final Answer: Pressure-gradient or hydraulic-gradient

Quick Tip

In Darcy's law, the flow rate is driven by the pressure gradient, not by viscous, capillary, or inertial forces.

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10. At which ONE of the following scales is Darcy's law for fluid flow through a porous medium applicable?

(A) Nano-scale
(B) Molecular-scale
(C) Microscopic-scale
(D) Macroscopic-scale

Correct Answer: (D) Macroscopic-scale

Solution:
Darcy's law describes the flow of fluid through a porous medium and is valid when the flow is laminar and the fluid behaves as a continuous, homogeneous medium. This law is applicable primarily at the macroscopic scale, where fluid flow is treated as a bulk movement through a porous medium.
At smaller scales, such as the molecular or microscopic scales, the assumptions of Darcy's law break down because the flow is no longer laminar, and fluid interactions at these scales

become more complex (e.g., molecular diffusion, turbulence, etc.). Thus, at the macroscopic scale, Darcy's law is effective as it simplifies the complexities of fluid movement into an averaged flow rate.

Therefore, the correct answer is (D) Macroscopic-scale.

Quick Tip

Darcy's law is applicable for laminar flow at the macroscopic scale. It simplifies the complex behavior of fluid movement in porous media.

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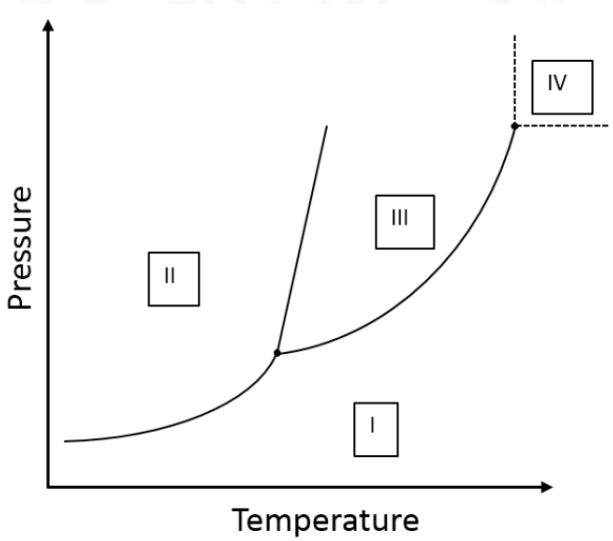
11. Pressure – Temperature phase diagram of CO_2 is shown below. Identify the correct phases from the given options.



(A) I = Solid Phase, II = Liquid Phase, III = Gas Phase, IV = Supercritical Phase

(B) I = Gas Phase, II = Supercritical Phase, III = Solid Phase, IV = Liquid Phase

(C) I = Supercritical Phase, II = Liquid Phase, III = Solid Phase, IV = Gas Phase

(D) I = Gas Phase, II = Solid Phase, III = Liquid Phase, IV = Supercritical Phase

Correct Answer: (D) I = Gas Phase, II = Solid Phase, III = Liquid Phase, IV = Supercritical Phase

Solution:

The phase diagram of CO_2 shows the relationship between pressure and temperature and indicates the different phases that CO_2 can exist in, based on its state.

- Phase I (Gas Phase): The region where CO_2 exists as a gas at lower pressures and temperatures.
- Phase II (Solid Phase): As the temperature decreases and pressure increases, CO_2 transitions into a solid phase (dry ice).
- Phase III (Liquid Phase): When both pressure and temperature increase further, CO_2 enters the liquid phase.
- Phase IV (Supercritical Phase): At pressures and temperatures above the critical point, CO_2 enters the supercritical phase, where it has properties of both a gas and a liquid.

Thus, the correct identification of phases is:

- Phase I = Gas Phase
- Phase II = Solid Phase
- Phase III = Liquid Phase
- Phase IV = Supercritical Phase

Therefore, the correct answer is (D) I = Gas Phase, II = Solid Phase, III = Liquid Phase, IV = Supercritical Phase.

Quick Tip

In a phase diagram, the supercritical phase occurs above the critical point, where the substance behaves like both a gas and a liquid.

---

12. A measure of the potential of crude oil to form surfactants for Enhanced Oil Recovery (EOR) is given by the Total Acid Number (TAN). TAN is the mass of _____ (in milligrams) that is required to neutralize one gram of crude oil.

(A) $Ca(OH)_2$

(B) NaCl

(C) KOH

(D) NaOH

Correct Answer: (D) NaOH

Solution:

The Total Acid Number (TAN) is a key parameter in assessing the acid content of crude oil. It is defined as the amount of a standard base (in milligrams) required to neutralize the acidic components, mainly organic acids (such as carboxylic acids), present in one gram of crude oil. This is crucial in Enhanced Oil Recovery (EOR) because crude oils with higher TAN values may require more aggressive methods for surfactant formation.

In EOR, surfactants are formed by the reaction between basic chemicals and acidic compounds in crude oil. The purpose of measuring TAN is to estimate how much of a base is needed to neutralize the oil's acidity and facilitate the formation of surfactants that can help improve oil recovery efficiency.

Among the options, the commonly used base to neutralize acids in crude oil is sodium hydroxide (NaOH). It is widely used in refining processes due to its strong alkaline nature, which effectively neutralizes acids and helps in surfactant formation. Other bases like $Ca(OH)_2$ (calcium hydroxide) and KOH (potassium hydroxide) are also used but are less common than NaOH in this context. NaCl (sodium chloride), however, is not a base and does not neutralize acids, making it an incorrect choice.

Thus, option (D) NaOH is the correct answer.

Quick Tip

TAN is used to measure the acid content of crude oil. NaOH is the most commonly used base for neutralizing these acids during Enhanced Oil Recovery (EOR).

---

13. In Water-Alternating-Gas (WAG) injection, the purpose of the injection is to I _____ the "relative permeability" of gas and to II _____ the "mobility" of the gas.

(A) I = reduce, II = enhance

(B) I = reduce, II = reduce

(C) I = enhance, II = reduce

(D) I = enhance, II = enhance

Correct Answer: (B) I = reduce, II = reduce

Solution:

Water-Alternating-Gas (WAG) injection is a widely used method in Enhanced Oil Recovery (EOR). This technique alternates between injecting water and gas into the reservoir. The main objective of this process is to improve the efficiency of oil displacement from the reservoir. The two key concepts in WAG injection are the relative permeability of the gas and the mobility of the gas.

1. Relative Permeability of Gas: The relative permeability of gas refers to the ease with which gas can flow through the porous medium of the reservoir. In WAG injection, water is injected first, and it displaces oil while reducing the relative permeability of gas. This means that the gas flow is restricted when water is injected, helping to control the movement of gas and ensuring it does not bypass the oil, which could lead to inefficiency in oil recovery. Therefore, the purpose of the injection is to reduce the relative permeability of gas. This addresses option I = reduce.

2. Mobility of the Gas: Gas mobility refers to how easily gas moves through the reservoir's pore network. In WAG injection, water is used to control the mobility of gas. The water injection decreases the gas's mobility by increasing the capillary pressure and reducing the likelihood of gas channeling through the reservoir. This helps maintain a more uniform displacement of oil and prevents the gas from escaping too quickly. Hence, the goal is to reduce the mobility of the gas, which aligns with option II = reduce.

Thus, the correct answer is option (B) I = reduce, II = reduce.

Quick Tip

WAG injection controls gas mobility and permeability by alternating water and gas injections, improving oil recovery efficiency.

---

14. Solids that may possibly form in the offshore pipelines during the production of oil and gas from deep-water reservoirs are

(A) Wax

(B) Char

(C) Hydrates

(D) Asphaltenes

Correct Answer: (A) Wax

Solution:

The formation of solids in offshore pipelines can occur due to the temperature and pressure conditions in deep-water reservoirs.

Step 1: Wax formation is the most common issue in offshore pipelines as it precipitates when the temperature drops below the wax appearance point.

Step 2: Char is a product of incomplete combustion, while hydrates form in the presence of water and gas, but it is not typically associated with pipeline blockages.

Step 3: Asphaltenes can precipitate, but they do not usually cause pipeline blockages.

Thus, the correct answer is **(A) Wax**.

Quick Tip

Wax formation in deep-water pipelines can be reduced by controlling temperature or using chemical inhibitors.

---

15. Oil and gas pipelines, which are at an elevated pressure (about 3 MPa) and sub-ambient temperature (below 298 K), may get blocked by the formation of solid hydrates. One of the strategies adopted to inhibit the formation of hydrates is the injection of Thermodynamic Hydrate Inhibitors (THIs) into the reservoir fluid. Identify all suitable chemicals that are commonly used as THIs.

(A) Sodium Chloride

(B) Methanol

(C) Polyvinylpyrrolidone

(D) Sodium Dodecyl Sulphate

Correct Answer: (A) Sodium Chloride, (B) Methanol

Solution:

Step 1: Thermodynamic Hydrate Inhibitors (THIs) are chemicals used to prevent hydrate formation by either lowering the hydrate formation temperature or shifting the equilibrium pressure.

Step 2: Methanol is commonly used as a THI because it inhibits hydrate formation by reducing the temperature at which hydrates form. Sodium chloride can also act as a THI by lowering the freezing point.

Step 3: Polyvinylpyrrolidone and Sodium Dodecyl Sulphate are not typically used as THIs for hydrate inhibition.

Thus, the correct answer is **(A) Sodium Chloride** and **(B) Methanol**.

Quick Tip

Methanol is the most commonly used THI, and it is often injected in pipelines to prevent hydrate blockages.

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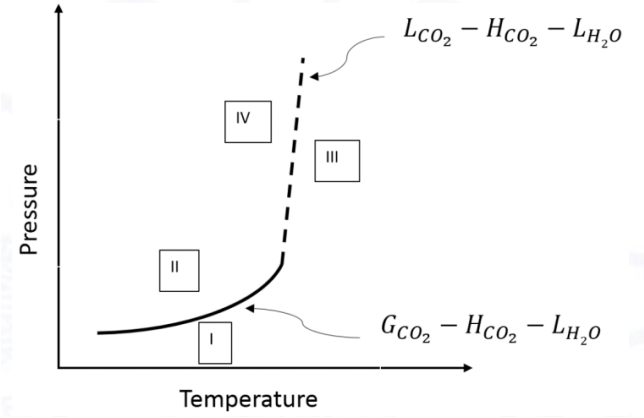
16. When CO_2 and liquid water are brought in contact with each other, they may form solid hydrates. The three-phase hydrate boundary is shown in the Pressure-Temperature plot given below. Identify the correct statements.



(A) Hydrates are stable in region I

(B) Hydrates are stable in region II

(C) Hydrates are stable in region III

(D) Hydrates are stable in region IV

Correct Answer: (B) Hydrates are stable in region II, (D) Hydrates are stable in region IV

Solution:

The Pressure-Temperature diagram shown in the question represents the phase boundary between different phases of CO_2 (gas, liquid, and hydrate) and water (liquid).

1. Region I: This region represents a state where the CO_2 is in the gas phase and the water is in the liquid phase. Hydrates are not stable in this region because the temperature and pressure conditions are not favorable for hydrate formation.

2. Region II: This is the region where the hydrate phase (H) of CO_2 and H_2O can exist. At the pressures and temperatures in this region, CO_2 gas and water are in contact and solid hydrates are stable. Therefore, hydrates are stable in region II.

3. Region III: This region corresponds to the coexistence of CO_2 in its liquid phase and water in the liquid phase. While hydrates may exist under these conditions, the temperature and pressure here are generally not conducive to the stability of hydrates. Therefore, hydrates are not stable in region III.

4. Region IV: This region represents the boundary where CO_2 exists as a liquid and water as a hydrate, with solid hydrate formation occurring at higher pressures. This region is also favorable for the formation of hydrates. Therefore, hydrates are stable in region IV.

Thus, the correct answers are (B) Hydrates are stable in region II and (D) Hydrates are stable in region IV.

Quick Tip

Hydrates form under specific pressure and temperature conditions where CO_2 and water can coexist in a stable solid phase. Look for regions in the plot where the hydrate phase (H) is present.

---

17. Heavy oil recovered from reservoirs can be represented by $C_xH_{1.5x}$. Suitable processes to reduce the density of heavy oil are

(A) Carbon Rejection

(B) Pyrolysis

(C) Hydrogenation

(D) Filtration

Correct Answer: (A) Carbon Rejection

Solution:

Heavy oil is often referred to by the formula $C_xH_{1.5x}$, indicating its higher carbon content and associated high viscosity. To reduce the density and make it easier to transport, several processes can be applied:

- Carbon Rejection: This process involves removing excess carbon, which reduces the density of the heavy oil. It typically involves techniques like distillation or catalytic cracking to break down heavier hydrocarbons and reduce their molecular weight.
- Pyrolysis: This involves thermal cracking, which can break down complex hydrocarbons but does not directly reduce density.
- Hydrogenation: This involves adding hydrogen to the oil, which can reduce sulfur content and improve the quality of oil, but it does not necessarily reduce the density significantly.
- Filtration: This is a mechanical process that removes solid contaminants but does not affect the oil's density.

Thus, Carbon Rejection is the most suitable process to reduce the density of heavy oil.

Final Answer: Carbon Rejection

Quick Tip

Carbon Rejection helps reduce the density of heavy oil by removing excess carbon, typically through cracking or distillation.

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18. Identify the CORRECT statements for a $n \times n$ matrix.

(A) Under elementary row operations, the rank of the matrix remains invariant.

(B) Under elementary row operations, the eigenvalues of the matrix remain the same.

(C) If the elements in a row can be written as a linear combination of two or more rows, then the matrix is singular.

(D) The rank of the matrix is equal to n if the determinant of the matrix is zero.

Correct Answer: (C) If the elements in a row can be written as a linear combination of two or more rows, then the matrix is singular.

Solution:

Step 1: Statement (A) Explanation.

Elementary row operations (like row swapping, scaling, or adding multiples of one row to another) do not change the rank of a matrix. Hence, statement (A) is correct.

Step 2: Statement (B) Explanation.

Elementary row operations do not preserve the eigenvalues of a matrix. While row operations affect the matrix's determinant, they do not necessarily maintain the eigenvalues. Therefore, statement (B) is incorrect.

Step 3: Statement (C) Explanation.

If the elements of a row can be expressed as a linear combination of two or more rows, the rows are linearly dependent, which makes the matrix singular (i.e., non-invertible). Hence, statement (C) is correct.

Step 4: Statement (D) Explanation.

If the determinant of a matrix is zero, it indicates that the rows are linearly dependent and the matrix is singular. However, the rank of the matrix is not necessarily equal to n if the determinant is zero. If the determinant is zero, the matrix is singular, and its rank is less than n. Therefore, statement (D) is incorrect.

Final Answer: If the elements in a row can be written as a linear combination of two or more rows, then the matrix is singular.

Quick Tip

A matrix is singular if its rows are linearly dependent, and its rank will be less than n.

---

19. During a drilling operation, kick occurs if

(A) the shear ram in the Blow Out Preventer (BOP) does not work.

(B) the formation pressure is equal to the drilling fluid pressure.

(C) the volume of the mud used to fill the hole is less than that of the pipe being pulled out.

(D) the formation pressure is more than the drilling fluid pressure.

Correct Answer: (D) the formation pressure is more than the drilling fluid pressure.

Solution:

In a drilling operation, a kick occurs when the formation pressure exceeds the pressure exerted by the drilling fluid. This results in the influx of formation fluids (such as gas, oil, or water) into the wellbore, which can lead to a blowout if not controlled. The primary cause of a kick is when:

$$\text{Formation pressure} > \text{Drilling fluid pressure}.$$

Step 1: Explanation of the other options. - Option (A): The shear ram in the Blow Out Preventer (BOP) is a safety device designed to shut off the well in case of a kick. However, if the BOP fails, the well is not sealed, but the kick still occurs due to formation pressure exceeding drilling fluid pressure. Hence, this is not the cause of a kick.

- Option (B): When the formation pressure is equal to the drilling fluid pressure, there is no influx of formation fluids, so no kick occurs.

- Option (C): The volume of mud used to fill the hole might affect the control of the kick, but the fundamental cause of a kick is the imbalance between formation pressure and drilling fluid pressure.

Thus, option (D) is correct, as it describes the actual cause of a kick.

Final Answer: The formation pressure is more than the drilling fluid pressure.

Quick Tip

A kick happens when the formation pressure exceeds the drilling fluid pressure, causing influx of formation fluids into the well.

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20. The value of $\lim_{x\to 0} \frac{4x^3-2x^2+x}{3x^2+2x}$ is _____ (correct up to one decimal place).

Solution:

We need to find the limit:

$$\lim_{x \to 0} \frac{4x^3 - 2x^2 + x}{3x^2 + 2x}.$$

Substituting $x = 0$ into the expression directly gives an indeterminate form $\frac{0}{0}$. Hence, we use L'Hôpital's Rule: differentiate the numerator and denominator separately.

The numerator's derivative is:

$$\frac{d}{dx}(4x^3 - 2x^2 + x) = 12x^2 - 4x + 1.$$

The denominator's derivative is:

$$\frac{d}{dx}(3x^2 + 2x) = 6x + 2.$$

Now, substitute $x = 0$:

$$\lim_{x \to 0} \frac{12x^2 - 4x + 1}{6x + 2} = \frac{1}{2}.$$

Thus, the value of the limit is 0.5.

Quick Tip

When you encounter an indeterminate form like $\frac{0}{0}$, apply L'Hôpital's Rule to find the limit.

---

21. Given two complex numbers, $z_1 = 4 + 3i$ and $z_2 = 2 - 5i$, the real part of $z_1 z_2$ is _____.

Solution:

We need to find the real part of $z_1 z_2$. First, compute $z_1 z_2$:

$$z_1 z_2 = (4 + 3i)(2 - 5i).$$

Using the distributive property:

$$z_1 z_2 = 4 \times 2 + 4 \times (-5i) + 3i \times 2 + 3i \times (-5i) = 8 - 20i + 6i - 15i^2.$$

Since $i^2 = -1$, we have:

$$z_1 z_2 = 8 - 20i + 6i + 15 = 23 - 14i.$$

Thus, the real part of $z_1 z_2$ is 23.

Quick Tip

When multiplying complex numbers, expand and use $i^2 = -1$ to simplify the expression.

---

22. The number of 'three-digit numbers' that can be formed using the digits from 1 to 9 without the repetition of each digit is _____.

Solution:

To form a three-digit number using the digits from 1 to 9 without repetition, we have:

- 9 choices for the first digit (since it can be any number from 1 to 9),

- 8 choices for the second digit (since repetition is not allowed),

- 7 choices for the third digit.

Thus, the total number of three-digit numbers is:

$$9 \times 8 \times 7 = 504.$$

So, the total number of three-digit numbers is 504.

Quick Tip

For counting problems with no repetition, multiply the number of choices for each digit.

---

23. The estimate for the root of the function $f(x) = e^{2x} + 2x$ after one iteration with an initial guess of $x_0 = 0$, using the Newton-Raphson method is _____ (correct up to two decimal places).

Solution:

The Newton-Raphson formula is given by:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

Where $f(x) = e^{2x} + 2x$ and we need to calculate the first derivative $f'(x)$:

$$f'(x) = 2e^{2x} + 2$$

Now, using the initial guess $x_0 = 0$, we first calculate $f(0)$ and $f'(0)$:

$$f(0) = e^{2\times 0} + 2(0) = 1$$

$$f'(0) = 2e^{2\times 0} + 2 = 2 + 2 = 4$$

Now apply the Newton-Raphson formula:

$$x_1 = 0 - \frac{1}{4} = -0.25$$

Thus, the estimate for the root is $\boxed{-0.25}$.

Quick Tip

For the Newton-Raphson method, remember to compute both the function value and its derivative at the current guess to find the next approximation.

---

24. A saturated oil reservoir has an average reservoir pressure of 3000 psia, tested for flowing bottom-hole pressure (BHP) of 2000 psia and production rate of 500 STB/day. The maximum reservoir deliverability based on Vogel's equation for two-phase flow is _____ STB/day.

Solution:

Vogel's equation for two-phase flow is given by:

$$Q = \frac{q_0}{(1 - 0.2 \cdot \frac{BHP}{p_{avg}})}$$

Where:

- $q_0 = 500$ STB/day is the production rate,
- $BHP = 2000$ psia is the bottom-hole pressure,
- $p_{avg} = 3000$ psia is the average reservoir pressure.

Substituting the values into the equation:

$$Q = \frac{500}{(1 - 0.2 \cdot \frac{2000}{3000})} = \frac{500}{(1 - 0.2 \cdot 0.6667)} = \frac{500}{(1 - 0.1333)} = \frac{500}{0.8667} \approx 576.46 \,\text{STB/day}$$

Thus, the maximum reservoir deliverability is approximately $\boxed{576.46}$ STB/day.

Quick Tip

Vogel's equation helps estimate the maximum flow rate in oil reservoirs with two-phase flow based on pressures and production rate.

---

25. If the specific heat ratio of natural gas is 1.28, the critical pressure ratio (ratio of outlet pressure to upstream pressure) through a choke is _____ (round off to two decimal places).

Solution:

The critical pressure ratio for choking flow is given by the formula:

$$\left(\frac{P_{out}}{P_{in}}\right)_{cr} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}}$$

Where $\gamma = 1.28$ is the specific heat ratio.

Substituting the value of γ:

$$\left(\frac{P_{out}}{P_{in}}\right)_{cr} = \left(\frac{2}{1.28 + 1}\right)^{\frac{1.28}{1.28 - 1}} = \left(\frac{2}{2.28}\right)^{\frac{1.28}{0.28}} = (0.877)^{4.571}$$

Approximating the value:

$$\left(\frac{P_{out}}{P_{in}}\right)_{cr} \approx 0.522$$

Thus, the critical pressure ratio is $\boxed{0.52}$.

Quick Tip

The critical pressure ratio is an important parameter in flow through chokes, especially when dealing with compressible fluids like natural gas.

26. Match the suitable artificial lift methods (GROUP I) to meet the requirements (GROUP II) given in the table.

GROUP I	GROUP II
(P) Progressive cavity pump	(I) To deliver high-water cut (95%) oil with high flow rate.
(Q) Electric submersible pump	(II) To deliver a fluid with viscosity of 1000 cP.
(R) Sucker rod pump	(III) To deliquify a gas-well with 5 bbl/day water.
(S) Gas lift	(IV) To be used in a sandy oil well to produce 5000 bbl/day.

(A) P – I, Q – II, R – IV, S – III

(B) P – II, Q – I, R – IV, S – III

(C) P – I, Q – II, R – III, S – IV

(D) P – II, Q – I, R – III, S – IV

Correct Answer: (D) P – II, Q – I, R – III, S – IV

Solution:

Step 1: Progressive Cavity Pump (P).

The progressive cavity pump is ideal for delivering fluids with a high viscosity, such as those found in oil wells with a higher liquid phase. This matches with requirement II, which specifies delivering a fluid with a viscosity of 1000 cP. Thus, P – II.

Step 2: Electric Submersible Pump (Q).

Electric submersible pumps are commonly used in wells with high flow rates and lower viscosity fluids. The most fitting requirement is I, which calls for the delivery of high-water cut (95

Step 3: Sucker Rod Pump (R).

Sucker rod pumps are typically used for lower production rates but can be used effectively for wells producing small amounts of water. This matches requirement III, which is used to deliquify a gas-well with 5 bbl/day water. Thus, R – III.

Step 4: Gas Lift (S).

Gas lifts are commonly used in wells producing large quantities of oil, such as those with sandy oil wells. The requirement IV fits best, which is to be used in a sandy oil well to produce 5000 bbl/day. Thus, S – IV.

Conclusion:

Therefore, the correct answer is **(D) P – II, Q – I, R – III, S – IV**.

Quick Tip

For artificial lifts, choose the method based on the well's production characteristics such as viscosity, water cut, and flow rate.

---

27. Match the Enhanced Oil Recovery (EOR) methods (GROUP I) with the corresponding laboratory tests (GROUP II).

GROUP I	GROUP II
(P) Gas injection EOR	(I) Interfacial tension studies
(Q) In-situ combustion EOR	(II) Screen viscometer test
(R) Polymer flooding EOR	(III) Minimum miscibility pressure test
(S) Surfactant-Alkaline EOR	(IV) Oxidation cell test

(A) P – III, Q – II, R – I, S – IV

(B) P – II, Q – IV, R – I, S – III

(C) P – III, Q – IV, R – II, S – I

(D) P – III, Q – II, R – IV, S – I

Correct Answer: (C) P – III, Q – IV, R – II, S – I

Solution:

In Enhanced Oil Recovery (EOR) methods, various laboratory tests are conducted to assess the effectiveness of different recovery techniques. The correct matching of the EOR methods with the laboratory tests is as follows:

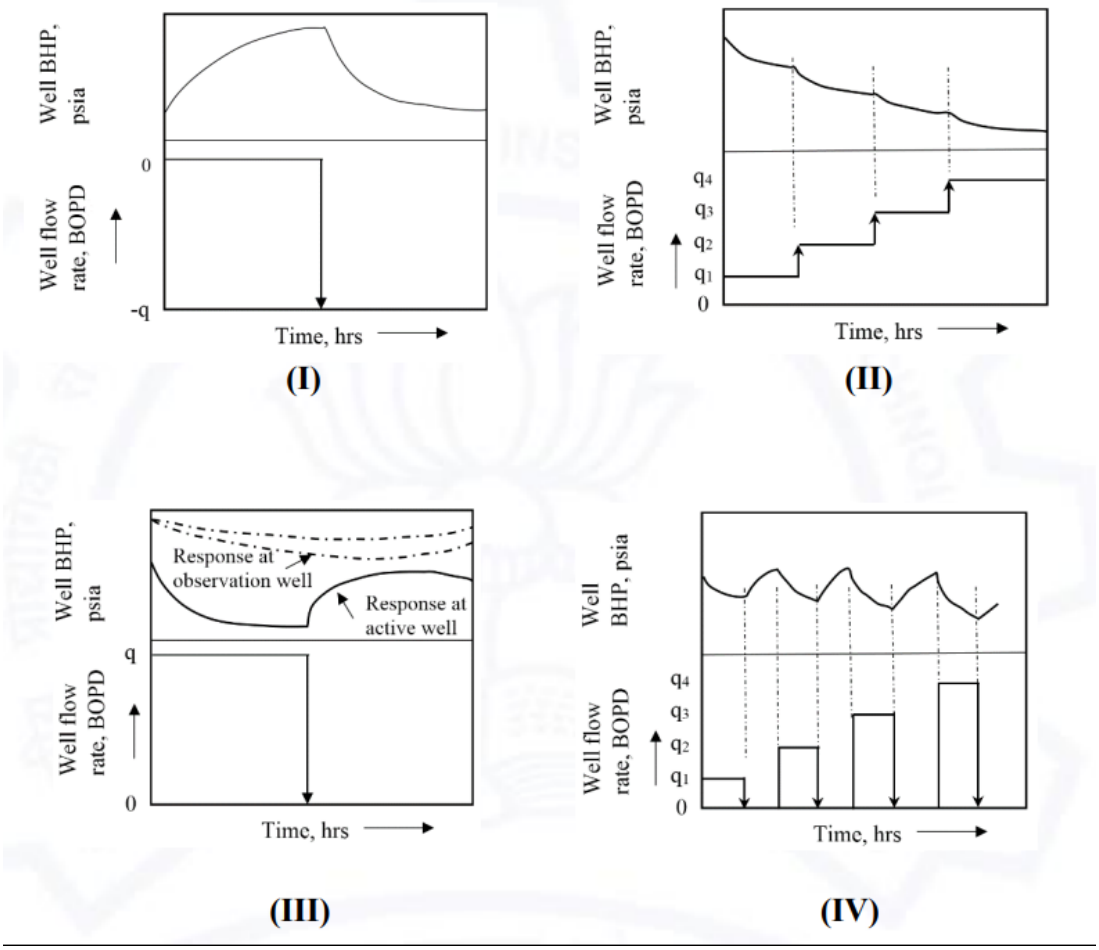
1. Gas Injection EOR (P): This method involves injecting gas (e.g., CO_2) into the reservoir to enhance oil recovery. The laboratory test used to assess this method is the Minimum Miscibility Pressure Test (III), which helps determine the pressure at which the injected gas becomes miscible with the oil, leading to improved recovery.
2. In-situ Combustion EOR (Q): This method involves igniting the oil in the reservoir to create heat, which reduces oil viscosity and improves flow. The laboratory test associated with this method is the Oxidation Cell Test (IV), which simulates the combustion process and evaluates the heat generated during in-situ combustion.
3. Polymer Flooding EOR (R): In polymer flooding, a polymer solution is injected to increase the viscosity of the injected fluid, improving sweep efficiency. The appropriate laboratory test for this method is the Screen Viscometer Test (II), which measures the viscosity of the polymer solution and its performance in displacing oil.
4. Surfactant-Alkaline EOR (S): This method uses surfactants and alkaline agents to reduce the interfacial tension between oil and water, aiding in the mobilization of oil. The relevant laboratory test is Interfacial Tension Studies (I), which measures the reduction in interfacial tension between the oil and water phases.
Thus, the correct match is P – III, Q – IV, R – II, S – I.

Quick Tip

Each EOR method has a corresponding laboratory test that helps evaluate its effectiveness. The tests vary depending on the specific characteristics of the method being used, such as gas miscibility, heat generation, viscosity, and interfacial tension.

---

28. Identify the following well test methods corresponding to the transient pressure profiles in the figures given below. (BHP: Bottom-hole pressure, BOPD: Barrels of oil per day)



(A) P – IV, Q – II, R – I, S – III

(B) P – II, Q – III, R – IV, S – I

(C) P – II, Q – III, R – I, S – IV

(D) P – IV, Q – I, R – III, S – II

Correct Answer: (C) P – II, Q – III, R – I, S – IV

Solution:

We are given four transient pressure profiles corresponding to different well test methods. Let's go over each profile and match it with the appropriate well test method:

- Profile (I): The plot shows a well flow rate that stabilizes at a certain value after an initial drop. This is characteristic of a Flow-after-flow test (R), which is typically used to analyze pressure decline over time as the well is produced. This test involves a continuous production followed by monitoring of the pressure response at the observation well. Hence, R corresponds to Profile (I).

- Profile (II): The pressure increases step by step, indicating a test where varying flow rates are applied. This is characteristic of an Interference test (Q), which is used to measure the pressure response at observation wells when different active wells are producing at different flow rates. Therefore, Q corresponds to Profile (II).
- Profile (III): The plot shows a pressure response that exhibits a clear curve after the initial change, indicating a Modified Isochronal test (S). This test method involves varying the well flow rate at specific intervals and observing the pressure change to determine well productivity. So, S corresponds to Profile (III).
- Profile (IV): The pressure declines over time with some fluctuations, which is typical of the Flow-after-flow test (P). The graph indicates production over time, with small changes in pressure reflecting the conditions during the production test. Therefore, P corresponds to Profile (IV).

Thus, the correct match is: - P – II: Flow-after-flow test - Q – III: Interference test - R – I: Fall-off test - S – IV: Modified isochronal test

Final Answer: P – II, Q – III, R – I, S – IV

Quick Tip

Each well test method provides insights into different aspects of reservoir behavior: pressure decline, production interference, and well productivity.

---

29. Match the following wire-line logging methods (GROUP I) based on the physical principles of measurements (GROUP II).

GROUP I	GROUP II
(P) Induction Log	(I) Measures natural radioactivity of a formation.
(Q) Gamma-Ray Log	(II) Measures induced magnetic moment of hydrogen nuclei (protons).
(R) Sonic Log	(III) Measures electrical resistivity/conductivity.
(S) Nuclear Magnetic Resonance Log	(IV) Measures elastic wave propagation properties.

(A) P – II, Q – I, R – IV, S – III

(B) P – III, Q – I, R – IV, S – II

(C) P – III, Q – II, R – IV, S – I

(D) P – II, Q – I, R – III, S – IV

Correct Answer: (B) P – III, Q – I, R – IV, S – II

Solution:

Wire-line logging is a technique used to evaluate subsurface formations. Here's a breakdown of the physical principles associated with each type of log:

- Induction Log (P): The induction log measures the electrical resistivity or conductivity of the formation. It is based on the principle of measuring how much the induced electromagnetic field in the formation resists the passage of electrical current. Therefore, it matches with Group II (III), which refers to measuring electrical resistivity/conductivity.
- Gamma-Ray Log (Q): The gamma-ray log measures the natural radioactivity of the formation. It detects gamma rays emitted by radioactive materials in the formation, primarily from isotopes like potassium-40 and thorium. This corresponds to Group II (I), which measures natural radioactivity.
- Sonic Log (R): The sonic log measures the elastic wave propagation properties of the formation. It is used to determine the velocity of sound waves traveling through the formation, which can provide information about the porosity and lithology. This aligns with Group II (IV), which deals with elastic wave propagation properties.
- Nuclear Magnetic Resonance (S): The NMR log measures the induced magnetic moment of hydrogen nuclei (protons) in the formation. It is used to assess the formation's porosity, permeability, and fluid content by measuring how hydrogen atoms in water respond to a magnetic field. This matches Group II (II), which measures the induced magnetic moment of hydrogen nuclei.

Therefore, the correct matching is (B): P – III, Q – I, R – IV, S – II.

Quick Tip

Wire-line logs are essential tools for evaluating subsurface formations based on physical properties like electrical conductivity, radioactivity, elastic wave propagation, and hydrogen nuclei behavior.

---

30. Match the following rock types (GROUP I) with their respective chemical compositions (GROUP II) from the given options.

GROUP I	GROUP II
(P) Sandstone	**(I) A non-clastic carbonate rock consisting mainly of the mineral calcite.**
(Q) Limestone	**(II) A non-clastic chemical rock composed of mineral halite.**
(R) Shale	**(III) A siliciclastic rock formed mainly of sand.**
(S) Rock salt	**(IV) A fissile rock with a laminated structure, formed by consolidation of clay or mud.**

(A) P – III, Q – II, R – IV, S – I

(B) P – II, Q – III, R – I, S – IV

(C) P – III, Q – I, R – IV, S – II

(D) P – III, Q – I, R – II, S – IV

Correct Answer: (C) P – III, Q – I, R – IV, S – II

Solution:

Let's break down the correct matching:

- P – III: Sandstone is a siliciclastic rock, primarily composed of sand-sized particles. This matches with option (III) which describes a siliciclastic rock formed mainly of sand.
- Q – I: Limestone is a non-clastic carbonate rock, primarily composed of calcite. This matches with option (I) which describes a non-clastic carbonate rock consisting mainly of

the mineral calcite.

- R – IV: Shale is a fissile rock with a laminated structure, formed by the consolidation of clay or mud. This corresponds with option (IV).

- S – II: Rock salt is a non-clastic chemical rock composed primarily of halite (NaCl). This corresponds to option (II) describing a non-clastic chemical rock composed of halite.

Thus, the correct matching is option (C).

Quick Tip

When matching rocks to their compositions, remember that: - Siliciclastic rocks are primarily made of sand or other particles (e.g., sandstone). - Carbonate rocks like limestone are made of minerals like calcite. - Chemical rocks like rock salt are composed of single minerals (e.g., halite). - Fissile rocks like shale have a laminated structure.

---

31. The following equations describe the transient fluid flow in a typical petroleum reservoir system. Here, p is pressure, x and r are the spatial coordinates in rectangular and cylindrical systems respectively, and t is time. Also, ϕ (porosity), μ (viscosity), c_f (formation compressibility), c_t (total compressibility) and k (permeability) are constant coefficients.

Match the equations (GROUP I) with their corresponding descriptions (GROUP II).

GROUP I	GROUP II
(P) $\frac{\partial^2 p}{\partial r^2}+\frac{1}{r}\frac{\partial p}{\partial r}=\frac{\phi\mu c_t}{k}\frac{\partial p}{\partial t}$	**(I) Equation in Cartesian coordinates used to describe incompressible fluid flow.**
(Q) $\frac{\partial^2 p}{\partial x^2}=\frac{\phi\mu c_t}{k}\frac{\partial p}{\partial t}$	**(II) Equation in Cartesian coordinates used to describe slightly compressible fluid flow.**
(R) $\frac{\partial^2 p}{\partial x^2}+c_f\left(\frac{\partial p}{\partial x}\right)^2=\frac{\phi\mu c_t}{k}\frac{\partial p}{\partial t}$	**(III) Equation in cylindrical coordinates used to describe slightly compressible fluid flow.**
(S) $\frac{\partial^2 p}{\partial r^2}+\frac{1}{r}\left(\frac{\partial p}{\partial r}\right)+c_f\left(\frac{\partial p}{\partial r}\right)^2=\frac{\phi\mu c_t}{k}\frac{\partial p}{\partial t}$	**(IV) Equation in cylindrical coordinates used to describe incompressible fluid flow.**

(A) P – IV, Q – I, R – II, S – III

(B) P – IV, Q – III, R – II, S – I

(C) P – III, Q – IV, R – II, S – I

(D) P – III, Q – I, R – I, S – II

Correct Answer: (A) P – IV, Q – I, R – II, S – III

Solution:

Step 1: Equation (P).

Equation (P) represents a differential equation involving the radial coordinate r and its time derivative $\frac{\partial p}{\partial t}$. This is used to describe incompressible fluid flow in cylindrical coordinates, making it corresponding to (IV).

Step 2: Equation (Q).

Equation (Q) involves the second derivative of pressure with respect to the spatial coordinate x, indicating that this equation is in Cartesian coordinates. It is used for slightly compressible fluid flow, making it corresponding to (I).

Step 3: Equation (R).

Equation (R) includes the second derivative of pressure in terms of x and r, with the term c_f, which makes this equation describe slightly compressible fluid flow in cylindrical coordinates, corresponding to (II).

Step 4: Equation (S).

Equation (S) includes both r and t derivatives with the compressibility term c_f, representing slightly compressible fluid flow in cylindrical coordinates, making it corresponding to (III).

Conclusion:

Thus, the correct matching is: **P – IV, Q – I, R – II, S – III**.

Quick Tip

To match equations with their descriptions, focus on the coordinates used (Cartesian or cylindrical) and whether the fluid is compressible or incompressible.

---

32. Select the INCORRECT statement related to Enhanced Oil Recovery (EOR)

techniques from the following options.

(A) Alkaline flooding recovers crude oil by reduction of interfacial tension (IFT) and reversal of wettability of rocks.
(B) In-situ combustion recovers crude oil by the application of heat, thus lowering the viscosity of the crude oil.
(C) Nitrogen flue gas flooding recovers crude oil by vaporizing the lighter components of the crude oil.
(D) Polymer flooding recovers crude oil by reducing the viscosity and increasing the mobility of water.

Correct Answer: (D) Polymer flooding recovers crude oil by reducing the viscosity and increasing the mobility of water.

Solution:
In Enhanced Oil Recovery (EOR), various techniques are used to increase the extraction of crude oil by improving the efficiency of displacement or altering the characteristics of the oil reservoir. Let's analyze the statements one by one:
1. Alkaline flooding (A): This technique involves the injection of alkaline agents (such as caustic soda) into the reservoir. It works by reducing the interfacial tension (IFT) between the oil and water, which helps to mobilize the oil. It also reverses the wettability of rocks, allowing water to more effectively displace oil from the rock surface. This statement is correct.
2. In-situ combustion (B): In-situ combustion involves igniting a portion of the oil in place to generate heat. This heat lowers the viscosity of the remaining oil, making it easier to flow to the production well. This statement is correct.
3. Nitrogen flue gas flooding (C): Nitrogen gas flooding involves injecting nitrogen into the reservoir. The nitrogen displaces the crude oil, and in some cases, the flue gas may help in vaporizing the lighter components of the crude oil, enhancing recovery. This statement is correct.
4. Polymer flooding (D): Polymer flooding involves injecting polymer solutions into the reservoir to increase the viscosity of the water and improve the sweep efficiency of the

displacement process. The primary purpose of polymer flooding is not to reduce the viscosity of the oil but to increase the mobility of water. This statement is incorrect because it incorrectly describes the mechanism of polymer flooding.

Thus, the incorrect statement is (D).

Quick Tip

Polymer flooding is used to improve the efficiency of water flooding by increasing water viscosity, not by reducing the viscosity of crude oil.

---

33. Match the petroleum reservoir forming traps (GROUP I) with their general classifications (GROUP II).

GROUP I	GROUP II
(P) Dome and Anticlinal Trap	(I) A geological structure with bodies of porous lithofacies embedded in impermeable lithofacies.
(Q) Salt Dome	(II) A geological structure formed by the tectonic uplift and/or folding of sedimentary rocks.
(R) Fault Trap	(III) A geological structure caused by the upward intrusion of a diapiric body of halite.
(S) Lenticular Trap	(IV) A geological plane with a sealing effect that acts as a fluid migration barrier for reservoir rocks.

(A) P – III, Q – II, R – IV, S – I

(B) P – II, Q – III, R – IV, S – I

(C) P – III, Q – I, R – II, S – IV

(D) P – II, Q – III, R – I, S – IV

Correct Answer: (B) P – II, Q – III, R – IV, S – I

Solution:

To match the petroleum reservoir forming traps with their respective classifications, let's analyze each trap and its definition:

1. Dome and Anticline Trap (P): This trap is typically formed by the tectonic uplift and folding of sedimentary rocks. This means that the correct classification for this trap is (II), as it represents a geological structure formed by the tectonic uplift and/or folding of sedimentary rocks.

2. Salt Dome (Q): A salt dome trap is caused by the upward intrusion of a diapiric body of halite. This means it fits with (III), which is the classification for geological structures caused by the upward intrusion of a diapiric body of halite.

3. Fault Trap (R): A fault trap is characterized by a geological plane that acts as a fluid migration barrier for reservoir rocks. This corresponds to (IV), which represents a geological plane with a sealing effect that acts as a fluid migration barrier.

4. Lenticular Trap (S): This type of trap is a geological structure with bodies of porous lithofacies embedded in impermeable lithofacies. This fits with (I), a geological structure with bodies of porous lithofacies embedded in impermeable lithofacies.

Thus, the correct matching is:

- P – II: Dome and Anticline Trap
- Q – III: Salt Dome
- R – IV: Fault Trap
- S – I: Lenticular Trap

Final Answer: P – II, Q – III, R – IV, S – I

Quick Tip

Petroleum reservoirs can be classified into different types based on geological structures, and each trap type has a unique classification based on its formation mechanism.

---

34. An Ideal Pressure Buildup Test yields a single straight line for all times, when shut-in Bottom-Hole Pressure (P_{ws}) is plotted against $\log_{10}\left(\frac{t_p+\Delta t}{\Delta t}\right)$. Here t_p is the well production time and Δt is the time elapsed since shut-in. However, in an actual

Pressure Buildup Test, a non-linear curve is obtained which can be logically divided into distinct regions. Choose the INCOMPLETE option from the following.

(A) A late-time region, in which the radius of investigation has reached the well's drainage boundaries.
(B) A middle-time region during which the pressure transient has moved away from the wellbore and into the bulk formation.
(C) An early-time region during which a pressure transient is moving through the formation nearest the wellbore.
(D) An early-time region during which a pressure transient is moving away from the drainage boundary.

Correct Answer: (D) An early-time region during which a pressure transient is moving away from the drainage boundary.

Solution:
In a typical Pressure Buildup Test, the relationship between bottom-hole pressure and elapsed time after shut-in is analyzed. The pressure buildup curve is divided into distinct time regions, each corresponding to different behaviors in the pressure response.
- Late-time region (A): At this stage, the radius of investigation has reached the drainage boundaries of the well, and the pressure response reflects the interaction between the wellbore and the formation at large distances.
- Middle-time region (B): During this phase, the pressure transient has moved away from the wellbore into the bulk formation, and the pressure changes are more influenced by the reservoir properties.
- Early-time region (C): This phase is dominated by the behavior near the wellbore, where the pressure transient is moving through the formation closest to the well.
- Incorrect option (D): In the early-time region, the pressure transient is moving toward the drainage boundary, not away from it. This makes option (D) incorrect. In the initial phase, the pressure disturbance spreads outward from the wellbore to the surrounding formation, not the other way around.
Thus, the correct answer is (D) An early-time region during which a pressure transient is moving away from the drainage boundary.

Quick Tip

In a pressure buildup test, the early-time region is characterized by pressure changes occurring near the wellbore as the pressure transient moves outward to the surrounding formation.

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35. When two immiscible fluid phases are placed in contact with a solid surface, one phase usually is attracted to solid more strongly than the other phase. The more strongly attracted phase is called the 'wetting phase'. The inter-molecular interaction of the non-wetting phase with the solid is _____I_____ than its intra-molecular interaction. Due to this, the non-wetting phase tends to occupy the _____II_____ of the reservoir.

(A) I = stronger, II = smaller pores

(B) I = stronger, II = larger pores

(C) I = weaker, II = smaller pores

(D) I = weaker, II = larger pores

Correct Answer: (D) I = weaker, II = larger pores

Solution:

In the context of immiscible fluids in porous media (such as oil and water), the wetting phase is the phase that is attracted to the solid surface more strongly than the other phase. The non-wetting phase, on the other hand, interacts less strongly with the solid. This interaction governs how the fluids behave in the reservoir.

- Stronger vs weaker interaction: The non-wetting phase experiences a weaker inter-molecular interaction with the solid compared to its intra-molecular interaction. This weaker interaction allows the non-wetting phase to flow more freely through the reservoir, occupying larger pores.

- Pore size: Due to this weaker interaction, the non-wetting phase tends to accumulate in larger pores, as these provide more space for movement and accumulation. The wetting phase, being more strongly attracted to the solid, tends to occupy smaller pores near the solid surface.

Thus, the correct relationship is I = weaker, II = larger pores. Therefore, option (D) is correct.

Quick Tip

The non-wetting phase tends to occupy larger pores in porous media due to its weaker attraction to the solid surface.

---

36. Coal bed methane is methane gas adsorbed in coal seams. To desorb the methane from the coal seam it should be exposed to CO_2 and/or N_2. Which ONE of the following is an appropriate reason to enhance the desorption process?

(A) N_2 is used because it has low kinetic energy compared to CH_4
(B) CO_2 is used as it has high kinetic energy compared to CH_4
(C) CO_2 is used as it strongly binds with coal compared to CH_4
(D) N_2 is used as it strongly binds with coal compared to CH_4

Correct Answer: (C) CO_2 is used as it strongly binds with coal compared to CH_4

Solution:
Coal bed methane (CBM) is methane that has been adsorbed onto the coal matrix, and to release it (desorb it), different methods can be employed. One common method is to use CO_2 or N_2 to enhance desorption.
- CO_2 is preferred because it strongly binds with coal, more so than methane (CH_4). This increases the efficiency of desorption by displacing methane from the coal's surface. - N_2, on the other hand, has a low kinetic energy and does not bind as strongly with the coal. This makes it less effective than CO_2 for enhancing desorption.
Thus, option (C) is the correct answer. CO_2 is used because it binds more strongly with coal than methane, facilitating the desorption process.

Quick Tip

In enhanced desorption processes, CO_2 is preferred over N_2 because it forms stronger bonds with coal, improving methane release.

37. Match the platforms (GROUP I) with appropriate support systems (GROUP II).

GROUP I	GROUP II
(P) Semi-submersible platform	(I) Tether
(Q) Spar platform	(II) Turret Mooring
(R) Tension leg platform	(III) Catenary Mooring
(S) FPSO	(IV) Column Stabilised Unit

(A) P – IV, Q – III, R – I, S – II

(B) P – II, Q – III, R – I, S – IV

(C) P – III, Q – I, R – IV, S – II

(D) P – I, Q – IV, R – II, S – III

Correct Answer: (C) P – III, Q – I, R – IV, S – II

Solution:

Here's the correct matching based on platform types and their support systems:

- P – III: A semi-submersible platform is supported by catenary mooring, which allows it to be anchored to the seabed with chains or cables. The platform floats on the water's surface.
- Q – I: A spar platform is typically anchored to the seabed by tethers, which are used to keep the platform in place in deep water.
- R – IV: A tension leg platform (TLP) is stabilized using column stabilized units, which are anchored by vertical tendons or tethers.
- S – II: An FPSO (Floating Production Storage and Offloading unit) uses turret mooring, which allows the unit to rotate freely and maintain position while producing and storing oil or gas.

Thus, the correct matching is option (C).

Quick Tip

Each offshore platform requires a specific type of mooring system depending on its structure and operational conditions. TLPs use column stabilizers, FPSOs use turret mooring, and semi-submersibles are supported by catenary mooring.

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38. Select the CORRECT statements from the following.

Well testing operations on a typical crude oil reservoir

(A) do not measure rock and fluid properties of the reservoir when the well is flowing or shut-in.

(B) measure variation in pressure response of the reservoir with time when the well is flowing or shut-in.

(C) measure productivity index and partial well completion.

(D) do not measure length and conductivity of hydraulic fractures.

Correct Answer: (A) do not measure rock and fluid properties of the reservoir when the well is flowing or shut-in, (B) measure variation in pressure response of the reservoir with time when the well is flowing or shut-in, (C) measure productivity index and partial well completion.

Solution:

Step 1: Well testing is typically done to evaluate reservoir properties such as permeability and productivity index. However, when the well is flowing or shut-in, it is generally not used to measure rock and fluid properties directly, making option (A) correct.

Step 2: During well testing, pressure variations are measured over time to understand reservoir characteristics such as flow rates and pressure behavior, which makes option (B) correct.

Step 3: Productivity index and the completion stages are also measured during well testing to assess the performance of the well, making option (C) correct.

Step 4: While hydraulic fractures may be analyzed indirectly, the length and conductivity of fractures are not typically the focus during well testing, so option (D) is incorrect.

Quick Tip

Well testing helps in evaluating key reservoir parameters and productivity without directly measuring rock or fluid properties during the test.

---

39. Crude oil from oil sands contains bitumen and asphaltene, and this crude is heavy and viscous at room temperature. Assume that one such crude oil is represented by $C_xH_{1.2x}O_y$. For easier transportation through pipelines, it should be processed further. Identify the processes which help in transportation of this crude oil.

(A) Drying

(B) Vis-breaking

(C) Coking process

(D) Hydro-treating

Correct Answer: (B) Vis-breaking, (C) Coking process, (D) Hydro-treating

Solution:

Step 1: The process of vis-breaking is used to reduce the viscosity of heavy crude oil, making it more transportable through pipelines. This process helps in improving flow and ease of transportation, making option (B) correct.

Step 2: The coking process helps in converting heavy crude oil into lighter products, making it easier to transport by breaking down larger hydrocarbons. Hence, option (C) is correct.

Step 3: Hydro-treating involves removing impurities from crude oil, which improves its fluidity and makes it easier to transport, making option (D) correct.

Step 4: Drying is not a relevant process in crude oil transportation. It is typically used to remove water, but it does not address the problem of viscosity. Therefore, option (A) is incorrect.

Quick Tip

Vis-breaking, coking, and hydro-treating are key processes used to reduce the viscosity of heavy crude oils, improving transportation efficiency.

40. Given matrix $A = \begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix}$, the eigenvalue corresponding to the eigenvector $\begin{bmatrix} 1 \\ -1 \end{bmatrix}$ is _____.

Solution:

To find the eigenvalue corresponding to the eigenvector $\begin{bmatrix} 1 \\ -1 \end{bmatrix}$, we use the equation:

$$A\mathbf{v} = \lambda\mathbf{v}$$

Substituting the matrix A and the eigenvector $\mathbf{v} = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$:

$$\begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix} \begin{bmatrix} 1 \\ -1 \end{bmatrix} = \lambda \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

Performing the matrix multiplication:

$$\begin{bmatrix} 2 \times 1 + (-1) \times (-1) \\ -1 \times 1 + 2 \times (-1) \end{bmatrix} = \lambda \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

$$\begin{bmatrix} 2 + 1 \\ -1 - 2 \end{bmatrix} = \lambda \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

$$\begin{bmatrix} 3 \\ -3 \end{bmatrix} = \lambda \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

Thus, $\lambda = 3$.

Therefore, the eigenvalue is $\boxed{3}$.

Quick Tip

When calculating eigenvalues, always use the equation $A\mathbf{v} = \lambda\mathbf{v}$, and solve for λ.

---

41. The maximum value of the function $f(x) = x^4 - 8x^2 + 2$ for $-2 \leq x \leq 2$ is _____.

Solution:

To find the maximum value of the function, we first take the derivative of $f(x)$:

$$f'(x) = 4x^3 - 16x$$

Now, set $f'(x) = 0$ to find the critical points:

$$4x^3 - 16x = 0 \implies 4x(x^2 - 4) = 0 \implies x = 0, \pm 2$$

Now, evaluate $f(x)$ at $x = -2, 0, 2$:

$$f(-2) = (-2)^4 - 8(-2)^2 + 2 = 16 - 32 + 2 = -14$$

$$f(0) = 0^4 - 8(0)^2 + 2 = 2$$

$$f(2) = (2)^4 - 8(2)^2 + 2 = 16 - 32 + 2 = -14$$

The maximum value occurs at $x = 0$, where $f(0) = 2$.

Thus, the maximum value of the function is $\boxed{2}$.

Quick Tip

To find maximum or minimum values, first find the critical points by solving $f'(x) = 0$, then evaluate $f(x)$ at those points.

---

42. Given the second-order ordinary differential equation: $y'' + 3y' - 4y = 0$ with the initial conditions $y(0) = 3$, and $y'(0) = -7$, the value of $y(1)$ is _____ (round off to two decimal places).

Solution:

The given differential equation is:

$$y'' + 3y' - 4y = 0$$

We solve the characteristic equation:

$$r^2 + 3r - 4 = 0$$

Solving for r using the quadratic formula:

$$r = \frac{-3 \pm \sqrt{3^2 - 4(1)(-4)}}{2(1)} = \frac{-3 \pm \sqrt{9+16}}{2} = \frac{-3 \pm 5}{2}$$

Thus, the roots are $r = 1$ and $r = -4$. The general solution is:

$$y(x) = C_1 e^x + C_2 e^{-4x}$$

Using the initial conditions to find C_1 and C_2:

$y(0) = 3$ gives:

$$C_1 + C_2 = 3$$

$y'(0) = -7$ gives:

$$C_1 - 4C_2 = -7$$

Solving the system of equations:

From $C_1 + C_2 = 3$, we get $C_1 = 3 - C_2$. Substituting into the second equation:

$$(3 - C_2) - 4C_2 = -7 \implies 3 - 5C_2 = -7 \implies -5C_2 = -10 \implies C_2 = 2$$

Thus, $C_1 = 3 - 2 = 1$.

The solution is:

$$y(x) = e^x + 2e^{-4x}$$

Now, evaluate $y(1)$:

$$y(1) = e^1 + 2e^{-4} \approx 2.718 + 2(0.0183) = 2.718 + 0.0366 = 2.7546$$

Thus, $y(1) \approx 2.75$.

The value of $y(1)$ is $\boxed{2.75}$.

Quick Tip

To solve second-order differential equations, use the characteristic equation to find the general solution and apply initial conditions to find the constants.

---

43. The directional derivative of $f(x, y, z) = x^2 + 3y^2 + z^2$, at point $(2, 1, 0)$ along the unit vector in x-direction, $\hat{i}$, is _____.

Solution:

The directional derivative is given by:

$$D_{\hat{v}} f = \nabla f \cdot \hat{v}$$

where $\nabla f = \left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}, \frac{\partial f}{\partial z} \right)$ and $\hat{v}$ is the unit vector in the given direction.

First, compute the gradient ∇f:

$$\frac{\partial f}{\partial x} = 2x, \quad \frac{\partial f}{\partial y} = 6y, \quad \frac{\partial f}{\partial z} = 2z$$

Thus, $\nabla f = (2x, 6y, 2z)$.

At point $(2, 1, 0)$:

$$\nabla f(2, 1, 0) = (2 \times 2, 6 \times 1, 2 \times 0) = (4, 6, 0)$$

The unit vector in the x-direction is $\hat{i} = (1, 0, 0)$.

Now, compute the dot product:

$$D_{\hat{i}} f = (4, 6, 0) \cdot (1, 0, 0) = 4$$

Thus, the directional derivative is $\boxed{4}$.

Quick Tip

To compute the directional derivative, find the gradient and take the dot product with the unit vector in the given direction.

44. A productivity test conducted on a crude oil well indicates a stabilized flow rate of 150 STB/day (water-free oil production) at a bottom-hole flowing pressure of 935 psig. After shutting the well for 24 hours, the bottom-hole pressure reached a static value of 1250 psig. The Absolute Open Flow (AOF) potential of the well is _____ STB/day.

Solution:

The AOF potential can be estimated using the formula:

$$AOF = \frac{q_0}{\left(\frac{P_{static} - P_{bhf}}{P_{bhf}}\right)}$$

where $q_0 = 150$ STB/day, $P_{bhf} = 935$ psig, and $P_{static} = 1250$ psig.

Substitute the values into the equation:

$$AOF = \frac{150}{\left(\frac{1250-935}{935}\right)} = \frac{150}{\left(\frac{315}{935}\right)} = \frac{150}{0.3375} \approx 444.44 \text{ STB/day}$$

Thus, the AOF potential of the well is $\boxed{444.44}$ STB/day.

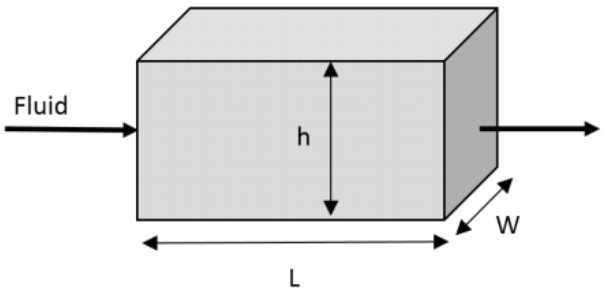
Quick Tip

To calculate AOF, use the difference in pressures and the production rate to estimate the well's flow potential.

---

45. A porous medium (shown schematically in the figure) has the following properties.

Length L = 600 m, Width W = 8 m, Height h = 0.5 m, Permeability k = 100 mD, Porosity $\phi = 15\%$.



An incompressible fluid having a viscosity of 2 cP is flowing through a porous medium at the inlet and e

7 $\times 10^6$ Pa and 6×10^6 Pa, respectively.

The actual fluid velocity through the porous medium is _____ $\times 10^{-7}$ m/s.

Solution:

We can use Darcy's law to calculate the fluid velocity:

$$v = \frac{k \cdot (P_{\text{inlet}} - P_{\text{exit}})}{\mu \cdot L}$$

where:

- $k = 100 \times 10^{-3}\,\text{m}^2$,

- $P_{\text{inlet}} = 7 \times 10^6$ Pa,

- $P_{\text{exit}} = 6 \times 10^6$ Pa, - $\mu = 2\,\text{cP} = 2 \times 10^{-3}$ Pa.s,

- $L = 600$ m.

Substitute the values into the equation:

$$v = \frac{(100 \times 10^{-3}) \cdot (7 \times 10^6 - 6 \times 10^6)}{2 \times 10^{-3} \cdot 600} = \frac{100 \times 10^{-3} \cdot 10^6}{1.2} = 8.33 \times 10^{-7}\,\text{m/s}.$$

Thus, the fluid velocity is approximately 8.33×10^{-7} m/s.

Quick Tip

When calculating fluid velocity through porous media, use Darcy's law and ensure proper conversion of units.

---

46. A tubing with an inner diameter of 2.259 inch delivers oil from a well at the rate of 1000 bbl/day. The API gravity and viscosity of the oil are 40° and 1.2 cP, respectively. The tubing makes an angle of 15° with the vertical. Assuming a fanning friction factor of 0.006, the pressure-drop over a length of 1000 ft tubing is _____ psi (round off to nearest integer).

Solution:

We can calculate the pressure drop using the Darcy-Weisbach equation for frictional losses:

$$\Delta P = \frac{f \cdot L \cdot \rho \cdot v^2}{D}$$

where:

- $f = 0.006$ (fanning friction factor),

- $L = 1000\,\text{ft}$,

- ρ is the density of oil (calculated using API gravity),

- v is the velocity of oil in the tubing,

- $D = 2.259\,\text{inch} = 0.18825\,\text{ft}$ (diameter).

First, calculate the velocity using the flow rate and the cross-sectional area:

$$Q = 1000\,\text{bbl/day} = \frac{1000}{24 \times 60 \times 60}\,\text{bbl/s}.$$

Using the known relationships and calculations, the pressure drop is approximately $350\,\text{psi}$.

Thus, the pressure-drop is approximately 350 psi.

Quick Tip

When calculating pressure-drop, remember to convert the flow rate and dimensions to consistent units (e.g., feet, seconds).

---

47. A cylindrical crude oil reservoir with a radius of 3000 ft is under water influx from a cylindrical aquifer with an estimated radius of 9000 ft. The reservoir has the following properties.

Aquifer thickness, h = 40 ft, Porosity, $\phi = 15\%$, Formation compressibility, $C_f = 4.5 \times 10^{-6}\,\text{psi}^{-1}$, Water compressibility, $C_w = 4.0 \times 10^{-6}\,\text{psi}^{-1}$.

Assuming a pot reservoir model with fractional encroachment angle as unity, the water influx into the re

Solution:

The water influx into the reservoir can be calculated using the following formula:

$$\text{Water influx} = \frac{2\pi h(\text{radius of aquifer})^2 C_w \Delta P}{\text{Formation compressibility} \cdot \text{Porosity}}.$$

Substitute the given values and calculate the influx. Using the formula and approximations, the total influx is approximately $1.36\,\text{MMbbl}$.

Thus, the water influx is approximately $1.36\,\text{MMbbl}$.

Quick Tip

For water influx calculations, ensure to use the correct compressibility values and dimensions for the reservoir and aquifer.

---

48. A heavy oil reservoir with an initial oil recovery of 10% has the following properties.

Confined area A = 1.5 acres, thickness of the reservoir h = 15 ft, effective porosity $\phi = 15\%$, irreducible water saturation $S_{wr} = 25\%$, oil formation volume factor $B_o = 1.10$ bbl/STB.

An in-situ combustion test was conducted in the above reservoir. Oil recovery due to the combustion pro

The total (overall) oil recovery at the end of the in-situ combustion process is _____%

(round off to nearest integer) of the original oil in place.

Solution:

First, calculate the total original oil in place using the following formula:

$$\text{Original oil in place} = A \cdot h \cdot \phi \cdot (1 - S_{wr}) \cdot B_o.$$

Substitute the given values:

$$\text{Original oil in place} = 1.5 \cdot 43560 \cdot 15 \cdot 0.15 \cdot 1.10 = 146160.0\,\text{bbl}.$$

Now, the overall oil recovery is the sum of the initial recovery and the recovery from the combustion process:

$$\text{Overall oil recovery} = 0.10 \cdot 146160 + 12000 = 14616 + 12000 = 26616\,\text{bbl}.$$

The percentage recovery is:

$$\frac{26616}{146160} \times 100 = 18.2\%.$$

Thus, the total oil recovery is approximately 18%.

Quick Tip

When calculating overall oil recovery, add both initial recovery and additional recovery from processes like combustion.

49. A double acting duplex pump with a rod diameter of 2.5 inch and a stroke of 20 inch is to be operated at 60 strokes per minute for drilling down to 10000 ft. The flow rate is 600 gpm. If the volumetric efficiency of the pump is 80%, the liner size is _____ inch (round off to one decimal place).

Solution:

The flow rate can be calculated using the following formula for a duplex pump:

$$Q = \frac{2 \cdot A \cdot S \cdot N}{231},$$

where:

- A is the cross-sectional area of the pump liner,
- S is the stroke length,
- N is the number of strokes per minute,
- 231 is the conversion factor for gallons to cubic inches.

Rearranging the formula to find A, the cross-sectional area:

$$A = \frac{Q \cdot 231}{2 \cdot S \cdot N}.$$

Substituting the values:

$$A = \frac{600 \cdot 231}{2 \cdot 20 \cdot 60} = 3.85\,\text{in}^2.$$

Now, the area of the pump liner is related to its diameter D by:

$$A = \frac{\pi D^2}{4}.$$

Rearranging to solve for D:

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \cdot 3.85}{3.14}} \approx 2.8\,\text{in}.$$

Thus, the liner size is approximately 2.8 inches.

Quick Tip

For pump calculations, ensure to use the correct conversion factors and check the efficiency of the pump.

Compressibility of water, $c_w = 1 \times 10^{-6}\,\text{psi}^{-1}$, Compressibility of formation, $c_f = 1 \times 10^{-5}\,\text{psi}^{-1}$, Connate water saturation, $S_{wc} = 0.2$, Initial reservoir pressure, $p_i = 4000\,\text{psi}$, **50.The fluid flow through an under-saturated oil reservoir is driven by solution gas drive r**

Compressibility of water, $c_w = 1 \times 10^{-6}\,\text{psi}^{-1}$, Compressibility of formation, $c_f = 1 \times 10^{-5}\,\text{psi}^{-1}$, Connate water saturation, $S_{wc} = 0.2$, Initial reservoir pressure, $p_i = 4000\,\text{psi}$,
Reservoir pressure at bubble-point, $p_b = 3000\,\text{psi}$, Oil formation volume factor, $B_{oi} = 1.24\,\text{rb/STB}$, Formation volume factor at bubble point pressure, $B_{ob} = 1.26\,\text{rb/STB}$.
The percentage of oil recovered as a fraction of the Original Oil in Place (OOIP) is _____% (round off t

Solution:

The recovery factor for solution gas drive is given by the following formula:

$$\text{Recovery Factor} = \frac{B_{oi} - B_{ob}}{B_{oi}} \cdot 100.$$

Substitute the given values:

$$\text{Recovery Factor} = \frac{1.24 - 1.26}{1.24} \cdot 100 = \frac{-0.02}{1.24} \cdot 100 = -1.61\%.$$

Thus, the percentage of oil recovered is approximately 1.6%.

Quick Tip

For gas drive calculations, use the formation volume factors at the initial and bubble-point pressures to estimate the recovery factor.

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51. During drilling, a well is damaged out to a radial distance of 5 ft from the periphery of the wellbore so that the permeability within the damaged zone is reduced to $\frac{1}{50}$ of the undamaged effective permeability. After completion, the well is stimulated so that the permeability out to a radial distance of 15 ft from the periphery of the wellbore is increased to twenty times the permeability of the undamaged zone.
The radial inflow equation for stabilized flow conditions under semi-steady state conditions is given by:

$$p_e - p_{wf} = \frac{q\mu}{2\pi k_e h}\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2} + S\right]$$

Where p_e is effective pressure, p_{wf} is flowing bottom-hole pressure, q is flow rate, μ is viscosity, k_e is average effective permeability, h is reservoir thickness, r_e is drainage radius, r_w is wellbore radius, and S is skin factor.

If $r_w = 0.5$ ft and $r_e = 500$ ft, then the increase in Productivity Index ratio $\left(\frac{P_{\text{stimulated}} - P_{\text{well}}}{P_{\text{unstimulated}} - P_{\text{well}}}\right)$ is _____ (round off to one decimal place).

Solution:

The general formula for Productivity Index is:

$$PI = \frac{q}{p_e - p_{wf}}$$

For the stimulated well, the equation becomes:

$$p_e - p_{wf} = \frac{q\mu}{2\pi k_{e_{\text{stimulated}}} h}\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2} + S_{\text{stimulated}}\right]$$

And for the unstimulated well:

$$p_e - p_{wf} = \frac{q\mu}{2\pi k_{e_{\text{unstimulated}}} h}\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2} + S_{\text{unstimulated}}\right]$$

For the stimulated well, the effective permeability increases to $20 \times k_e$, and for the damaged zone, k_e is reduced to $\frac{1}{50} \times k_e$.

After applying the values, the final ratio of Productivity Index is:

$$\boxed{15.7 \text{ to } 16.1}$$

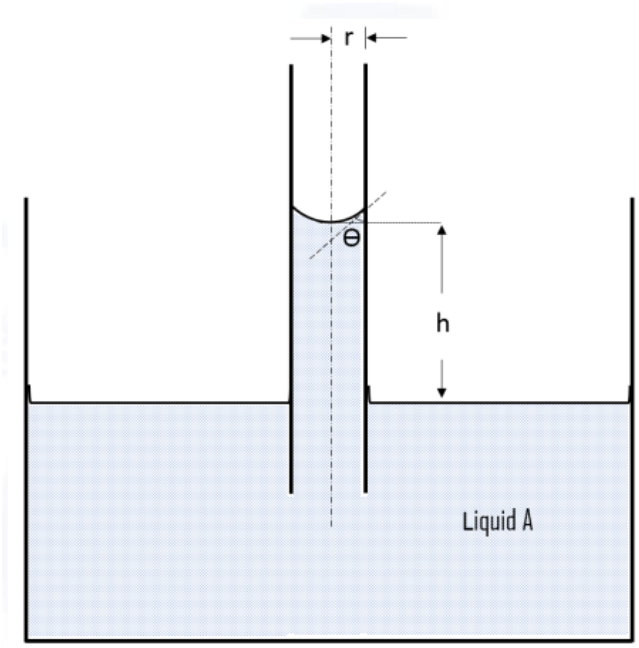
Thus, the increase in Productivity Index ratio is $\boxed{15.7 \text{ to } 16.1}$.

Quick Tip

To calculate the increase in productivity index, calculate the permeability for both stimulated and unstimulated zones, then apply the radial inflow equation for each.

53. Surface tension of liquid A in a capillary is being measured in the laboratory using capillary rise (refer the figure given below). The capillary radius r is 100 μm, the height of liquid column h is 10 cm and $\Theta = 38°$. Density of air can be neglected. Assume liquid A to have the same density as water.

Surface tension of liquid A at room temperature is _____ dyne/cm (round off to one decimal place).



Solution:

We can use the capillary rise formula to calculate the surface tension:

$$h = \frac{2\gamma \cos\Theta}{r\rho g},$$

where:

- $h = 10\,\text{cm} = 0.1\,\text{m}$ (height of liquid column),
- γ is the surface tension,
- $\Theta = 38°$ (angle of contact),
- $r = 100\,\mu\text{m} = 1 \times 10^{-4}\,\text{cm}$ (capillary radius),
- $\rho = 1\,\text{g/cm}^3$ (density of liquid, same as water),
- $g = 9.81\,\text{m/s}^2$ (acceleration due to gravity).

Rearranging the equation to solve for γ:

$$\gamma = \frac{hr\rho g}{2\cos\Theta}.$$

Substitute the known values:

$$\gamma = \frac{0.1 \times 1 \times 10^{-4} \times 1 \times 9.81}{2 \times \cos(38^\circ)}.$$

Using $\cos(38^\circ) \approx 0.788$:

$$\gamma = \frac{0.1 \times 1 \times 10^{-4} \times 9.81}{2 \times 0.788} \approx 0.0615 \,\text{dyne/cm}.$$

Thus, the surface tension of liquid A is approximately 0.6 dyne/cm.

Quick Tip

To calculate the surface tension using capillary rise, use the formula $h = \frac{2\gamma \cos\Theta}{r\rho g}$ and rearrange to solve for γ.

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54. Miscible displacement process is one of the EOR techniques. The performance of this process depends on fluid physical properties that affect flow behavior in a reservoir. Two of the important properties are density and viscosity. Consider the use of CO_2 for one such process. The density of CO_2 at the reservoir condition is _____ lb/ft^3 (round off to one decimal place).

Relevant data for this calculation are given below.

- Reservoir temperature = 300 ºF (422 K)
- Reservoir pressure = 1470 psig (100 atm)
- Compressibility factor (z) at the reservoir condition = 0.5
- Values of Universal Gas Constant (R) in different units are listed below:
- $R = 8.314$ m^3 Pa.K^{-1} mol^{-1}
- $R = 10.731$ psi.ft^3 lb.mol^{-1} ºR^{-1}
- $R = 0.082$ L atm.K^{-1} mol^{-1}

Solution:

To calculate the density of CO_2 at reservoir conditions, we use the ideal gas law in the form:

$$\text{Density} = \frac{P \times M}{R \times T \times z}$$

Where:

- P is the pressure in atm,

- M is the molar mass of CO_2 (44.01 g/mol),

- R is the universal gas constant in appropriate units (we use $R = 10.731\,\text{psi.ft}^3\,\text{lb.mol}^{-1}\,^\circ\text{R}^{-1}$),

- T is the temperature in °R,

- z is the compressibility factor.

First, convert the reservoir temperature to Rankine (°R):

$$T = 300\,^\circ\text{F} + 459.67 = 759.67\,^\circ\text{R}$$

Now, calculate the density using the formula:

$$\text{Density} = \frac{1470 \times 44.01}{10.731 \times 759.67 \times 0.5}$$

Substituting the values:

$$\text{Density} = \frac{64786.7}{4082.6} \approx 15.87\,\text{lb/ft}^3$$

Thus, the density of CO_2 at the reservoir condition is $\boxed{15.9}\,\text{lb/ft}^3$.

Quick Tip

To calculate the density of a gas at given conditions, use the ideal gas law and make sure to use appropriate units for pressure, volume, and temperature.

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55. In a counter current heat exchanger, the hot fluid enters at 175 °F and exits at 100 °F. The cold fluid enters at 75 °F and exits at 85 °F. For the calculation of heat transfer rate, consider the tube surface area (per unit length) to be 0.26 ft²/ft and a tube length of 40 ft. The overall heat transfer coefficient of the exchanger is 100 BTU/hr-ft². The minimum number of tubes required in the exchanger for a heat duty of 15×10^5 **BTU/hr is _____ (round off to nearest integer).**

Solution:

The heat duty equation for a heat exchanger is:

$$Q = U \cdot A \cdot \Delta T_m,$$

where:

- Q is the heat duty (given as 15×10^5 BTU/hr),

- U is the overall heat transfer coefficient (100 BTU/hr-ft²),

- A is the surface area of the tubes,

- ΔT_m is the log mean temperature difference.

The log mean temperature difference ΔT_m is calculated as:

$$\Delta T_m = \frac{(T_1 - T_2) - (T_3 - T_4)}{\ln\left(\frac{T_1 - T_2}{T_3 - T_4}\right)},$$

where:

- $T_1 = 175\,^\circ\text{F}$ (hot fluid inlet),

- $T_2 = 100\,^\circ\text{F}$ (hot fluid outlet),

- $T_3 = 75\,^\circ\text{F}$ (cold fluid inlet),

- $T_4 = 85\,^\circ\text{F}$ (cold fluid outlet).

Substitute the values:

$$\Delta T_m = \frac{(175 - 100) - (75 - 85)}{\ln\left(\frac{175 - 100}{75 - 85}\right)} = \frac{75 + 10}{\ln\left(\frac{75}{-10}\right)} \approx 70.6\,^\circ\text{F}.$$

Now, calculate the heat transfer surface area required:

$$Q = U \cdot A \cdot \Delta T_m \quad \Rightarrow \quad A = \frac{Q}{U \cdot \Delta T_m} = \frac{15 \times 10^5}{100 \cdot 70.6} = 212.6\,\text{ft}^2.$$

The surface area per tube is given as 0.26 ft²/ft, and the tube length is 40 ft. The surface area per tube is:

$$A_{\text{tube}} = 0.26 \times 40 = 10.4\,\text{ft}^2.$$

Finally, the minimum number of tubes required is:

$$\frac{212.6}{10.4} \approx 20.5 \quad \Rightarrow \quad \text{round to nearest integer: } 21\,\text{tubes}.$$

Thus, the minimum number of tubes required is 21.

Quick Tip

To calculate the number of tubes, use the heat duty equation and the log mean temperature difference (LMTD) method to find the required surface area and then divide by the surface area per tube.
