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Moore And Chien Correlation To Address The Issue Of Hole Cleaning In Guba Field – Libya

Mahfoud Zayed Abdulla Aghanaya
Oil And Gas Department, Faculty of Engineering, Bani Waleed University
maghanaya@gmail.com. Or maghanaya@bwu.edu.ly.

Abstract- **Hole cleaning and hydraulics are important part of drilling operations that need to be carefully reviewed and incorporated in drilling program. Poor hole cleaning could lead to various problems like slow rate of penetration (ROP), excessive torque and drag, excessive wear on bit, pipe sticking problems, and possibly fracturing of formation.**

In this work, Since hole cleaning is a major problem associated with drilling operations. There is an evaluation of the effect of the drilling fluid rheology parameters and flow rate on hole cleaning. Correlation methods such as Moore and Chien correlation have been made to provide the most suitable approach to address the issue of a hole cleaning. On the other hand, also explains the effect of the flow rate in the equivalent circulating density (ECD) in terms of frictional pressure loss in the annulus. The result of analysis demonstrates how the rheology parameters and flow do affect the hole cleaning and concludes that the ECD and frictional pressure loss in the annulus are affected by the flow rate.

Index Terms: ***Flow Rate, Rheology, Chien, Moore, ECD, Cleaning Hole.***

I. INTRODUCTION

During drilling operations, poor hole cleaning may result in slow rate of penetration (ROP), excessive torque and drag, excessive drilling wear, pipe fusion problems, possible formation fracture, etc. Production time (NPT). Cleaning holes in highly skewed wells or horizontal wells is more complicated than cleaning vertical holes.

Removal of cuttings in vertical wells is much easier to control than in high skew wells or horizontal wells. A vertical well can be classified as a wellbore with an inclination angle of less than 10 degrees. Wellbore sections with a slope of 10° -30° can be classified as low inclination or borehole sections. Basically, the three main factors affecting orifice cleaning in vertical wells are annular velocity, slip velocity, and fluid viscosity.

For vertical wells, the principle of hole cleaning is mainly based on overcoming the slip velocity of the cutting, while including sufficient annular velocity and cutting bearing capacity in the drilling fluid program. In other words, it is assumed that any fluid velocity greater than the settling velocity of the largest pieces will eventually raise all the pieces to the surface. [1]

For vertical wells, a laminar flow system is preferred over turbulent flow system so as to avoid drift, ensuring that drilling fluid and annular velocity are sufficient to transport and suspend cutting to the surface.

Mud rheology is the primary function of plastic viscosity (PV) and its production point (YP). Mud rheology has a significant impact on hole cleaning. PV and YP are calculated from the FANN reading at 300 rpm and 600 rpm. An increase in PV and YP tends to improve slot cleaning. It has been observed that increasing mud viscosity has a positive effect on hole cleaning and is particularly effective if the shear rheology is low and the YP/PV ratio is high. However, it was noted that a significant increase in the viscosity of the clay (above the optimum viscosity) affect the cleaning of the hole. [2]

The mud flow rate provides the lift force on the cutting to move the cutting out of the well. Greatly increasing the flow rate helps to clean the nozzles. According to the majority of authors, an increase in the flow rate is necessary to reduce the height of the cutting bed. The increase in the annular velocity of the drilling fluid helps to clean the hole efficiently.[3]. The following guideline for annular velocity has been established

- 1 m/s – Ideal hole cleaning.
- 0.75 m/s – Minimum required hole cleaning.
- 0.5 m/s – Poor hole cleaning and possibly barite sag in deviated sections.

ECD is defined as the sum of the mud hydrostatic pressure and the annulus pressure loss acting on the formation [4]

The ECD is used to control formation pressure and prevent kicks without breaking the drilled formations. When mud pumps are switched too, a reduction in ECD may result under balanced conditions requiring good knowledge of ECD to avoid any drilling problems. At the same time, the weight of the mud cannot be increased due

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to the limitation of fracture pressure. Continuous Circulation System (CCS) instruments are used to control of the formation pressure [5], [6].

Annular clearance, mud weight, mud rheology, annular velocity (pumping rates), cutting concentration in the annulus, and hole depth are the main factors affecting annular pressure losses (APL). The cutting portion in the annulus is expressed as equivalent static density (ESD), and the parameters related to the mud [7], [8], [9].

II. BACKGROUND

The Guba field is located in the Southern part of the Hugfa trough, at the central part of Sirte basin.

The Sirte Basin province ranks 13th among the world's petroleum provinces, having known reserves of 43.1 billion barrels of oil equivalent (36.7 billion barrels of oil, 37.7 trillion cubic feet of gas, 0.1 billion barrels of natural gas liquids).

It includes about 490,000 square Kilometers. The province contains one dominant total petroleum system, the Guba field is a part of the Sirte basin, based on geochemical data. The Upper Cretaceous Sirte Shale is the primary hydrocarbon source bed.

Reservoirs range in rock type and age from fractured Precambrian basement, a clastic reservoir in the Cambrian-Ordovician Gargaf sandstones. There are 22 vertical wells were drilled in this field. The production of the field was 14,000 bopd and decreases in the last years to 12,000 bopd. The thickness of the reservoir is about 1500 ft, the main pay zone of these fields (Gargaf sandstone).

The porosity and permeability of the field reservoir are 0.11% and 70 MD respectively. The reservoir radius is about 3170ft and the bottom hole temperature ranges from (280 – 310F˚). The drilling problems that have been faced while drilling this field are sand production problems, stuck pipe, hole enlargement, sloughing shale, And loss of circulation.

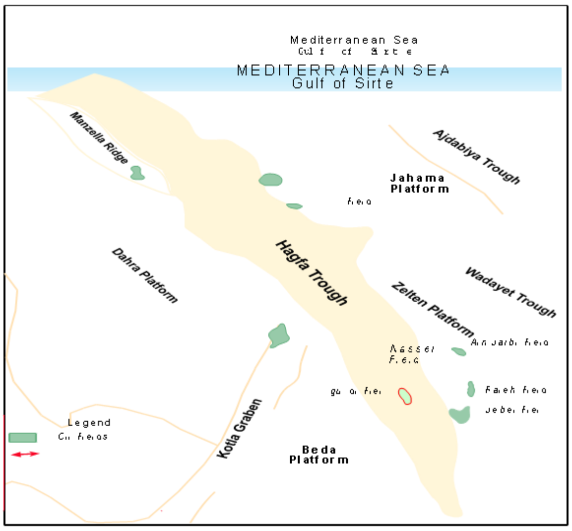

Figure. (1) map of Field Location

A. Common Problems in Guba Oil Field:

- Hole cleaning.
- Differential sticking.
- Lost circulation.

The hole cleaning is one of the major problems in Guba field using conventional drilling however, the hole cleaning in directional wells (extended reach, horizontal, and multilateral) can be an order of magnitude more difficult.

B. Identification of the Problem Gargafe zone:

Fluid velocity and Rheology both have a crucial role in this process in terms of performance and efficiency. A fluid's velocity can simply controlled by increasing or decreasing the flow rate at the mud pumps; with a constant area, the maximum extent to which the annular velocity can be increased however, is governed or limited by the ECD acting on the formation. When the flow in the annulus is in a turbulent regime, annular pressure losses can dramatically increase with slight increases in flow rate, the result is a greater ECD acting on the formation, thus increasing the risk of inducing fractures and taking losses.

C. Data Analysis:

The data calculation will be presented in two parts; the first part will demonstrate the calculations used to determine the actual cuttings transport ratio which represents the effectiveness of that particular cuttings transport system. The second part will demonstrate the calculations required calculating the ECD aspect of the hole-cleaning model. Given that the Yield Power Law fluid model is normally the closest mathematical representation of an actual non-Newtonian drilling fluid. Three parameters are used for the Yield Power Law as opposed to Bingham and Power Law that use two, a sample set of calculations is presented using this model. The flow rate in this particular case was 200 gallons per minute (GPM) with a fluid Density of 9.2 pounds per gallon (PPG).

D. Field data:

Table 1. Field data

Parameter	Value	Unit
O.H.	5 7/8"	Inch
DP.	3 ½"	Inch
M.wt.	9.2	ppg
Bottom hole pressure	280 F	
Cutting Diameter	0.25	In^2
Cutting Density	21.58	ppg
Flow rate	200	gpm
Rheology Data @ 280 F		
RPM	**Dial Reading**	
600	25	
300	17	
200	14	
100	10	
6	4	
3	3	

III. RESULT AND DISCUSSION

3.1 Effect of Rheology

Initially the annular velocity is calculated from values of volumetric flow rate and annular cross sectional area. The following equation can be used:

$$V_a = \frac{q}{2.45(OH^2 - DP^2)} \quad (1)$$

For yield Power Law fluid, True Yield (τ_0) , the flow Behavior Index (n) and consistency Index (K) must be calculated**.**

A value of **(**τ_0**)** is found by using the stated Equation (**2**) as well as viscometer reading at (3 and 6 rpm) are (3 and 4 respectively) from table (**1**).

$$\tau_0 = 2\theta_3 - \theta_6 \quad (2)$$

a value of (n) can be calculated by using the stated equation (**3**).

$$n = 0.5 \log \tau_{300}/\tau_3 \quad (3)$$

(K) can be calculated from the consistency equation presented in the Yield Power Law equation (**4**).

$$K = 100\tau_{300}/\gamma_{300}^{n} \quad (4)$$

Once values of τ_0**,** n and K have been calculated as follows,(9.58, 0.564 and 229) respectively, a transport ratio can be calculated Either. the Moore or the Chien correlation can be used for this.

Four varying values of the consistency index (K) were taken for the analysis of consistency index effect on hole cleaning, while the flow behavior index (n) and the flow rate were kept constant. The results are shown in the **Table (2)** and **Figure (2).**

Table 2. Consistency Index (K) and Transport Ratio Correlation

K (dimensionless)	Transport Ratio %
129	79%
179	81%
229	82.59%
279	83%

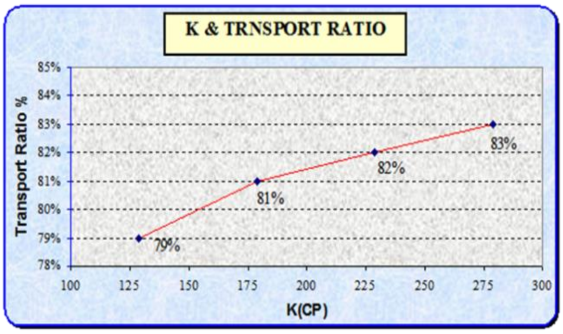

Figure. (2) Consistency Index (K) and Transport Ratio Correlation

From the Figure (2) the transport ratio slightly effect by changing of the consistency index (K).

In ambush as the (K) value is the viscosity of the fluid at (γ = 1.0 sec^{-1}) any material that affects low shear rate viscosity or (gel strength) well affect (K). The most effective material for reading (K) values is Bentonite and xanthan gum. Flocculation or benefaction of Bentonite also raises (K), where the deflocculating or dispersion lowers (K). dilution is the most effective method of lowering (K).

By taking Four varying values of the flow behavior index (n) while the consistency index (K) and the flow rate were kept constant. The results are shown in the Table (3) and Figure (3).

Table 3. Flow Behavior index (n) and Transport Ratio Correlation

n (dimensionless)	Transport Ratio %
0.15	75.6
0.30	76.34
0.56	83
0.90	90

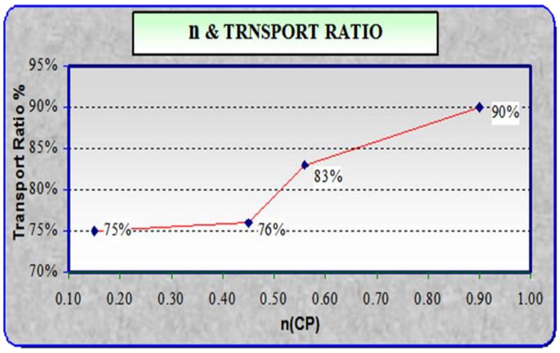

Figure. (3) Flow Behavior Index (n) and Transport Ratio Correlation

Figure (3) shows that the transport ratio increases with increasing flow behavior index (n).

Most common mud additives lower the n of a water base mud to some degree (water has an (n) value of 1.0). The (n) values below 0.5, however, usually can be reached only by adding Bentonite or Xanthan gum. Dilution and addition of solids usually cause an increase in the n value

A- Moore Correlation:

After calculated values of (K) and (n) along with actual dimensions, the apparent viscosity can be calculated by the equation (**5**) as follows:

$$\mu_a = \frac{K}{144}\left(\frac{D_2 - D_1}{V_a}\right)^{1-n}\left(\frac{2+\frac{1}{n}}{0.0208}\right)^{n} \quad (5)$$

The result value of this equation will be used to calculate the velocity at which the cutting partials fall through the fluid column as per equation (**6**)

$$v_s = \frac{2.90 * d_s * (\rho_s - \rho_f)^{0.667}}{\rho_f^{0.333} * \mu_a^{0.333}} \quad (6)$$

The use of this equation is depended on the resulting of Reynolds number is within a criterion of greater than 3 and less than 300. From the equation (**7**) it can be seen that, as the calculated Reynolds number is between these values the use of this equation is justified in this case.

$$N_{RE} = \frac{928 * \rho_f * v_s * d_s}{\mu_a} \quad (7)$$

By using the equation (**8**) can be calculate the transport ratio as follows:

$$F_T = \frac{v_a - v_s}{v_a} \quad (8)$$

Four varying values of flow rate were taken with keeping K and n constants to check how the flow rate effect in the hole cleaning: as shown in the **Table (4)** and Figure (4)**.**

Table 4. Flow Rate and Transport Ratio (Moore)

Flow rate GPM	**Transport ratio %**
150	77.77
200	82.59
240	85.13
300	88.21

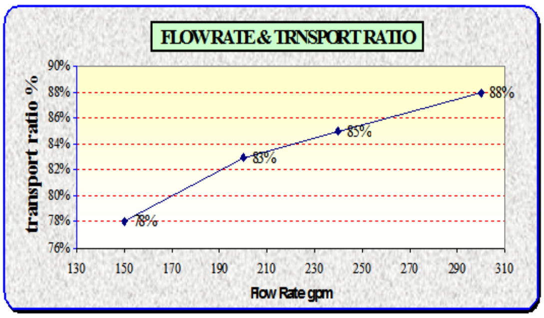

Figure. (4) Flow Rate and Transport Ratio (Moore correlation.

As shown in the Figure (4) the higher the flow rate, the greater the hole cleaning efficiency.

B- Chien correlation;

The Chien correlation is presented using Equations (9) and (10) respectively

$$\mu_P = \theta 600 - \theta 300 \quad (9)$$

$$\mu_a = \mu_p + \frac{5(\tau_y d_s)}{v_a} \quad (10)$$

This value, together with the other calculated values are then entered in to the equation (**11**) , to gain a value of slip velocity as shown below. In the Chien used the same data that in Moore .

$$v_s = 0.0075 * \left(\frac{\mu_a}{\rho_f - d_s}\right) * \left[\sqrt{\frac{36800 * d_s}{\left(\frac{\mu_a}{\rho_f * \rho_s}\right)^2} * \left(\frac{\rho - \rho_f}{\rho_f}\right) + 1} - 1\right] \quad (11)$$

The slip velocity means that one cutting particle of the size and density previously stated will fall through the mud column at speed (**0.796 ft/sec**). Therefore; to clean the hole, the mud fluid must be travelling at speed greater than this value to avoid settling of the cutting and the net particle movement is in an upward direction. This movement is known as the transport ratio that is demonstrated below in the next equation, where the velocity of the annular fluid is 3.66 ft/sec at flow rate 200gpm.

By using equation (8) In the Chien correlation, the cuttings transport ratio across the open hole by (78.25%) due to 200 gpm flow rate.

By taking another three different reading for the flow rate to check how much the transport ratio effected by change in the flow rate. As shown in the **Table (5)** and Figure (5) below.

Table 5. The Flow Rate and Transport Ratio (Chien)

Flow rate (GPM)	Transport ratio (%)
150	71.08%
200	78.25%
240	80.97%
300	85.45%

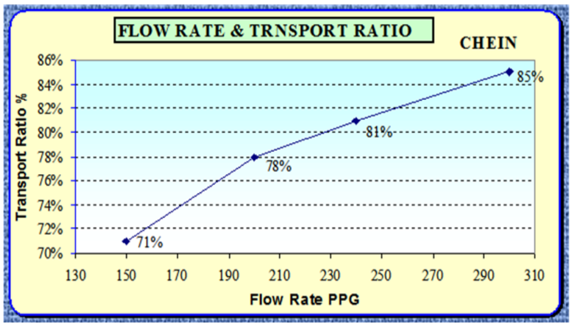

Fig. (5) Flow Rate and Transport Ratio Correlation (Chien)

Figure (5) illustrate the relationship between the flow rate and transport ratio. The transport ratio increased with increase the flow rate. Which means that the flow rate effected in the hole cleaning.

Table (6) shows the comparison between the flow rate and transport ratio in Moore & Chien correlations.

Table 6 . Shows Flow Rate and Transport Ratio (Moore& Chien)

Flow Rate gpm	Moore	Chein
150	77.77%	71.08%
200	82.59%	78.25%
240	85.13%	80.97%
300	88.21%	85.45%

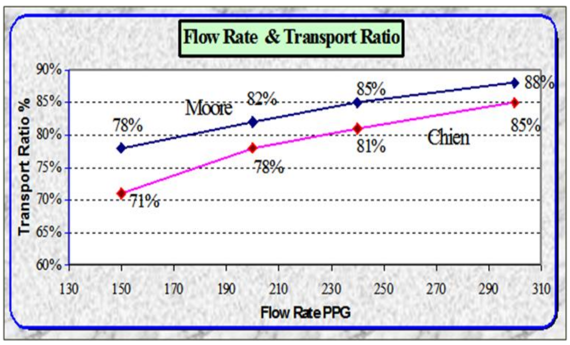

Figure. (5) Relationship between the flow Rate and Cutting Transport Ratio in Moore and Chein.

Figure (5) shows the relationship between the flow rates and cutting Transport Ratio in Moore and Chien. The Chien is lowers results than Moore correlation.

Therefore: in order to optimize hole cleaning efficiency the rheological behavior of the drilling fluid need to be defined. Because Moore correlation can be used for Power Law and Herschel Bulkley, but fluids while Chien correlation can be apply only for Bingham plastic fluids.

3.2 *Equivalent Circulating Density Analysis (ECD)*

The process of removing cutting from a well basically comes down to a balancing act between maximum uplift of cuttings and the ECD constrains of that particular well.

The data can be used to determine the ECD or e`/quivalent circulating density this is determined by the equation (12).

$$ECD = \frac{BHCP}{0.052 * TVD} = (PPG) \qquad (12)$$

$$BHCP = HP + \Delta P_{annulus} \qquad (13)$$

Where**:**
BHCP = Bottom hole circulating pressure.
TVD = True vertical depth. Ft.
Hp = hydrostatic pressure psi
ΔP = Annulus pressure losses psi In equation (**13**) all the variables are known as shown in **Table (7)** and the annular pressure losses ($\Delta P_{annulus}$), can be calculated.

Table 7. Open hole and Casing 7" Data.

Casing (7")	**Length = 11347 ft.**	**ID = 6.276"**
OH (5 7/8")	Length = 1500 ft.	5 7/8"
DP (3.5")	Length = 12103 ft.	ID = 2.764"
HWDP (3.5")	Length = 186 ft.	ID = 2.5"
DC (4 ¾")	Length = 558 ft.	ID = 2 ¼"
3.5" DP In OH	Length = 765 ft.	
3.5" dp in casing 7"	Length = 11347 ft.	
3.5" (DP & HWDP)	Length = 12289 ft.	
Mud weight	9.2 (ppg).	

Initially an actual value of Reynolds Number is calculated based on the annular parameters as seen in the following equation.

$$R_e = \frac{109000 * \rho_f * V_a^{(2-n)}}{K} * \left[\frac{0.0208 * (d_2 - d_1)}{2 + \frac{1}{n}}\right]^n \qquad (14)$$

This value of Reynolds Number can then be compared to a Critical Reynolds Number which is determined by graphical means using the previously calculated value (n).By using the Dodge and Metzner published Charts a friction factor for use with Reynolds Number can be determined through cross Referencing (n), the flow Behavior index and calculated Reynolds Number to give the friction Factor.

The flow behavior index, (n) determines the Critical Reynolds Number, for the transition between Laminar and Turbulent flow.

Due to using the Dodge and Metzner Charts we observed that, by following the line with (n) value of (**0.564**) previously calculated from equation **(3)**, the Reynolds Number less than the Critical Reynolds Number.

Therefore; laminar Flow pressure Drop equation can be used as follows:

$$\Delta_p = \frac{L * K * v^n}{144000(d_2 - d_1)^{(1+n)}} * \left[\frac{2 + \frac{1}{n}}{0.0208}\right]^n \qquad (15)$$

When the Reynolds Number is greater than the Critical Reynolds Number the flow pressure drop will be Turbulent and the following equation can be used:

$$\Delta_P = \frac{fL * \rho * v^2}{21.1(d_2 - d_1)} \qquad (16)$$

Table (8**)** shows the relationship between the flow rate and the ECD, at different reading for the flow rate.

Table 8. Flow Rate and ECD Correlation

Flow Rate (GPM)	**ECD (PPG)**
150	9.47
200	9.45
240	9.61
300	9.84

From this correlation it can be seen that the ECD increases with increasing flow rate as shown in the Figure (6).

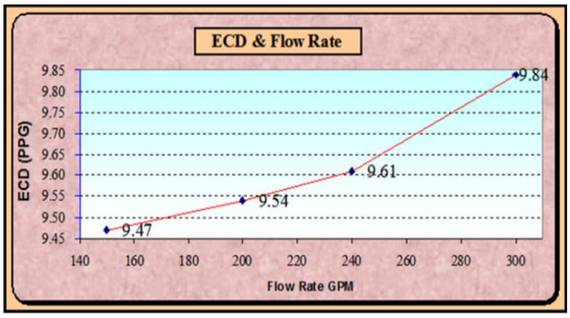

Figure. (6) Flow Rate and ECD Correlation

Table (9) shows the relationship between the flow rate and the frictional pressure drop in annulus.

Table 9. Flow Rate and Annulus Pressure Drop Correlation

Flow Rate gpm	ΔP psi	Type of Flow
DC & OH		
150	35	Laminar
200	60	Turbulent
240	86	Turbulent
300	134	Turbulent
DP & OH		
150	13	Laminar
200	15	Laminar
240	17	Laminar
300	31	Turbulent
DP & CSG 7”		
150	109	Laminar
200	127	Laminar
240	83	Laminar
300	214	Turbulent

The correlation shows that the frictional pressure drop increases with increasing the flow rate as illustrate in Figure (7).

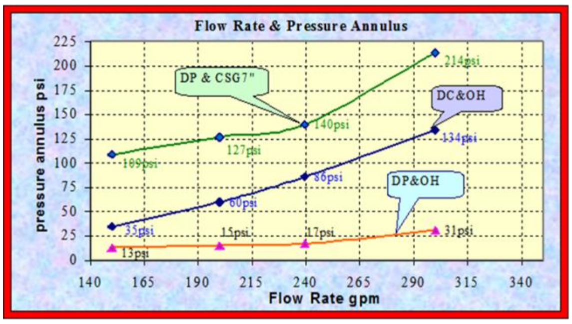

Figure. (7) Flow Rate and Annulus Pressure Drop Correlation.

Figure (7) concluded that the annular frictional pressure loss is the key parameter to obtaining optimum hole cleaning.

however, a difference may be expected as lower flow rates give less hole cleaning efficiency and lower ECD, the higher the flow rates give the better hole cleaning efficiency and higher ECD. Therefore, it is important to maintain frictional pressure loss with consideration to ECD in terms of flow rate and rheological properties.

IV. CONCLUSION

Form this work analysis we reached to the following analysis:

The hole cleaning can be effected by changing in the mud rheology and the flow rate.

More analysis could be used to find good rheology properties and suitable flow rate. This would give a better correlation between the rheology and hole-cleaning efficiency.

The Herschel Buckley Model is likely to give the closest match to the hole cleaning at the same reading of the flow rate.

The ECD clearly affected by the increasing of the flow rate.

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BIOGRAPHIES

Mahfoud Zayed Aghanaya was born in Bani Waleed / Libya, January 01, 1960. He received Bsc degree in Exploration Department from Higher Petroleum Institute Tobruk in 1982.sincec1982 -2003 he works in Libyan oil companies as Geologist and Pressure Engineer. He got Msc degree in Drilling and Well Engineering from Robert Gordon University, Aberdeen UK. In 2004 with distinguish. From 2004 -2007 A head of Geologist Department at Jowfe Company. 2007 – 2011 lecturer in Petroleum Department at Misurata University at the same time a head of Oil and Gas Department in Engineering Collage Bani Waleed. 2011-2014 lecturer in Al Zaytwana University . 2020 he got PhD degree in Environmental Studies from Institute of Graduate Studies and Research, Alexandria University. He is currently lecturer in Oil and Gas Department at Bani Walleed University.