Processes: Extraction of Resources

PRRE1003
Resources, Processes & Materials Engineering

LECTURE 6

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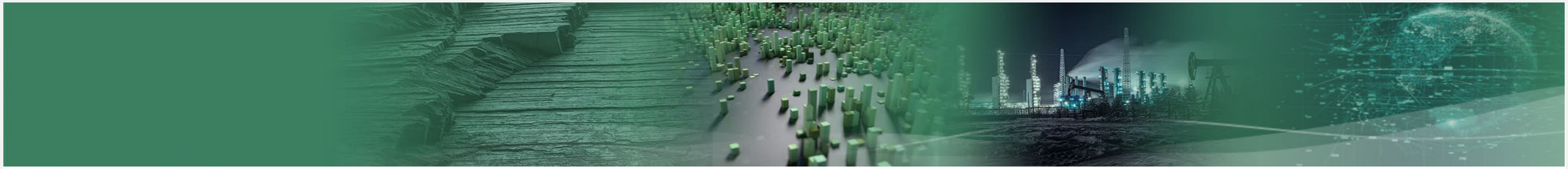

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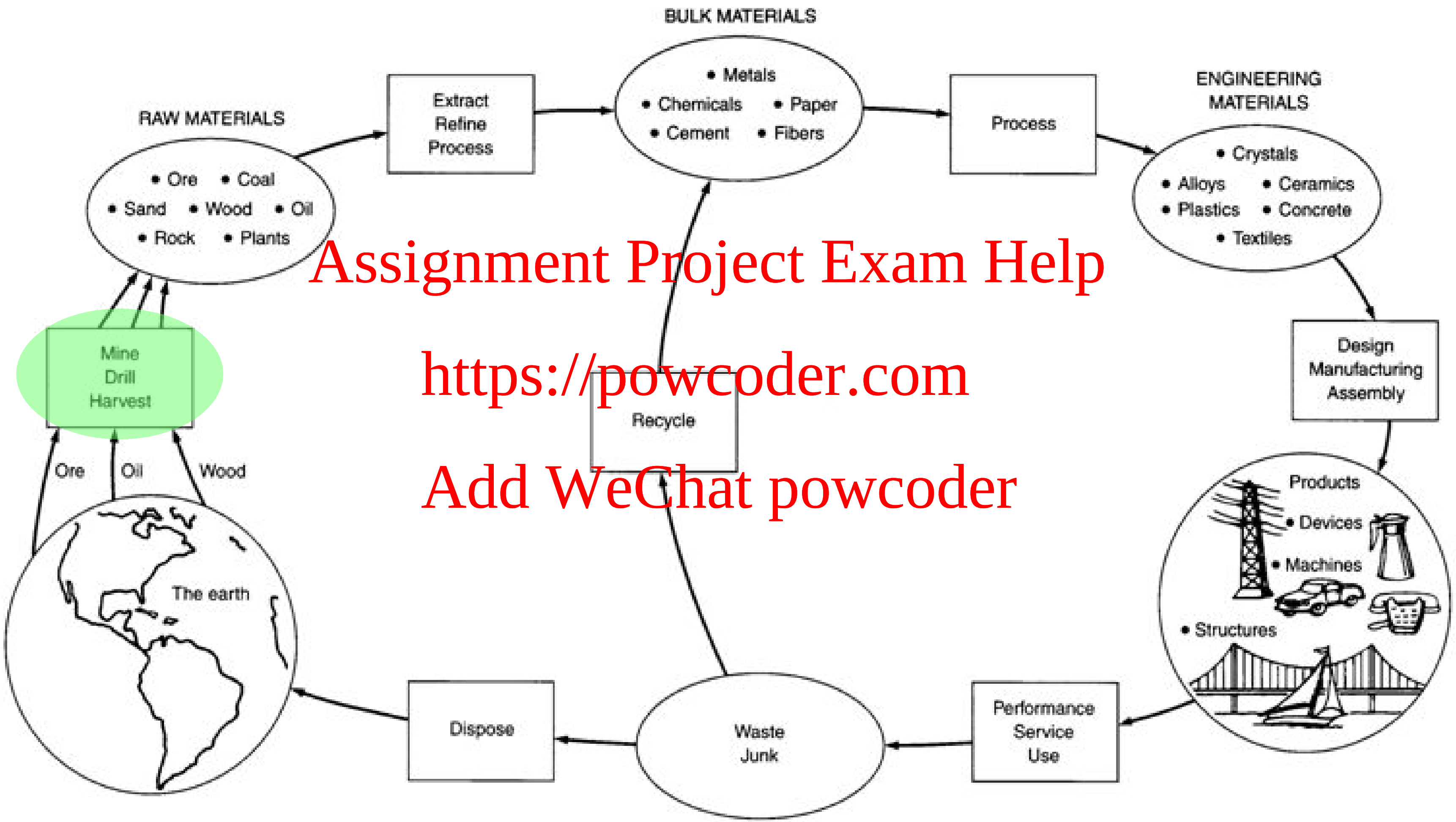
Lecture focus



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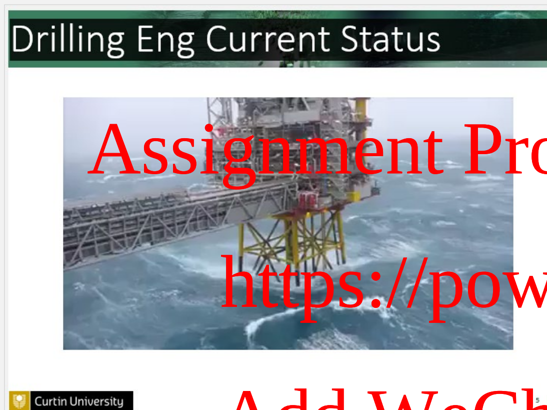
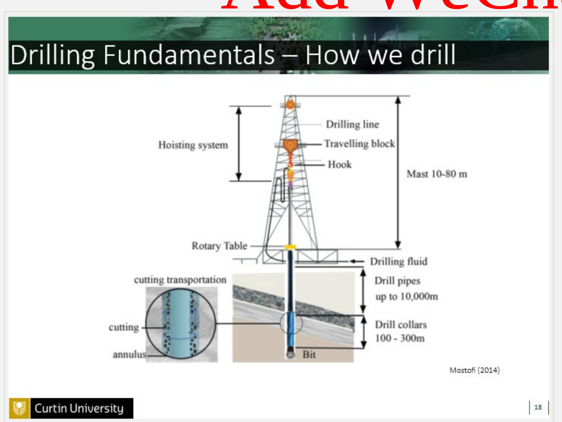
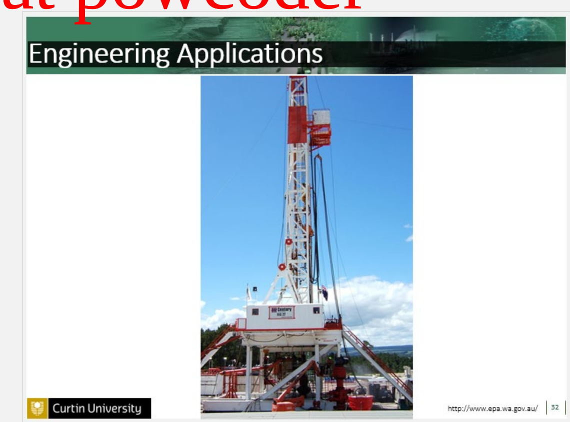






Drilling Eng Current Status

Drilling Engineering: Current Status

- Drilling offshore and onshore
- Drilling downward, drilling deviated/horizontal, drilling upward
- Drilling wells of a few kilometres in 1-2 months
- Remote Control and Automation Drilling

Well = Borehole = Wellbore

http://rogermontgomery.com/

https://www.boartlongyear.com/

http://www.energyandresources.vic.gov.au/

Examples of Drilling: Deepest Well in the world

Kola Borehole:

- A research project in Soviet Union started at 1970.
- 12,262 m: the deepest artificial point in the world
- 24 years of drilling in Russia
- Research well rather petroleum well
- Drilling stopped due to unexpected temperature of the wellbore exceeding 180° C.
- Thickness of crust is about 30 to 50 km.

Deepest Well in the world!

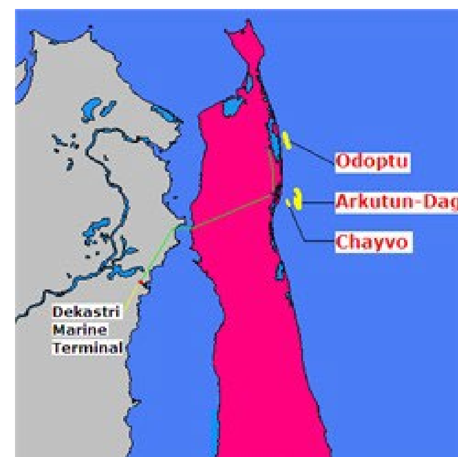
Welded well head after scraping the project!

https://en.wikipedia.org

Examples of Drilling: Longest Well in the world

- M**easured depth** of 12,344 m with **horizontal departure** of 11,475m
- Drilled in only 60 days by Exxon Mobil Corporation
- Onshore drilling enabling targeting about 10 km from the shore

http://petroleuminsights.blogspot.com.au/



http://www.subseaiq.com/

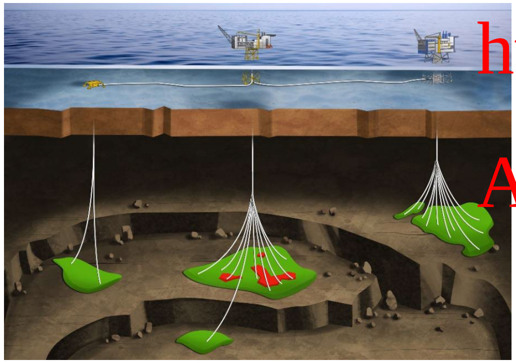
ExxonMobil

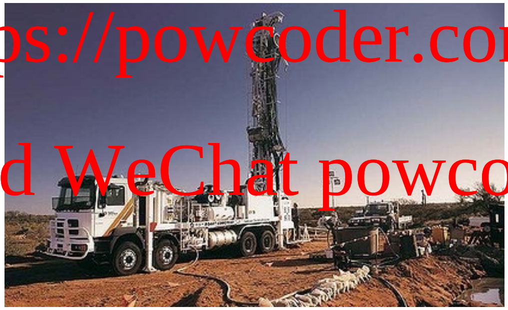
Application of Drilling Engineering

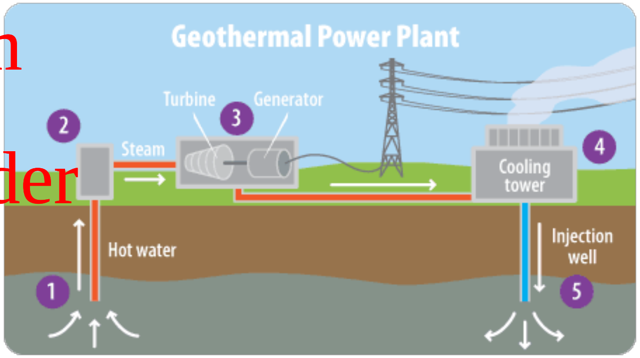
Petroleum Eng (Oil & Gas)

Mining Eng

Geothermal industry







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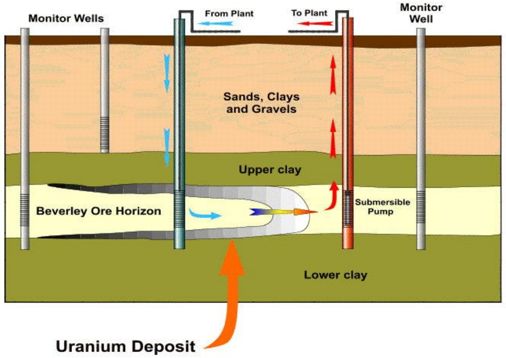
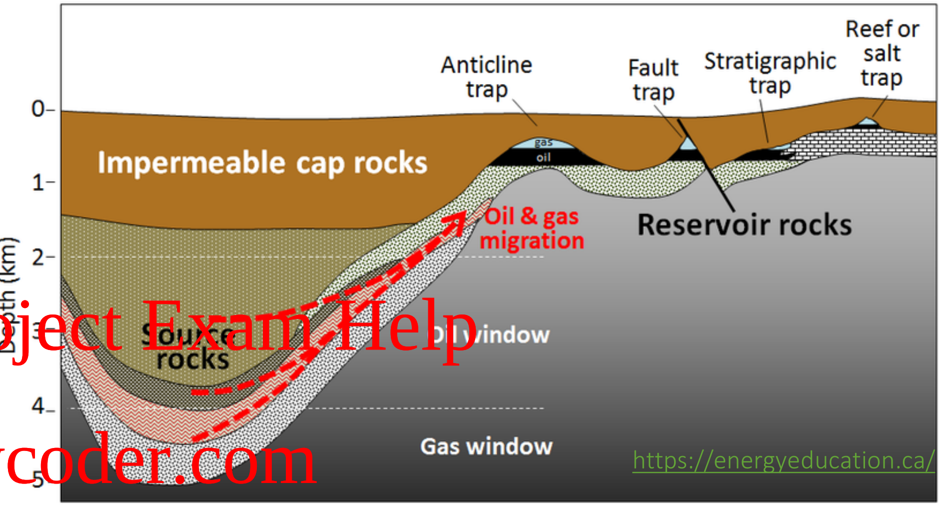


Drilling Application: Oil and Gas

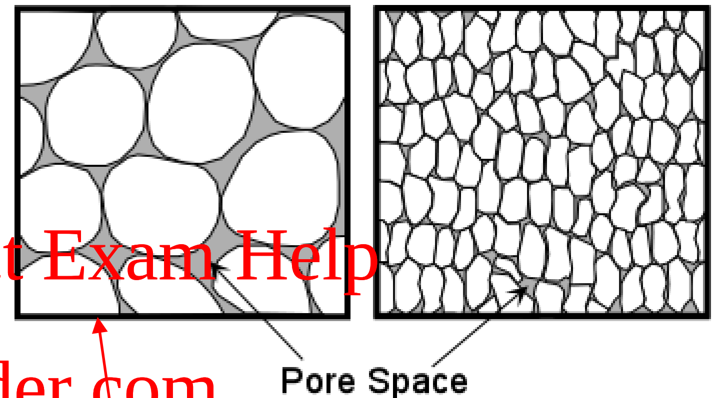
- Petroleum engineering: extraction of organic hydrocarbon resource
- Hydrocarbon: an organic compound entirely comprised of hydrogen and carbon.

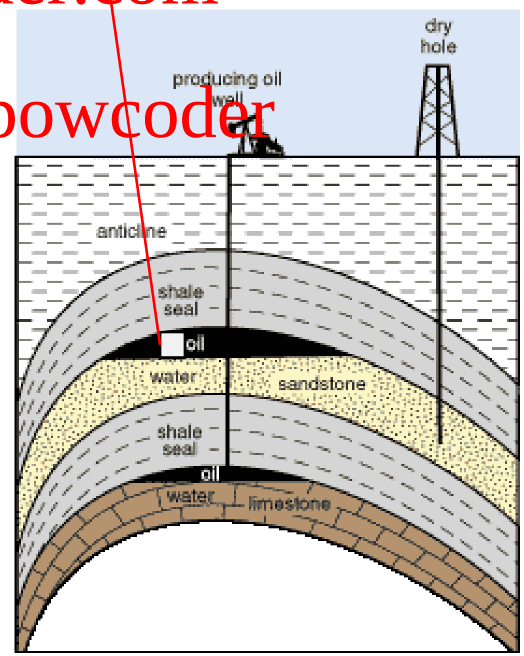


- Hydrocarbon: the result of transformation (maturation) of organic materials into hydrocarbon under certain pressure and temperature condition.
- Source rock: maturing organic matters and producing hydrocarbon
- Hydrocarbon migration from source rock to reservoir rock

Drilling Application: Oil and Gas

- Hydrocarbons are stored in reservoir rocks: a rock which is porous
- Ratio of pore space over the total rock space is 0.05 – 0.3 (5-30%) – called porosity.
- The thickness of a reservoir rock filled with hydrocarbon is 5 to 100 m
- Drilling into reservoir rock facilitates draining hydrocarbons out of the reservoir
- Cost of drilling: few million dollars to a few hundred million dollars
- Well can be dry or wet!
- Average success rate calculated is 18% - in Australia [Jonasson (2011)]





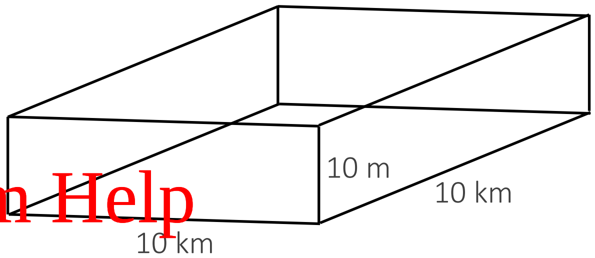
Drilling Application: Oil and Gas

Cost of hydrocarbon production: back of the envelope calculations

Height of the hydrocarbon reserve = 10 m

Extend of hydrocarbon 10 km by 10 km

Porosity (ratio of pore volume over total rock volume) = 0.2



Assuming to withdraw 50% of all available hydrocarbon

Assuming oil price to be \$100 per barrel which is \$625 per m^3

$$\boldsymbol{Total\ volume\ of\ rock = 10\ m \times 10 \times 10^3 m \times 10 \times 10^3 m}$$

$$\boldsymbol{Total\ hydrocarbon(m^3) = Total\ volume\ of\ rock\ (m^3) \times \frac{Pore\ spcae}{Total\ volume\ of\ rock}}$$
$$\boldsymbol{= Total\ volume\ of\ rock \times porosity = 1.0 \times 10^9 \times 0.2 = 2 \times 10^8\ m^3}$$

$$\boldsymbol{Total\ dollar\ value\ of\ production = Total\ hydrocabon\ (m^3) \times 0.5 \times 625 \frac{\$}{m^3} = \$6.2 \times 10^{10}}$$

Drilling Application: Mining | Exploration

- Drilling in mineral exploration: to collect information about rocks (to be compared with oil and gas)
- Much higher number of wells (borehole) but shallower (depth range is mostly 100 m to 2 km)
- Drilling is conducted using land rigs
- Green Field Exploration to find new mines
- Brown Field Exploration to track the ore body in an existing mine
- Surface or underground drilling

Drilling Application: Mining | Exploration

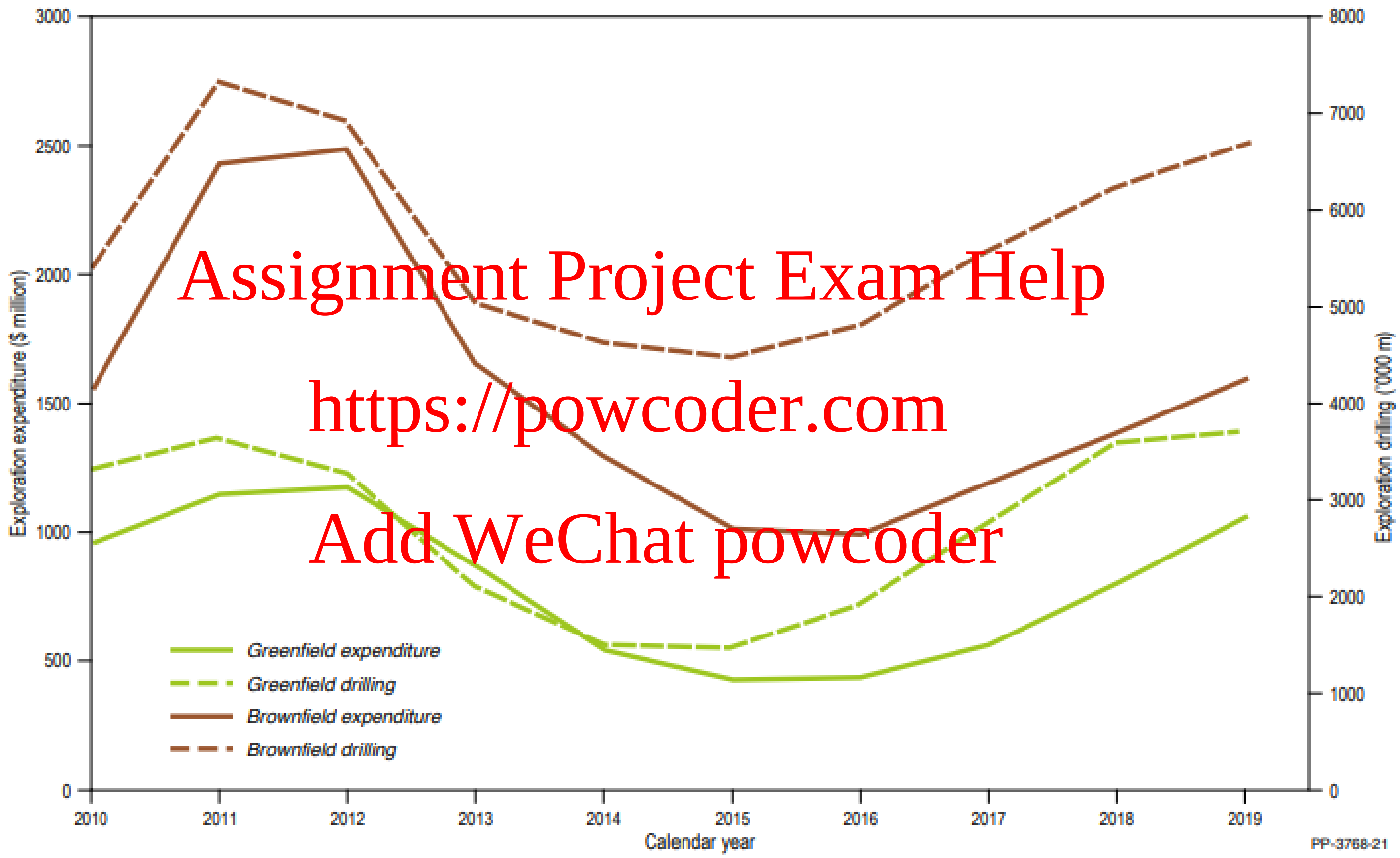
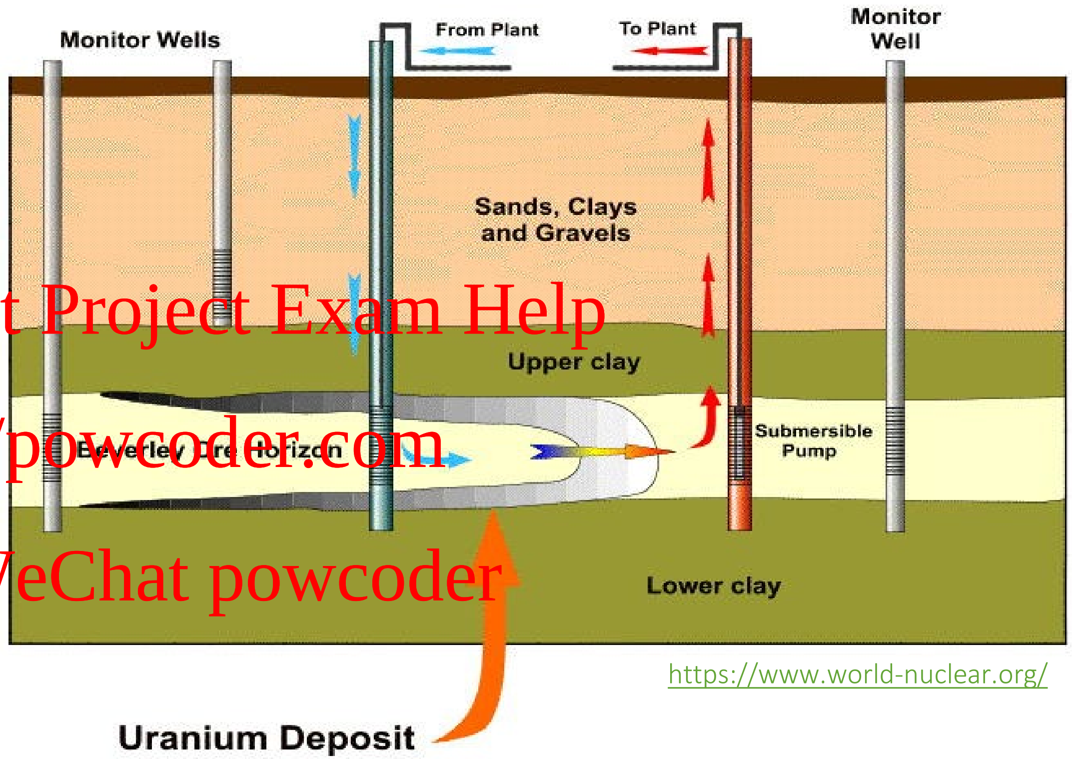


Figure 4 Greenfield and brownfield mineral exploration expenditure and drilling, 2010–2019.

Perth to Brisbane: 3,600 km
Earth Circumference: 40,000 km

Drilling Application: Mining | In-situ Leaching

- Injection chemical (acid or alkaline solutions) to dissolve minerals and bring them to surface
- Also known as in situ recovery (ISR)
- 48% of global uranium mined produced from in-situ leaching in 2016.
- Very popular in USA, Kazakhstan and Uzbekistan and also in Australia, China, and Russia.
- Cost effective and environmentally acceptable method of mining
- Requires many drilling…



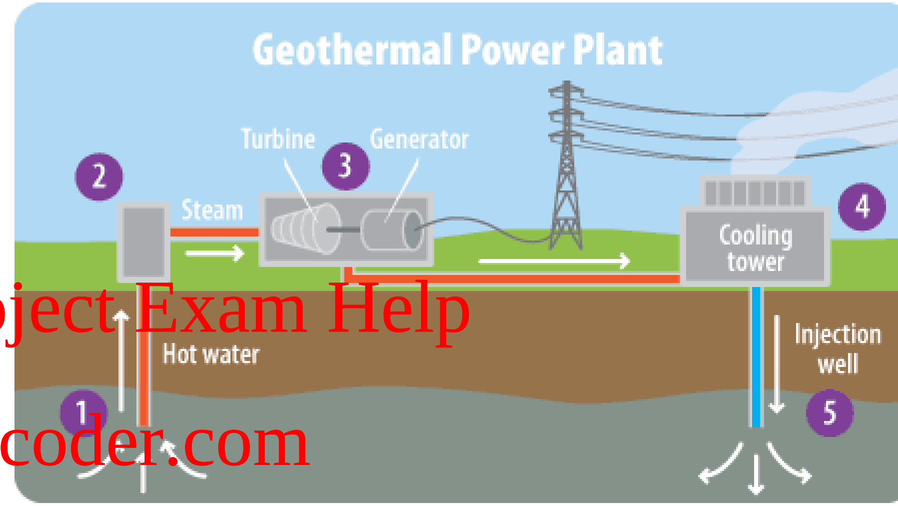
https://www.world-nuclear.org/

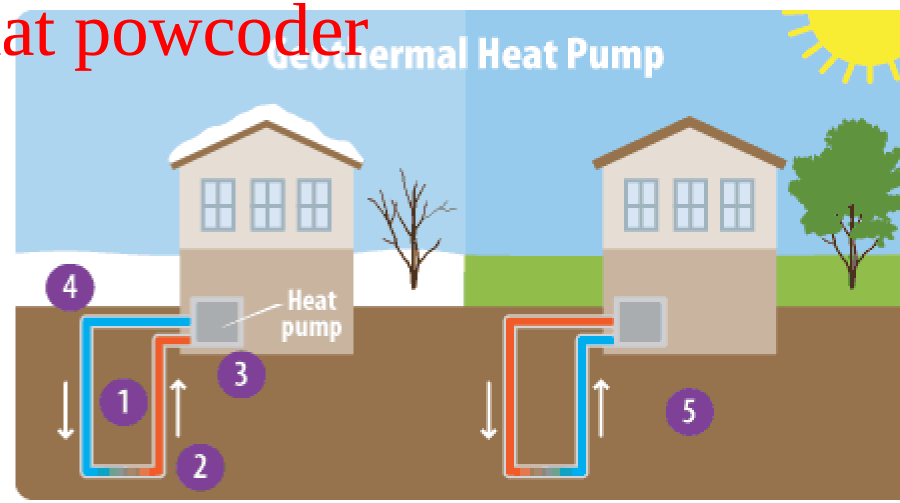
- A solution for accessing to deeper solutions where conventional mining is not effective

Drilling Application: Geothermal

- Accessing heat from underground
- Two applications: Geothermal Power Plan & Geothermal Heat Pump
- In Geothermal Power Plan, water will be converted to steam using heat from deep inside the Earth. Steam will be used to generate electricity
- In Geothermal Heat Pump, Earth will be used as a regulator of temperature for buildings.
- A good example: cooling down super computers (Perth)

PAWSEY supercomputing centre



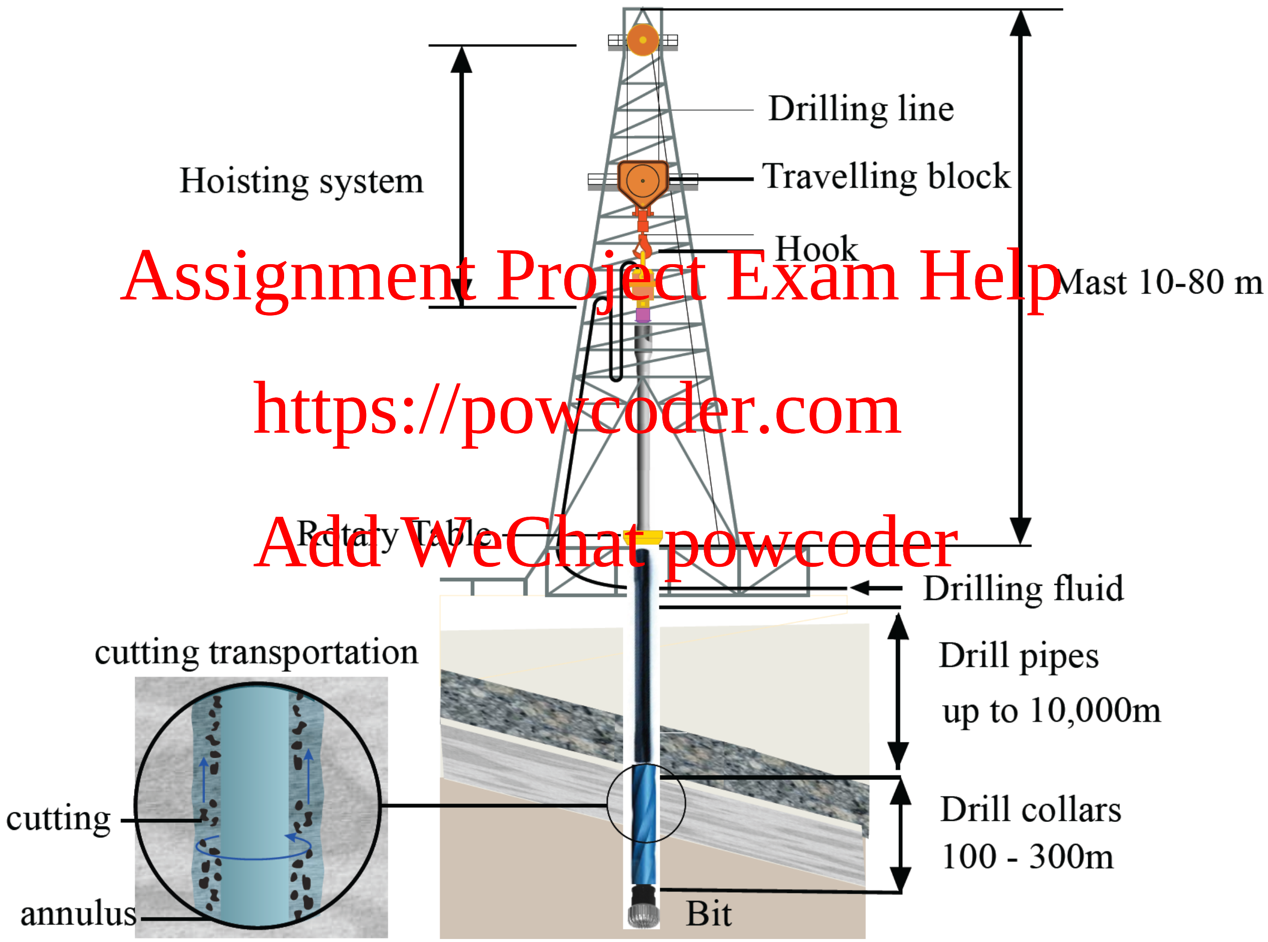


https://archive.epa.gov/

Learning Outcome Check

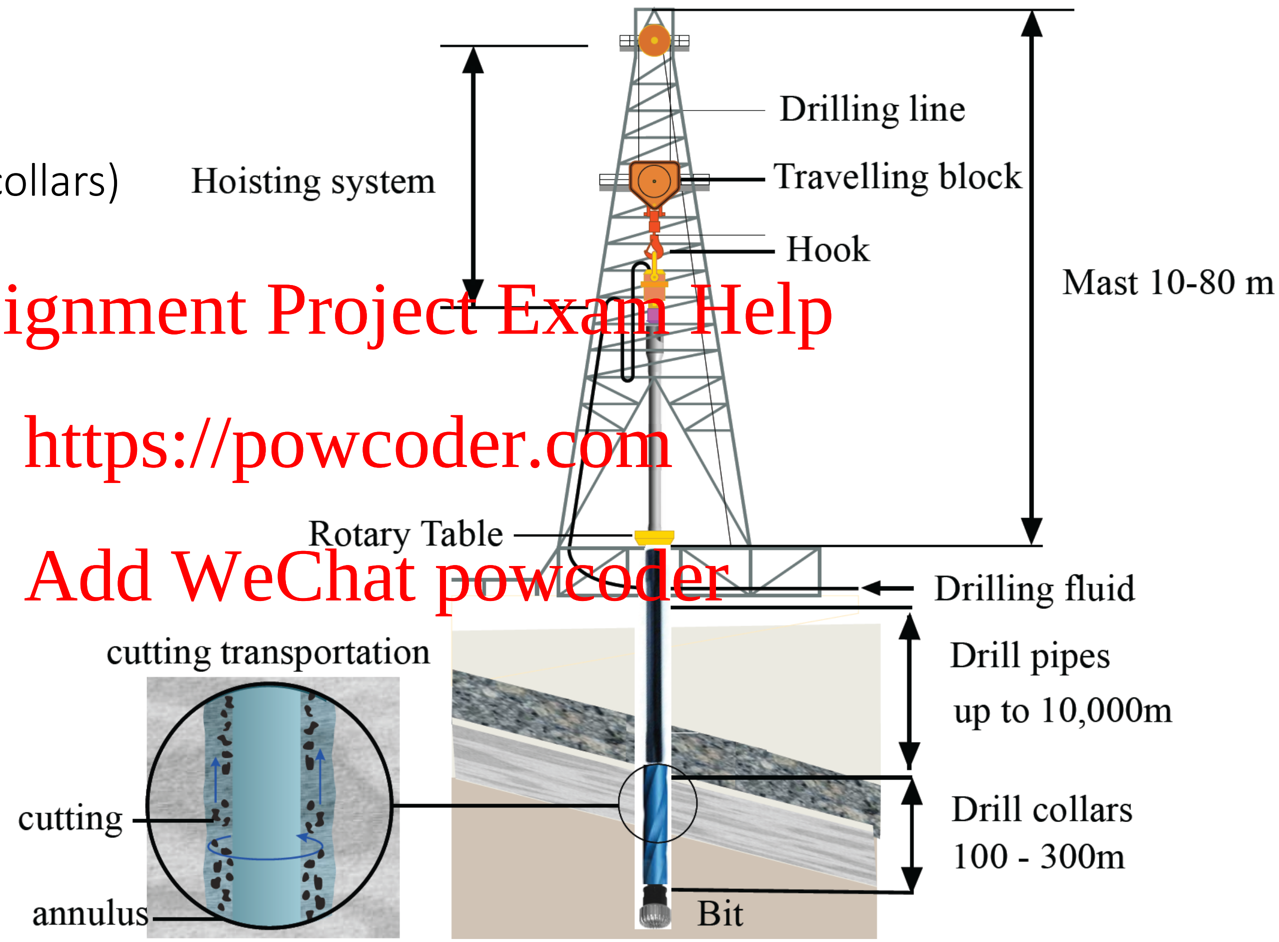
- Drilling onshore vs offshore
- Impact of porosity on success of petroleum exploration
- In-situ leaching and its advantage
- how geothermal wells can be used as a source of energy

Drilling Fundamentals – How we drill

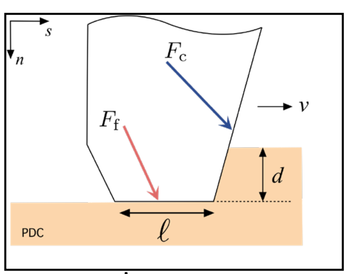


Mostofi (2014)

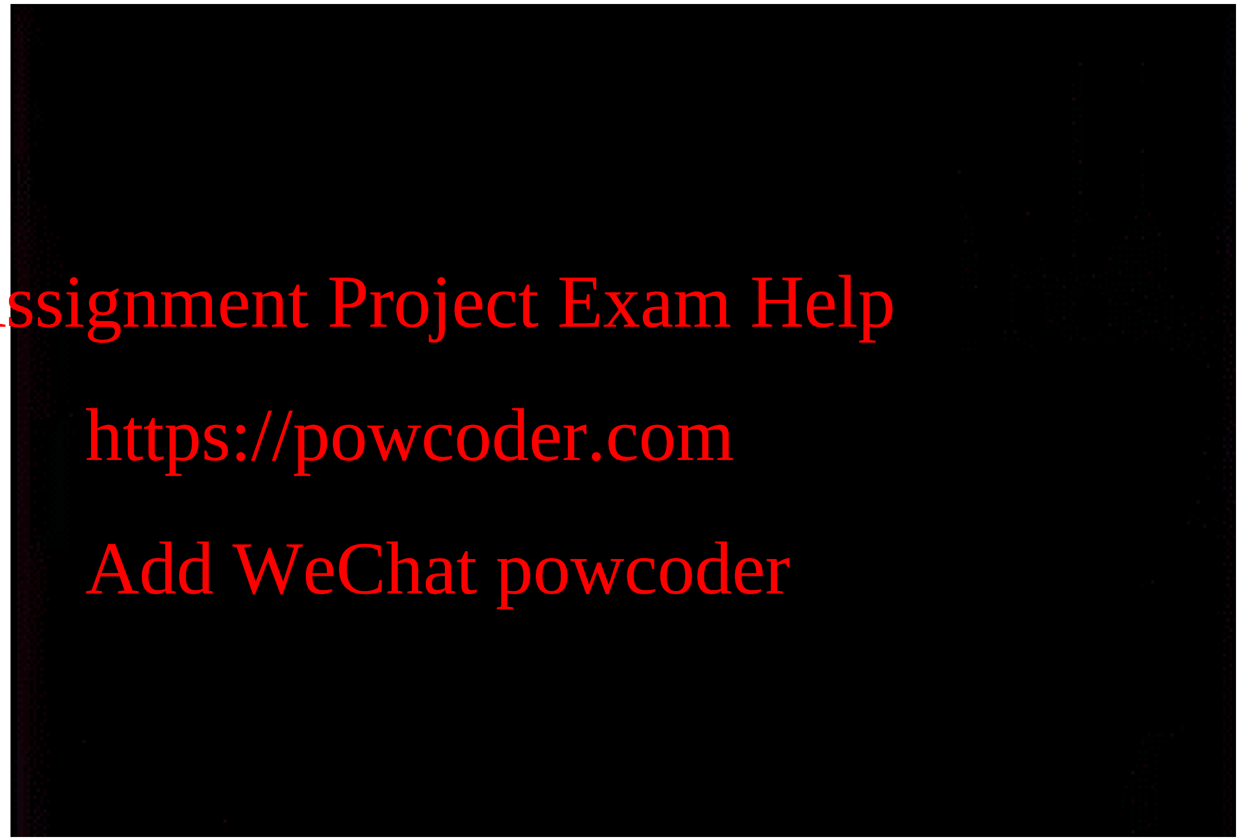
- Drill bit
- Drillstring (drill pipe, drill collars)
- Drilling rig and its hoisting system
- Drilling fluid circulation
- Rotation of drill string



Mostofi (2014)



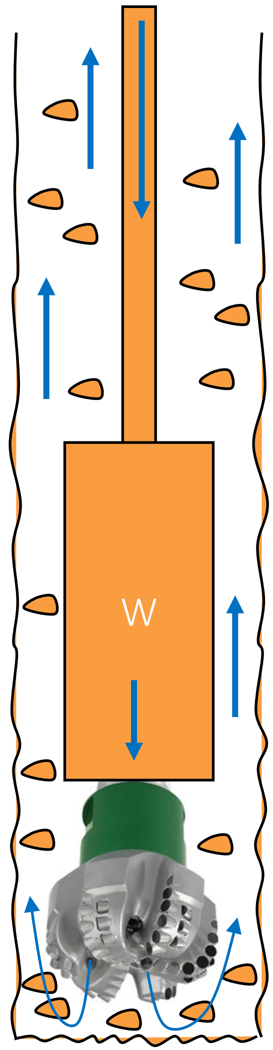
Shear



https://www.youtube.com/watch?v=3EUOafLYLH0&ab_channel=PYRAMIDGeo-Engineering%26Construction.

Drilling Fundamentals – Drilling Systems

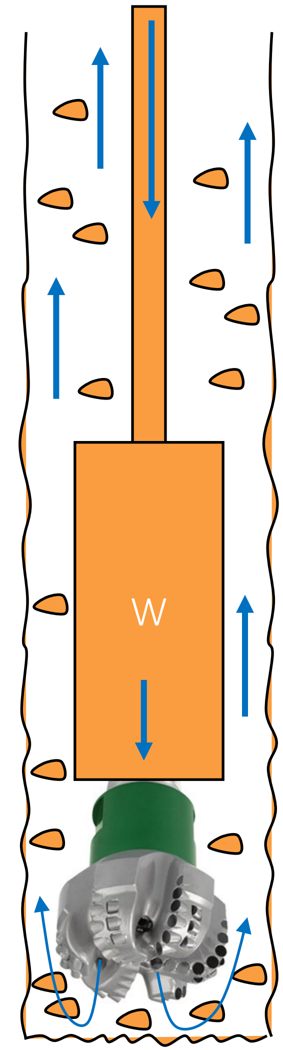
- Three main systems in drilling are: rotary, circulating and hoisting
- Bit rotates, weight on bit applied, torque on bit provided, rock fragments, cuttings generated, cuttings transported to surface by drilling fluid (hole cleaning), drill string weight increases by depth, drill string is supported by the hosting system
- Tripping to change the bit
- Drilling to increase the hole depth



Drilling Fundamentals – Drilling Systems | Rotation

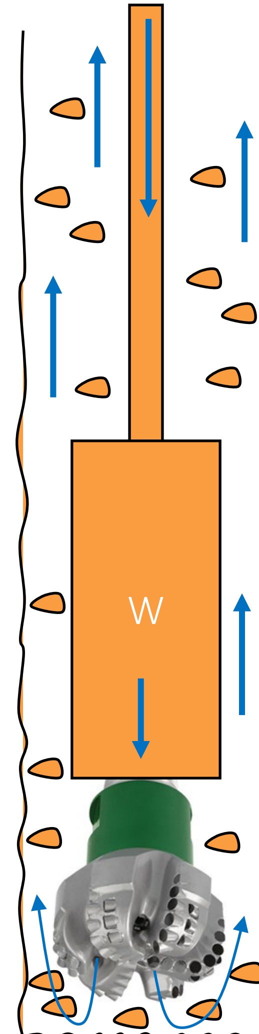
- Rotary system to rotate the drill string and bit
- The main component is the **top drive**
- The top drive holds the drilstring in place and rotates the entire drill string with speeds of 50 – 300 revolution per minute (RPM)

Top drive



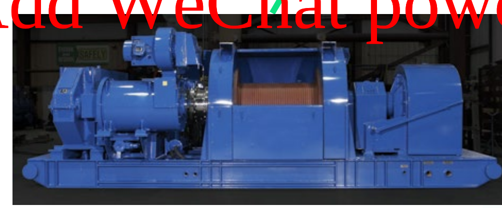
Drilling Fundamentals – Drilling Systems | Circulation

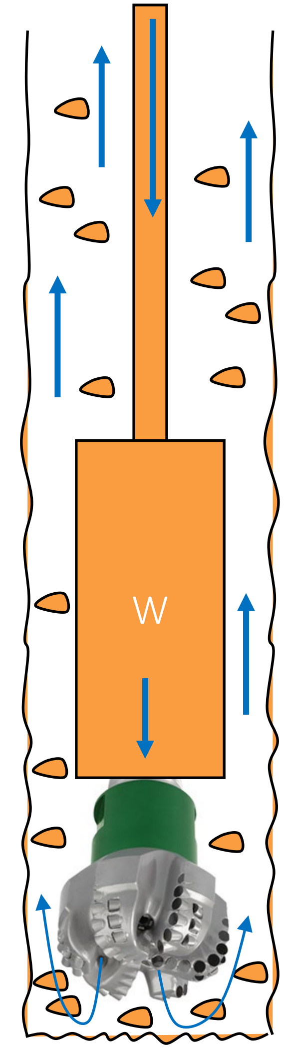
- Circulation system to circulate the mud to transport the cuttings to surface
- Main components are drilling fluid and mud pumps
- Drilling fluid is contained in mud tanks
- Volume of drilling fluid is the range of 5– 10 m^3 for shallow wells (mostly mining and coal seam gas) and 100 – 500 m^3 for deeper holes (mostly oil and gas)



Drilling Fundamentals – Drilling Systems | Hoisting

- Hoisting system to move the drill string up or down.
- Main component is draw-work which is a motor driving a crane like system
- Hoisting system consumes energy mainly during tripping





- Tripping is pulling the drill string out of the well one by one to change bit

Drilling Fundamentals – Drill String

- Length of drill pipes (3 m – 10 m)
- Connecting pipes together
- Duration of making a connection (1-15 min)
- Two Operations:
  - Drilling:

    Increasing hole depth
  - Tripping:

    Changing the bit by pulling all the pipes out

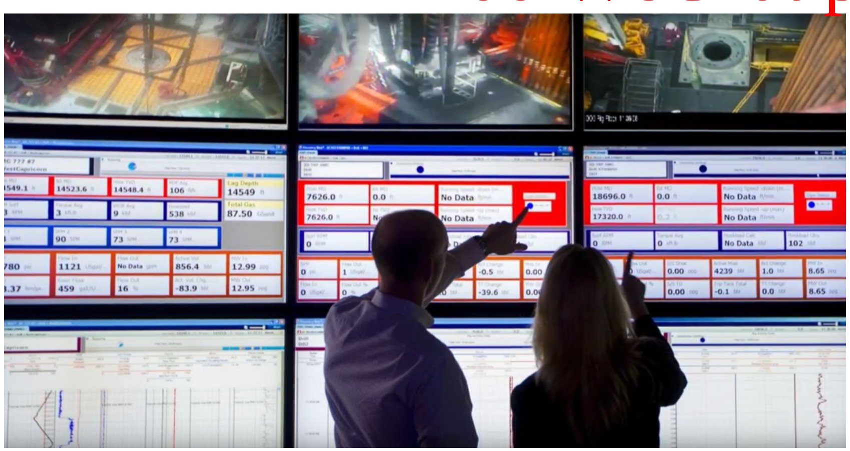
    (few hours to 1-2 days)

https://www.youtube.com/watch?v=eNohnMixPxI

Drilling Fundamentals – Monitoring and Automation

- Collecting all important data from different places of the rig.
- Providing real time reports to key people on site and drilling engineers' office. (Rate of penetration, weight on bit, torque on bit, drilling fluid loss, etc.)

http://www.weatherford.com/



Quiz

1. Drilling in oil and gas is typically between 100 m to 500 m:

   a) True
   b) False

2. To produce hydrocarbon, the target is:

   a) Reservoir rock
   b) Source Rock

3. Number of wells drilled in mining is small

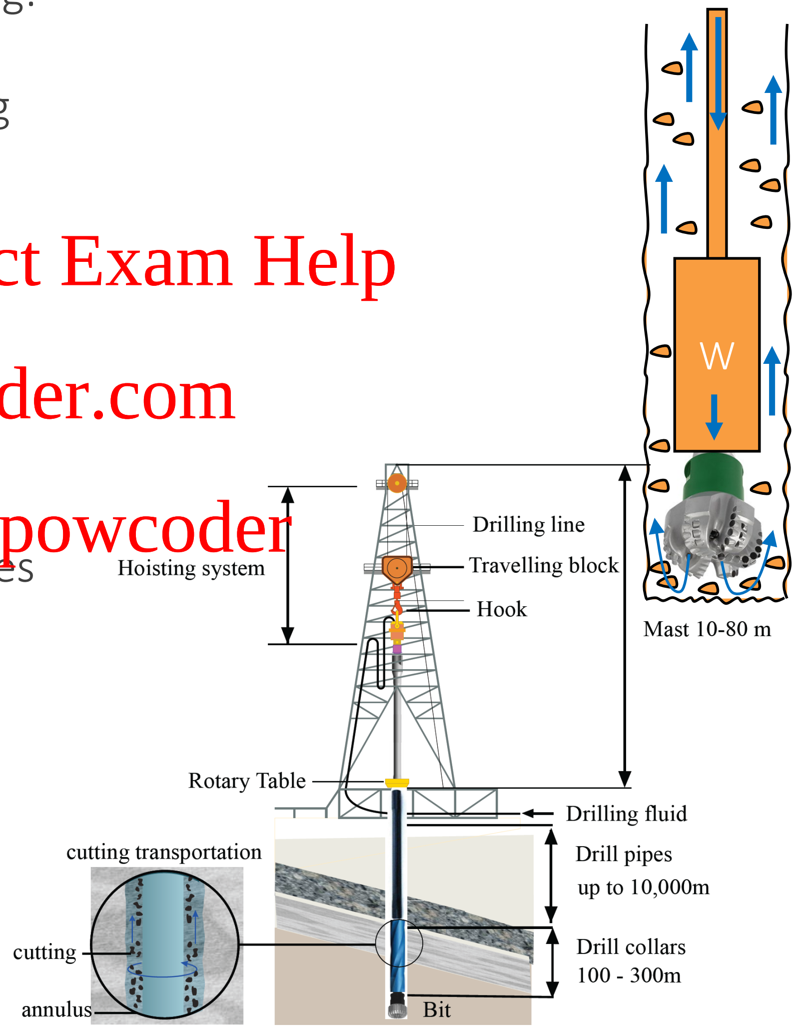
   a) True

   a) False

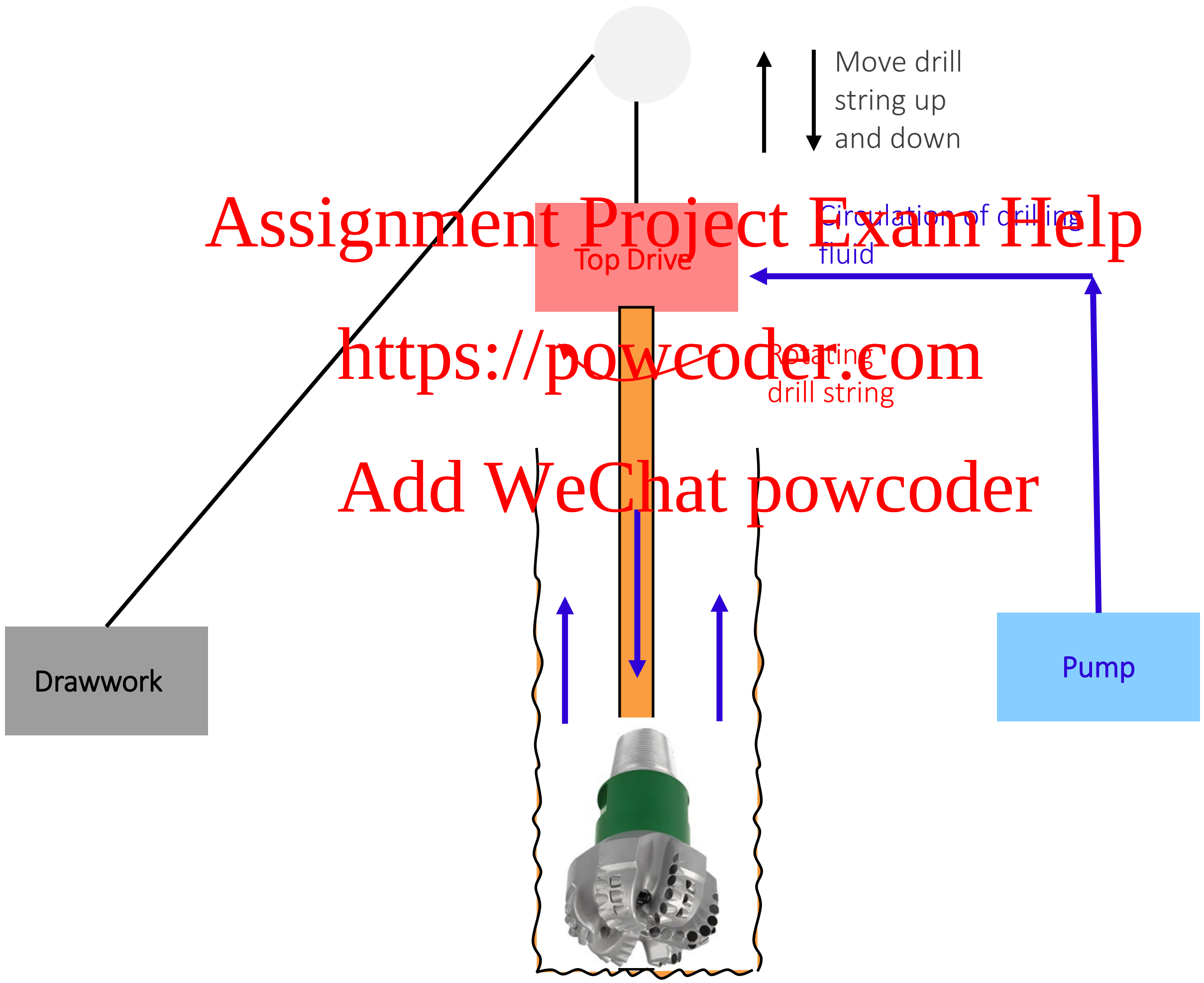
Drilling Engineering Application: Power Consumption

Main Energy consumption systems of rotary drilling:

- Rotary system rotates the drill string (only during drilling)
- Circulate the mud (only during drilling)
- Hoisting (only during tripping)
  - Under drilling mode the hoisting system uses minimum amount of energy



Drilling Engineering Application: Drilling and Tripping



Drilling Engineering Application: Power Consumption

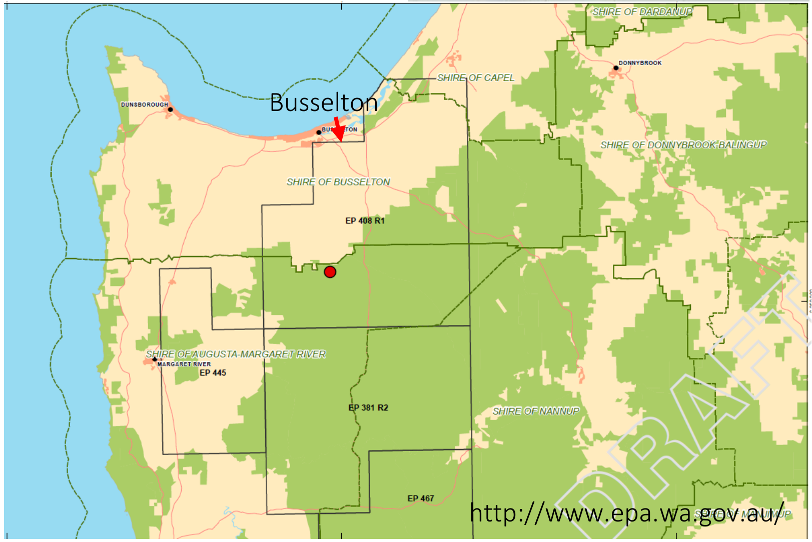
Case Study:

- Drilling Rig Century Rig 27 drilled a 4,575 m (hole name Whicher Range 4)
- Hoisting system power: 1200 kW
- Circulation system (mud pumps): 2000 kW
- Rotary system (top drive): 750 kW

Calculate:

Available power = 3500 kW

- Total power consumption While Drilling: ?
- Total power consumption while tripping: ?
- Compare the power consumptions with a home air condition unit 4kW.



http://www.epa.wa.gov.au/

Learning Outcome Check

- Role of hoisting and rotary systems
- Tripping vs drilling
- How often circulation system is active, and why.
- Power consumption of the hoisting system during drilling operation

Engineering Applications

Drilling Engineering Application: Power Consumption

Case Study continues:

- Power is provided by diesel generators (power pack)

Fuel

Diesel

Mechanical power

Generator

Electrical power

Hoisting system

Rotary system

Circulating system

- Fuel consumed by diesel motors to produce mechanical power
- The mechanical power converted to electricity via generator
- The produced power by the generator will be distributed to different system for the rig operation.
- Main three power consuming systems are rotary, hoisting and circulating

Drilling Engineering Application: Power Consumption

Case Study continues:

Efficiency from diesel to electric power:

$$\eta = \frac{P}{Q}$$

Output Power (P)

Drilling: 2750kW
Tripping: 1200kW

Input Power

$$Q = \dot{m} \times H$$

Fuel consumption rate ($\dot{m}$)

Heat energy (H)

Fuel

Diesel →

http://www.dieselgasturbine.com/

Generator → Electrical power

Drilling Engineering Application: Power Consumption

Case Study continue:

- Calculate the Fuel consumption rate while drilling (2,750 kW) assuming efficiency of 28%, and heat energy of diesel is equal to 40 MJ/lit

$$\eta = \frac{P}{Q} \qquad Q = \frac{2750}{0.28} = 9821.4\ kW = 9.821MW$$

$$Q = \dot{m} \times H \qquad 9.821 \times 10^6 \frac{J}{s} = \dot{m} \times 40 \times 10^6 \frac{J}{lit}$$

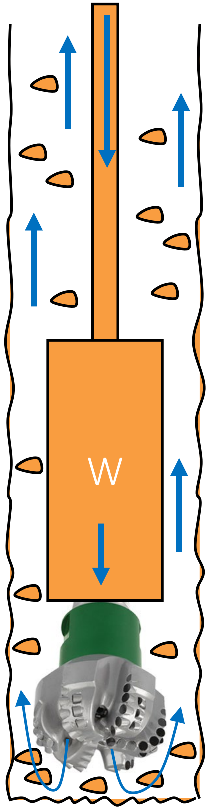
$$\dot{m} = \frac{9.821 \times 10^6 \frac{J}{s}}{40 \times 10^6 \frac{J}{lit}} = 0.24 \frac{lit}{s}$$

$$\dot{m} = 0.24 \frac{lit}{s} \times \frac{60s}{1\ min} \times \frac{60\ min}{1\ hr} \times \frac{24\ hr}{1\ day} \times \frac{1\ m^3}{1000\ lit} = 21.21 \frac{m^3}{day}$$

Comparison: A sedan's fuel capacity is approx. 60 Lit
$21.21\ m^3 = 21.21 \times 10^3\ Lit \approx 353$ Sedan fuel tanks

Roles of drilling fluid:

- Drilling fluid has different roles in drilling
- Some of these roles are:
  - Hole cleaning: carrying the cuttings to the surface (fluid velocity and viscosity).
  - Wellbore stability: to keep the borehole open during and after drilling
  - Fluid loss control: to minimise fluid being lost into fractures and formations
  - Drill string lubrication: decreasing friction between drill string and wellbore
  - Cool down drill bit

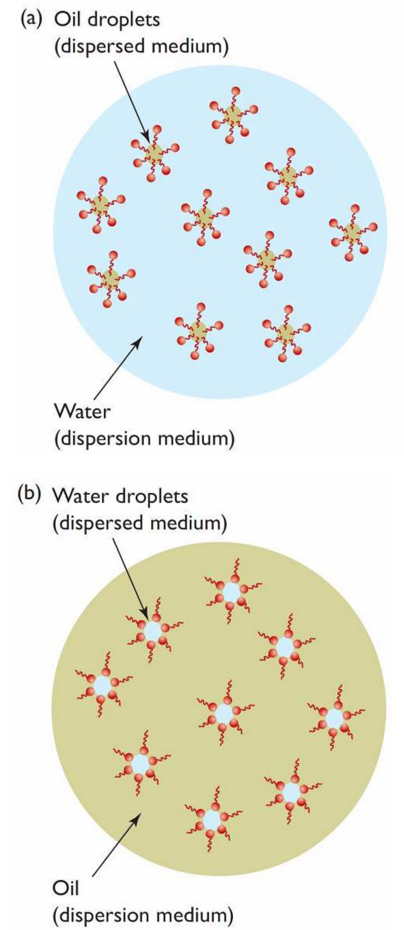


Drilling Engineering Application: Drilling Fluid | Types

- Drilling Fluid
  - Water Based Drilling Fluid
  - Oil Based Drilling Fluid
    - Oil in water emulsion
    - Water in oil emulsion
  - Synthetic Drilling Fluid
  - Air and Foam

Oil in water emulsion

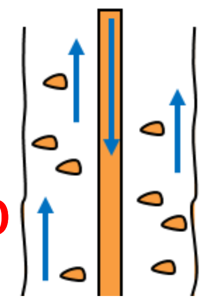
Water in oil emulsion



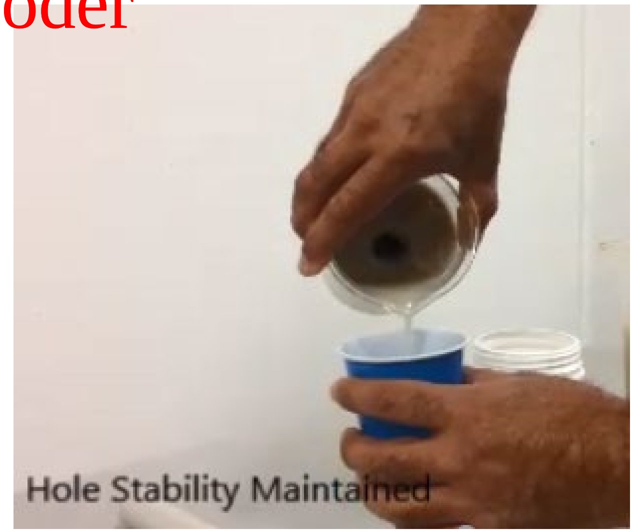
http://nsb.wikidot.com/

Drilling Engineering Application: Drilling Fluid | Composition

- Water base mud is the most common drilling fluid
- Water base mud composition: water + additives
- Additives : to control density and viscosity of drilling fluid
- Density is important for borehole stability
- Viscosity is important for borehole stability, hole cleaning and fluid loss control



Effect of viscosity on hole stability



Drilling Engineering Application: Drilling Fluid | Borehole stability

Borehole (Wellbore) stability:

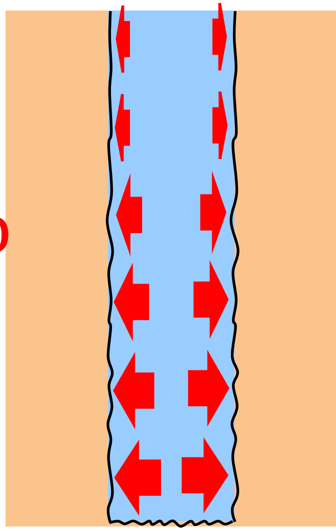
- provide sufficient hydrostatic pressure to provide mechanical stability
- To have minimum reaction with formation
- Reaction with formation

  → decreases strength of rock

  → borehole instability

- Bottom hole pressure can be increased by increasing density of mud.
- Borehole can be stabilised (mechanically) by providing sufficient bottom hole pressure
- Suspended solid particles are often used to increase the density of mud
- Pressure is calculated from:

$$P(Pa) = \rho(\frac{kg}{m^3}) \times g(\frac{m}{s^2}) \times h(m)$$

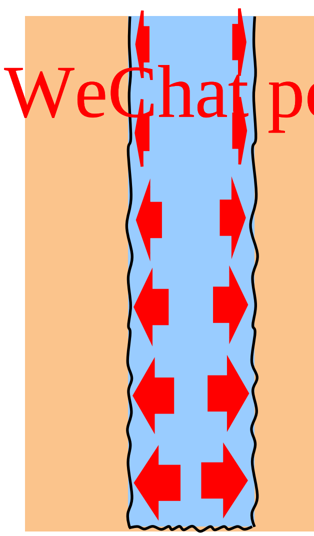


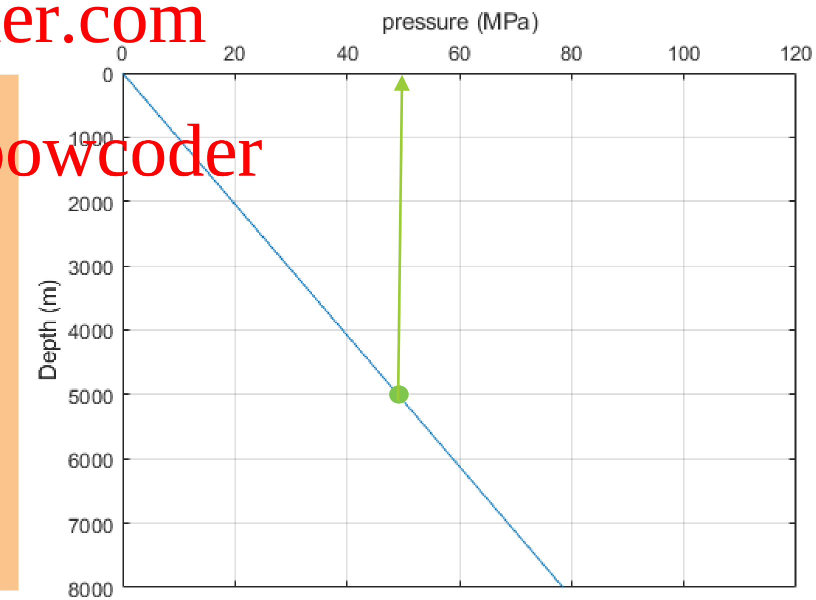
- Borehole can be stabilised (mechanically) by providing sufficient bottom hole pressure
- Hydrostatic pressure increases with depth
- Higher confining pressure (mud pressure) provided by increasing mud weight

$$P(Pa) = \rho(\frac{kg}{m^3}) \times g(\frac{m}{s^2}) \times h(m)$$

Depth = 5 km

$$P(Pa) = 1000\left(\frac{kg}{m^3}\right) \times 9.8\left(\frac{m}{s^2}\right) \times 5000(m)$$
$$= 49 \times 10^6 Pa = 49\ MPa$$

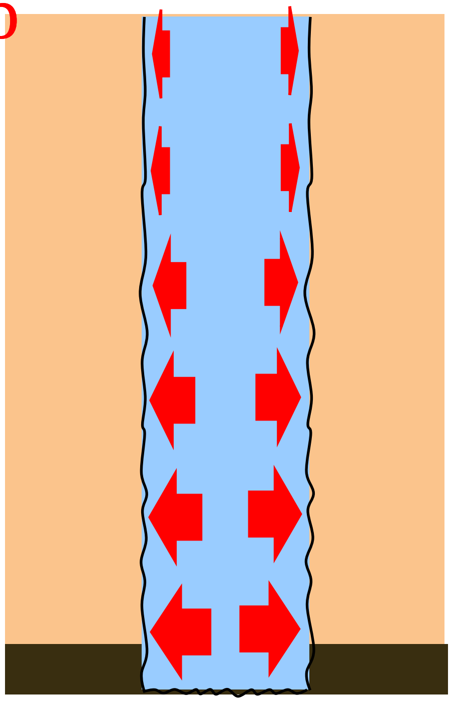




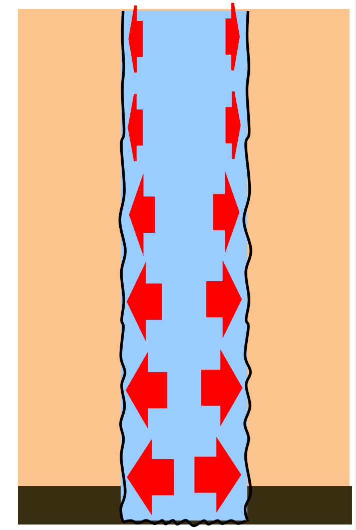
Drilling Engineering Application: Drilling Fluid | Density Selection

- Available mud pressure with 1000 kg/m^3 mud @ 8 km= 78.48 MPa
- Assume required mud pressure @ 8 km is 100 MPa
- What should be the mud density and the plot of mud pressure versus depth:

D = 8 km,
100 MPa is required



Drilling Engineering Application: Drilling Fluid | Density Adjustment



- Barite is an additive typically added to increase the mud weight
- Mud Density is the ratio of mass of mud components on volume of mud components

Water

Barite (weighting agent)

Polymer (viscosifier)

$$\rho = \frac{M_{mix}}{V_{mix}} = \frac{\Sigma m_i}{\Sigma V_i} = \frac{m_{water} + m_{barite} + m_{polymer}}{V_{water} + V_{barite} + V_{polymer}}$$

Drilling Engineering Application: Drilling Fluid | Density Adjustment

Example:

Calculate the density of a mixture of made of 300 kg of barite (density of 4200 kg/m^3), 2 kg of polymer (density of 3000 kg/m^3), and 1 m^3 of water.

Water

Barite (weighting agent)

Polymer agent (Viscosifier)

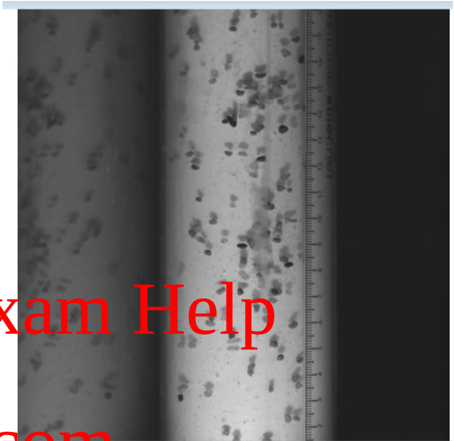
Solution:
Total Mass = 1302 kg
Total Volume = 1.072 m^3
Density = 1214 kg/m^3

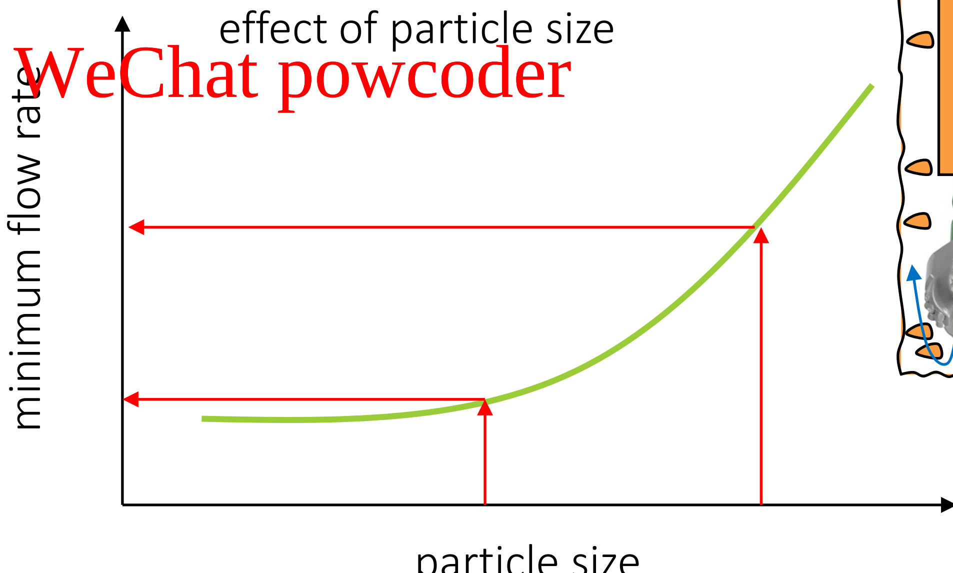
$$\rho = \frac{M_{mix}}{V_{mix}} = \frac{\Sigma m_i}{\Sigma V_i} = \frac{m_{water} + m_{barite} + m_{polymer}}{V_{water} + V_{barite} + V_{polymer}}$$

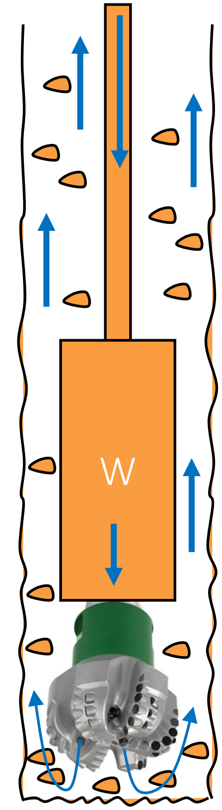
Drilling Engineering Application: Drilling Fluid | Hole cleaning

Hole cleaning (Cutting transportation):

- Effective transportation of cuttings to surface is hole cleaning.
- Sufficient fluid velocity and viscosity to transport the cuttings to surface
- Consequence of poor hole cleaning: slower drilling
- Link to fluid mechanics and drilling engineering (viscosity, flow rate, flow regimes, etc.)

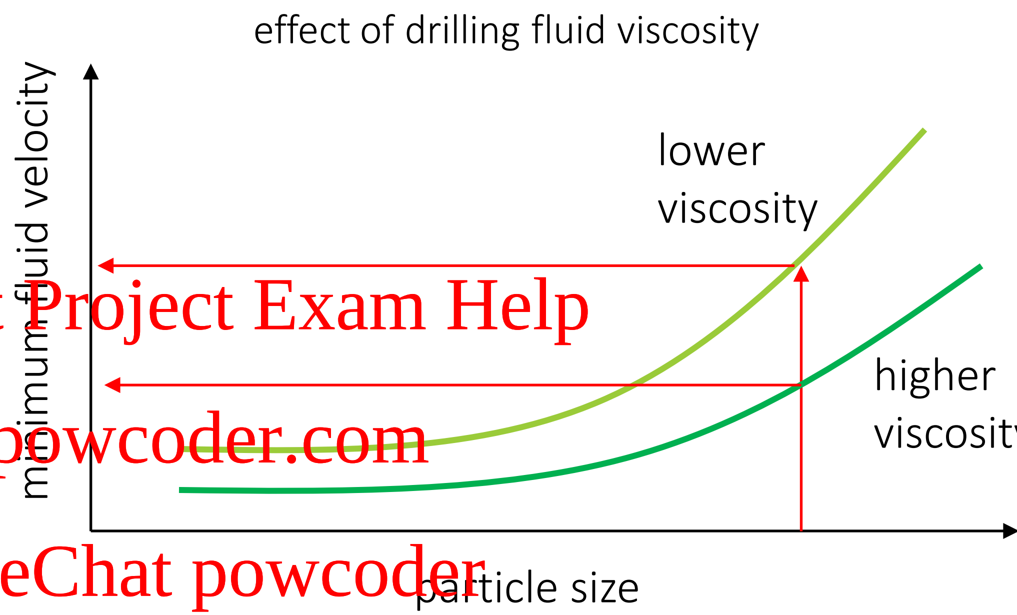






Drilling Engineering Application: Drilling Fluid | Hole cleaning & Viscosity

- Increase of minimum fluid velocity with increase of particle size
- Fluid velocity will be converted to flow rate (engineering application)
- The relationship between minimum fluid velocity and particle size is function of particle size
- Higher the viscosity, the transportation of cuttings is easier → lower minimum fluid velocity

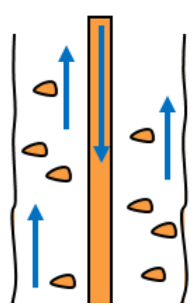


Fluid velocity (m/s)

Flow rate $(\frac{m^3}{s})$

$$q = v \times A$$

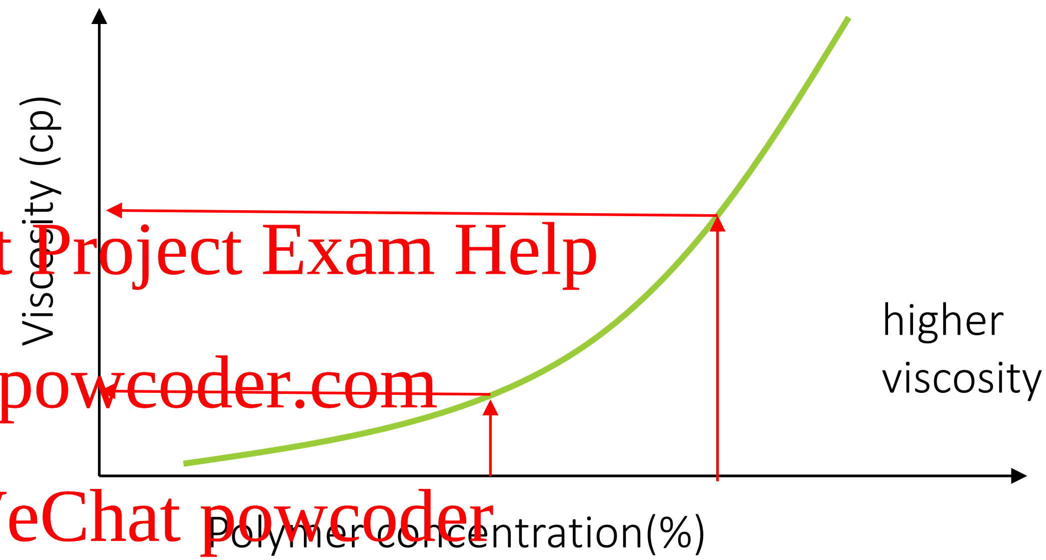
Cross section area (m^2)



Drilling Engineering Application: Drilling Fluid | Viscosity Adjustment

- A common engineering unit for viscosity is centipoise (cp)
- Viscosity can be increased by adding polymers to drilling fluid
- Higher the concentration of polymer, higher the value of viscosity
- The amount of polymer added is recorded in polymer concentration (weight/lit or weight/weight): numerator is polymer and denominator is water.

Variation of drilling fluid viscosity



Learning Outcome Check

- Roles of drilling fluid
- How viscosity and mud density is important properties of mud
- Cutting transportation controlled by size of cutting and impact of viscosity
- Practical methods to increase the density and role of viscosity

Thank You!

Any questions:

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