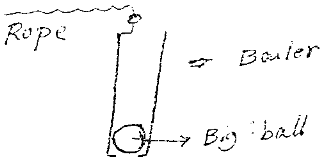
Drilling Engineering (P.1)

Drilling Engineering (I)

Instructor : S.R. Shadizadeh, Ph.D, PE

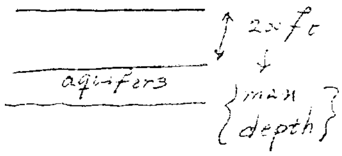
□ Bailing : using a bailer to bring cuttings to the surface (Taking sample from River, sea, ocean and oil wells) ⇒ Throwing the bailer → collecting sample



At First → Drilling wells just for water.

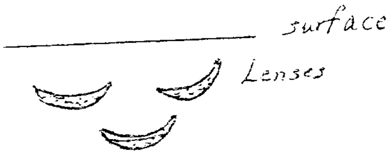
In Iran : Depth of wells : 1300 m – 6000 m

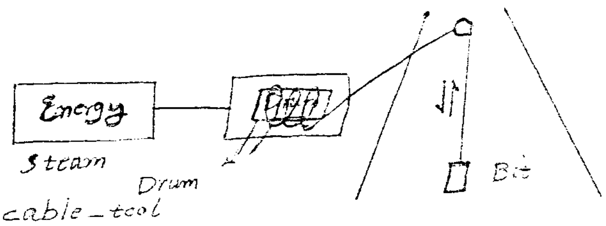
Reaching to ground water (200 ft) → aquifer



First oil in drilling history : 69 ft (By Drake)

In shallow formations : Lenses





cable – tool
Percussion

Hand → percussion → → cable – tool → Rotary Drilling

□ Drilling has 2 revolution :

(1) From Drake (1859) → Cable – Tool

(2) Antony Lucas (1900 – 1901) (using a rotary technology) Drilled a discovery well.

- percussion and Rotary Difference :

in Percussion → hitting ground by bit.

But in Rotary → Rotating Bit through the ground.

current drilling technology : 40,000 ft depth

- Two super-Rig in Iran before 1979 → were sent after 1979 out of Country.

- Drilling Methods :

(1) old time (drilling By hand)

(2) Percussion By Animals

(3) percussion By Steam

(4) Cable-tool drilling

(5) Rotary Drilling

- Rotary Drilling :
  (1) Rotary Table : Rotating Bit From surface with string.
  (2) Down-hole motor : a pump down the hole Behind the bit and rotate the bit only not the whole drilling string (+ Geostring)
  (3) Top drive : Rotating the whole drill string
  (4) Coil Tubing : مغزی سیار

Combinations of these Four ⇓ Rigs in U.S.A

- Rig : has a combination of all above methods.

In "Iran" Rigs are based on "Rotary Table".

- Well Trajectory : Different path to reach the target zone.

Geostrings help us to reach to the area of target in Down-hole motor technology (Auxiliary Technology)

In U.S.A : on average 2500 wells/year are drilled

In Iran (100 years production of oil and gas) → 2400 wells → 1300 produce → 35 wells/year

H.W #1 : List the oil and gas fields and reservoirs with name and Location.

Also, List the number of wells in each field.

Drilling Engineering (P.3)

- Drilling Environment : (A) surface environment : Geographic Location
  - ocean offshore
  - continental onshore (Land)

(B) Subsurface Environment

Rotary Drilling Rigs: (1) Marine
- Floating — 7500 ft
  - Drill ship
  - Semisubmersible — For water depth of up to 3500 ft
- Bottom support
  - Platform
    - Self-contained
    - Tendered
  - Barge
  - Jackup → For water depth of up to 350 ft

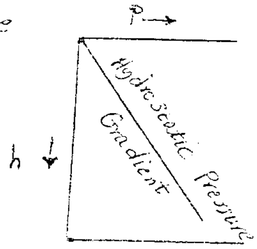
(2) Land
- Conventional
- Mobile
  - Jackknife
  - Portable mast

Subsurface Environment : Pressure

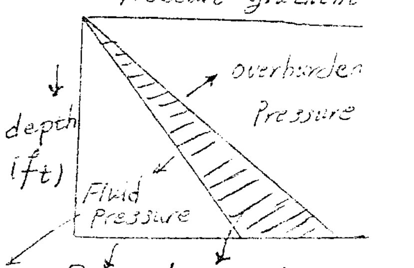
Hydrostatic Pressure : $P_h = \gamma_w h$

γ_w: quality of water

$\gamma = \rho g$, $\rho = \frac{mass}{volume}$ → Composition



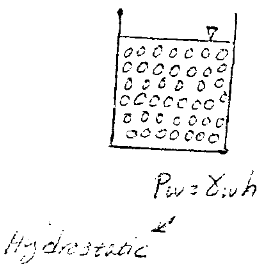
Graph of normal subsurface Pressure gradient

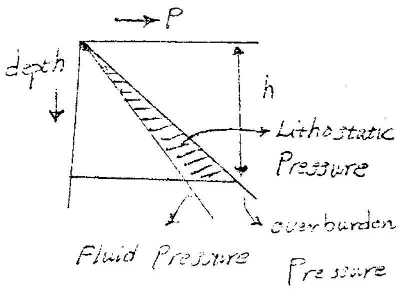


H.P. gradient depends on the quality of water (Fresh, salt, etc)

Fresh water gradient = 0.433 psi/ft

Salinity of 55000 mg/L → Pressure gradient = 0.45 psi/ft





Hydrostatic pressure

Formation pressure

Reservoir pressure

overburden Pressure Gradient = Formation Fluid Pressure gradient + Stress of Formation (wt of rocks)

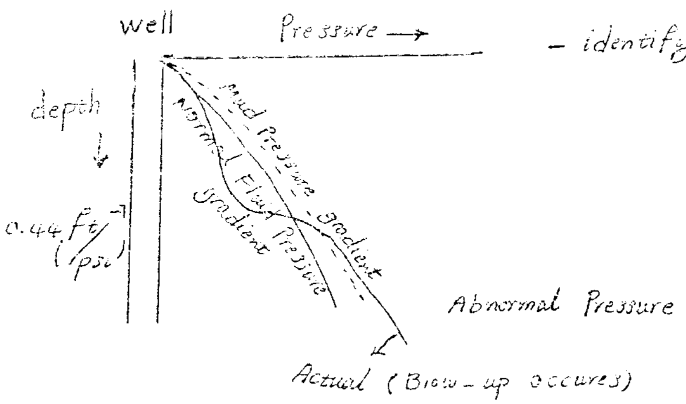
$P_{mud} = 0.052 \times (TVD) \times MW$

TVD : True Vertical depth (ft)

MW : mud weight (lb / gallon : PPG)

$P_{mud} <<< P_f$, P_{mud} (psi)

– Drilling is equivalent to controlling the subsurface pressure.



– identify → abnormal pressure zone for the drilling operation to prevent Blow-out when reaching to a productive layer.

□ Causes Of Abnormal Pressure

surface Environment depends on geometric location.

Location dictate : Personnels , Rig Types

Two subsurface factors : pressure , temperature

Any well has two depths : (i) True Vertical Depth (TVD)

(ii) Actual Depth or depth along the trajectory of the well.

if $P_{mud} >> P_f$ ⇒ Lost of mud (Lost circulation)

if $P_{mud} \simeq P_f$: Prevent Flowing of formation fluid

if $P_{mud} << P_f$: Blow-out → Kick

– Coming of formation fluid in the well is called "Kick".

$P_f + 200\,(psi) \rightarrow P_{mud} = 0.052 \times MW \times TVD \Rightarrow$ "MW" must be corrected to drill

□ Formation Fluid Pressure Gradient (FFPG) is found by :

(1) Resistivity Log (2) Sonic Log (3) Rate of penetration equation.

Drilling Engineering (P.5)

$P_{mud} = P_f + 200$

$P_f \ll P_{mud}$: over balanced drilling (OVB)

$P_f = P_{mud}$: Balanced Drilling

$P_f \gg P_{mud}$: Underbalanced Drilling (UBD)

NOTE: UBD is for those formations that will drill in a tight sand that has not high porosity (ϕ) and formation fluid.

NOTE: Base for choosing mud weight is formation fluid pressure gradient.

$OPG = FFPG + LPG$

$(1\ psi/ft) = (0.5\ psi/ft) + (0.5\ psi/ft)$

FFPG around the world is about 0.487 psi/ft.

NOTE: Any formation that contains water and this water does not flow into the surface almost has 1atm pressure and is called undersaturated water.

□ Subsidence

Causes of Abnormal pressure zone are :

(1) Rapid Sedimentation

(2) Piezometric surface Contrasts

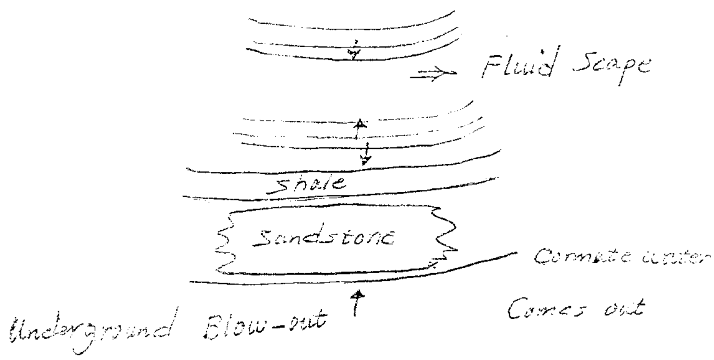
(3) Chemical Diagensis

(4) Fluid Density Contrasts

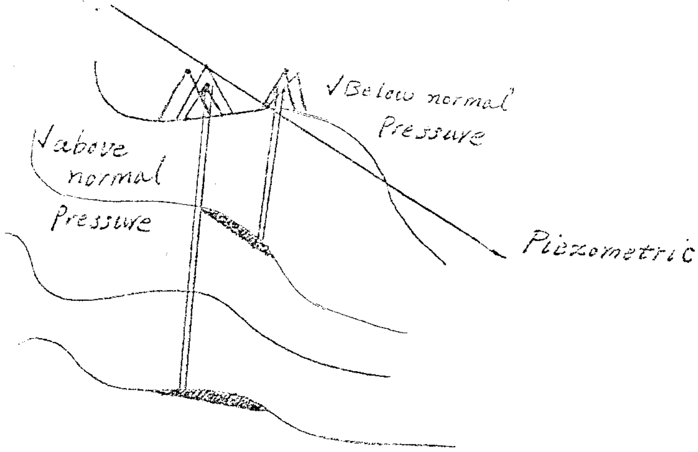
(5) Structural Movement

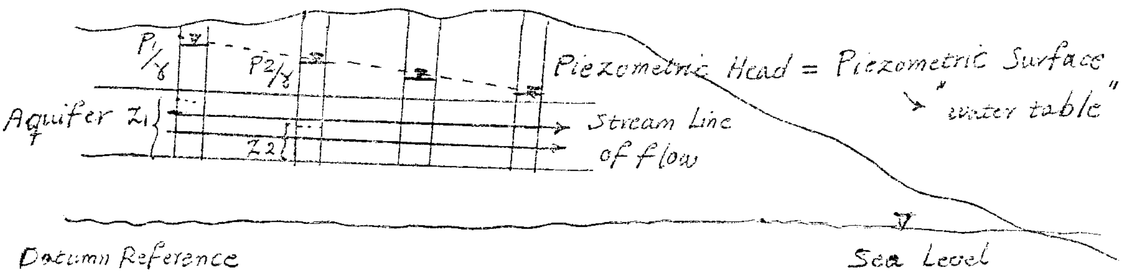
(6) Charging تزریق کردن

(1) Rapid Sedimentation



(2) Piezometric Surface Contrasts

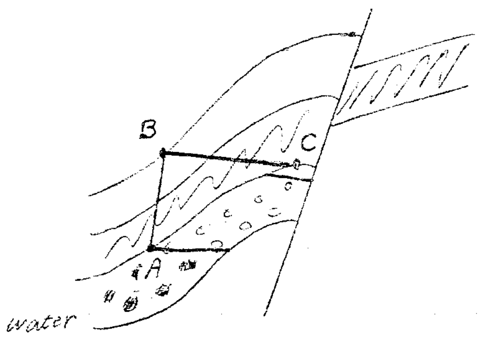




$$\underbrace{\frac{P_1}{\gamma} + \frac{v_1^2}{2g} + Z_1}_{\text{Fluid Mechanic Energy}} = \frac{P_2}{\gamma} + Z_2 + \frac{v_2^2}{2g} + \text{Losses}_{1-2}$$

(3) Chemical Diagensis : Diagentic change of one type of rock to another type of rock, Like change of clay from one type to another.

(4) Fluid Density Contrasts



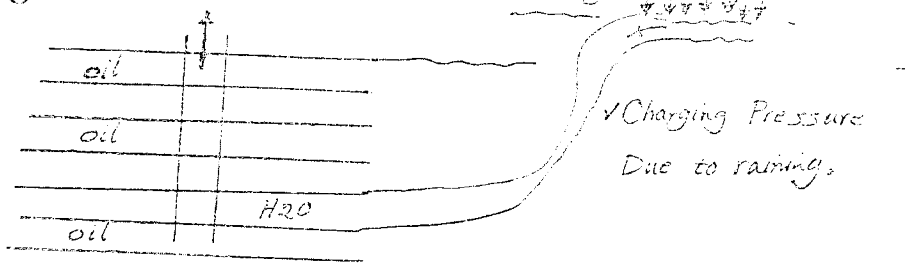
$$\left.\begin{aligned} P_A - \gamma_w h_{AB} &= P_B \\ P_A - \gamma_{gas} h_{AB} &= P_C \end{aligned}\right\} \Rightarrow P_C \gg P_B$$

NOTE: $\gamma_{gas} \ll \gamma_{water}$

(5) Structural Movement :

Drilling Engineering (P.7)

(6) Charging



□ Second Subsurface factor : Temperature

وقتی که دمای یک لایه به طور غیر منتظره افزایش یابد، گل توانایی تحمل دما را نداشته باشد اصطلاحاً Break می‌شود و خاصیت انتقال خرده‌ها را از دست می‌دهد. (حالت شیر بریده را دارد)

□ Thermal Conductivity

Some problems including are : (1) In Cementing تبخیر آب سیمان

(2) Effect on quality of drilling mud

NOTE: Vaporization of water in cement will produce some microfractures.

وجود microfractures باعث می‌شود تا مدت زمانی پس از تولید، گازهای تولید شده به اطراف casing در micro fractures داخل شوند و با فشار زیاد باعث ایجاد فروریختگی Collapse شوند.

High temperature can influence :

(1) Cement Setting Time

(2) Thermal Expansion or contraction of tubular (Tubing, Casing)

(3) Bit Life

(4) Change of Drilling mud property

(5) Formation Evaluation Equippment (Logging Devices, ...)

Drilling Engineering (P.9)

□ The Well Planning Process

Major components are :
I. Well Selection
II. AFE Preparation (Authorization For Expenditure)
III. Organizing and Data gathering
IV. Well Design
V. Rig Design
VI. Procedures
VII. Contract
IX. Cost Estimate

Team Members : ✓Geo science : Geophysicists → Exploration Methods
Geologists → Well-logging, sedimentary Facies, Lithology

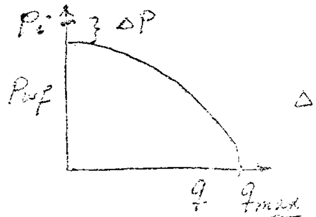
✓Engineering : Drilling : optimizing drilling : Safety, useful well, Low cost
Production : well completion and production
Reservoir Engineers : Reservoir Performance (IPR)

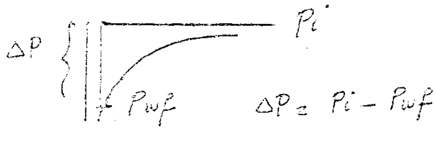
✓operations : Drilling manager : oil company (1)
Drilling superintendent : supervise more than one Location (b/w 1, 3)
Drilling Supervisor : is responsible for the rig (3)
Logistic coordinator : Road Construction, Transportation (equips, people, ...)

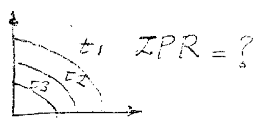
✓support : Loss Prevention - Safety : Checking equipments
Environmental and Regulatory : Air Polution, surface water pollution, Ground water pollution, Noise Polution
Purchasing : providing tools for drilling or materials and equipments.

□ well completion and production : Downhole equipments and surface facilities

□ IPR : InFlow Performance Relationship → How the reservoir Perform at different times at different Pressures.







max flowrate : well Potential (when $P_{wf} \approx 0$)

✓ Drilling company : Contractors

✓ Oil Company : Ownes the well

Environmental Assesment before drilling, during drilling, Post-Drilling.

□ Oil company : Formation Evaluation
(well operator)
Accounting Department
Operations
Production Engineering
Land department
Reservoir Engineering
Drilling Engineering
Geology, Drilling Superintendent : Company Representative → other wells in progress

□ Drilling Contractor : ✓ Accounting Department
✓ Rig Design and Maintenance
✓ Drilling Superintendent : ✓ Tool Pusher → Other Rigs under contract
Driller
Derrickman
Rotary Helpers
(Rig Crew)

□ Drilling Services Companies : ✓ Drilling Fluids
Drilling Cements
✓ Well monitoring
Formation Evaluation
Well casing
✓ Directional Drilling
✓ Drilling Bits
Well Completion Equipments
✓ Blowout Prevention
MISC

Drilling Engineering (P. 11)

□ Well selection:

(1) Budget objectives, (2) Prospect identification: Identifying reservoir and lithology

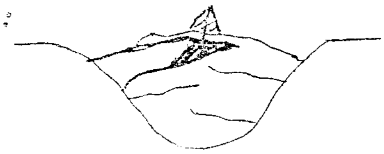
(3) Reservoir potential Evaluation (How much gas, oil, $K, \phi = ?$, S_o, ...)

Prospect aquisition: Gathering surface and subsurface data

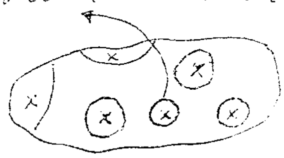
(4) well Location selection

□ Well Type:

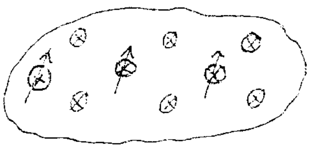
Exploration

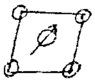


Infill well (Between wells)



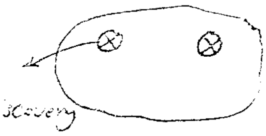
Well Type: injection well





spot-pattern

Well Type: Developed well



Discovery wells

Well Types: wildcat well, Exploration well, Discovery well, Developed well, Infill well, Injection well, Monitoring well, observation well

- Wildcat wells ↗ Exploration well (did not reach to oil)
  ↘ Discovery well (Reaches to oil)

✓ Keys of the well planning: Low costs, safety, usable well (useful well)

most of the developement wells are production wells.

deep well: depth > 30000 ft

Hazardous agents: (1) toxics (2) Flammable (3) Reactive (4) Corrosive (5) Nuclear wastes

Observation well: a well used to observe other wells in a field, it can be a production well or not. (shut-in well)

Monitoring well: monitor subsurface ground water, etc.

Prospect Identification: possibility of oil and gas possibility, presence.

NOTE: Middle valves may be used as choke for controlling flowrate.

□ well Planning Process Flow chart

□ AFE Preparation :

✓AFE cost Estimation ⇐ Geological input. / completion and testing Requirements. / Drilling Consideration. / Production Facilities.

⇓

✓AFE Approval

AFE cost Estimation : a paper for oil company to sign it.

□ Organizing and Data gathering :

✓Initial planning meeting : Location, support and Logistics
Pressure Prediction
Potential Drilling Problems
Directional plan
Environmental and Regulatory Requirements

□ Type of wells in terms of direction = well trajectory

OR : Type of well trajectory : (1) vertical well
(2) Deviated wells : S-shape, Horizontal well, (Geostring wells) Multi-branch wells (offshore wells)
(3) planned well trajectory (path)

□ Well Design :

Casing depths and sizes selected → Mud Program and Solids Control → Tabular and Well head design
Cementing program
Drilling mechanics
Hydraulics program
Logging, Coring, and testing programs

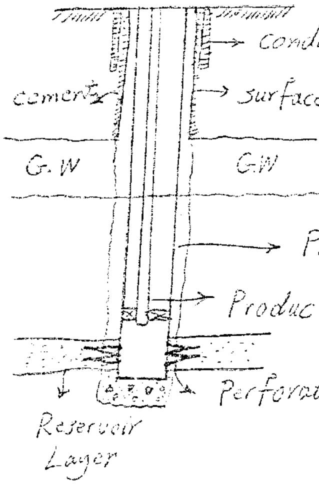
Government Regulation ↑ ↓

Permit application submit

✓□ Depth of casing : f (Mud weight, formation fracture gradient, Pore Pressure Lithology Type , Drilling Problems)

✓NOTE : For "Killing job" in reservoirs, some fluids (muds) are injected to the well with a pressure greater than the pressure of the mud and/or formation. but this process may resulted in formation damage, in order to Prevent formation damage in these cases, two master valves are used.

Drilling Engineering (P.13)



□ Hydro-pressured wells and Geo-pressured wells

✓ Intermediate Casing OR Protective Casing (in Geo-pressured)

✓ Liner after intermediate casing is established. (in Geo-pressured wells)

□ specification for pipes: ID, OD, Length, grade.

Grade shows the strength of pipe.

✓ Carbonate Layer → Doing casing in order to prevent mud Loss in fractures.

□ Wellheads and Flow control equippments:

Well head provides the control mechanisms b/w downhole and surface equipments. As the well is drilled, casing is placed at intervals specified by well design. The casing depth can be determined by abnormally pressured zone, lost circulation zones, sticky formations or other reasons as dictated by various situations.

□ Casing and casing programs:

Casing Head ⇐ { (1) Conductor casing or drive pipe (16 to 48 inch) → 100 to 400 ft
(2) Surface casing ($3\frac{5}{8}$ to 20 in) in OD (L → 200 to thousand feet)

Casing Spool ⇐ { (3) Intermediate casing ($7\frac{5}{8}$ to $13\frac{3}{8}$ in OD) (3000 to 8000 ft)
(4) Production Casing ($4\frac{1}{2}$ to $9\frac{1}{4}$ in) → 1000 ft Depth Set (total depth)

Tubing head ← (5) production tubing (1 to 7 inch):

production optimazation → Diameter of production tube is important.

Total Depth: 10,000 ft (near total depth) For Length or depth of production tube which is fitted.

□ Wellhead Assemblies : Casing head
Casing spool
Tubing head

Each spool : valve, Gauge

Christmas Tree : for production from both sides.

2 master valve : (1) in order to preventing formation damage in Killing reservoirs.
one at surface
one at bottom
(2) one checks other valve in gas Leakage for solution-gas drive reservoirs when oil is produced.

Choke : flowrate controling in production (it is not a valve).

(1) positive choke : is fixed to a flowrate.

(2) Adjustable : have option to adapt to the flowrate.

Master valves are used to open or close the well. (P↓, P↑)

BOP : Blow-out Preventor : (1) for drilling (during drilling or after)
(2) for workover jobs

"BOP" is set on casing spool after drilling. (usually on casing head flange)

NOTE : BOP for drilling , Christmass tree for production.

□ Rig Design : ✓BOP equipment and procedures
✓Rig specifications

Rig types : Light Rigs
↓ Medium Rigs (3000')
f(depth) Heavy Rigs (25000')
Super Rigs (>30000')

NOTE : The deeper the well → The heavier the BOP is used.

Generally : BOP's stand for 10,000 psia pressure.

BOP : Pipe ram , Shear ram , Annular
hold the pipes, cuts the pipes, Finally Kill the well.

BOP : (for workover jobs) : Pipe Ram , Blind Ram

Drilling Engineering (P.15)

□ Procedures : Drilling procedures → Drilling-time curve

support → Emergency procedures

Completion and Testing procedures → Completion and Testing Time

Rig Bid Solicited : According to Rig's specifications.

اداره کردن، درخواست کردن

□ Cost Reviews : Bids evaluated

مزایده

Drilling cost estimates

Completion and testing cost estimates ⇒ { Completed Estimation

AFE preparation Review

□ The Drilling Rigs :

(1) The drilling Rig, more comprehensively the well site, include the followings:

✓ production primary energy

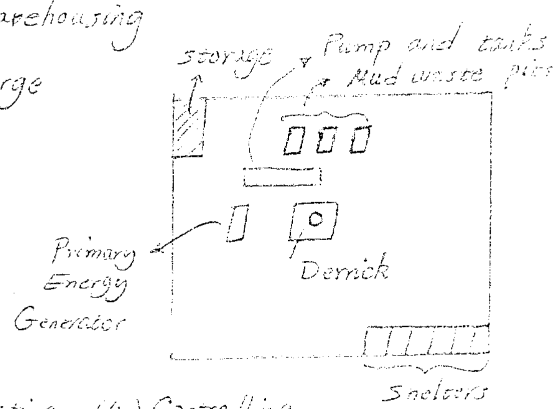
✓ Expandable product storage, and warehousing

✓ Facilities For handling waste discharge

✓ Shelters

✓ The Derrick

✓ Pump facilities and tanks



Four Basic Drilling Functions :

(1) Hosting (2) Rotating (3) Circulating (4) Controlling

□ Hosting Equipments :

(1) Drawworks : It is the heart of Hosting.

(2) Big wire : Drilling Line

(3) Crown Block

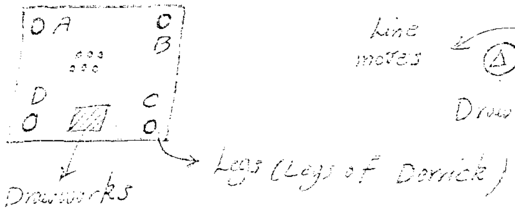
(4) Travelling block

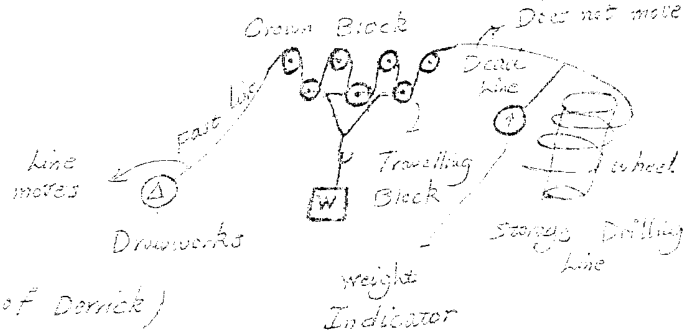
(5) Hook : For Hanging Equipments } Travelling Block & Hook

(6) Elevator

(7) Tongs (Connection and Disconnection)

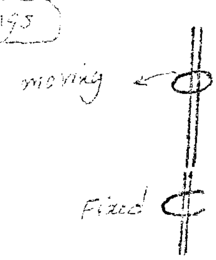
A Rig has Four place :



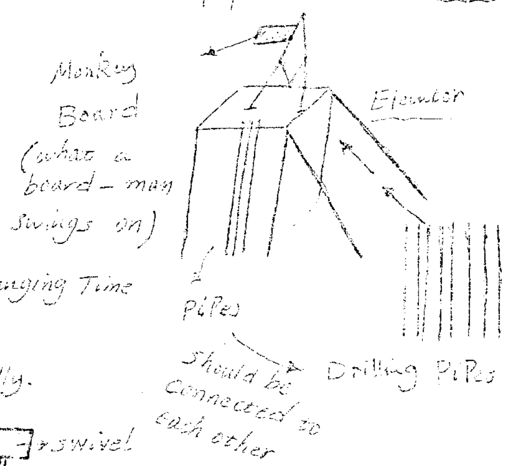


Monkey Board : A man standing on , trying to connect pipes to each others
pipes elevated by Elevator must be connected to the pipes on the Derrick
by the Board-man on Monkey Board.

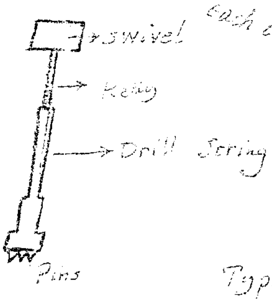
- (Tongs)

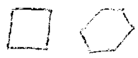


Connection and Disconnection (Elevator, Kelly and swivel) Bit changing Time



All Drilling Pipes are connected to the Kelly.
Kelly : maximum 40 ft Length.
slips : prevending movement and vibration of Drill strings.



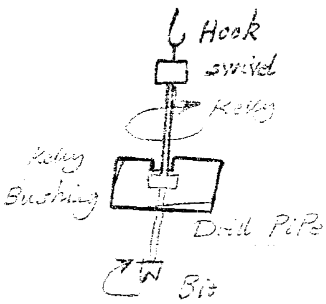

Typical Kelly Shapes

Elevator graps drilling pipes and brings them up , Connecting and then Kelly will be connected to upper part of pipes.

Set of pipes : stand (30', 60', 90', 120', ...) ⇒ Stand By Stand Connection
stand depends on Rig Heights , specification.

□ Rotating :

✓ Rotary Table : It is the heart of Rotating.
✓ Rotary Table Bushing
✓ Kelly Bushing



Only the Kelly is rotated by Rotary Table.

Drilling Engineering (P. 17)

□ Circulating Equipments :

(1) Mud Pumps: Are the heart of circulating (Bernoulli's Equation)

(2) Manifold

(3) Stand Pipe (standing up to the nearly middle of the tower)

(4) Hose

(5) Swivel

(6) Mud - Return Line

(7) Shale Shaker

(8) Desander

(9) Desilter

(10) Centrifuge

(11) Degaser

(12) Mix pits

(13) Circulating Pits

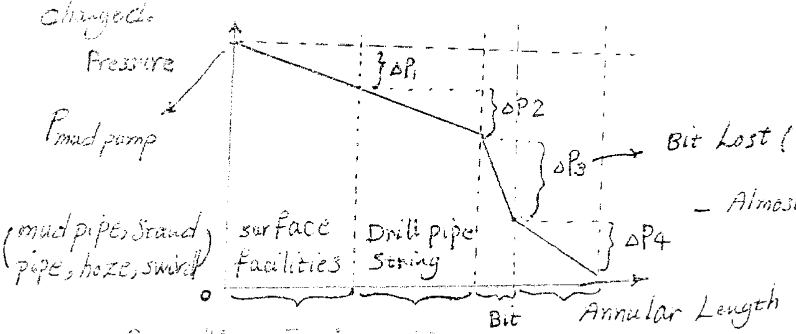
(14) Reserve Pits

(15) Trip pits

Most of energy is consumed by Bit to drill.

Hydraulic Drilling : Calculations for pressures in Drilling operation.

When pumps are not changed, to modify the system, Drilling Fluid should be changed.



- Almost 75% of energy of fluid is used in bit for penetration and cutting

□ Controlling Equipments :

BOP (Blow-out preventer)

Annular Preventer : used to shut-in the well

more than one of each : Ram pipe : used to hold pipes.

Shear : used to cut pipes.

Blind : used to separate top section of well from the bottom

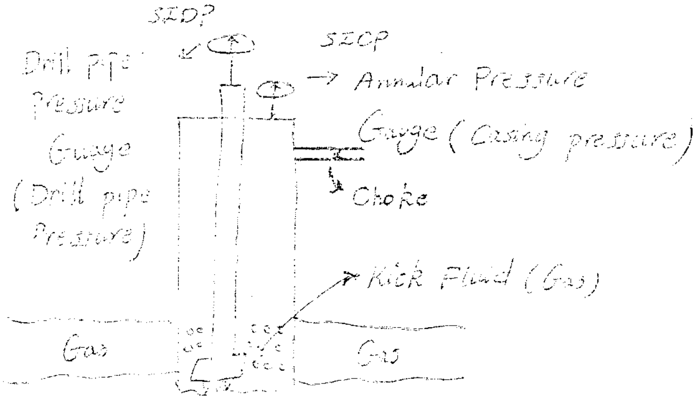
✓ Choke line, Kill line : used to remove any Kill fluids out of the well.

SICP : Shut-in casing pressure.

SIDP : Shut-in drill-pipe pressure.

✓ Heavy mud : making Kill fluid out of well to the choke.

✓ Choke is used to not allow sudden pressure drop.



√(1) Hoisting:

Put weight on the Bit (lbf), $\underline{w}$

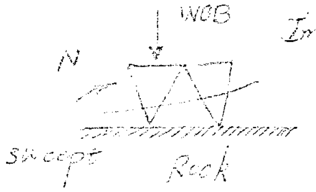
√(2) Rotating:

Rotate the Bit, rpm, $\underline{N}$

√(3) Circulating:

Pump Fluid Through the bit, psi, P

q, gpm (Gallon Per minute)



Impact Force

75% of Hydraulic Energy is used (Impact Force)

"sweeping" cutting from Rock Face in Drilling by energy. (part of 75%)

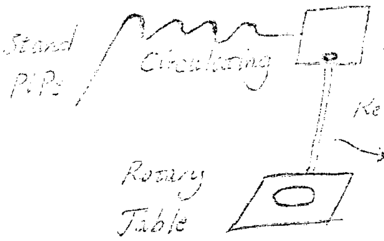
ROP = Rate of penetration (ft/hr)

$$\frac{cost}{feet} = \frac{\$}{ft} = \frac{\text{cost of Bit} + \text{Rig Cost}(\text{Time of Drilling} + \text{Time of Tripping})}{\text{Depth}}$$

$$C = \frac{C_B + C_R(T+t)}{D} \quad ; \quad cost \propto \frac{1}{D/T} \Rightarrow \boxed{cost \propto \frac{1}{ROP}}$$

√ Time of Tripping: Time of Connection and interconnection and disconnection. (Bit change)

√ The whole swivel does not rotate, only a part Connected to Kelly, Rotates.



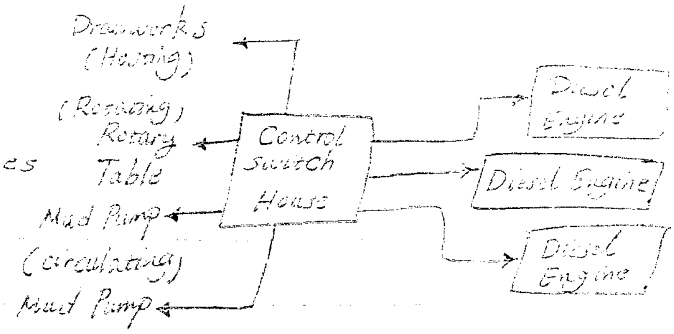
Swivel (It is a connection b/w Hoisting, Circulating and Rotating Operations)

Rotating Only Kelly is Rotated by Rotary Table.

□ Rig Power System:

one, two or more Diesel Engines

Engine Capacity may range from 500 - 5000 HP and power may be Transmitted to the rig by either mechanically or electrically.



□ Rig Power :

Efficiency of Drawworks ⇒ $E_f = \frac{P_{out}}{P_{in}}$

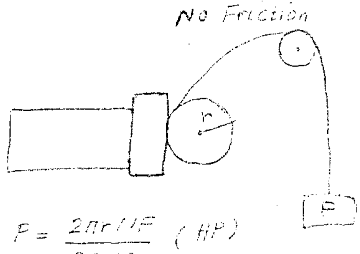
The heat energy input to engines: $Q_i = w_f H$

w_f : fuel combustion , mass rate (lb/min)

H: Heating value of fuel type (Btu/lbm)

$P = \omega T$, $T = F \times r$, $\omega = 2\pi N$

$P = 2\pi r N F$



Define: 1 HP = 33000 lb_f-ft/min $E_f = \frac{P}{Q_i}$, $P = \frac{2\pi r N F}{33000}$ (HP)

$$Power = \frac{torque\ (ft\text{-}lb_f) \times rpm}{5252}$$

$$E_f = \frac{rNF}{5252\, w_f H} \qquad HP = \frac{rNF}{5252}$$

□ Drilling String : Kelly, Drill pipe, Heavy-weight Drill pipes, Drill Collars, Bit

Drill Collars, Bit → Bottom-Hole Assembly (BHA)

Purpose:

The main purpose of the drill string to transmit energy from the Rig's surface to the Bit.

✓(1) The weight of the drilling string itself ⇒ WOB (comes from Drill Collars)

NOTE: too much wt on the bit ⇒ flunder (stuck)

✓(2) Hydraulic Power of the fluid that is pumped down the drill string.

✓(3) Turning motion of a Rotary table, Power swivel, top drive and downhole mud pumps.

□ NOTE: Type of Rotation: ✓(1) Rotary Table

✓(2) Power Swivel

For Deep formation, wells → ✓(3) Top Drive (Does Rotating and Hoisting)

Rotating Drill pipes ⇒ Rotating Bit.

At the End of MWD or MLD there is Bit and only Bit Rotates ⇒ Downhole Mud Pumps

In Deviated Wells

{ MWD: Measurement While Drilling
{ LWD: Logging While Drilling

– Top Drive: Used For Shortening the time of tripping to prevent sticking.

□ Downhole mud pumps : In Deviated wells when the Rotation of Drillstring is difficult.

Power Swivel → Top Drive → Downhole mud Pump (History of Drilling)

Power Swivel → Rotary Table

□ Stresses On Drillstring : Tension, Compression, Vibration, torsion, friction, formation pressure, Circulating fluid pressure, Also it is exposed to abrasive Solids and Corrosive fluids.

Hence : ✓(1) To withstand the hostile Environment.

✓(2) Must be light weight and manageable to be efficiently handled within the limits of the rig's hosting system.

✓(3) It must provide weight on the Bit.

✓(4) It must allow control over wellbore deviation.

✓(5) It must help ensure that the hole stays in "gauge".

□ Drilling Problems associated with Drill string :

✓(1) Dog Legs : Sudden change of drilling well trajectory (Causes Well Deviation)

✓(2) Key Seats : Well Deviation + Drill pipe stucking

✓(3) Bit Gauge Wear : Stucking (collar ?)

Gauge wear (Errosion of Bit) ⇒ Diameter Reduction of Bit Gauge ⇒ Stucking

□ Conclusion : Selection of the right drill string can reduce the dog Legs, Key Seats, Stuck pipe, Drill Crooked (Drill Deviated) and help produce a smooth bore.

□ The Length and make up of the drill string depends on:

Factors such as : ✓(1) Well Depth

✓(2) hole Size

✓(3) Operating Parameters ⇒ WOB, N, ρ(mud)

✓(4) Directional Consideration (angle of deviation)

□ Kelly : Is part of drill string which goes into rotary table.

Shape of Kelly is square or hexagonal.

A Kelly is special Machined PiPe.

Drilling Engineering (P.21)

□ API Kelly come in two standards:

(1) 40 ft overall, with a 37 ft working space.

(2) 54 ft overall, with a 51 ft working space.

✓ Kelly Saver Sub : ⇒ A sub that save the kelly.

✓ Kelly cock : Prevents fluid escaping from drill string.

✓ Automatic Check valve : Installed Below the Kelly. (Inside BOP)

□ Drill pipe = It is the major section of drill string (90% of Drill string Length)

✓ OD, ID, weight, grade of steel.

✓ Drill pipe is specified according to its upset.

□ Factors that influence drill pipe section:

(1) Hole Size

(2) Well depth

(3) Circulating System

(4) Drilling Mud Parameters

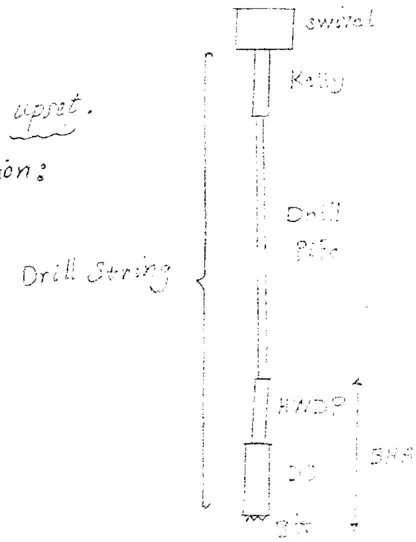
(5) Hosting capacity

(6) pipe availability

(7) Contract provision

(8) Casing and Cementing Requirement

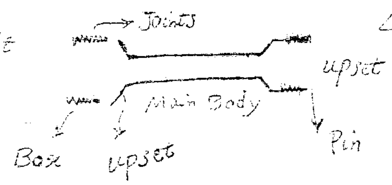
(9) Subsurface Pressure



Four Standard Drill Pipe is available: in 3 Length ranges:

✓ Range 1: 18 - 22 ft ✓ Range 2: 27 - 30 ft (The most commen used)

✓ Range 3: 38 - 45 ft ∠ Available Work space is 30 ft.



□ Tool Joints: Should stand torsional force :

Torsional yield strength is an important consideration in tool joint design.

Tool joints are identified by a series of 5 marking stenciled at the base of the pin connections:

For Example: ZZ S 89 B E → PiPe grade

ZZ: Company name Symbole; S: # of months; 89: year; B: mill code company symbole

PiPe capacity $= \frac{\pi}{4} (ID)^2$ in^3/in or bbl/Ft

Displacement : Annular Capacity $= \frac{\pi}{4} \left(\text{Hole Diameter}^2 - OD_{PiPe}^2 \right)$, bbl/Ft

- Drill Collar : is the heaviest part of drill string.

Functions of Drill Collars:

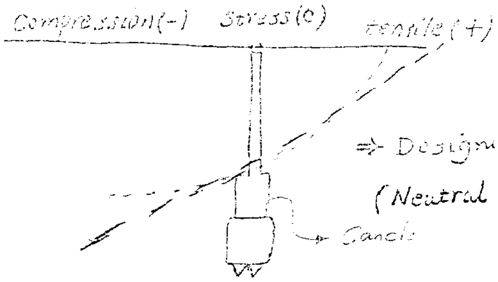
✓(1) They provide weight on the Bits while holding the drillstring in tension.

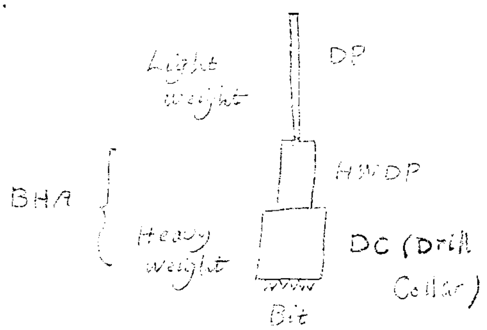
✓(2) They act as pendant to keep the hole straight.

✓(3) They maintain rigidity to drill a straight hole.

- Range of WOB: 0 → wt of Drill Collar

- HWDP: Serves as an intermediate weight drill string member between Drill pipe and the more heavier, drill Collar.





✓This part cancels the weight on the drill pipe.

- Bottom-Hole Assembly: (BHA)

Stabilizer : "In guage" in hole and to be on well trajectory.

Reambers : "In guage", it is used , to enlarge the hole diameter.

Bitwear : stuck pipe

Shock-sub: prevents a shock to the drill-string.

Jar : to prevent stuck pipe or to remove stuck pipe. (placed in different sections of the drill string.).

Vibration dampener: to prevent the drill string from vibration.

Drilling Engineering (P. 23)

□ Drilling Bits: (1) Drag Bits (2) Roller cone bits (Rock Bit)

(3) Diamond Bits (the same as Drag Bit)

↳ The whole bit rotates and cuts the formation.

✓ Drag Bit: Low wt on Bit and high speed of bit rotation.

✓ Bits drill through the rock by:

(1) Scraping: touching the rock surface

(2) Chipping: making small pieces

(3) gouging: Take it out

(4) grinding: making powder

There are many Vibrations (Variations) in the design of drill bits and bit selected for a particular application will depend on the type of the formation to be drilled.

□ Type of Rock are classified according to the rock hardness:

(1) Very soft (2) soft (3) medium (4) hard (5) Very hard

Long tooth (Rock Bits) (not diamond Bit) — Diamond

For: unconsolidated formations the WOB is Low and RPM is high. → Drag Bits

✓ very unconsolidated formations: WOB = 0, High ject velocity ⇒ Hydraulic efficiency

□ Drag Bits: Todays, Drag Bits are used for drilling unconsolidated ground water formation, or For very soft shale formation.

No Longer used (up to 1900), due to dragging /scrapping of this type of bit, high RPM and Low WOB are applied.

□ Roller Cone bits: (Rock Bits)

most common type of bits used world-wide Classified as:

✓ milled tooth bits, Insert Bits.

The first successive roller Cone bit was designed by Hughes in 1909.

1930 → 3 cones

The cones of the 3-cone bits are mounted on bearing pins, or arm journals which extend from the bit body. (Journal is body of the bit)

- Diamond Bit:

Natural Diamond Bits : The cutting action of a diamond bit is achieved by scapping away the rock.

The major dissadvantage of diamonds bits is their cost.

Advantages: ✓Long rotating hours.

✓reduction in the number of round tripps and offsets the capital cost of the bit.

- PDC bits: polycrystalline Diamond Compact (Diamond Layer and WC substrate)

Introduced in 1980's.

They have particularly successful (Long Bit Runs and high ROP) when run in combination with turbodrills and oil-base mud. (OBM).

- TSP Bits: Thermal Stable polycrystalline → For Geothermal Formations

- Design of Bits:

The design of cone bits can be described in terms of 4 principles:

Bearing Assemblies, Cones, cutting elements, Fluid Circulation.

Bearing Assembly: There are 3 types of bearing used in roller cone bits:

✓Roller Bearings which forms the outer assembly and help to support the radial Loading (or WOB).

✓Ball Bearing: which resists Longitudinal or thrust Loads and also help to secure the bearing pins on journals.

- Offset: small ⇒ For Hard Formations.

Large ⇒ For Soft Formations.

- Bit Selection: IADC (International Associated Drilling Companies)

preparing some sheets and tables

(Bit Selection Chart)

Drilling Engineering (P. 25)

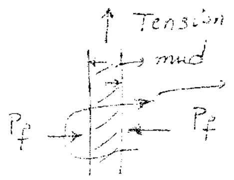
IADC Code For Bits :

If a bit is classified as 1-2-4.E , it is a soft formation, milled tooth Bit with sealed roller bearing and extended nozzles.

□ Drill string design :

Involves the determination of the Lengths, weights and grades of drill pipe which can be used during drilling, coring or etc, or DST.

Drill-Stem Test (DST) , DST Tools ⇒ Type of fluid, ϕ, K



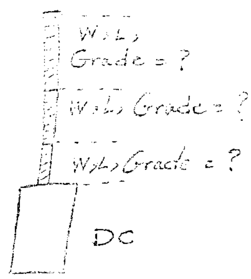
⇒ Design stands on the collapse pressure During Drilling or DST operation.

□ Design Depends on :

Hole depth, Hole Size, mud weight, desired safety factor, Length and weight of drill collars, desired drill pipe sizes and inspection, class

/ Following design Criteria will be used to select a suitable drill string :

Tension , collapse , Shock Loading , Torsion .



Length of DC = $L_{HWDP} + L_{DC} + L_{Bit}$

_ Shock Loading means sudden stop of the pipe by slip.

□ Tension : P = wt of Drill pipe + wt of DC

submerged weights are considered.

Bouyancy Force = Fluid volume displaced x Fluid Density

→ Greater
$W_{Air} \neq W_{mud}$ → smaller
$W_{mud} = W_{Air} \times BF$

$$W_{mud} = W_{Air} \times BF \quad , \quad BF = \left(1 - \frac{\rho_m}{\rho_s}\right) = \left(1 - \frac{\gamma_m}{\gamma_s}\right)$$

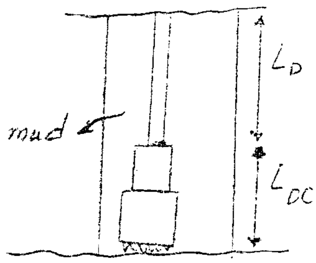
P = (wt of drill pipe in mud) + (wt of drill collar in mud)

$$P = (L_{dp} \times W_{dp} + L_{dc} \times W_{dc}) \times BF \text{ (Bouyancy Factor)}$$

$$BF = \left(1 - \frac{MW_{mud}}{W_{steel}}\right) = \left(1 - \frac{\rho_m}{\rho_s}\right)$$

P_t : tension yield strength of pipe

$$P_a = 0.9\, P_t \text{ (10\% Less is for Safety)}$$



\- ρ_s : Steel Density = 489.5 lbm/cuft. = 65.5 lbm/gallon

P_a : Applied Tension (max. tensile design Load) , P_t : table tension from manufactury (max. wt. can be used on pipe)

□ **Example:** Determine the maximum wt on bit provided by 450 ft of 7 3/4 inch O.D, 144 lb/ft drill collar for both of the following mud wt. (Assume that all of the compression of drill string is in DC.)

9.5 lbm/gal

16 lbm/gal

□ Solution:

$$WOB = \underbrace{(W_{DC} + W_{HWDP} + W_{BH})}_{L_{DC}} BF = W_{DC}\left(1 - \frac{\rho_m}{\rho_s}\right)$$

– NOTE: ↑MW ⇒ WOB↓ ⇒ ROP↓

MW↑ ⇒ N↓

API was tabulated the strength properties of drill string.

Margin of Overpull (MOP) : $MOP = F_a - P = 0.9\,P_t - P$ ("P" is applied during work)

$$SF = \text{Safety factor} = \frac{P_a}{P} = \frac{0.9\,P_t}{(L_{dp} \times W_{dp} + L_{dc} \times W_{dc})\,BF} \quad \text{OR :}$$

$$L_{dp} = \frac{0.9\,P_t}{SF \times W_{dp} \times BF} - \frac{W_{dc}}{W_{dp}} L_{dc} \quad \text{OR :}$$

$$\boxed{L_{dp} = \frac{0.9\,P_t - MOP}{W_{dp} \times BF} - \frac{W_{dc}}{W_{dp}} L_{dc}}$$ (max. Length of D.P can be used to bear W_{DC})

↳ Drill String Design

□ NOTE: We can pull the drill pipe without disconnecting them. (MOP)

□ **Example:** An Exploration Rig has the following grades of drill pipe to be run in a 15000 ft deep well.

Grade E : 5/4.276 in (OD/ID), 19.5 lbm/ft, yield strength = 395600 lb (Light pipe)

Grade G : 5/4.276 in, 19.5 lbm/ft, yield strength = 553830 lb (heavy pipe)

if the total Length and wt of DC plus heavy weight drill pipe is 940 ft and wt 157374 lb respectively, Calculate :

Drilling Engineering (P.27)

(a) The max. Length that can be used from each grade of pipe, if MOP of 50000 lb is maintain for Lower grade. (Light pipe)

(b) The MOP of the heavier grade. (NOTE: M.W = 100 lb/ft^3 or 13.4 ppg)

□ Solution:

The max. expected mud wt of 15000 ft is 100 ft (13.4 ppg or 1.6 kg/L)

$$BF = \left(1 - \frac{100}{489.5}\right) = 0.796$$

$$L_{dp} = \frac{395600 \times 0.9 - 50000}{19.5 \times 0.796} - \frac{157374}{19.5} = 11646 \text{ ft} \quad (\text{Grade E pipe})$$

Grade G pipe:

$$L_{dp} = 15000 - (984 + 11646) = 2370 \text{ ft}$$

The Grade G will carry a combined wt of Grade E (11646 ft) + DC + HWP

$$= 11646 \times 19.5 + 157374 = 384471 \text{ lb}$$

For Grade E or [illegible]

$$\text{and: } L_{dp} = 9175 \text{ ft} = \frac{553830 \times 0.9 - 50000}{19.5 \times 0.796} - \frac{384471}{19.5}$$

↳ feasible, Length of grade G = 2370 ft

(b) $MOP = 0.9 P_t - P$

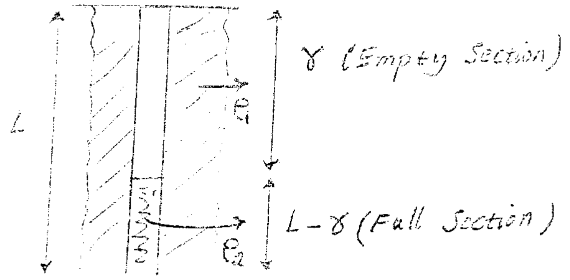
$P = 342826$ lb , $MOP = 155621$

$$P = (2370 \times 19.5 + 11646 \times 19.5 + 157374) \times 0.796 = 342826 \text{ lb}$$

$$MOP = 0.9 P_t - P = (553830 \times 0.9) - 342826 = 155621 \text{ lb}$$

□ Collapse Pressure: may be defined as a hydrostatic pressure that is produced due to the mud weight, and this pressure will be the difference between internal and external pressure.

During Drilling operation, inside the pipe is filled up with mud fluid and outside of the pipe with the mud and cuttings.



□ Drill Stem tool : is connected to drill pipe instead of bit and contains Pressure meter + Temperature meter + Flow meter.

Mud resists from flow of formation, but in D.S.T we use Kushing (partial salt water, not fully) to allow flow of formation fluid to measure the amount of pressure and temperature, and flow.

Sometimes we want to fluid will be flow, at these times we use mud not fully (partially).

□ Collapse pressure: $\Delta P = \frac{L\rho_1}{19.25} - \frac{(L-\gamma)\rho_2}{19.25}$

L, γ = ft

ρ_1, ρ_2 = lbm/Gallon (PPg)

$$\boxed{\Delta P = \frac{L\rho_1}{144} - \frac{(L-\gamma)\rho_2}{144}} \quad , \quad L, \gamma = ft \quad \rho_1, \rho_2 = lb/ft^3$$

$$SF = \frac{\text{Collapse Resistance}}{\text{Collapse pressure}} = \frac{\text{From Table}}{\Delta P} \Rightarrow \text{Table} = SF \times \Delta P$$

NOTE: Safety Factor (SF) of 1.8 normally is used.

Drilling Engineering (P. 29)

Example: If 10000 ft of drill pipe 5 in OD, 19.5 lb/ft and grade X-95, is used, Determine the maximum Collapse pressure that can be encountered and the resulting SF. The mud density is 75 pcf (10 ppg). If the fluid Level inside the drill pipe drops to 6000 ft below the rotary table, determine the new SF?

Solution:

maximum collapse pressure occur when we have 100 % empty pipe.

$$\Delta P = \frac{L\,\rho_m}{144} = \frac{(10000\ ft)(75\ pcf)}{144} = 5208\ psi$$

$$SF = \frac{\text{Collapse resistance}}{\text{Collapse pressure}} = \frac{12010}{5208} = 2.3 \Rightarrow SF = 2.3$$

NOTE: Collapse Resistance = From the given table-2 for grade X-95, New pipe.

$$\Delta P = \frac{L\,\rho_m}{144} - \frac{(L-Y)\,\rho_m}{144} = \frac{Y\rho_m}{144} = \frac{6000 \times 75}{144} = 3125\ psia$$

$$SF = \frac{12010}{3125} = 3.8 \Rightarrow SF = 3.8$$

NOTE: In preceding problem we only considered collapse pressure for the bottom pipe with no tension.

□ Tension and Collapse (Biaxial Loads):

Tension Load can reduce the thickness of the pipe and therefore we are forced with Large collapse pressure compared with when we do not have tension Load. (Tension Lowers the collapse Resistance and [illegible] the SF)

□ Example: A drill string consists of 10000 ft of drill pipe and a Length of drill collar weighting 80000 lb. The drill pipe is 5 in OD, 19.5 lb/ft grade S-135, premium class.

(a) Determine the safety factor in collapse.

(b) Determine the actual collapse resistance of the bottom joint of drillpipe? Assume collapse resistance of 10050 psi and mud weight of 75 pcf.

□ Solution:

for a 5 in OD new drill pipe, the nominal ID is 4.276 in. (i.e, thickness of 0.362 in), for a premium drill pipe, only 80% of the pipe thickness remains, therefore the reduced wall thickness of premium pipe will be:

$0.8 \times 0.362 = 0.2896$ in (premium thickness)

premium pipe = Nominal ID + 2 (premium thickness)

New (OD) $= 4.276 + 2(0.2896) = 4.8552$ in

Cross-Section of pipe $= \frac{\pi}{4}(OD^2 - ID^2) = \pi/4(4.8552^2 - 4.276^2) = 4.1538\ in^2$

Tensile Stress of the bottom Joint of pipe:

$$\frac{\text{Tensile Load (wt of DC)}}{C.S.A} = \frac{80000}{4.1538} = 19259.5\ psi$$

The average yield strength of grade S135 = 145000 psi (from table)

$$\text{Tensile Ratio} = \frac{\text{Tensile Stress}}{\text{average yield Strength}} = \frac{19259}{145000} = 0.1328 \simeq 13.3\%$$

From manufacture, given figure for biaxial Loading, a tensile ratio of 13.3 reduces the nominal collapse resistance to 93%.

(a) Collapse Resistance $= 10050 \times 0.93 = 9347$ psi.

$$SF = \frac{9347}{\Delta P} \quad , \quad \Delta P = \frac{L \rho_m}{144} = \frac{10000 \times 75}{144} = 5208\ psi$$

$$SF = \frac{9347}{5208} = 1.8 \Rightarrow SF = 1.8$$

— the slip (is connected to rotary Table)

Slip is holding the pipe to be stop and it causes shock Loading:

□ Shock Loading:

It can be shown that additional force (F_s) generated by shock Loading is calculated from: $\boxed{F_s = 3200\ W_{dp}}$, W_{dp} (lb/ft)

Drilling Engineering (P.31)

□ Example: If 10000 ft of X-95 has been selected from previous example (in tension) determine:

(a) S.F during drilling

(b) The magnitude of Shock Load.

(c) Calculate the S.F when shock Loading is included.

□ Solution:

Total wt carried by pipe $= (L_{dp} \times W_{dp} + L_{dc} \times W_{dc}) \times BF$

$= (10000 \times 19.5 + 600 \times 160.4) \times 0.847 = 246680\ lb$

(a) $SF = \dfrac{0.9 \times \text{yield strength}}{P} = \dfrac{501090 \times 0.9}{246680} = 1.83$

(b) $F_s = 3200\ W_{dp} = 3200 \times 19.5 = 62400\ lb$

total Load at top joint = tension Load + Shock Load

$= 246680 + 62400 = 309080\ lb$

$S.F = \dfrac{501090 \times 0.9}{309080} = 1.46$ (Tension + shock reduces strength of drill pipe)

□ Torsion:

__pure torsion:__ $Q = \dfrac{0.096167\, \dot{J}\, Y_m}{D}$ (D → OD)

اگر در هنگامی که کشش نیز داشته باشیم، این کشش باعث کاهش مقدار
بار گشتاور (مثلاً برای آزادسازی لوله گیر کرده) برای لوله حفاری خواهد شد.

Q: minimum torsional yield Strength (lb.ft)

$\dot{J}$: Polar moment of Inertia

$\dot{J} = \dfrac{\pi}{32}(OD^4 - ID^4)$

Y_m: minimum yield strength (psi)

__Torsion + Tension:__ $Q_t = \dfrac{0.096167\, \dot{J}}{D}\sqrt{Y_m^2 - \dfrac{P^2}{A^2}}$

Q_t: minimum torsional yield strength under tension, lb-ft

$\dot{J}$: Polar moment of Inertia, $\dot{J} = \dfrac{\pi}{32}(OD^4 - ID^4)$

Y_m: minimum unit of yield strength (psi)

P: Total Load in tension, $lb = (L_{dp} \times W_{dp} + L_{dc} \times W_{dc}) \times BF$

A: Cross-sectional area of the pipe (in^2)

□ Example : The following data refer to drill-string stuck and the drill collars:

Drill pipe : 10000 ft , 5/4.276 in , 19.5 lb/ft , grade E , class 2.

Drill Collar : 600 ft , total weight = 80000 lb

make-up torque for drill pipe tool joints = 20000 lb.ft

The drill-string 100% free point = 9900 ft

to free pipe from stucking point to release the pipe, we can apply reverse rotation of drilling.

Determine the maximum torque that can be applied at the surface without exceeding the minimum yield strength of drill pipe.

□ Solution : $Q_t = \dfrac{0.096167\, J}{D} \sqrt{Y_m^2 - \dfrac{P^2}{A^2}}$

P = tensile Load $= 9900\,ft \times 19.5\ lb/ft = 193050\ lb$, $D = 5$

$A = \frac{\pi}{4}(OD^2 - ID^2) = \frac{\pi}{4}(5^2 - 4.276^2) = 5.27\ in^2$

$J = \frac{\pi}{32}(OD^4 - ID^4) = \frac{\pi}{32}(5^4 - 4.276^4) = 28.5383\ in^4$

Tensile strength (Table-5 given) = 311540 lb

$Y_m = \dfrac{311540}{5.27} = 59116\ psi$

$Q_t = 25468\ lb.ft$; maximum allowable torque for pipe body.

Since $Q_t \gg$ tool joint torque, thus we use the tool joint torque as a maximum torque to be applied for releasing the free section of the stuck drilling string.

□ Hoisting System :

IF we know the Rig's drawwork horse power, we can calculate at which depth, the given draw work does have ability to give us energy for hosting.

Block and Tackle : Comprised of ; Crown block
travelling block
Drilling Line

Drilling Engineering (P.33)

$$Ef = \frac{\text{output power}}{\text{Input power}}$$

If we have no friction at sheaves (either in travelling block and crown block)

mechanical advantage $= \frac{W}{W/N} = N \Rightarrow$ Advantage $= \frac{HL}{FL}$

No friction : $FL = \frac{W}{N}$

Ideal mechanical advantage (No friction) $= N$

NOTE: The use of 6, 8, 10, 12 Lines is common, depending on the Loading condition.

Efficiency of block and tackle system:

$$Ef = \frac{\text{output power}}{\text{input power}} = \frac{\text{Travelling block}}{\text{Fast Line}} = \frac{V_b \times W}{V_F \times FL}$$

Power = Velocity x weight

$V_b = \frac{V_F}{N}$, No friction, $FL = \frac{W}{N}$

If we move fast Line 1 unit, each Line b/w travelling block and crown block moves $1/N$ unit.

If there is no friction: $Ef = \frac{V_b \times W}{V_F \times FL} = \frac{V_f/_N \times W}{V_f \times \frac{W}{N}} = 1 = 100\%$

The decreament in EF with increasing N is because of increasing in friction.

Having Friction: $\boxed{Ef = \frac{K(1-K^N)}{N(1-K)}}$; K is sheave and Line efficiency.

Horse power of Drawwork: $\frac{HL \times V_L}{Ef \times 33000}$ (hp)

$H_L = W$ (Hook Load)

$V_L = V_b$ (movement of travelling block)

$$\begin{cases} \text{No Friction: } F_L = \frac{W}{N} \\ \text{Having Friction: } FL = \frac{W}{N \times Ef} \end{cases}$$

Drilling Engineering (P.35)

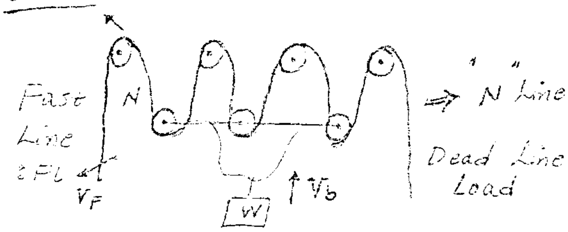
W is the wt of drill string + wt of Swivell + wt of travelling block + wt of Hook

"mechanical advantage of block and tackle = Efficiency of the system"

$$\text{Efficiency of the system} = \frac{\text{Load supported by travelling block}}{\text{Load imposed on the Drawwork}} = \frac{W}{FL}$$

□ Fast Line and Dead Line Loads:

Hook Load = W = wt of drill string in mud + wt of travelling block including Hook



V_b : movement of travelling block

V_F : movement of FL

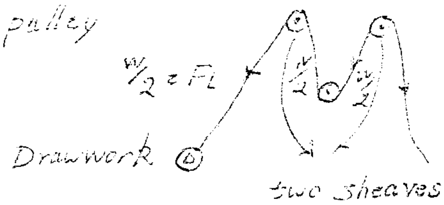
In absence of friction : $FL = \frac{\text{Hook Load}}{N} = \frac{HL}{N}$

owing to Friction: $\boxed{FL = \frac{HL}{N \times EF}}$ (E_F : Efficiency of Hoisting system)

Dead Line Load: $\boxed{DL = \frac{HL \times K^n}{N \times EF}}$ (K : Friction of Sheaves on pulleys)

□ Static and Dynamic Crown Loading (or Derrick):

Static: single pulley



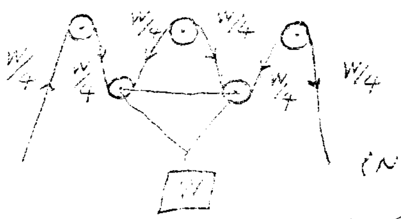
$D_L = W/2$, $N = 2$

Static Crown Load (SCL) = Fast Line Load + Hook Load + Dead Line Load

$$= \frac{W}{2} + W + \frac{W}{2}$$

$FL = \frac{W}{n}$ (No Friction)

IF the crown block has 3 Sheaves:



$SCL = W/4 + W + W/4 = \frac{3}{2} W$

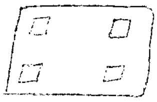
(No Friction)

In General Under Static Condition: Fast Line Load = $\frac{W}{N}$

Dead Line Load = $\frac{W}{N}$

For N Lines: $SCL = \frac{W}{N} + W + \frac{W}{N} = W(1 + \frac{2}{N}) = W(\frac{N+2}{N})$

$$SCL = W\left(\frac{N+2}{N}\right)$$

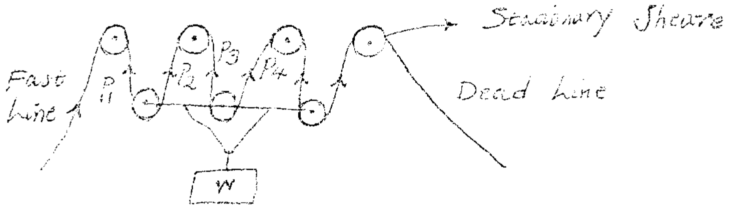


Four Legs

wt to be sustained by each Leg: $SCL/_4$

- Dynamic Crown Load:

Efficiency of the Hosting System:



EF = Block and Tackle Efficiency

K = Sheave and Line efficiency per sheave

N = Number of Lines string to travelling block

F_L = Fast Line Load

D_L = Dead Line Load

✓ Starting From a hosting Fast Line of F_L.

$P_1 = F_L \times K$, $P_2 = P_1 \times K$, $P_3 = KP_2$, $P_4 = K \times P_3$

$P_N = FL \times K^N$

$W = P_1 + P_2 + P_3 + \dots + P_N$

$W = FL \times K + FL \times K^2 + FL \times K^3 + \dots + FL \times K^N$

$W = FL\,(K + K^2 + K^3 + \dots + K^N)$ (Geometric Sum = $\frac{K(1-K^N)}{1-K}$)

$$W = FL\,\frac{K(1-K^N)}{1-K}$$

$$FL = \frac{W(1-K)}{K(1-K^N)}$$ (NOTE: Statically : $FL = \frac{W}{N}$)
NO Friction

The Efficiency of block and Tackle : ✓ $Ef = \frac{\text{Load without Friction}}{\text{Load with Friction}}$

Drilling Engineering (P.37)

$$EF = \frac{W/N}{\dfrac{W(1-K)}{K(1-K^N)}} \Rightarrow \boxed{EF = \frac{K(1-K^N)}{N(1-K)}}$$

✓ Block and Tackle Efficiency

N	EF
6	0.874
8	0.841
10	0.810
12	0.77
14	0.74

Hence: $FL = \dfrac{W}{N \times EF}$

No friction: $EF = 1 \Rightarrow FL = \dfrac{W}{N}$

□ Power Requirement For Hosting:

Power at drum (Drawwork) $= FL \times V_f$, $FL = \dfrac{HL}{N \times Ef}$

$V_f = N \times V_L \; (N \times V_b)$

V_L: is velocity of travelling block or hook, v_f = fast Line velocity

$$Power = \frac{HL}{N \times EF} \times N \times V_L \Rightarrow Power = \frac{HL \times VL}{Ef}$$

✓ P = Drum power output $= \dfrac{HL \cdot V_L}{Ef \times 33000}$; $P = hp$, $V_L = ft/min$, $HL = lbf$

Dynamic Crown Load: DCL = Fast Line Load + Hook Load + Dead Line Load

$$DCL = \frac{HL}{Ef \times N} + HL + \frac{HL}{N} \Rightarrow ✓\, DCL = \frac{(1 + Ef + Ef \times N)}{Ef \times N} \times HL$$

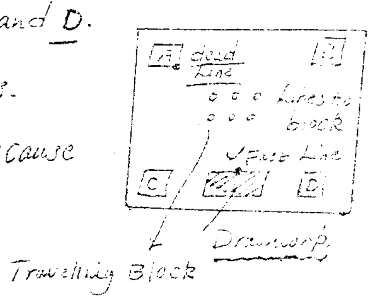
NOTE: Importance of DCL, SCL can help to design the Rig.

□ Load Distribution For each Leg:

Load Source	Total Load	Leg A	Leg B	Leg C	Leg D
1 Hook Load	HL	$\frac{HL}{4}$	$\frac{HL}{4}$	$\frac{HL}{4}$	$\frac{HL}{4}$
1 Fast Line Load	$\frac{HL}{N \times Ef}$	—	—	$\frac{HL}{2N \times Ef}$	$\frac{HL}{2N \times Ef}$
1 Dead Line Load	$\frac{HL}{N}$	$\frac{HL}{N}$	—	—	—

✓ Fast Line Load is distributed only b/w C and D. because of drawwork is b/w these two Legs.

✓ Dead Line Load is distributed only on A because dead Line is attached to it.



✓ maximum Load on each Leg:

Leg A	Leg B	Leg C	Leg D
$\frac{HL(N+4)}{4N}$	$\frac{HL}{4}$	$\frac{HL(E_f \times N+2)}{4E_f \times N}$	$\frac{HL(E_f \times N+2)}{4E_f \times N}$

□ Derrick Efficiency Factor (E_d):

$$E_d = \frac{\text{Actual Derrick Load } (F_d) \rightarrow DLL}{\text{Maximum Equivalent Derrick Load } (F_{de})}$$

$$F_{de} = 4(\text{Leg A. Load}) = \left(\frac{N+4}{N}\right) HL$$

Dead Line Leg Load

$$E_d = \frac{\left(\frac{1+E_f+E_f \times N}{E_f \times N}\right) HL}{\left(\frac{N+4}{N}\right) HL} \Rightarrow \boxed{E_d = \frac{E_f(N+1)+1}{E_f(N+4)}}$$

NOTE: We must change the wire rope because it may be thin during drilling after movement b/w sheaves. we can change the used wire rope from storage line rope. We can replace used part with new part by using draw work after anchor be free. and then cut the used part from new part inside draw work.

□ Example: The following data refer to a 1½ in block line with 10 lines of extra improved plough steel wire rope strong to the travelling block.

hole depth = 10000 ft

Drill pipe = 5 in OD / 4.276 in , 19.5 lb/ft

Drill Collars = 500 ft , 8 in / $2\frac{3}{16}$ in , 150 lb/ft

mud weight = 75 pcf = 10 ppg

Line and sheave efficiency = 0.9615

Calculate: (a) wt of drill string in air and mud.

(b) Hook Load assuming wt of travelling block and hook = 23500 lb

(c) Dead Line and Fast Line Loads, assumming an efficiency factor of 0.812.

Drilling Engineering (P. 39)

(d) Dynamic Crown Load

(e) Design Factor of wire if breaking strength of wire is 228000 lb.

(f) Design Factor when running 7 in casing of 29 lb/ft.

□ Solution:

(a) $W_{in\ air} = (10000 - 500)\,19.5 + 500 \times 150 = 260250$ psi

$$BF = 1 - \frac{\rho_m}{\rho_s} = 1 - \frac{75}{489.5}$$

$W_{in\ mud} = 260250 \times BF \Rightarrow \quad W_{in\ mud} = 220432$ lb

(b) HL = wt of drill string in mud + wt of travelling block + Hook wt

$HL = 220432 + 23500 = 243932$ lb

(c) $$FL = \frac{HL}{E_f \times N} = \frac{243932}{0.81 \times 10} = 30115 \text{ lb}$$

$$DL = \frac{HL}{N} \times \frac{K^{10}}{E_f} \Rightarrow DL = \frac{243932}{10} \times \frac{(0.9615)^{10}}{0.81} = 20336 \text{ lb}$$

(d) $DCL = FL + HL + DL = 30115 + 243932 + 20336 = 294383$ lb

(e) $DF = \dfrac{228000 \text{ lb}}{30115} = 7.6$ ✓ $\left(DF = \dfrac{\text{Breaking Strength}}{FL} \right)$

(f)

$$DF = \frac{\text{Strength of wire rope}}{FL}, \quad FL = \frac{HL}{E_f \times N},$$

HL = wt of string in mud + wt of travelling block + Hook weight

$$\text{wt of casing} = (10000 \times 29)\left(1 - \frac{75}{489.5}\right) = 245630 \text{ lb}$$

✓ $HL = 245630 + 23500 = 269130$ lb

$$FL = \frac{269130}{0.81 \times 10} = 33226 \text{ lb}$$

$DF = (228000 \text{ lb} / 33226) \Rightarrow \quad DF = 6.9$

□ NOTE: API recommendation during: Hosting; DF = 3

Casing Landing; DF = 2

The values For DF should be over these amounts.

□ Hosting : Draw work horse power = ?

DCL , DF , E_d = ?

Drill string : torsion , tension , shock loading , vibration, ... ⇒ max L_{dp} = ?

□ Circulating : mud pump power = ?

Fluid mech. ; Reology states about the fluid flow properties.

Pressure loss across the circulating conduits (a channel)

Flow behavior : Laminar , Turbulent , Eddy

$\boxed{P_H = \frac{q\,\Delta P}{\cancel{1417}}}$ (P_H : pump hours power , ΔP = psi , q = gal/min)

1417

□ Controlling Section :

Blow-out ⇒ Kick fluid (extra fluid coming to the surface and may be water, oil or gas.).

volume of the Kick = ?

Pressure of the Kick = ?

Flowrate of mud pump injection for displacement of Kick fluid = ?

weight of new mud for Killing the well = ?

□ Circulating :

Pumps : Reciprocative positive displacement pumps that work with displacement work. (process)

√ Types of pumps in drilling :

(1) Douplex pumps : 2 pistons , each piston acts forward and backward.

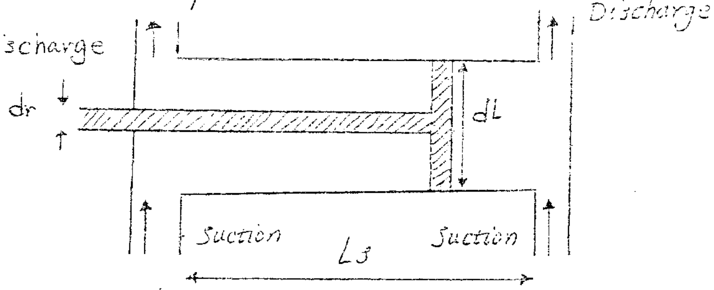
(2) Triplex pumps : 3 pistons , each piston acts forward.

□ Douplex pumps :

dr : Rod Diameter

dL : Liner Diameter

Ls : Stroke Length



one cycle of stroke is one forward stoke and one backward stroke.

Reservoir Engineering (P.41)

Forward displacement volume $= \pi/4 \; d_L^2 L_s$

Backward displacement volume $= \pi/4 \; (d_L^2 - d_r^2) \times L_s$

□ Pump Efficiency : mechanical efficiency $= E_m \simeq 90\%$

volumetric efficiency $= E_v \simeq 100\%$

Total Efficiency $= E_t = E_v \times E_m$

E_m is the efficiency of pump to transfer electrical energy to mechanical.

E_v refer to amount of displaced fluid across o-ring of piston and if we have no displacement across it, we have 100% efficiency.

□ Pump Factor (PF or F_p) :

$F_p =$ Pump displacement mud volume $\times E_v$

$$\checkmark F_p = \left[\frac{\pi}{4} (d_L^2 L_s) + \frac{\pi}{4} (d_L^2 - d_r^2) \times L_s \right] \times E_v \times K = \frac{volume}{stroke}$$

NOTE : If we have two piston ; $K = 2$ and deuplex.

Speed of the pump $= N = \frac{stroke}{time}$, "Recording by gauge"

↳ Number of movement of piston per time.

$q = F_p \times N$

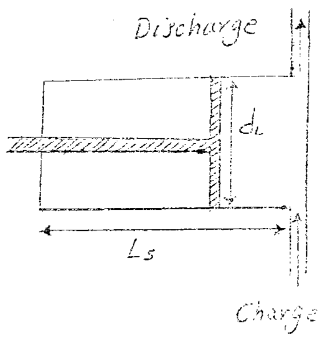
_ If we want to calculate the q for rig , we must multiply the right side of upper eqn. to the number of pumps exist in Rig.

$P_{mud\,pump} = \Delta P(\text{surface facilities}) + \Delta P_{ds} + \Delta P_{bit} + \Delta P_{Ann}$

□ Pump Factor For Triplex pumps :

we have only forward movement in this type and each pump contains three single pistons.

one single acting pump having 3 cylinders.



$$\checkmark F_p = 3 \left(\frac{\pi}{4} d_L^2 L_s \right) \times E_v \quad \text{(Forward Displacement)}$$

$$\boxed{q = F_p \times N} \; , \; \boxed{P_H = \frac{q \, \Delta P}{1417}}$$

□ Drilling Hydraulic :

$P_{Pump} = \sum_{i=1}^{n} \Delta P_i$, $\Delta P =$ Pressure Lost

to calculate ΔP, we need to know drilling fluid reology.

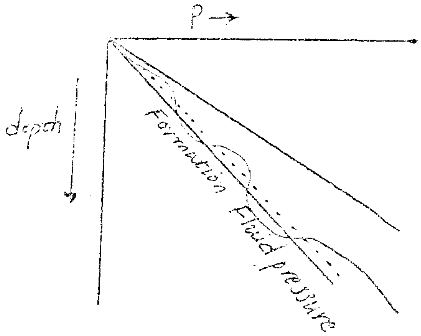
Reology deals with fluid flow properties such as μ, gel strength, etc.

- Type of drilling fluids ($q = \frac{\pi r^4 \Delta P}{8 \mu L}$, Poiseulli's Law)
- Use of drilling fluids
- Function of drilling fluids

□ Drilling Fluids:

✓□ Drilling Fluid Functions:

✓(1) To stabilize the well-bore while maintaining the subsurface pressure.



Hydrostatic mud pressure (Psi) = 0.052 x MW (PPg) x TVD (ft)

✓Dynamic mud pressure = 0.052 x EMW x TVD

$$EMW = MW + \frac{\Delta P(\text{annular Loss})}{0.052 \times TVD}$$

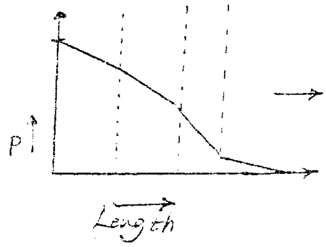
↓
Equivalent mud weight

- We have to identify abnormal pressure zones and then mud fluid may be prepared to prevent formation flow during drilling.

✓(2) To suspend drill particles (Drilling cuttings) and sloughing (usually shale) and to transport to the surface. (Removal of cuttings)

- We need drilling fluid to have enough gel strength in order to prevent falling of cuttings to the bottom of the well-bore.

✓(3) Cooling and Lubricating the bit and drill string.



→ Energy ⇒ Pressure Lost ⇒ Heat energy should be absorbed.

- A simple drilling fluid that is (water + bentonite) has ability to absorbe heat.

Drilling Engineering (P.43)

√(4) Gathering information to assist in formation evaluation while minimizing Formation damage.

- Some of the fluids may penetrate to the formation. The part of formation that the fluid penetrate is called "Damaged Zone".
- As the drill string comes out, the well should be filled fully with mud in order to prevent fluid flow.
- Logging tools to help gathering informations: Sonic Logs, Resistivity Log, Neutron, ...
- Note: We can not run resistivity Logs in OBM's drillings.

MWD: Formation Lithology and Fluid Analysis ⇒ "LWD" tools.

√(5) Bouyancy: Helps to set the casing, by assist to support the suspended drill string or casing.

Note: wt of drill String in mud = (wt of drill string in air) × $\left(1 - \frac{\rho_{mud}}{\rho_{steel}}\right)$

√(6) Transmitting hydraulic horse power to the drill bit (The most important)

□ Transport cuttings:

Factors affecting the "removal capacity" of cuttings are:

(1) Cuttings density (Gravity Force)

(2) Fluid Density

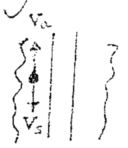
(3) Fluid Reology → Gel Strength and viscosity

(4) Annular Velocity

(5) Hole Angle

(6) Cuttings slip velocity.

- Todays problem in drilling deviated wells is cutting removal.
- Circulation of drilling fluid by mud pumps, causing cutting come to the surface from the bottom of the well-bore.



Cutting Removal Velocity = $V_{annulus} - V_{slip}$

✓ $$\text{Annular velocity } (ft/min) = \frac{\text{Pump output } (bbl/min)}{\text{Annular Capacity } (bbl/ft)}$$

$$\text{Annular Capacity} = \frac{\pi}{4}\left(d_{bore\text{-}hole}^2 - OD^2\right)\ in^2,\ in^3/in,\ bbl/ft$$

✓ $$\text{Effective Average Annular Velocity} = \frac{depth\ (ft)}{\left(\begin{array}{c}\text{Measured}\\ \text{time}\end{array}\right) - \left(\begin{array}{c}\text{time calculated in}\\ \text{drill pipe}\end{array}\right)}$$

Time of Corn Travelling

$$time = \frac{depth\ (ft)}{velocity\ (ft/min)}$$

Drill String Length

velocity of mud pumped

– we use corn grains at the first pipe and record time when they pass well and comming into the shale-shaker ⇒ Calculating measured time.

– There is a "Limit" in using annular velocity:

Annular velocity > Limit ⇒ Collapse

Annular Velocity < Limit ⇒ no cutting removal.

□ Types of Drilling Fluids:

✓(1) water-base Fluids: fresh water mud : (1) spud mud (2) Natural mud

"no calcium added" ← chemically treated mud : (1) Phosphate (2) Organically Treated

calcium treated mud : (1) Lime (2) $CaCl_2$ (3) Gypsum

Salt water mud : (1) Sea-water (2) Saturated salt-water

oil-emulsion mud (Oil in water)

special modifications : (1) Low-solid (2) surfactant (3) Low clay-solid

✓(2) Oil-based fluids: Oil base mud

Invert-emulsion mud (water-in oil)

✓(3) Air-gas fluid: Air or natural gas

mist

foam

Aerated mud

Drilling Engineering (P.45)

√□ Drilling Fluid phases:

Continuous phase : suspending fluids : liquids.

Discontinuous phase: suspended fluids : Liquid droplets, Gases, solids.

Discontinuous phase: Inert, Active

-Example : Simple drilling fluid (water + bentonite)

- most of drilling muds used are H2O- base mud.

- OBM's is used when we are drilling a reservoir formation which is sensitive to water (shaly formations) because of clay swelling.

□ Water- Based Mud (WBM):

□ Water or continuous phase may be : Fresh water (has enough O_2)

Brackish water (not enough O_2)

Sea water

Concentrated Brine

□ Discontinuous phase may be: Clay

Bentonite

attapulgite (prehydrated bentonite)

Sepiolite

- Yield of Clay or shale: is defined as the number of barrels of 15 cp mud that can be obtained from 1 ton (2000 lb) of material.

- 15 cp mud is as a base because of rapid change after it.

- That type of bentonite is good that we get more value (amount) of mud when we add it to the water.

- We qualify the WBM by the type of bentonite : clay swelling ⇒ Yield of clay

- using polymer ⇒ making "mud-cake" ⇒ preventing mud filteration (continuous phase) Losses ⇒ They may be called "Liquid Casing". ⇒ Creating Career

□ Drilling Fluid Components and products:

3rd Century, In Egypt, where "quary-borehole" were drilled to a depth of 20ft used water to soften the rock and assist in cutting removal.

– in some cases we don't need to add chemicals to water to make mud, here we use fresh water and dissolve cutting in them and we get drilling fluid.

– Use of drilling fluid to do more aid in cutting removal was proposed in Late of 1800's. Water, clay and cement may used to produce plastic material and would plaster the well-bore wall and reduce caving tendencies.

– mud cake: √(1) to prevent Fluid Loss. (Filteration Loss)

√(2) to stabilize the well bore or preventing well-bore collapse.

– By using additives or some chemicals to remove cutting deposits. Those chemicals may dissolve in continuous or discontinuous phase.

– Changing drilling mud: Change in continuous or discontinuous phase.

□ Using Additives:

√(1) making heavier mud for deeper part of formation.

√(2) Supporting Gel-Strength to remove cutting by adding viscosifying agents.

√(3) preventing filteration (continuous phase) Losses in formation.

√(4) Holding or adjusting PH in a suitable range or value.

□ Lost Circulation: √(1) Fracturing Formations

√(2) Fluid pressure exceeding

√(3) Naturally Fractured Formations

√(1) Shale Stabilizers:

Shale Can swell when exposed to WBM's, So we use some chemicals which can prevent shale releasing in the bore-hole.
Gilsonite

Drilling Engineering (P. 47)

√(2) Surfactants :

They chemicals reducing IFT and removing the oil – water film and mixing up to produce one-phase fluid flow.

√(3) Flocculants :

Are used for solids removal.

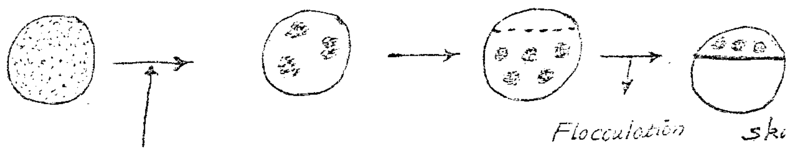
– NOTE : √Caogulation : Attachment of suspended particles together.

√Flocculation : Making Caogulated matters Light to separate soids from fluids.

√Filteration : Column of packed sand or coal to filterate water to remote suspended materials after flocculation or Caogulation.

√□ Water Treatment :

Taking water and send it to the tank and they separate solid from water by gravity "segregation" and then pass it from "softening" to separate all suspended particles and then "filterate" again to remote remained suspended particles and then "chlorized".



NOTE : Al^{3+} → additive matters (Caogulant) → after caogulation some suspended matters can precipitate but some can not.

– By using "Skimmers" we can separate flocculated materials, chemicals like polymers are called flocculants.

√(4) Corrosive and Toxic agency :

Adding to prevent chemical reaction of mud with drilling "equipments."

√(5) Biocides:

Killing the micro-organisms by biocides. because some micro-organisms may react with oil or different parts of the well-bore.

- Salt: is used in mud in order to make it heavier. such as: Barite ($BaSO_4$)
  (KBr) Potassium Bromide

- Bentonite acts as an viscosifying agent. (or Fluid-Loss agent)
- Lignosulfonate is the most common Thinner, dispersant.
- Starches from potato prevents loss in continuous phase of mud (filtration)
- Caustic Soda and Lime are the most common for alkalinity and PH-control.
- Mica, plastic, Saw-dust (wood chips), paper and Cellophane are used as flake for fractures.

□ Notes: By adding some additives such as above we modify the mud quality.

□ Drilling Fluid Systems:

Selection of drilling Fluids is based on Factors such as:

(1) Formation characteristic and composition.

(2) Temperature

(3) Anticipated Drilling Hazards.

(4) Quality and Source of the water.

(5) Chemical compounds added to the water.

(6) Required Treatment Concentration.

(7) Adequate supplies of required products.

(8) Maintenance of the selected fluids.

□ Classification of WBM systems:

When attemping to classify drilling fluids systems, one must remember that all drilling fluids are unique.

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✓The following designation are normally used to classify WBM:

(1) Non-dispersed Inhibited Systems.

(2) Non-dispersed Non-inhibited Systems.

(3) Dispersed Non-inhibited systems.

(4) Dispersed Inhibited Systems.

✓(1) Nondispersed Noninhibited Systems:

Fluids do not contain inhibiting ions such as Cl^-, Ca^{2+}, K^+, ..., in the continuous phase and do not utilize chemical thinner or dispersant to affect flow control (viscosity).

These systems use native water and do not use chemical thinner to effect the solids remaining in the system or inhibitive ions to prevent solids swelling.

(1) spud mud: (2) Polymer / Bentonite muds

(3) Extended Bentonite muds.

✓spud mud: are used to: (For shallow Formations)

✓(1) Clean the hole

✓(2) prevents sloughing of the surface hole.

✓(3) provides a viscous sweep to clean gravel/sand from the bore-hole.

✓(4) Form a filter cake to prevent seepage to the formations.

✓spud muds are used in drilling soft "gumbo-type" shale and these used in drilling hard-rocks (Limestones, anhydrite, dolomite)

Formulated as follows:

- water: (Fresh, Brackish, Salt)

- Caustic : 8.5 - 10.5 PH in fresh water muds.

10.5 - 11.5 PH in salt-water muds.

- Clay: MBT of 10 - 35 lb/bbL, depending on mud weight. (Miami Bentonite)

Fresh-water: sodium bentonite, Salt water: prehydrated bentonite (Attapulgite)

Salt-water: Attapulgite or prehydrated bentonite

√ Polymer/bentonite mud:

Are used in areas where the formation to be drilled contains Low reactive solids.

- Formulation: √water (Fresh, salty, Light calcium)

√Sodium bentonite (10 lb/bbL)

√polymers: CMC (Low viscosity) 0.5 - 1.5 lb/bbL

PAC (Low viscosity) 0.5 - 1.5 lb/bbL

or: Corn or potato starch 2-4 lb/bbL

√ Extended Bentonite muds:

Use chemicals to extend the yield of bentonite and import the desired properties to the mud while maintaining minimum solid contents.

- Formulation: √water (treat out Ca with sand ash)

√Bentonite (10-15 lb/bbL)

√Polymers → Polyacrylate (0.04% by volume)

polyacrylamide (0.5 - 3 lb/bbL)

- There is no additive chemical in this type of muds to prevent from reaction or other phenomena that is called non-dispersive, non-inhibited systems.

√(2) Non-dispersed inhibited system:

- Fluids don't utilize chemical thinner or dispersant but they contain inhibiting ions.

- Prehydrated sodium bentonite fluid finds its own equilibrium.

- Containing salt ions (NaCl, KCl) that inhibite drilled formation solids from swelling and breaking into smaller particles as they are transported to the

Drilling Engineering (P.51)

surface : this will make it easier for solid-control equipments to remove these particles.

- Attapulgite - starch - salt muds
- Saturated Salt muds (NaCl)
- Potassium - Chloride polymer muds (KCl)

✓□ Attapulgite - starch - salt muds:

are used to improve bore-hole stability through the inhibiting effects of the salt (s) present in the make-up water, to minimize hole washout, to prevent drilled solids from disintegrating as they are transported to the surface.

- Formulation: Sea water or natural brine
  - ✓ Caustic Soda → PH ≃ 9.0
  - ✓ Attapulgite → 10 - 20 lb/bbl
  - ✓ potato or corn starch → 0.5 - 5.0 lb/bbl
  - polymer → 0.45 - 1.25 lb/bbl
  - (polyanionic cellulose, CMC, Xantham gum, guar gum)

✓□ Saturated Salt mud:

are used to prevent solution cavities in salt domes and stringers.

- Formulation: Saturated salt water → 189500 mg/L NaCl
  - ✓ Attapulgite → 10 - 25 lb/bbl
  - ✓ potato or Corn Starch → 0.5 - 2.5 lb/bbL
  - ✓ polymers → 0.25 - 1.0 lb/bbL
  - (polyanionic cellulose, xanthum gum)

✓□ Potassium Chloride - polymer muds:

Inhibit clay swelling in thin, mod rating active clay formations.

- Formation : KCl water (5 - 15 % K^+ ion) → 17.5 - 59.5 lb/bbl

✓ Caustic Soda (Low PH)

✓ Attapulgite or prehydrated bentonite → 10 - 15 lb/bbl

✓ polymer → 0.5 - 5 lb/bbl

- Starch

✓(3) Dispersed - Noninhibited System:

- Chemical thinners are added to encapsulate the sodium bentonite and reactive drilled solids.

- system do not contain inhibitive electrolyte.

✓- Lignite - Lignosulfonate muds

✓- phosphate - bentonite muds → Shallow wells

✓(4) Dispersed - Inhibited Systems:

Utilize chemicals to disperse clays, drilling solids, and inhibiting ions to prevent the hydration and the dispersion of formation and cuttings.

✓- Lime muds: Gyp - Lignosulfonate muds

Seawater - prehydrated Bentonite muds

□ Testing For Funnel Viscosity:

The marsh - funnel viscometer:

They pour the mud in cap and fill up the funnel and then remove their finger and record time that mud go to leave funnel.

Results are used only as an indicator for change in flow properties such as viscosity and gel strength.

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√ The marsh funnel is: 6" diameter at the top.

12" Long and tapers to a join of tube.

2" Long and ID of $\frac{3}{16}$".

10 mesh-screen fitted across one-half of the top.

Capacity of funnel from bottom to the bottom of wire screen = 1500 cc

– Its dimensions are such that one Liter fresh water at a temprature of 70°F flow through the funnel in 26 (± 0.5) seconds.

– It is important to calibrate the funnel before field works (removing scales inside funnel before doing field works.)

– This funnel is made with plastic.

– Record the funnel viscosity on the API standard drilling mud reports such as: seconds per 1000 cc at x°F.

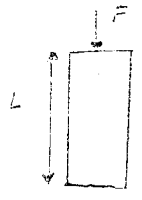
seconds per quart at x°F.

□ Testing For Plastic Viscosity; Yield point; Gel Strength

Rheometers are used to measure the property of fluid by use of fluid mechanics.

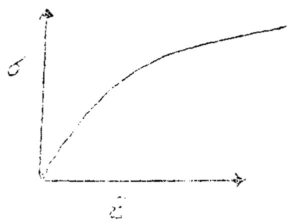
– mechanic: fluid mechanic, solid mechanic

Solid mechanics → Tensimeter



$\varepsilon = \frac{\Delta L}{L}$ = strain

σ = stress



√ – approximate fluid behavior:

√ (1) Newtonian Model

√ (2) Bingham plastre model

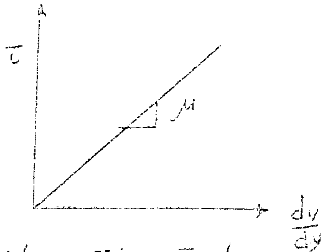
√ (3) Power-Law model

- Fluids: ✓ Ideal Fluids (No viscosity)

  ✓ Real Fluids : ✓ (a) Newtonian Fluids

  ✓ (b) Non-Newtonian Fluids

✓ ◻ Newtonian Fluids:

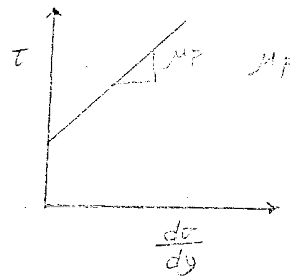


$\frac{dv}{dy}$ (velocity gradient), Shear strain

Laminar Flow

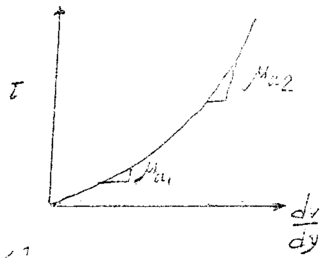
✓ ◻ Non-Newtonian Fluids: (Time-Independent)

- Bingham plastic fluids:



$\mu_p = \theta_{600} - \theta_{300}$

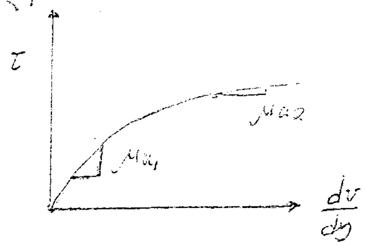
- Dilatant Fluids: $n > 1$



$\mu_{a_2} > \mu_{a_1}$

$\frac{dv}{dy} \uparrow \Rightarrow \mu_a \uparrow$

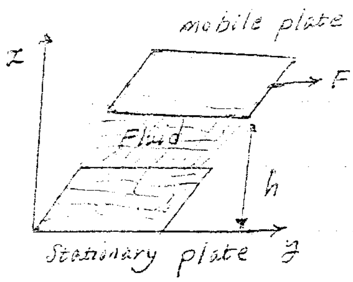
- Pseudo-plastic Fluids: $n < 1$



$\mu_{a_1} > \mu_{a_2}$

$\mu_a \downarrow$; as $\frac{dv}{dy} \uparrow$

◻ Newton's Experiment:

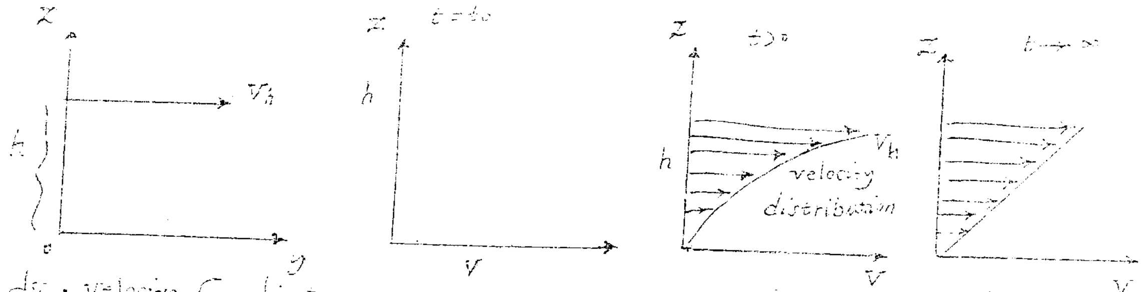


$$\text{momentum Rate} = \frac{\partial (V \times m)}{\partial t}$$

$$\text{momentum Rate} = m \frac{\partial v}{\partial t}$$

$$\text{momentum Rate} = F = ma$$

Drilling Engineering (P. 55)



$\frac{dv}{dy}$: Velocity Gradient

Non-Linear Non-S/S   Linear S/S

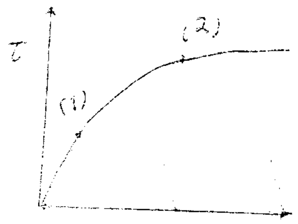
In Laminar condition: (S/S)

$\tau = \frac{F}{A} \propto \frac{dv}{dz} \Rightarrow \frac{F}{A} = \mu \frac{dv}{dz}$, μ: Dynamic viscosity, property of fluid

Shear angle

$\tau = \mu \gamma$, $\gamma = \frac{dv}{dz}$

□ Pseudo-plastic Fluids:

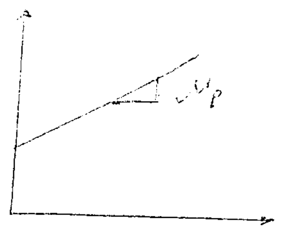


$\frac{dv}{dy}$

- If we suppose the fluid behavior in pseudo-plastic Fluids as Newtonian fluids, we will have apparent viscosity (μ_a).

$\mu_{a1} > \mu_{a2}$, $\mu_a \downarrow$ as $\frac{dv}{dy} \uparrow$

□ Bingham plastic Fluids:



μ_p: Plastic viscosity

✓ In Bingham plastic fluids, fluid can not move, until a deffinite amount of force (τ) is exerted on. → Yield Point

- Note: All above figures are in S/S Conditions.

✓□ Non-Newtonian Fluids:

That have shear time-dependent.

✓ Non-Newtonian Fluids include: (time dependent)

(1) Thixotropic : μ_a decreases, with time, after shear rate is increased to a new constant rate.

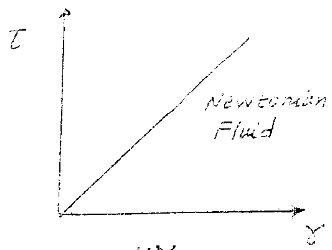
(2) Rheopectic

(3) Viscoplastic

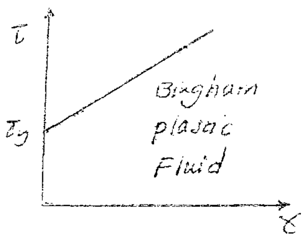
Fluid Type	Example
✓ Newtonian	Water, Diesel, Oil
✓ Non-Newtonian (Time-Independent):	
✓ Bingham	grease, putty
✓ pseudo-plastic	polymer solutions, WBM. (water-base Fluids)
✓ Dilutant	Starch, mica solution.

✓ Non-Newtonian (Time-dependent):

Type	Example
✓ Thixotropic	Drilling mud, paint.
✓ Rheopectic	Greases, Gypsum, suspension.
✓ Viscoplastic	Drilling Fluids, Long-chain polymers.

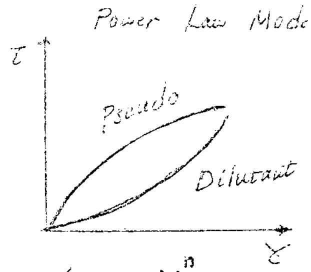


✓ $\tau = \mu\gamma$

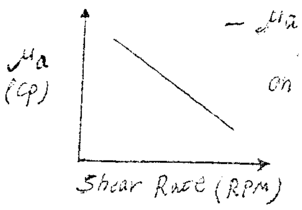


✓ $\tau = \tau_y + \mu_p\gamma$

Power Law Model



✓ $\tau = K\gamma^n$



– μ_a vs. shear rate on Log x log paper

n: Flow Behavior index

K: consistency number

(For special cases: $K = \mu$)

Drilling Technology (P.57)

A drilling fluid will demonstrate different flow behavior in the shear rate Ranges in a circulating system.

✓– Shear Rate Range in a circulating system:

Circulating Segment	Shear Rate
Drill pipe	100 ≃ 500
Drill Collar	700 ≃ 3000
Bit Nozzle	10000 ≃ 100000
Annulus	20 ≃ 100
Pits	0 ≃ 5

✓Note: Shear Rates are determined by a variable_speed viscometer.

$$\boxed{\mu_a = \frac{300\theta}{rpm}} \qquad (\mu_a)_{600} = \frac{\theta_{600}}{2} \;,\; (\mu_a)_{300} = \theta_{300}$$

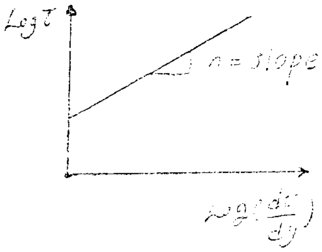
rpm speed	$\times\underbrace{1.5}_{\text{Conversion Factor}}$ Shear Rate (sec^{-1})	θ (Dial Reading)	multiplier (300/rpm)	μ_a (CP)
600	–	–	–	–
300	–	–	–	–
200	–	–	–	–
100	–	–	–	–
6	–	–	–	–
3	–	–	–	–

□ Annular Shear Rate (sec^{-1}) $= \dfrac{2.4 \times \overset{\text{annular Velocity}}{V}}{D_H - D_P}$ (D_H → Hole Diameter, D_P → pipe Diameter)

Shear Rate at the bit : $\dfrac{72\, V_n}{D_n}$ (V_n → Nozzle Velocity, D_n → Nozzle Diameter)

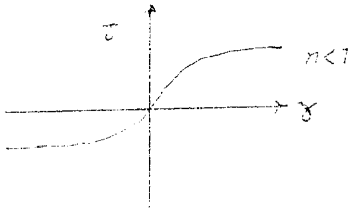
Power Law model:

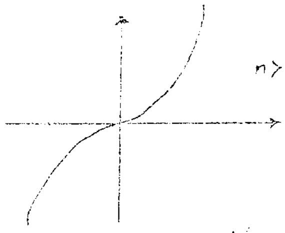
$$\tau = K\left(\frac{dv}{dy}\right)^{n-1}\frac{dv}{dy} \Rightarrow \log\tau = \log K + n\log\left(\frac{dv}{dy}\right)$$

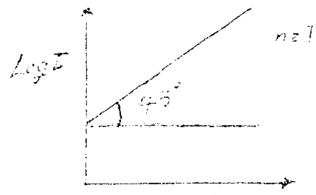


$$\boxed{\mu_a = K\left(\frac{dv}{dy}\right)^{n-1}}$$

$$\boxed{n = 3.32\log\left(\frac{\theta_{600}}{\theta_{300}}\right) \qquad K = \frac{\theta_{300}}{(511)^n}}$$







- P.V.: ✓ $\mu_p = \theta_{600} - \theta_{300}$, cp

θ_{600} : Dial Ready at 600 rpm

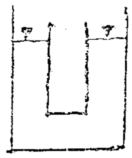
θ_{300} = Dial Ready at 300 rpm

- Y_p: Y.P. ✓ $Y.P. = \theta_{300} - \mu_p$, $lbf/100\,ft^2$

✓Gel strength:

In unit of $lbf/100\,ft^2$ is obtained by noting the maximum dial deflection when the rotational viscometer is turned, at a low rotor speed (usually 3rpm). often the mud remain static for some period of time. If the mud is allowed to remain static in the viscometer for a period of 10 second, the maximum dial deflection obtained when the viscometer is reported as initial gel.

rpm = 3



10 sec
10 min

$\gamma_{300} = 511\ sec^{-1}$

$$\boxed{K = \frac{\theta_{300}}{(511)^n}}$$

Power-Law model: $\tau = K\left(\frac{dv}{dy}\right)^n$

$\tau = K\gamma^n \Rightarrow K, n = ?$

θ_{300} , $(511)^n$

□ Drilling mud Laboratory:

To measure the properties of flow:

If the mud is acting as Newtonian → measuring μ

If the mud is acting as Bingham plastic → μ_p , τ_y

If the mud is acting as pseudo-plastic, dilutant → K, n

Drilling Engineering (P.57)

□ Drilling Hydraulic:

$$P_{pump} = \sum_{i=1}^{n} \Delta P_i = \Delta P_{surface} + \Delta P_{drill\,pipe} + \Delta P_{bit} + \Delta P_{Annulus}$$

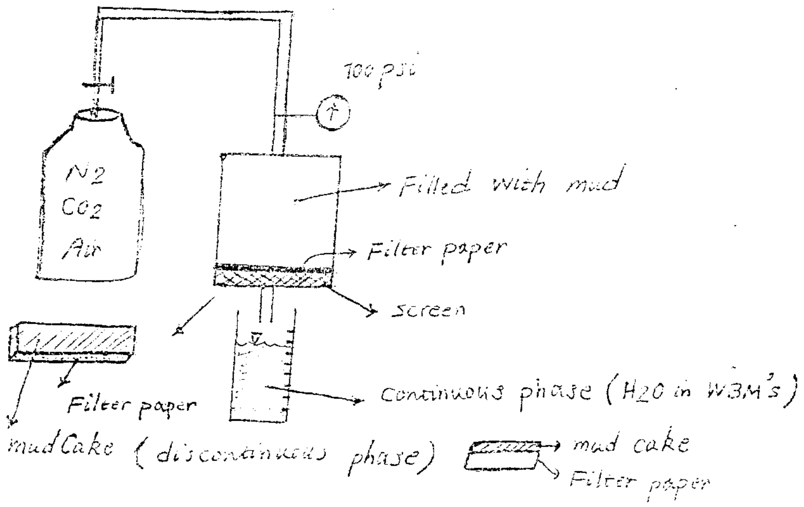
knowing P_{Pump}, ΔP_s, ΔP_d, ΔP_A => we can calculate ΔP_{bit}.

– Drilling optimization process:

Getting maximum pressure at the nuzzle in order to cut the formation.

✓– Mud Cake is used to stabilize the well-bore and prevent from formation fluid flow.

□ Filteration Amount Measurement:



✓– Report the physical properties of mud cake (Soft, firm, brittle, flexible)

✓– The important of filtercake quality can not be overstated, a film of thin, firm cake is desired.

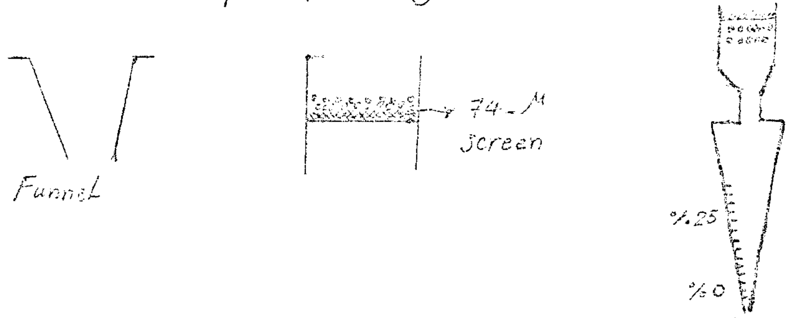
□ Sand Content Analysis:

We must know how much sand, mud carry before touching the formation, that is important to prevent erosion of equipments (In Recirculation).

Solid particles Larger than "74" micron (200 mesh) are classified as API sand.

✓_ Kit: Is a box that contain all things that we need for doing test.

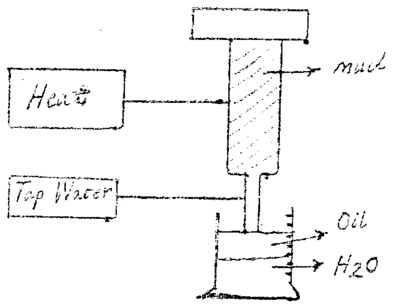
_ We take a volume of mud sample and pour it on the tube and it filter the sample. and any particle that is Larger than 74_micron diameter remains on screen. Then we reverse tube on the connected funnel and fill graduated funnel by sand (we can use water to assure that there is no sand on screen and we can report percentage of sand content. (percent by volume) $\frac{x \text{ cc. sand}}{100 \text{ cc mud}}$



✓□ Oil, Water, solid Content Determination :

The knowledge of the Liquid, solid content of a drilling mud is important for controlling the mud properties:

The equipment used is called "Retort Kit".



Oil / water → vaporization → Condensation

Volume of oil / volume of sample = % oil content

Volume of water / volume of Sample = % water content

✓□ Solid Determination :

Total solid: ✓(1) settable solids : They can separated from Liquid by gravity

✓(2) Non_settable solids

- soluble solids (dissolved Solids)
  - organic
  - Inorganic
- Suspended solids (Non_dissolved Solids)
  - organic
  - Inorganic

; Engineering (P. 61)

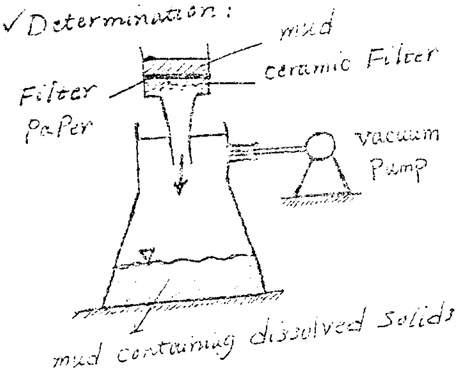
✓ In drilling Engineering, we need non-settable solids, so we have:

Total solids = Total Suspended Solids + Total Dissolved Solids

Total Suspended Solids ⇓ Inorganic Suspended + Organic Suspended

Total Dissolved Solids ⇓ Inorganic Dissolved + Organic Dissolved

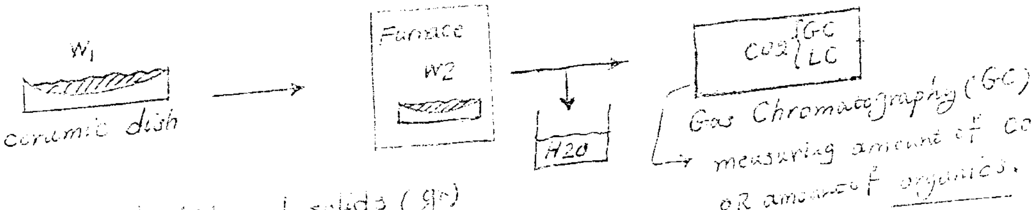
✓ Determination:



We vacuum the fluid and Liquid with solids + dissolveds pass and suspended remain on Filter paper. Having initial wt of filter paper and again weight it. Then we will know amount of suspends.

$$\text{Total suspended solids} = \frac{W_2 - W_1}{\text{sample volume}}$$

✓ to determine amount of organic and inorganic matter in suspended solids we can use following stages: {organic → $H_2O + CO_2$}

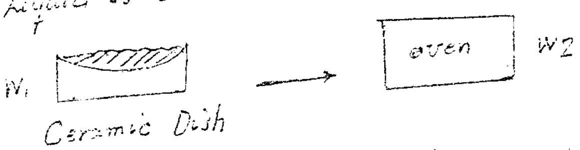


W_1: dry wt of dish and solids (gr)

W_2: wt of dish after burning (gr)

$W_2 - W_1$: wt of organic solids (gr)

✓ If we take filterated water and put it in Oven and vaporize it, the Liquid is driven off, the remaining will be dissolved solids.



W_1: Wt of dish ; W_2: wt of dish after oven , $W_2 - W_1$: Total dissolved solids (gr)

√ □ PH Determination:

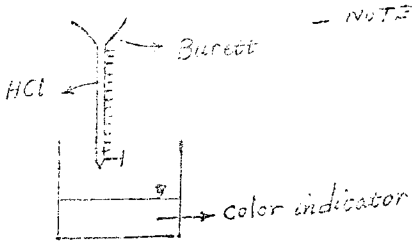
There are two methods: (1) Electronic devices
(2) Color Paper (more reliable)

√ □ Conducting the Methylene Blue Capacity (MBC):

"Methylene Blue" is a color chemical indicator.

Titration: We can determine how much ion exists in the sample.

– NOTE: Treating in mud recirculation after circulation.



– IF we add "MB" to the mud, the color changes to blue and we know how much we add, Hence we can determine how much ion exists in the sample.

– The "MBC" is designed to determine the amount of reactive clay and also its cation exchange capacity in the drilling mud sample. It will show some chemical reactions of mud, prospect with shale formations.

$$MBC = \frac{cc \text{ of methylene Blue}}{cc \text{ of mud}}$$

(lb/bbl) Bentonite $= 5$ MBC (Amount of clay in one barrel mud)

√ – The difference b/w amount of clay before and after circulation show amount of clay in the formation.

– We Can determine amounts of Cl^-, Ca^{2+}, mg^{2+}, Al^{3+}, ..., by titration.

– We Should determine the value of radioactivity by tests mentioned above. the value of "Ur" in the formation will show how much formation is fractured.

□ Mud Treatment: Solid – Liquid separation (Solid Removal)

Includes: (1) Settling (2) Dilution (3) Mechanical separation (4) Chemical Treatment

✓□ Chemical Treatment:

Some chemical additives are used to fine the mud. This approach is not recommended due to effect on mud properties.

✓□ Settling:

(1) Size and shape of particles.

(2) Density relative to liquid.

(3) Time available for Retension.

✓□ Dilution:

Adding water to decrease mud concentration.

✓□ Mechanical Separation:

(1) Vibrating / Screening devices:

✓ Shale shaker (d > 150 microns)

(2) Centrifugal Devices utilizing centrifugal forces.

✓ Desander (50 - 70 microns)

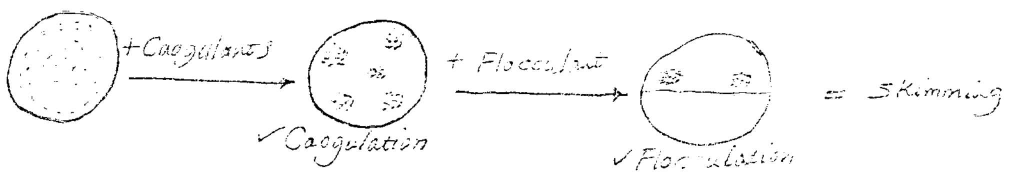
✓ Desilter (d < 50 microns)

✓ Mud Cleaner (d > 75 microns) → Desilter + high speed shaker

✓ Centrifuge (2-5 microns)

Note: The cheap method for mud cleaning is dilution, Adding water to decrease the solid concentration, then use the amount of mud needed and throw away rest of the mud, Can not be used where is the strong environmental agents.

□ Chemical Treatment: Using Caogulant and Flocculants.



▪ Manufacture, chemistry and classification of Oilwell cement:

√▫ Cement manufacture and chemistry:

Cement is manufactured with materials and methods that have changed little over the last 160 years.

Joseph Aspdin: builder from Leeds, U.K., was granted a patent in 1924, for a cement of superior quality resembling portland stone.

√portland cement:

(1) Calcareous materials (Limestone, chalk, seashelf)

(2) Alominosilicates (clays)

These are mixed at 1425 – 1535°C, the resulting material mineral which is called "clinker" is then coold and ground with gypsum to form Portland cement.

√Portland Cement Component:

The principle components are:
- 50% tricalcium silicate ($3CaSiO_2$) ⇒ C_3S
- 25% dicalcium silicate ($2CaSiO_2$) ⇒ C_2S
- 10% tricalcium Aluminate ($3CaC, Al_2O_3$) ⇒ C_3A
- 10% tetracalcium Aluminoferrite ($4CaO, Al_2O_3, Fe_2O_3$) ⇒ C_4AF
- 5% Other oxides

C_3S: Has greatest effect on overall cement strength

C_2S: Slow reaching (gradual gain on strength)

C_3A: Fastest rate of hydration

C_4AF: Low heat of hydration in cement.

neat cement: Cement + H_2O (no additive)

slurry cement: Cement + H_2O + additives (sand)

Thickenning Time: The time allowed to cement to reach 100 cp viscosity (up to 100 cp viscosity cement could be pumped)

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✓- Thickenning Time depends on temperature, the Less temperature, the more will be the Thickenning time.

- We add chemicals to allow the easy movement of cement (Lowering viscosity).

□ Cement Hydration:

✓- The hydration of cement is accelerated by increasing temperature.

- As the reaction proceeds, the slurry shows an increase in viscosity.

□ Type of API Cement:

Halliburton is the first company that did cementing job.

Different classes: A, B, C, D, E, F, G, H, J

class A, G: Construction cement for outside of U.S. or common cement.
From surface - 6000 ft

Class A, G, H: Most oil-well cementing, world-wide operations. (In Iran → G)

Class D, E, F, J: For High Temperature.

□ Cement Testing procedure:

Needs for Laboratory cement tests: (1) 5 Kg of dry cement
(2) 4 Liter mix-water cement (well-site)

Particularly useful tests are: (1) Thickenning time test
(2) Fluid-Loss Test
(3) Slurry Density
(4) Compression-Strength Test
(5) Normal and minimum water content of slurry.

✓NOTE: Compression-Strength test is useful for establishing WOC time and monitoring the stability of the test material.

WOC: Waiting on cement time (WOC): excessively Long thickenning time necessitates usually Long waiting on cement.

It is generally accepted in the industry and by Laboratory that a compressive strength of 500 psi is adequate for most operations.

Cementing additives:

most additives in current use are free-flowing powders that are dry-blended with the cement prior to its transportation to the well.

✓properties modified by additives:

(1) Thickenning Time (Acceleration, Retardation)

(2) Density (extenders, weight increase/reduction)

(3) Friction During Pumping (friction reducers Lower μ (energy Loss))

(4) Fluid Loss (by filtrate)

(5) Lost-Circulation resistance (whole slurry Loss)

Almost all cement used in oil and gas wells is portland cement However neat cement is seldom is seldom used throughout a job, since various cement additives are usually added.

For Set Comment:

✓- Compressive Strength Stabilizers

✓- Strength retrogression (Loss with time)

✓- Expansion / Contraction

✓ $\boxed{F = 0.969\, S_c\, d\, H}$; where:

F: Force or Load to break cement bond

d: OD of casing

Sc: Compressive strength (psi)

H: Heighof Cement column

note: The above equation is used for cement squeezing ($P_p < F$)

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□ Cementing Equipment :

✓– major components of surface – cementing equipments are :

(1) mixer or blender

(2) pumping / displacement unit

(3) Cementing or plug – released head

Note : Top plug is solid and bottom plug is or empty, they are made by rubber.

✓– subsurface equipments are :

(1) Guide Shoe : To guide casing to desired depth (heavy).

(2) Centralizer : Put casing at the center.

(3) Float Collar : Has setting section and valve and is set above shoe.

(4) Wipers and scratchers : Is a sharp devices to remove mud cake and clean well – bore for better cementing job.

□ Conventional Cementing :

First we remove bottom plug (in order to separate mud and cement) and then put cement force on behind it. Bottom plug is set at the bottom of casing and then inject displacing Fluid behind top plug and it will cause casing empty from cement and cement goes behind the casing, and we wait on cement to be solid.

Note : For further deep drilling we must drill on plug and we can remove them after cementing.

– When top plug reaches to bottom plug a noise is produced and this is an indicator of cementing job.

– Flushing Fluid : or spacer Fluid is injected in order to prevent mud and cement contact and reactions prospect with them, by injecting spacer Fluid, the composition of mud (Cement) is kept constant.

□ Cementing applications:

(1) For Lost Circulation prevention

(2) Diverting Drilling (Trajectory plugging)

(3) For plugging abandoned wells

(4) Strata Isolation

(5) Formation Tests (DST) (Doing isolation in high fractured carbonates)

(6) Squeeze Cement job:

Squeezing cement with high pressure to plug perforations or fill previous cementing pores.

✓Note: Liner cementing ⇒ Coil Tubing

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□ Example: Using Bingham plastic model, calculate for the well, described below, the pressure drop (ΔP_{bit}):

Depth = 9500 ft

Hole Diameter = 8.5"

Drill pipe = 5/4.726 , 10000 ft

Drill collar = 8/3" , 500 ft

MW = 13 ppg

Y_p = 30 lb/100 ft^2

PV = 20 cp

Circulation rate = 350 gpm

maximum pump pressure = 2500 psi

Surface equipment type = 4

□ Solution: (a) Required: ΔP_{bit} = ?

$P_{mud\ pump} = \Delta P_{ds} + \Delta P_{bit}$

ΔP_{ds} =

ΔP_{ds} = ΔP(Drill pipe including surface facilities pressure drop) + ΔP_{dc}

$\Delta P_{annulus} = \Delta P_{Hole\text{-}dp} + \Delta P_{Hole\text{-}dc}$

$\bar{v} = \frac{q}{A}$

Critical velocity (V_c): if: $\bar{v} < V_c \Rightarrow$ flow is Laminar

$\bar{v} > V_c \Rightarrow$ flow is Turbulent

NOTE: Changing $P_{Pump} \Rightarrow$ we should change bit nuzzel.

(b) Nuzzle Velocity ($V_n \times A_T = q$)

3-nuzzles exist

Note: Uncemented Slotted Liner Completion

$\Delta P_{surface\ facilities} = \Delta P_{stand\ pipe} + \Delta P_{hose} + \Delta P_{swivell} + \Delta P_{kelly}$

Since we have equivalent drill pipe length instead of surface facilities:

∴ in calculation ΔP for surface facilities will appear in ΔP for drill pipes : $\Delta P = \Delta P_{DS} + \Delta P_{annulus} + \Delta P_{bit}$

$\Delta P_{DS} = \underbrace{\Delta P_{dp}}_{\text{Including surface facilities pressure drop.}} + \Delta P_{dc}$

$\Delta P_{annulus} = \Delta P_{Hole-DC} + \Delta P_{Hole-DPS}$

$\bar{v} = \dfrac{q\,(\text{Pump flowrate})}{A\,(\text{area at that section})}$

Note: if some part of well is cased-hole and other part is open-hole then we must evaluate ΔP for each section separately.

$\Delta P_{ds} = \Delta P_{dp-casing} + \Delta P_{dp-hole} + \Delta P_{dc-hole}$

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