Rock Drill Bit Wear & Optimization

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Declaration

I certify that this research work titled "*Rock Drill Bit Wear & Optimization*" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student

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Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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Abstract

In Pakistan, petroleum deposits are often found in hard rock formations as well as greater depths. Different drilling techniques are used to drill the oil & gas wells main tool for drilling the well is “Drill Bit” and conditions on which drilling process is carried through. Main problem in drilling process is drill bit wear and time for drilling the well because drilling process is very expensive and it involves man power as well as finances for Drilling rig and other equipment. Main aim for efficient drilling is less time for drilling process and minimum wear rate in drill bit. There is therefore a strong need to optimize the drilling process by identifying the key process variables that contribute towards drill bit wear and drill life. Based on this analysis and field data, drill bit wear and most optimized conditions for drilling can be mapped and we can select our region for drilling operation.

Thus study aims to select optimized conditions on drill bit i.e.

- Weight on Drill Bit
- RPM

Thus the region with minimum wear rate in drill bit and maximum rate of penetration is desired objective for oil & gas companies it will save their time and money.

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CHAPTER 1: INTRODUCTION

The engineering problem of wear has been known to mankind since antiquity (1). Lubricants such as animal fat were used in axles of chariots to reduce friction and to avoid the excessive material-loss which is when dry surfaces rub together. Modern engineering approach has gone a step further and looked into the mechanisms of wear such as wear caused by adhesion, abrasion, oxidation, delaminating and melting.

The process of oil drilling is analogous to the process of metal drilling, albeit on a much larger scale. The tools used in this process are also of similar categories that include high speed steel (HSS), carbide (tungsten carbide), diamond (various grades of diamond) and coated tools. However, as compared with metal cutting, very few researchers have reported work done on the wear.

The type of wear process will, to a large extent, govern whether it can be modeled at reduced scale and whether accelerated testing is valid. As a rule, contacts involving both sliding friction and wear can be modeled at reduced scale and with accelerated testing. This is because it is usually possible to increase the loading conditions in the contact without changing the wear regime. While drilling drill bit condition cannot be determined and to check the drill bit condition it requires to pull out the drill bit from deep hole which requires a plenty of time, as time is very important factor in drilling process thus it adds to cost of drilling process so if we have wear behavior of drill bit it is easy to operate drilling operation similarly optimized conditions for drilling operation such as weight on drill bit and rpm of drill bit can be found which will help oil and gas exploration companies for efficient drilling process.

The research work in this dissertation has been presented in two parts. First part is related to the detailed drilling process of oil & gas wells equipment used in this process and drilling problems focusing on drill bit wear. The second part includes the experimentation for wear in drill and in rock sample and plotting results and selecting the desired range of operations.

CHAPTER 2: LIETRATURE REVIEW

2.1 Oil Well Drilling [1]

The well is created by drilling a hole 12 cm to 1 meter (5 in to 40 in) in diameter into the earth with a drilling rig that rotates a drill string with a bit attached. After the hole is drilled, sections of steel pipe (casing), slightly smaller in diameter than the borehole, are placed in the hole. Concrete may be placed between the outside of the casing and the borehole. The casing provides structural integrity to the newly drilled wellbore, in addition to isolating potentially dangerous high pressure zones from each other and from the surface.

With these zones safely isolated and the formation protected by the casing, the well can be drilled deeper (into potentially more-unstable and violent formations) with a smaller bit, and also cased with a smaller size casing. Modern wells often have two to five sets of subsequently smaller hole sizes drilled inside one another, each cemented with casing.

The drill bit, aided by the weight of thick walled pipes called "drill collars" above it, cuts into the rock. There are different types of drill bit; some cause the rock to disintegrate by compressive failure, while others shear slices off the rock as the bit turns.

Drilling fluid, a.k.a. "mud", is pumped down the inside of the drill pipe and exits at the drill bit. The principal components of drilling fluid are usually water and clay, but it also typically contains a complex mixture of fluids, solids and chemicals that must be carefully tailored to provide the correct physical and chemical characteristics required to safely drill the well. Particular functions of the drilling mud include cooling the bit, lifting rock cuttings to the surface, preventing destabilisation of the rock in the wellbore walls and overcoming the pressure of fluids inside the rock so that these fluids do not enter the wellbore. Some oil wells are drilled with air or foam as the drilling fluid.

Mud log in process, a common way to study the lithology when drilling oil wells, the generated rock "cuttings" are swept up by the drilling fluid as it circulates back to surface outside the drill pipe. The fluid then goes through "shakers" which strain the cuttings from the good fluid which is returned to the pit. Watching for abnormalities in the returning cuttings and monitoring pit volume or rate of returning fluid are imperative to catch "kicks" early. A "kick" is when the formation pressure at the depth of the bit is more than the hydrostatic head of the mud above, which if not controlled temporarily by closing the blowout preventers and ultimately by increasing the density of the drilling fluid would allow formation fluids and mud to come up through the annulus uncontrollably.

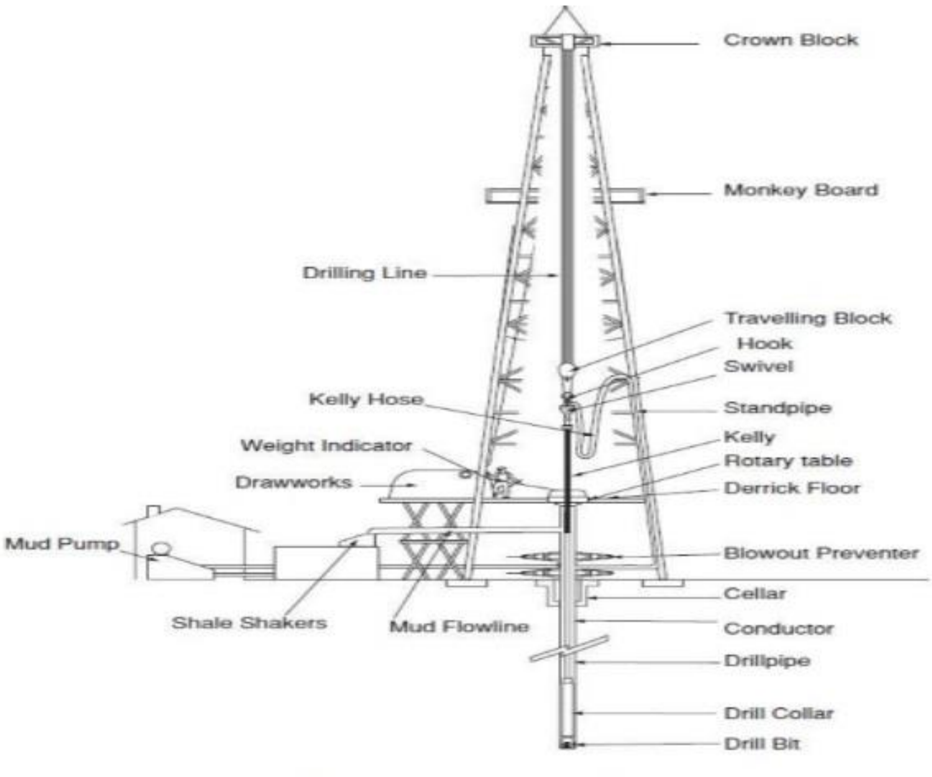

Figure 1: Drilling rig

The pipe or drill string to which the bit is attached is gradually lengthened as the well gets deeper by screwing in additional 30-foot (9 m) sections or "joints" of pipe under the Kelly or topdrive at the surface. This process is called making a connection, or "tripping". Joints can be combined for more efficient tripping when pulling out of the whole by creating stands of multiple joints. A conventional triple, for example, would pull pipe out of the hole three joints at a time and stack them in the derrick. Many modern rigs, called "super singles," trip pipe one at a time, laying it out on racks as they go.

This process is all facilitated by a drilling rig which contains all necessary equipment to circulate the drilling fluid, hoist and turn the pipe, control downhole, remove cuttings from the drilling fluid, and generate on-site power for these operations.

2.2 Drilling Problems

There are lots of problems involved with drilling of oil well but main problems which affect the drilling process are

1. Drill Bit Wear
2. Optimized Condition for drilling

2.2.1 Drill Bit Wear [2]

In materials science, wear is erosion or sideways displacement of material from its "derivative" and original position on a solid surface performed by the action of another surface.

Wear is related to interactions between surfaces and more specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface. The need for relative motion between two surfaces and initial mechanical contact between asperities is an important distinction between mechanical wear compared to other processes with similar outcomes.

Rock roller drill bits operate under the simultaneous action of static, dynamic, and alternating bending, impact and friction against ore and are subjected to abrasive and abrasive-impact wear in the presence of a flushing fluid at a high pressure.

A typical drill bit consists of three cones, a bearing body for each cone, and a bit body [3]. The cones are covered with small teeth, and during drilling are rotated on the bearing bodies, forcing the teeth to chip and gouge away the rock face at the bottom of the borehole.

It is found that when bits cut through soft and relatively non-abrasive rocks, such as clay and limestone, the teeth are worn slowly, and therefore the tools usually have extremely long drilling lives before they need to be replaced. However, when drilling abrasive rocks such as sandstones the teeth wear much more rapidly.As when teeth of drill bit are worn out their cutting efficiency decreases, it becomes less efficient and takes more time for drilling the hole therefore it needs to be changed which adds cost to drilling operation

Figure 2 Worn Tricon Drill Bit

because pulling out drill bit from deep hole requires time which adds to cost of drilling process. This problem can be solved by finding wear behavior of drill bits of different materials at different operating conditions so that we can predict when to change the drill bit without wasting our time.

2.2.2 Optimized Conditions for Drilling

Finding optimized conditions for drilling is also one of major problem in drilling process. Important conditions for drilling operation are

I. Weight on Drill Bit (WOB)
II. RPM of Drill Bit

Operating on most desired conditions helps with maximum rate of penetration in rock and minimum wear rate of drill bit therefore it is important to have knowledge about desired conditions for drilling because it helps in reducing the cost and time of drilling. This problem is solved by using wear testing in both rock sample and in drill bit wear in rock sample is referred as rate of penetration so tests can be conducted according to conditions as real field data and we can observe behavior of rock sample and drill bit and can select conditions of weight on drill bit and RPM with which drill bit is operating for maximum rate of penetration and minimum wear in drill bit.

2.3 Apparatus for Wear Measurement:

There are different types of apparatus to measure wear in metals some of these are discussed below

2.3.1 THE PIN ON DISK TRIBOMETER:

The tribometer [4] selected for development in this study is the standard pin-on-disk tribometer. It consists of a disc sample rotated at a given frequency, and a loaded pin brought into contact with the rotating disc. This contact brings about wear of both the contacting surfaces; this wear is recorded, and wear-mechanism maps are constructed based upon different experimental iterations with varying conditions. Some example uses of the pin-on-disk apparatus modified for different tribological investigations are as follows:

a) Magnetic recording media:

Experiments have been carried out for identifying the wear behavior of magnetic disk sliders, identifying the mechanisms of wear in these cases and thus different methods have been suggested for the improvement of performance and reliability of magnetic discs and magnetic disc sliders.

b) Thermo-chemical environment tribological investigations:

There are two such types of environmental tribometers:

- Tribometers which control the chemical environment of the contact interface.
- Tribometers which control both the chemical and thermal environment of the experimentation

Environmental tribometers which control the thermal and environmental aspects of the experiment are not very common because of the technological complexity involved.

c) Wear Test for locomotive industry:

Pin-on-disk tribometers have been used for performing different tests in the locomotive industry. These tests have been performed with the standard pin-on-disk apparatus placed in an environmental chamber for varying loads, humidity conditions, lubricants, lubrication conditions, and contact conditions.

2.3.2 OTHER TRIBOMETERS [7] :

Besides the pin-on-disk tribometers, some other tribometers used and developed for different tribological purposes are as follows:

i. Pin and V-blocks tribometer:

It consists of a standard pin and v-blocks arrangement suspended on a frame with two built-in transducers, one connected to screws that grip the V-blocks, for measuring the applied load P, and the other connected to the force sensor, via a flexible coupling, for measuring reaction torque T at the sliding contacts. Disc springs are fitted on each arm to adjust the stiffness of the loading system.

ii. **Ball-on-disk tribometer:**

It consists of a servo-driven main shaft supported by an air bearing, and upon the main shaft is bolted the tub-shaped (for the option of lubricant-use) support for the disc specimen, whereas three sample balls are glued to a sample-holder which is assembled onto the sample-holder disc allowing the arrangement to be able to trace three separate trajectories (and thus 3 different surface speeds), or a single circular track (averaging effect).

iii. **Mastication simulating tribometer:**

It consists of a sample holder, a counter-sample placed in a container of artificial saliva or any other lubricating liquid, the container being attached to an oscillating disc driven by a crank-rocker mechanism connected to a motor, and a pneumatic actuator which asserts the load through a spring loaded loading beam. The loading and friction forces are detected and monitored using strain gauge.

iv. **Polymer testing ring-on-disk tribometer:**

Tribometers used for testing wear mechanisms involved in the wear of polymeric materials require temperature monitoring to prevent the alteration of the co-efficient of friction due to melting of the polymers at raised temperatures. Therefore, a ring-on-disk tribometer with a water-cooling system was developed for studying the wear properties of polymers. This tribometer is equipped by instrumentation to detect and monitor the temperature at the contacting interface, and strain gauges for recording the loading and friction forces, and a quick data acquisition system.

v. **Linear Reciprocating tribometers:**

Linear reciprocating tribometers are used for simulating wear mechanisms arising during reciprocating motion. It employs the principle of a slider on a flat-disk, using proximity sensors and switches to reverse the direction of translation at each reversal point.

vi. **Three-pins on disk tribometer for friction drives:**

It consists of three axi-symmetrically placed pins and a rotor with a torsional brake, so that both normal and torsional loads can be applied: this tribometer simulates the function of an ultrasonic motor. It has been used to observe the stick-slip behavior in friction drives, and the wear arising thereof.

2.4 WEAR VOLUME DETERMINATION

Wear is determined by using ASTM G99-005 standard [5]. In which pin-on-disk and other tribometry tests are conducted and the amount of wear can be determined by measuring appropriate linear dimensions of both specimens before and after the test, or by weighing both specimens before and after the test.

2.3.3 Pin Wear:

There are three methods for determining the wear volumes:

a) Mass loss (gravimetric measurements):

It is unable to detect miniscule wear, such as that involved in friction tests of advanced wear-resistant materials.

b) Two-dimensional (2D) analysis based on the measurements of wear scar sizes:

It is valid only for flat wear scars, mostly used in cases in which the wear resistance of the disc specimen is higher than that of the slider, and the wear scar can safely be assumed to be flat.[6]

The wear volume is then implicitly expressed as,

$$V=1/3\pi h^2 * (3R_o-h)$$

Where; R_o is the sphere diameter, and the wear depth h is given:

$$h=R_o-\sqrt{R_o^2-d^2_{scar}/4}$$

Where; d_{scar} is the wear scar diameter

c) Three-dimensional (3D) analysis which involves multi-trace stylus profile-metry:

It is very accurate but also very tedious. The method has no closed-form analytical solution, and requires rigorous and complicated numerical integration.

The "single-trace wear volume analysis" method for accurately and quickly determining the wear volume in tribology tests is as follows

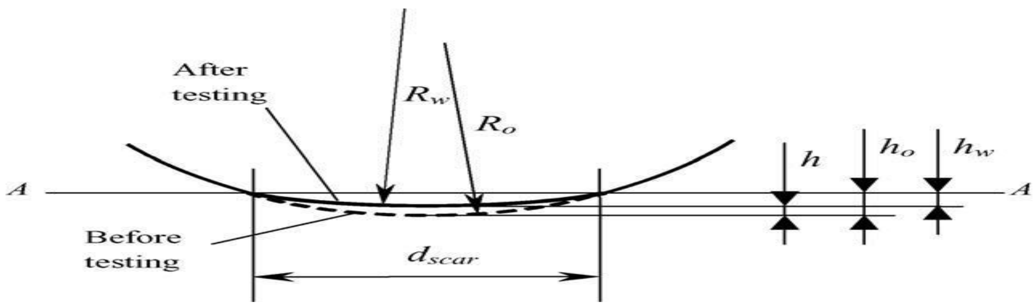

Figure 3: Side view representation of the worn tip of a spherically tipped slider

The single-trace method for spherically tipped sliders shows that for a system with relatively homogenous materials, surface conditions and distribution of wear debris, assuming a constant surface curvature, the wear cap can be approximately represented by a spherical surface, then the wear volume can be obtained from figure.

$$V=(Volume\ of\ original\ cap\ below\ AA)-(Volume\ of\ worn\ cap\ below\ AA)$$

Thus,

$$V= 1/3\ [h^2{}_o(3R_o-h_o)-h^2{}_w(3R_w-h_w)$$

$$h=h_o-h_w$$

Where,

$$h=Ro-\sqrt{}R^2{}_o-d^2{}_{scar}/4$$

$$h_W=R_w-\sqrt{}R^2{}_W-d^2{}_{scar}/4$$

Where the subscript "o" is for original and "W" is for worn**.**

2.3.4 Disk wear:

Generally, the disc-wear for pin-on-disc or ball-on-disc tests is calculated from the depth and the average cross-sectional area of the wear track. For cases in which direction reversal occurs at every stroke, the aforementioned method is no longer reliable when the magnitude of the wear track length is approximately the same width of the wear track.

The single trace method has a solution for this. A wear scar, of length L_s and width W, is divided into three regimes, a cylindrical surface sandwiched between two spherical surfaces of radius.

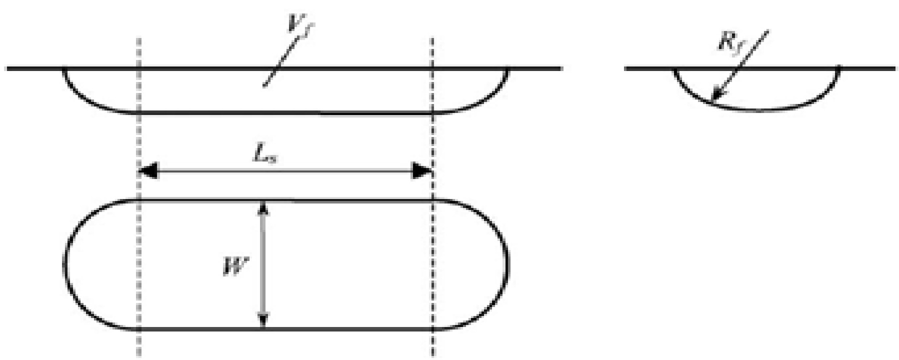

Figure 4: Wear scar on flat specimen against spherically tipped slider

The wear volume, according to the single trace method, is then given by:

$$V_f=[R^2{}_f\sin^{-1}(W/2Rf)-W/2(R_f-h_f)]+\pi/3h^2{}_f(3R_f-h_f)$$

$$h_f=R_f-\sqrt{R^2{}_f-W^2/4}$$

Although the single-trace analysis is such a reliable and time-saving technique, it is not employed in this work because profilometry technology was not easily available; furthermore, the accuracy of the wear volume measurement does not lie well within the scope of this work.

CHAPTER 3: DRILLING DATA:

To check the wear behavior of drill bit and rock sample on tribometer requires operating them on appropriate conditions. So it requires collecting real field data and translating this data into operating conditions for tribometer.

3.1 Data Collection from OGDCL

Drilling data is collected from OGDCL Pakistan, they provided with ZIN Baluchistan field data. Data was in form of daily drilling report which included size of drill bit, Weight on drill bit, RPM, rate of penetration and other information regarding rig.

3.1.1 Extraction of Useful Data:

From the drilling report provided by OGDCL useful data was extracted and drilling data is given below:

Formation: PIRKOH (Lime Stone)
Drill Bit Data:
Size = 17-1/2”
Make: VAREL
Bit No= RR
Bit type = HE1GJMRSV

Date	Weight on Bit (Tons)	RPM	Linear Velocity (m/s)	Meters(Drilled)	Hours	Rate of penetration	Simulation weight kg
24-4-13	0-2	65-70	3.0256-3.2585	23	18	1.23	0.833
25-04-13	1-2	60-65	2.793-3.0256	47	15	1.42	0.4165-0.833
26-04-13	2-3	65-70	3.0256-3.2585	58	09	1.38	0.833-1.2496

Table 1: PIRKOH (limestone)

Formation: PIRKOH (Lime Stone)
Drill Bit Data:
Size = 12-1/4”
Make: HUGHES
Bit type = RC127
Bit No: NB#1

Date	Weight on Bit (Tons)	RPM	Linear Velocity (m/s)	Meters(Drilled)	Hours	Rate of penetration (m/h)	Simulation weight kg
04-05-13	2-3	50	1.629	3	02	1.5	1.7-2.55
05-05-13	2-3	50.55	1.6469	67	25.5	2.62	1.7-2.55

Table 2 : PIRKOH (limestone)

Formation: SIRKI (Shale with thin bands of Clay-Clay stone)
Drill Bit Data:
Size = 12-1/4”
Make: HUGHES
Bit type = RC127
Bit No: NB#1

Date	Weight on Bit (Tons)	RPM	Linear Velocity (m/s)	Meters(Drilled)	Hours	Rate of penetration (m/h)	Simulation weight kg
06-05-13	4-5	60-65	1.9548-2.1177	162	44	3.62	3.4-4.25

Table 3 : SIRKI (Shale)

Formation: HABIB RAHI (Lime stone with thin bands of MARL)
Drill Bit Data:
Size = 12-1/4”
Make: HUGHES
Bit type = RC127
Bit No: NB#1

Date	Weight on Bit (Tons)	RPM	Linear Velocity (m/s)	Meters(Drilled)	Hours	Rate of penetration (m/h)	Simulation weight kg
07-05-13	4-5	60-65	1.9548-2.1177	257	65	3.95	3.4-4.25
08-05-13	4-5	60-65	1.9548-2.1177	331	85	3.89	3.4-4.25
09-05-13	4-5	60-65	1.9548-2.1177	392	105	3.73	3.4-4.25
10-05-13	4-5	60-65	1.9548-2.1177	410	114	3.59	3.4-4.25

Table 4 : HABIB RAHI (limestone)

Drill Bit changed:
Size = 12-1/4”
Make= HTC
Bit Type: RC137

Date	Weight on Bit (Tons)	RPM	Linear Velocity (m/s)	Meters(Drilled)	Hours	Rate of penetration (m/h)	Simulation weight kg
05-07-13	4-5	60-65	1.9548-2.1177	25	35	0.77	3.4-4.25
	Drill Bit has been changed to Bit No. RR#2						
06-07-13	12	60	1.9548	50	51.5	0.97	10.20
07-07-13	12	60	1.9548	54	55	0.97	10.20
08-07-13	10-12	90-100	2.9322-3.258	72	64	1.12	8.5-10.20
09-07-13	10-12	60	1.9548	78	70	1.12	8.5-10.20
	Drill Bit has been changed to Bit NB#3						
10-07-13	10-12	60	1.9548	60	18	3.33	8.5-10.20
11-07-13	10-12	60	1.9548	100	36	2.77	8.5-10.20
12-07-13	10-12	60	1.9548	157	55	2.855	8.5-10.20

Table 5 : HABIB RAHI (limestone)

Formation change:
GHAZIJ (Shale with traces of Marl & Lime stone)

Date	Weight on Bit (Tons)	RPM	Linear Velocity (m/s)	Meters(Drilled)	Hours	Rate of penetration (m/h)	Simulation weight kg
13-07-13	10-12	60	1.9548	168	58	2.89	8.5-10.20

Table 6 : GHAZIJ (shale)

Bit changed;
Bit Size = 8-1/2”
Make: VAREL
Bit type: HE3GMR

Date	Weight on Bit (Tons)	RPM	Linear Velocity (m/s)	Meters(Drilled)	Hours	Rate of penetration (m/h)	Simulation weight kg
20-07-13	5	60-65	1.3565-1.469	12	4	3	8.82
21-07-13	5-6	70-80	1.582-1.808	24	10	2.4	8.82-10.59
22-07-13	5-6	70-80	1.582-1.808	82	32	2.56	8.82-10.59
23-07-13	5-6	70-80	1.582-1.808	132	52	2.53	8.82-10.59
24-07-13	5-6	70-80	1.582-1.808	195	74	2.63	8.82-10.59
25-07-13	5-6	70-80	1.582-1.808	251	93.5	2.68	8.82-10.59

26-07-13	5-6	70-80	1.582-1.808	312	115	2.71	8.82-10.59
27-07-13	5-6	70-80	1.582-1.808	318	118	2.69	8.82-10.59
	Bit has been changed						
28-07-13	5-7	70-80	1.582-1.808	90	35	2.57	8.82-12.36
29-07-13	5-7	70-80	1.582-1.808	152	55	2.76	8.82-12.36
30-07-13	5-7	70-80	1.582-1.808	158	61	2.59	8.82-12.36

Table 7 :GHAZZIJ (shale)

Bit make = VAREL
Bit Type = CH3G
Bit No. RR#5
Formation change:
SUI MAIN (Lime stone)

Date	Weight on Bit (Tons)	RPM	Linear Velocity (m/s)	Meters(Drilled)	Hours	Rate of penetration (m/h)	Simulation weight kg
31-07-13	5-7	70-80	1.582-1.808	55	19.5	2.82	8.82-12.36
01-08-13	5-7	70-80	1.582-1.808	23	3.65		8.82-12.36

Table 8: SUI MAIN (limestone)

On the basis of above data we can select our rock specimen and drill bit material thus from above data rock samples are

- **LIMESTONE**
- **SHALE**

And drill bit used for drilling is made of

- **HSS DRILL BIT**

3.1.2 Translation of Data:

Data provided by OGDCL was according to real field data and weight on drill bit and RPM was according to size of drill bits used in drilling. Therefore there is need to translate real field conditions of weight on bit and RPM according to size of HSS pin used in experimentation.

I. **Translation of Weight on Bit:**

As weight on bit in real field conditions is in Tons of weight, while during experimentation we have limitations to use weight on drill bit. Therefore following is the method to translate real field data into experimentation conditions.

i. Change weight on drill bit of real field data into pressure. By using this formula

$$P=F/A$$

Here F=m*g, m=mass

A= area of drill bit = $\prod r^2$, r = radius of drill bit

Thus we have translated real field weight on drill bit into pressure now we can use this pressure and can find weight on drill bit in experimentation according to size of drill bit used in experimentation.

II. **Translation of RPM:**

In real field conditions RPM was given according to different sizes of drill bits and there is a need to change this RPM into linear velocity and when we have this linear velocity we can translate this speed into RPM according to size of drill bit used in experimentation.

$$\omega \text{ (radian per second)} = (\text{RPM} * 2\prod) / 60$$

$$\textbf{Linear Velocity} = v = r * \omega$$

Here r = radius of drill bit

Thus it gives the linear velocity and we can use it in our experimentation according to position of drill bit on rock sample

CHAPTER 4: EXPERIMENTATION:

Experimentation is an important phase of the project because all our research is cross checked by performing experiments.

4.1 Experimentation Apparatus:

1. **Tribometer:**

   Tribometer used for experimentation in PIN ON DISK TRIBOMETER

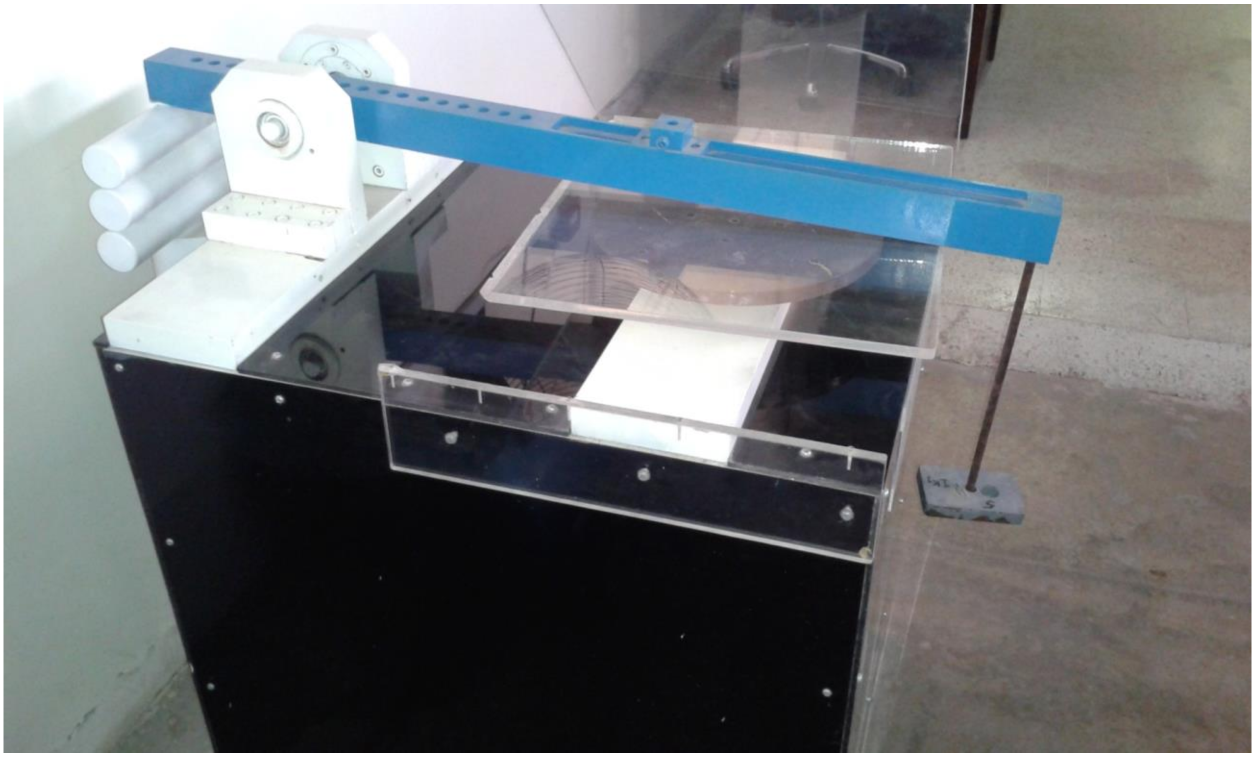

Figure 5 : Pin on Disk Tribometer

In this tribometer rock sample is placed on disk which rotates with motor and motor is controlled by a motor controller and drill bit material pin is fixed above on surface of rock sample and weight is attached to the hanger. Motor RPM is controlled by motor controller.

2. **Electronic Weighing Balance:**

   Mass loss of drill bit material pin and rock is measured by electronic weighing balance.

3. **Stop Watch:**

Time for running the motor was measured by using stop watch.

Figure 6: Stop Watch

4.2 Experimentation Materials:

Materials used in experimentation are given below:

- **Rock Samples:**

  Rock samples were procured from West rage Rawalpindi and rock samples used in experimentation are:

1. **Limestone**
2. **Shale**

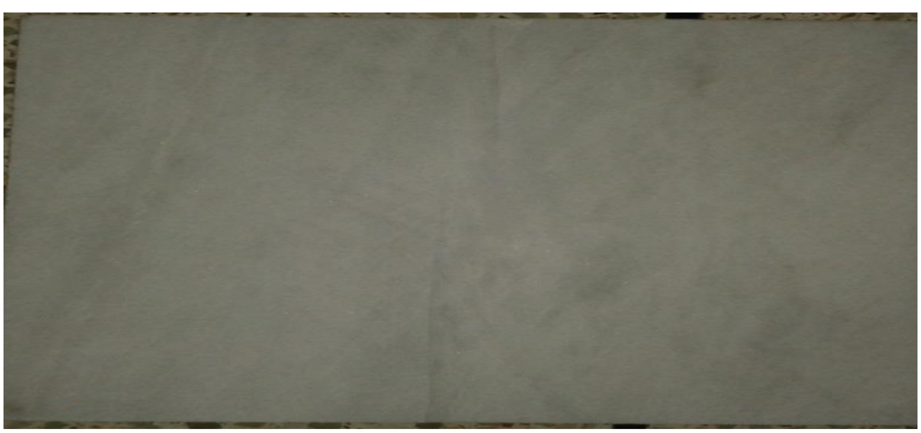

Figure 7: Limestone Rock Sample

Figure 8 : Shale rock Sample

- **Drill bit material pin:**

  As drill bits used in real field data are made of steel therefore high speed steel pin was procured from College Road Rawalpindi

Figure 9 : High Speed Steel(HSS) pin

Specification of HSS pin

Diameter = 9.525 mm

Length = 152.4 mm

4.3 Experimental Setup:

Rock sample is place on top of the disk which rotates with motor which is controlled by the motor controller and we can set rpm on motor controller drill bit material pin is fixed on top of the rock sample and weight on drill bit pin is applied by attaching weights on hanger.

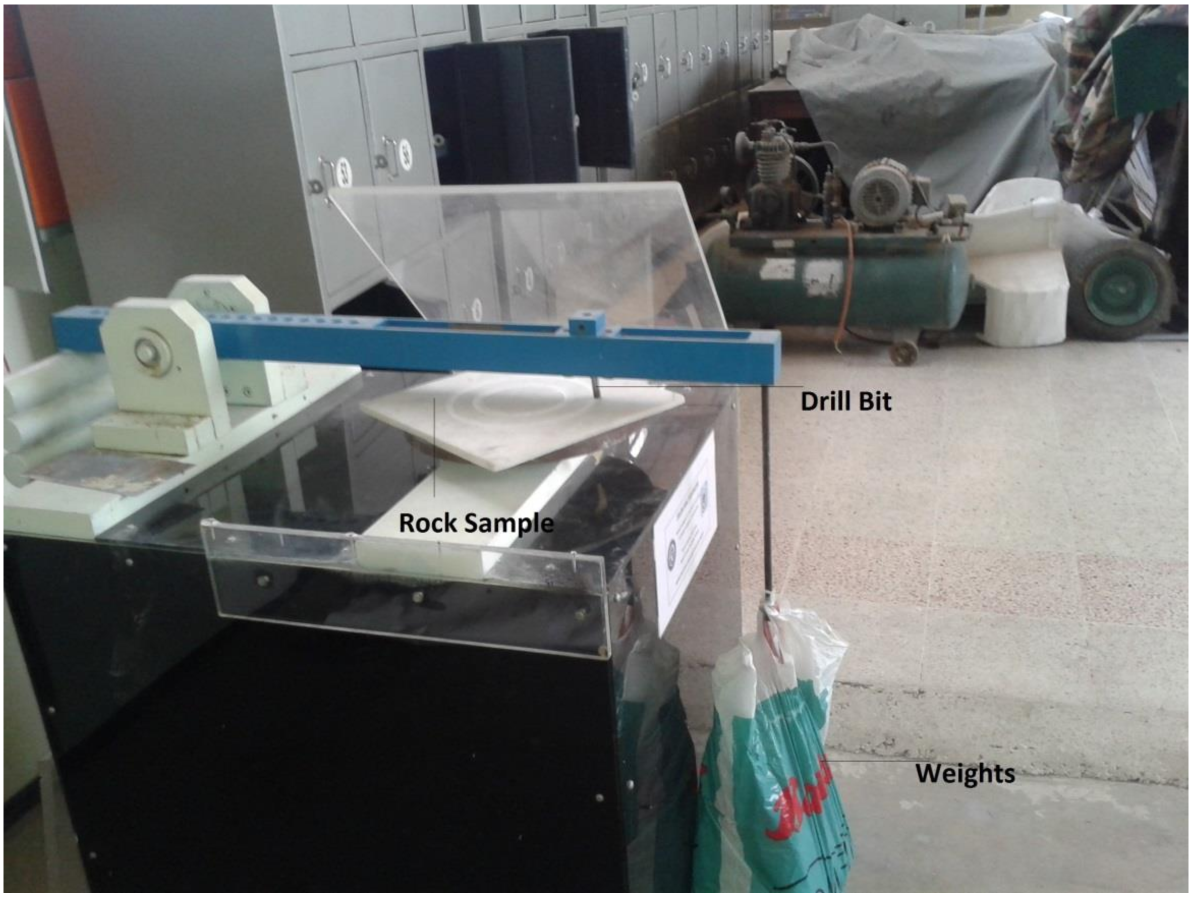

Figure 10: Experimentation Setup

CHAPTER 5: ANALYSIS AND RESULTS:

After completing the proper experimentation setup, experiments were started and according to experiments respective results were plotted.

5.1 Experimentation of Limestone with HSS pin:

In this experimentation setup we used limestone as rock sample and HSS pin as drill bit. Experimentation data for this experiment was derived from OGDCL drilling report and it is given in table:
All calculations are in accordance to pin diameter used in experimentation:
Pin dia = 9.525 mm

Linear Velocity(ms^{-1})	**Weight(g) on HSS pin**
1.582	8820
1.629	2550
1.808	12360
2.793	416.5
3.0256	833.3
3.2585	12496

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Table 9 : Real field Data for limestone

Above mentioned conditions were used in real field data. As aim is to find the most optimized conditions for drilling therefore there is need to select more points so that we can get more detailed map of results and can select optimized conditions.

So maximum and minimum points of linear velocity and weight are selected and divided limits into equal parts so now new conditions for experiments are given below.

Experimentation Conditions:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4	400
1.6	800
1.8	1200
2.0	2000
2.2	2500
2.4	4000
2.6	6000
2.8	8000
3.0	8800
3.2	10000
3.4	12000

Table 10 : Experimentation Data for limestone

Pin dia = 9.525 mm

Based on above conditions experiments were conducted by fixing one quantity like linear velocity and changing weight on bit and so on. Overall sixty (60) experiments were conducted for limestone rock sample.

5.1.1 Wear Results for Limestone with HSS pin:

First of all experiments were conducted to check whether wear behavior of rock sample gives a linear relationship or not so that we can fix a time to conduct our experiment. Therefore three experiments at three different times were conducted and change in mass of rock was recorded.

Conditions for experiments are:

Linear Velocity = 1.4 ms^{-1}

Weight on pin = 2000 kg

Time = 3, 6, 9

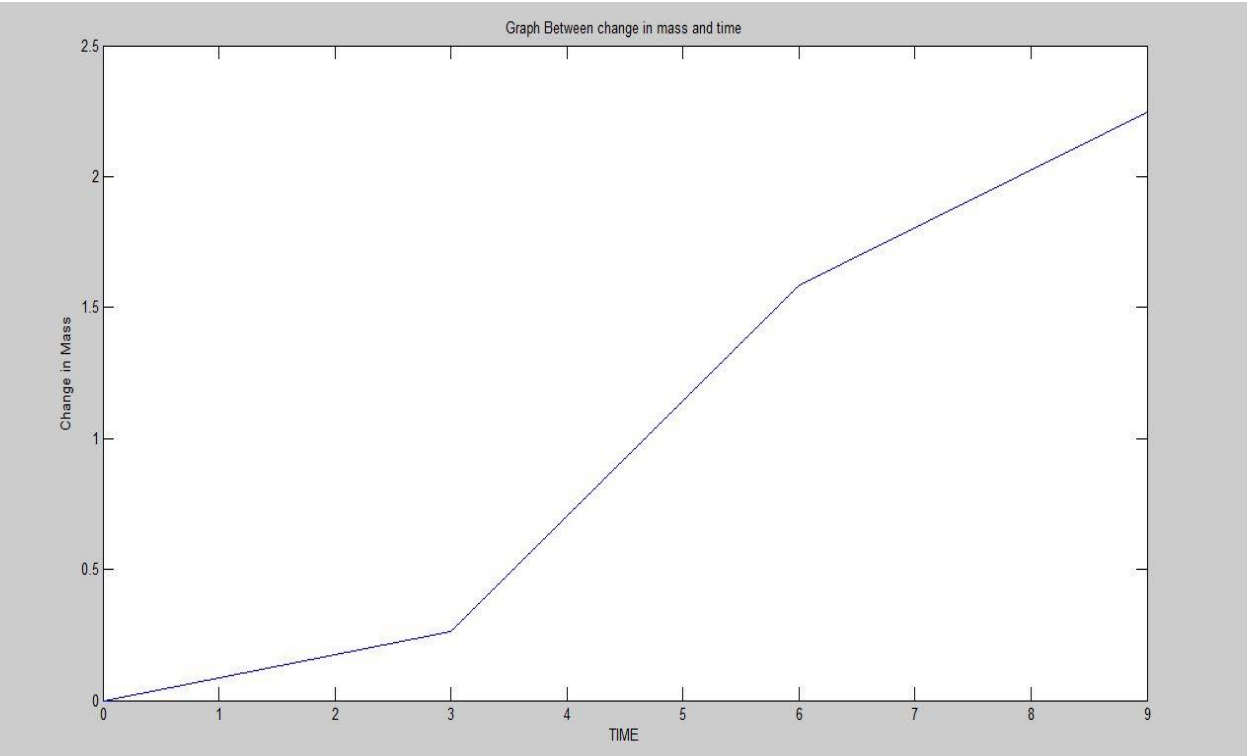


Figure 11 : Wear behavior of limestone with time

As trend is linear so experiments can be conducted for any suitable time. And in the end we can make them uniform by converting change in mass into Change in mass per minute.

Wear in HSS pin is also recorded to check the linear behavior of wear in pin.

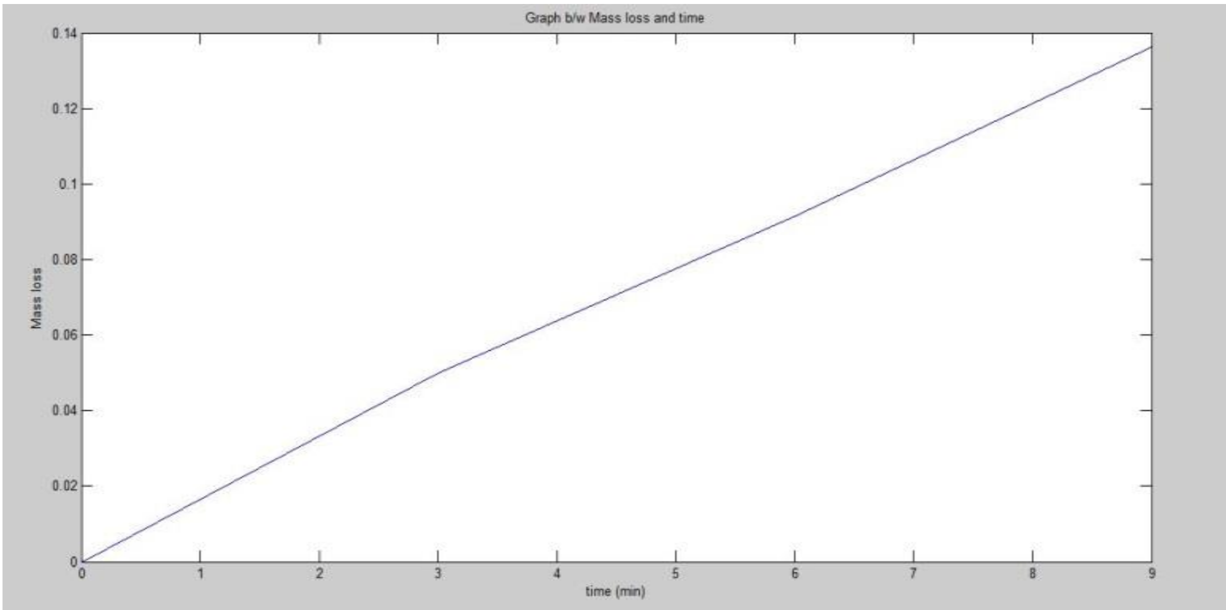


Figure 12 : Wear behavior of HSS pin with time

As graphs shows that wear in pin also changes linearly.

All results for limestone rock sample with HSS pin are given below:

Wear Rate (g/min) in Limestone with HSS pin

Linear Velocity (ms^{-1})		1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4
Weight (g)	400	0.066	0.066	0.1002	0.1002	0.1002	0.132	0.132	0.132	0.1662	0.1662	0.132
	800	0.1002	0.1002	0.132	0.1662	0.1662	0.198	0.198	0.198	0.1662	0.1662	0.1662
	1200	0.132	0.132	0.1662	0.198	0.198	0.198	0.2328	0.2328	0.2328	0.198	0.198
	2000	0.264	0.33	0.33	0.198	0.1662	0.1662	0.1320	0.1320	0.1320	0.1320	0.1320
	2500	0.264	0.33	0.33	0.228	0.18	0.18	0.18	0.18	0.1662	0.18	0.1662
	4000	0.1662	0.3	0.3	0.198	0.198	0.3	0.3	0.264	0.4998	0.198	0.1662
	6000	0.3	0.4998	1.03	0.4998	0.3	0.1662	0.1332	0.1332	0.1332	0.1332	0.1662
	8000	0.75	0.9	1.002	1.26	1.296	2.7498	1.7496	1.0062	1.278	0.4998	0.4998
	8800	0.75	0.6	1.002	1.30	1.30	1.98	1.7496	1.002	1.2	0.4998	0.4998
	10000	0.75	0.75	1.30	0.75	0.75	0.6	0.75	0.6	0.4998	0.4998	0.25
	12000	1.2	1.30	1.9002	1.278	1.278	1.278	0.75	0.75	0.4998	0.4998	0.3

Table 11 : Wear data for limestone with HSS pin

5.1.2 Wear plot for Limestone with HSS pin:

All points of wear are plotted against linear velocity and weight on bit and wear map for limestone is constructed in MATLAB.

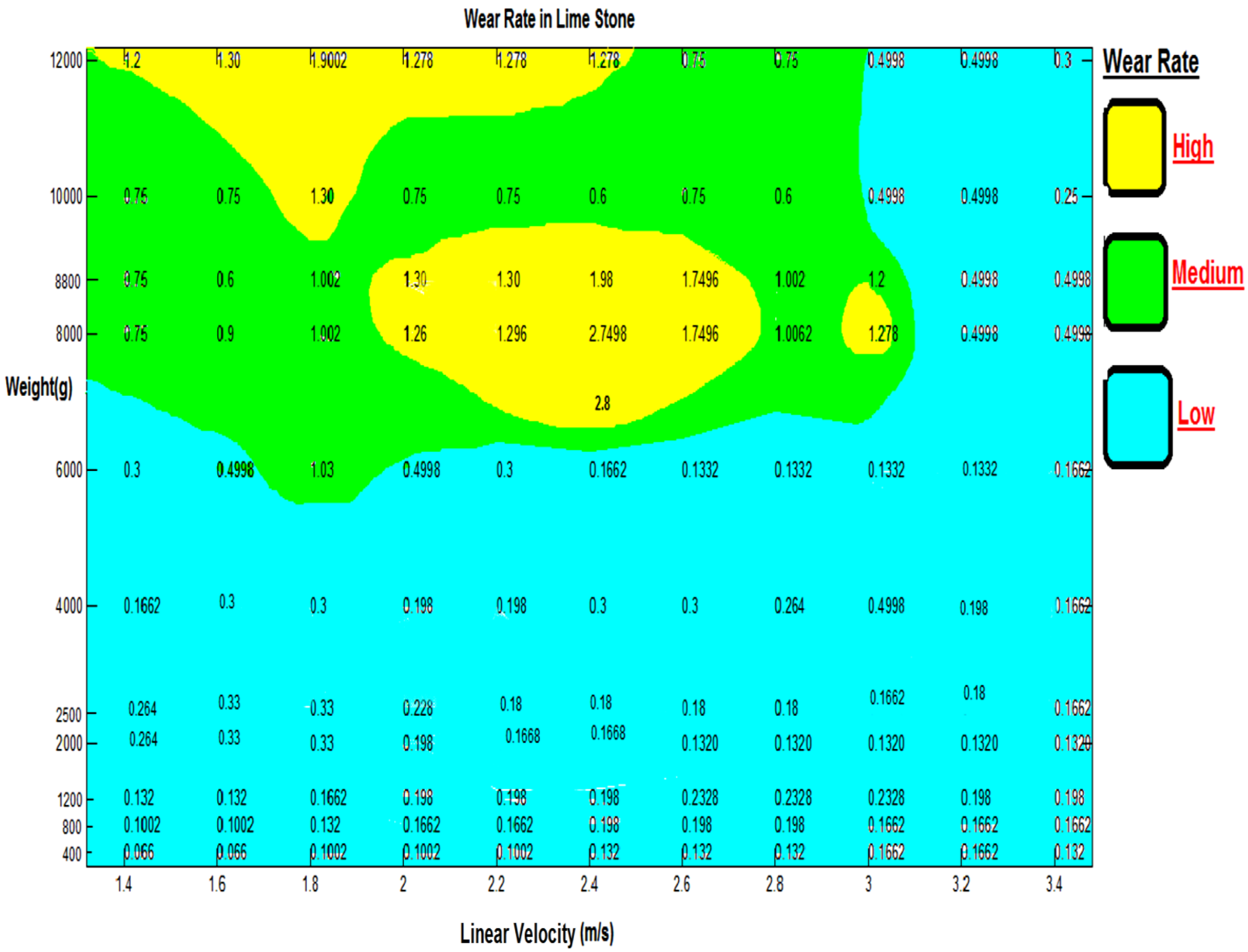


Figure 13 : Wear map of Limestone with HSS pin

On the basis of wear results ranges for wear are selected and with the help of these ranges regions for maximum minimum and medium wear in limestone are defined. As wear in rock sample is referred as rate of penetration therefore now we have wear plot and regions for maximum medium and minimum we can select our operating conditions of linear velocity and weight. As maximum rate of penetration is related with less time for drilling therefore the ranges of linear velocity and weight on bit for maximum rate of penetration are our desired conditions.

On basis of results we can select approximate ranges of linear velocity and weight on drill bit for wear in lime stone and wear in drill bit.

Approximate Conditions for High Rate of penetration for Limestone:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-2.4	11000-12000
1.7-2	10000-12000
2-2.7	8000-9000
2.9-3.1	8000-8800

Table 12 : Conditions for High RoP for limestone

Approximate Conditions for Medium Rate of penetration for Limestone:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-1.6	10000-11000
1.4-1.6	8000-9500
1.6-1.9	8000-9500
2.1-2.8	10000-11500
2.8-2.9	7000-10000
1.9-2.2	6500-8000
3-3.2	8000-8800

Table 13 : Conditions for medium RoP for limestone

Approximate Conditions for Minimum Rate of penetration for Limestone:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-2	400-5500
2-3.4	400-6000
3.2-3.4	6000-12000
2.9-3.1	10000-12000
2.9-3.1	6000-6500

Table 14: Conditions for minimum RoP for limestone

5.1.3 Wear results for High Speed Steel (HSS) with limestone:

Wear results for HSS pin with limestone are given below:

Wear Rate (g/min) in HSS pin with limestone

Linear Velocity (ms^{-1})		1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4
Weight (g)	400	0.66	0.66	0.66	1.0	1.0	1.0	10.	1.32	1.32	1.32	1.66
	800	1.0	1.0	1.0	1.32	1.66	1.66	1.98	1.98	2.33	2.33	2.33
	1200	1.98	1.98	1.66	1.98	2.33	2.33	2.33	2.66	2.66	2.66	3.0
	2000	16.62	16.62	16.62	16.62	16.62	16.62	19.8	19.8	23.28	19.8	23.28
	2500	16.62	16.62	16.62	16.62	16.63	17.28	19.98	23.28	23.84	23.84	23.84
	4000	16.62	16.62	16.62	16.62	16.62	16.99	23.66	23.28	23.28	23.66	23.66
	6000	16.99	16.99	16.99	16.99	16.99	19.8	23.66	23.66	23.66	26.4	26.4
	8000	19.8	19.8	19.8	19.8	25.5	25.5	25.5	25.5	30	30	30
	8800	19.8	19.8	19.8	25.0	25.5	25.5	25.5	30.0	30.0	35.0	35.0
	10000	33.0	33.0	33.0	33.0	35.0	35.0	40.2	40.2	45.0	45.0	50.0
	12000	40.0	40.0	41.60	45.0	45.0	45.0	45.0	50.0	50.0	55.0	60.0

x 10^{-3}

Table 15 : Wear data for HSS pin with limestone

5.1.4 Wear Plot for HSS pin with Limestone:

On the basis of above wear results of HSS pin, wear map can be constructed. Wear map is constructed using MATLAB.

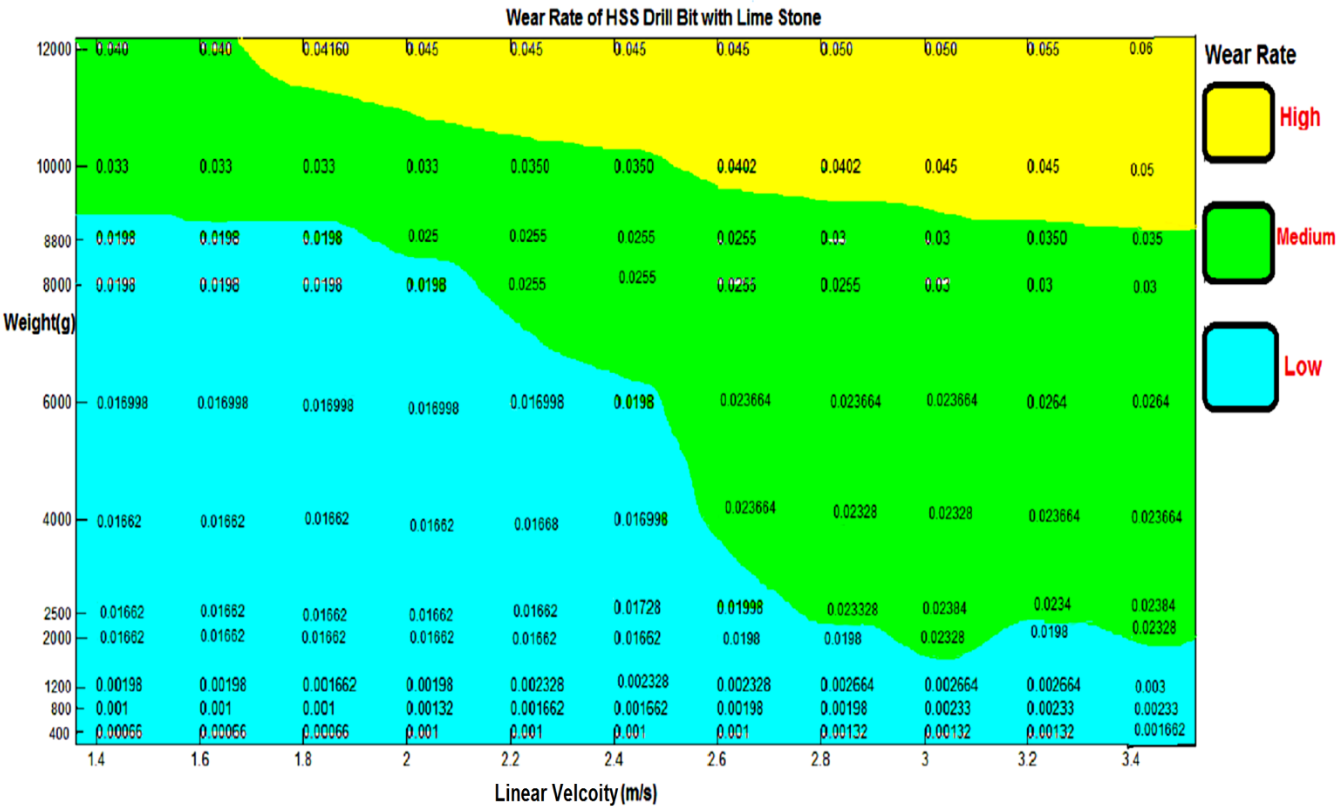


Figure 14 : Wear map of HSS pin with Limestone

So wear results are plotted in accordance to linear velocity and weight on bit and we have now regions for maximum medium and minimum wear in drill bit pin. As maximum wear in drill bit is worst condition for drilling therefore conditions of linear velocity and weight on drill bit in this region should be avoided.

Approximate Conditions Maximum wear rate in HSS pin:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-3.4	10000-12000
3-3.4	8000-10000

Table 16 : conditions for Maximum wear in HSS pin with limestone

Approximate Conditions Medium wear rate in HSS pin:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-2.4	8000-9500
1.4-2.4	6800-8000
2.5-3.4	6800-8000
2.5-3.4	2000-6800
2.4-2.5	8000-9500
2.4-2.5	5000-6800

Table 17 : conditions for Medium wear in HSS pin with limestone

Approximate Conditions Minimum wear rate in HSS pin:

Linear Velocity (ms^{-1})	Weight(g)
1.4-2.3	400-6000
2.3-2.4	400-4000
1.4-3.4	400-2000

Table 18: conditions for Minimum wear in HSS pin with limestone

But there is always a compromise between bit wear and rate of penetration so it is upon operator which factor has most importance.

5.2 Experimentation of Shale with HSS pin:

In this experimentation setup we used Shale as rock sample and HSS pin as drill bit. Experimentation data for this experiment was derived from OGDCL drilling report and it is given in table:
All calculations are in accordance to pin diameter used in experimentation:

Linear Velocity (ms^{-1})	Weight(g) on Bit
1.9548	8502
1.9548	10203
1.469	8820
1.582	8820
1.808	10590
1.808	12.36

Table 19 : Real field data for shale

As above mentioned data was derived from real field data, so this data is not enough to analysis behavior of shale and HSS pin. Therefore I selected the range of linear velocity and weight on bit to analyze all points. So new data for experimentation is given below:

Experimentation Conditions:

Linear Velocity (ms^{-1})	Weight(g) on Bit
1.4	8000
1.6	9000
1.8	10000
2.0	11000
	12000

Table 20 : Experimentation data for shale

Based on above conditions experiments were conducted by fixing one quantity like linear velocity and changing weight on bit and so on. Overall 20 experiments were conducted for shale rock sample.

5.2.1 Wear Results for Shale with HSS pin:

Similarly as limestone rock we have to check the trend for shale rock sample whether it gives a linear behavior or not. Therefore three (3) experiments were conducted for three different times.

Conditions for these experiments:

Weight on bit = 8000 g

Speed = 1.6 ms^{-1}

Time = 3, 9, 6

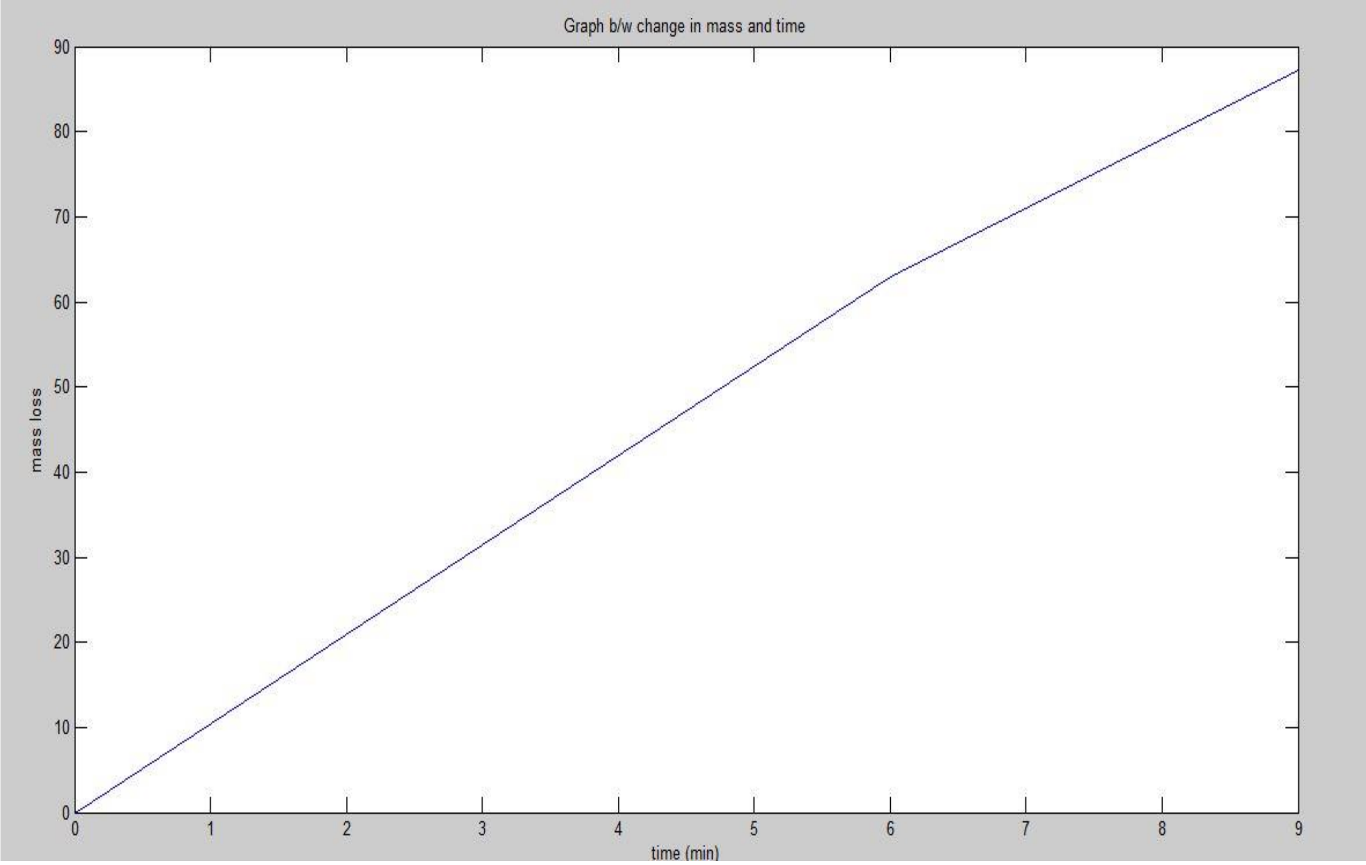


Figure 15: Graph b/w change in mass and time for shale

Thus graph shows that change in mass of rock sample has linear relationship with time. Therefore we can select a suitable time to conduct experiments. And in the end we can make them uniform by converting change in mass in to Change in mass per minute.

Wear behavior of HSS pin is also recorded:

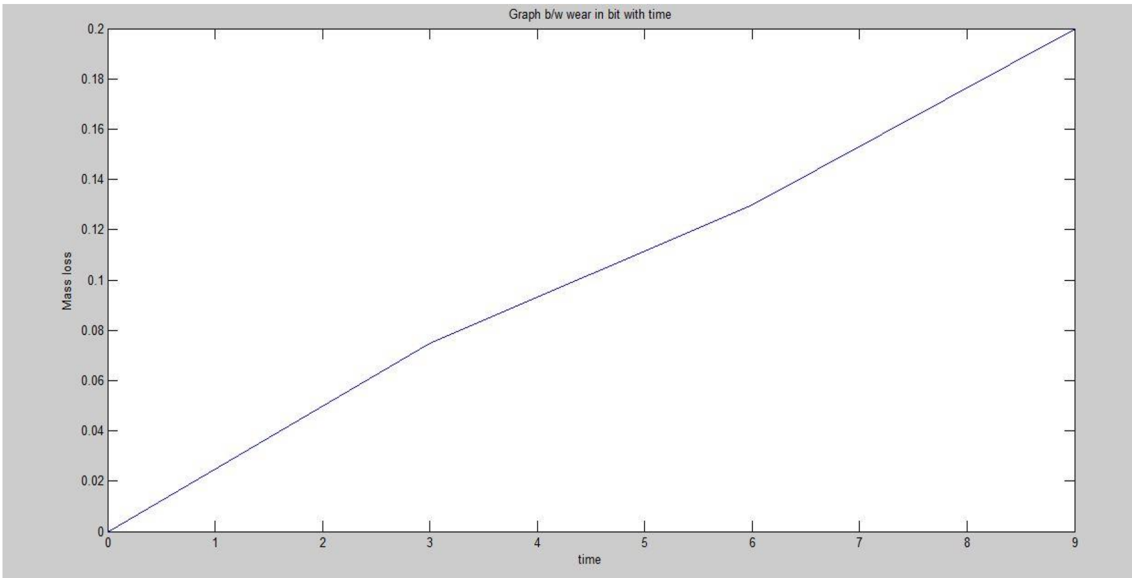


Figure 16 : Wear Behavior of HSS pin with time

Graph shows that wear in pin have also linear behavior with time.

All results for limestone rock sample with HSS pin are given below:

Wear Rate in Shale (g/min):

Linear Velocity (ms-1)		1.4	1.6	1.8	2
Weight (g)	8000	7.98	10.5	9.4998	10.5
	9000	10.998	12.4998	13.98	12
	10000	9.048	11.7	16.5	14.50
	11000	13.896	13.0	11.898	8.5
	12000	14.20	18.198	24.50	21

Table 21: Wear data for shale

5.2.2 Wear plot for Shale with HSS pin:

All points of wear are plotted against linear velocity and weight on bit and wear map for shale constructed in MATLAB.

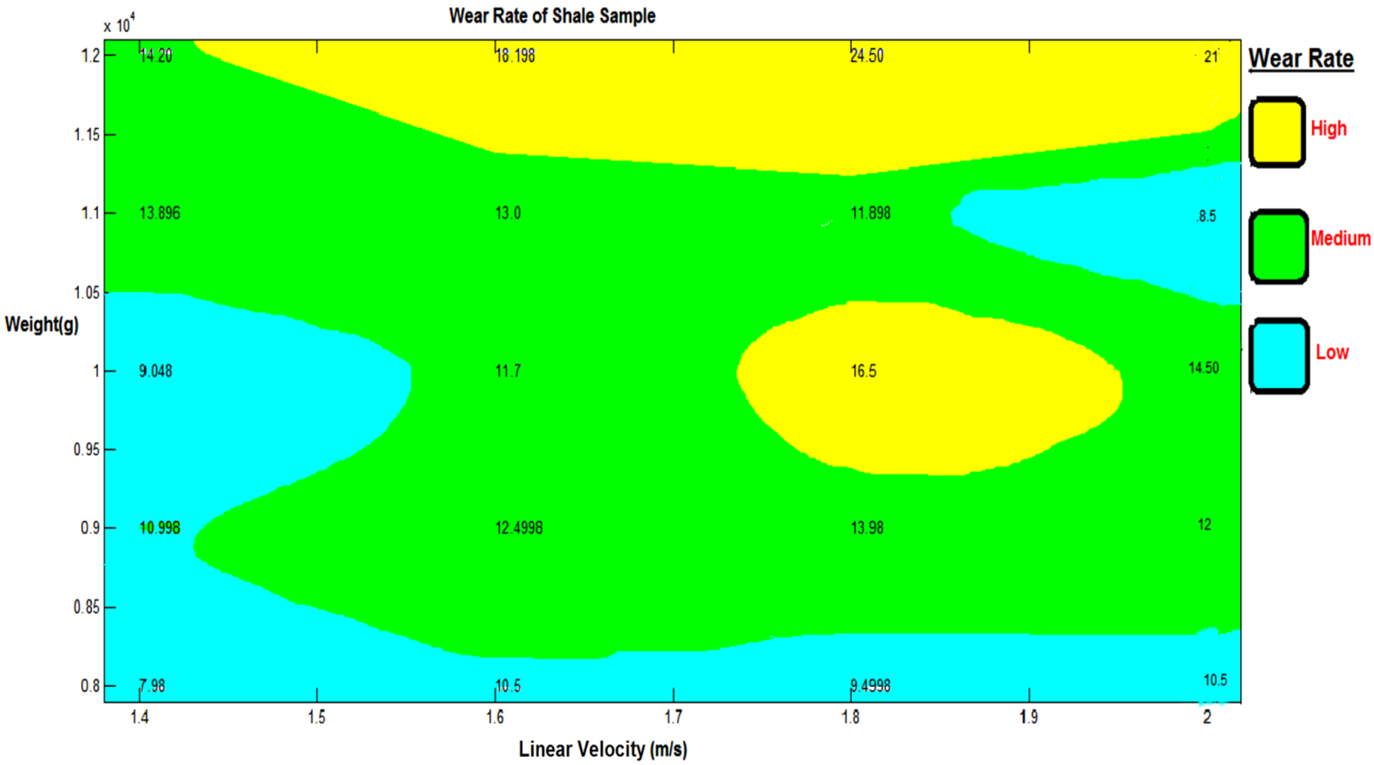


Figure 17 : Wear map of Shale with HSS pin

As wear in rock sample is referred as rate of penetration thus on basis of wear plot we can find conditions of linear velocity and weight on bit for maximum rate of penetration. So conditions for maximum medium and minimum rate of penetration can be selected from wear map for shale rock.

Approximate Conditions for Maximum Rate of penetration for Shale:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.45-2	11100-12000
1.75-1.95	9500-10500

Table 22 : Conditions for maximum RoP for Shale with HSS pin

Approximate Conditions for Medium Rate of penetration for Shale:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-1.85	10500-11100
1.55-1.75	8250-10500
1.75-1.95	8250-9300
1.95-2	8250-10500

Table 23 : Conditions for medium RoP for Shale with HSS pin

Approximate Conditions for Minimum Rate of penetration for Shale:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-1.55	9300-10500
1.4-2	8000-8300
1.85-2	11300-11100

Table 24: Conditions for minimum RoP for Shale with HSS pin

5.2.3 Wear results for High Speed Steel (HSS) with Shale:

Wear results for HSS pin with limestone are given below:

Wear Rate (g/min) in HSS pin with limestone

Linear Velocity (ms-1)		1.4	1.6	1.8	2
Weight (g)	8000	0.040	0.050	0.050	0.0667
	9000	0.040	0.050	0.0554	0.0667
	10000	0.06	0.06	0.07002	0.0798
	11000	0.066	0.07002	0.075	0.0798
	12000	0.075	0.0798	0.0798	0.09

Table 25: wear data for HSS pin with limestone

5.2.4 Wear plot for High Speed Steel (HSS) with Shale:

All points of wear are plotted against linear velocity and weight on bit and wear map for HSS pin was constructed in MATLAB.

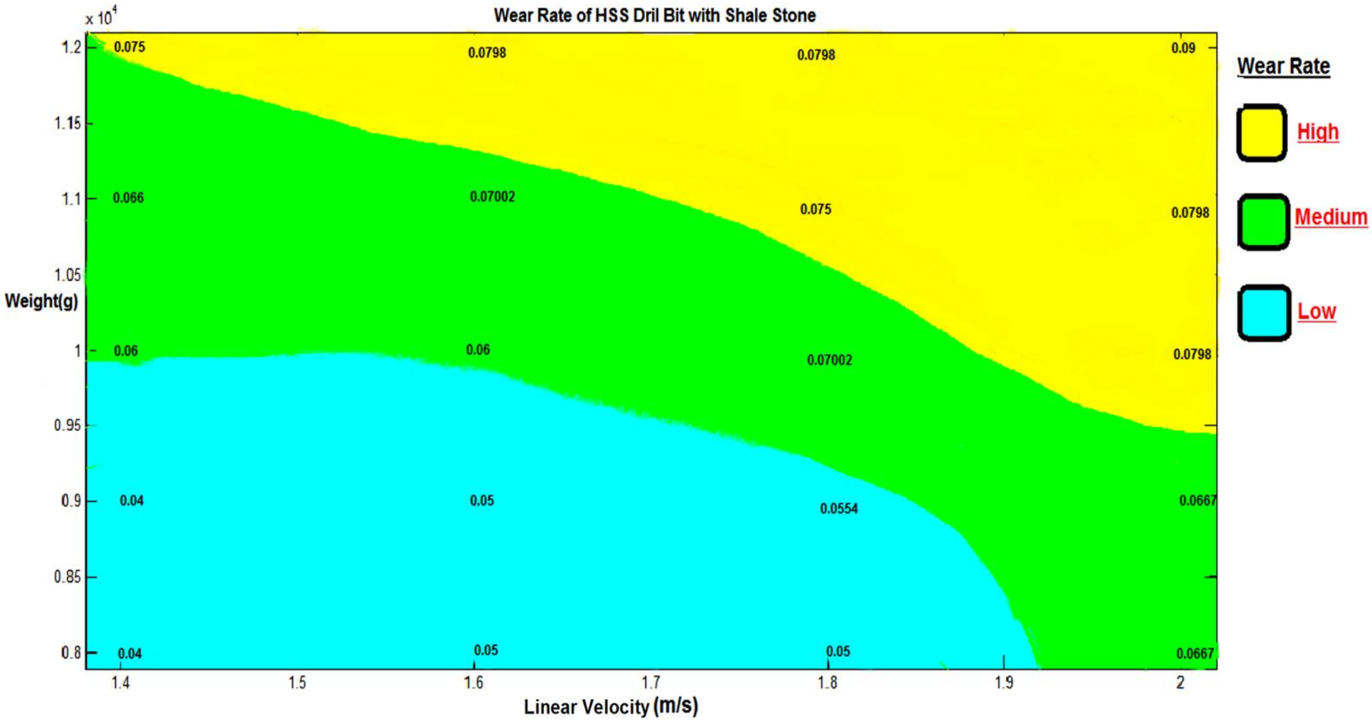


Figure 18 : Wear map of HSS pin with Shale

<u>Approximate Conditions for Maximum wear rate for HSS pin:</u>

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-2	**11500-12000**
1.75-1.8	10800-11500
1.85-2	9500-11500

Table 26: conditions for Maximum wear in HSS with shale

Approximate Conditions for Medium wear rate for HSS pin:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-1.58	10000-11400
1.58-1.75	10000-11000
1.92-2	8000-9500
1.75-1.92	9500-10000

Table 27: conditions for Medium wear in HSS with shale

Approximate Conditions for Minimum wear rate for HSS pin:

Linear Velocity (ms^{-1})	Weight(g) on HSS pin
1.4-1.65	8000-10000
1.4-1.8	8000-9250
1.4-1.88	8000-8500

Table 28: conditions for Minimum wear in HSS with shale

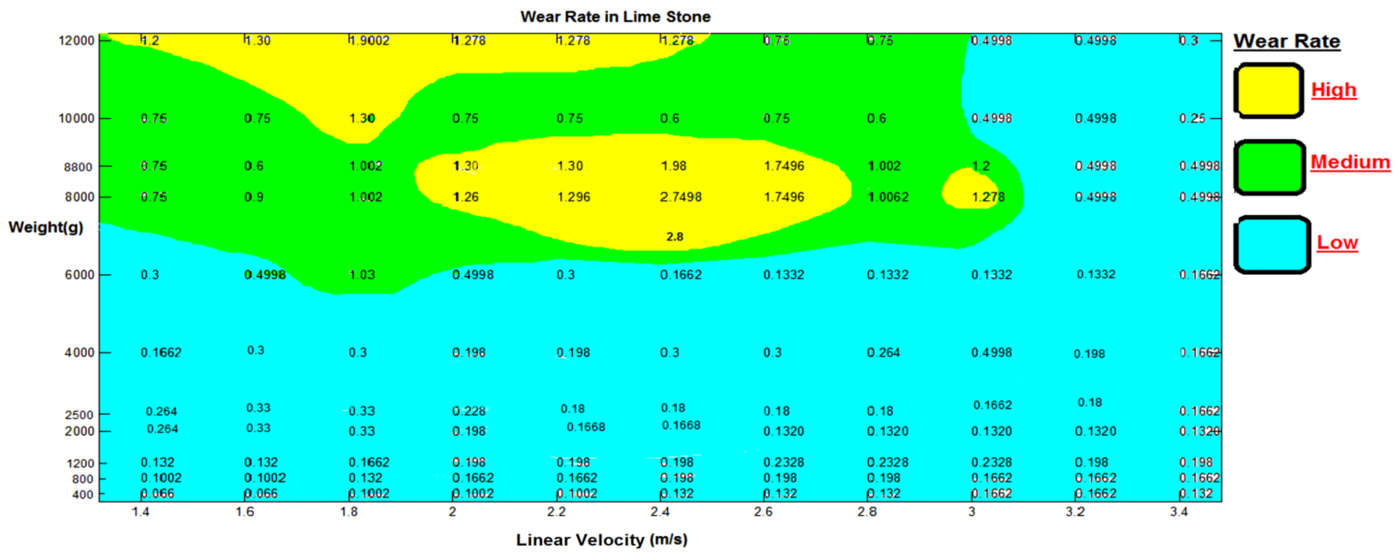
Thus on basis of wear map we can predict wear in drill bit as wear in drill bit is worst condition in drilling operation therefore region of maximum wear in drill bit is avoided so range of linear velocity and weight on drill bit should be avoided.

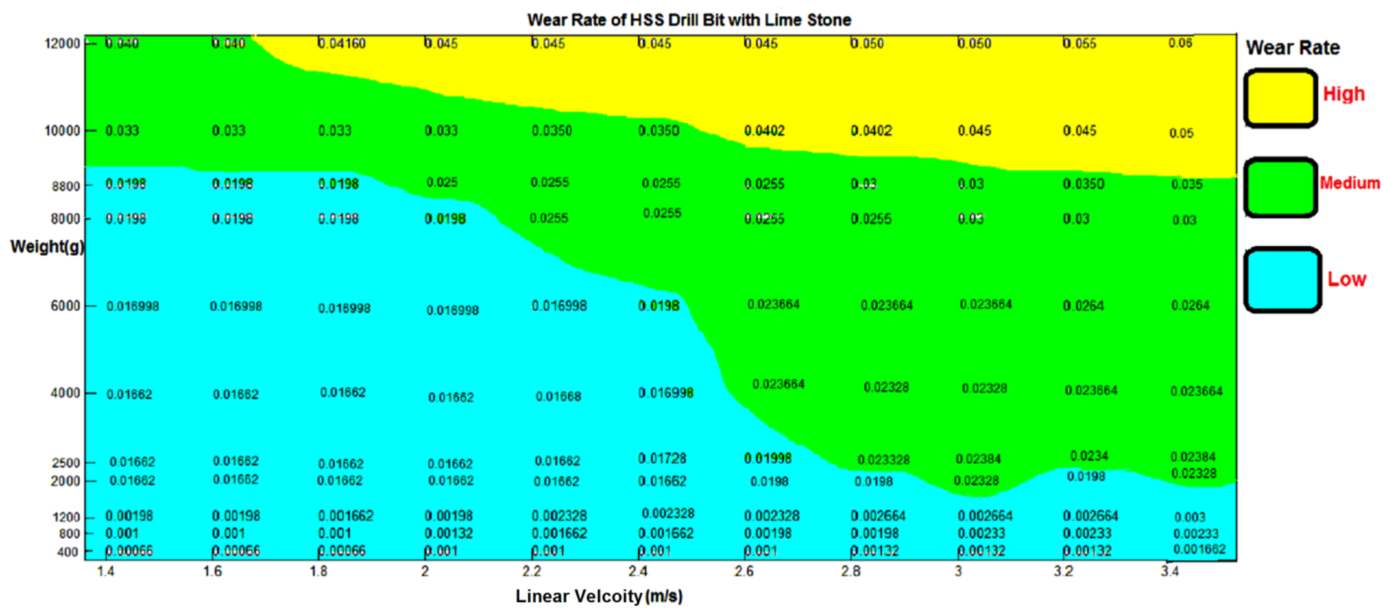
CHAPTER 6: OPTIMIZATION FOR ROCK SAMPLES & DRILL BIT

6.1 Optimization for Limestone & HSS pin:

As in drilling operations desired conditions are maximum rate of penetration and minimum wear in drill bit. Based on experimental results and wear maps of limestone and HSS pin we can select conditions of linear velocity and weight on bit to get our desired conditions of maximum rate of penetration and minimum wear rate in drill bit.

We can select linear velocity and weight on bit by comparing two wear maps.





Thus comparing these two wear maps we can select ranges of linear velocity and weight on drill bit. If we compare these two maps we can see that as wear in limestone increases similarly wear in drill bit also increases therefore it is compromise between rate of penetration and wear in HSS pin. So we select maximum wear in limestone and medium range of drill bit material pin wear. These conditions are suitable if time is important factor and we want to drill well in most possible less time. So conditions for linear velocity and weight on drill bit are:

Linear Velocity (ms^{-1})	**Weight(g) on HSS pin**
1.9-2.7	6500-9500

Table 29: Optimized Conditions for limestone with HSS pin for maximum RoP

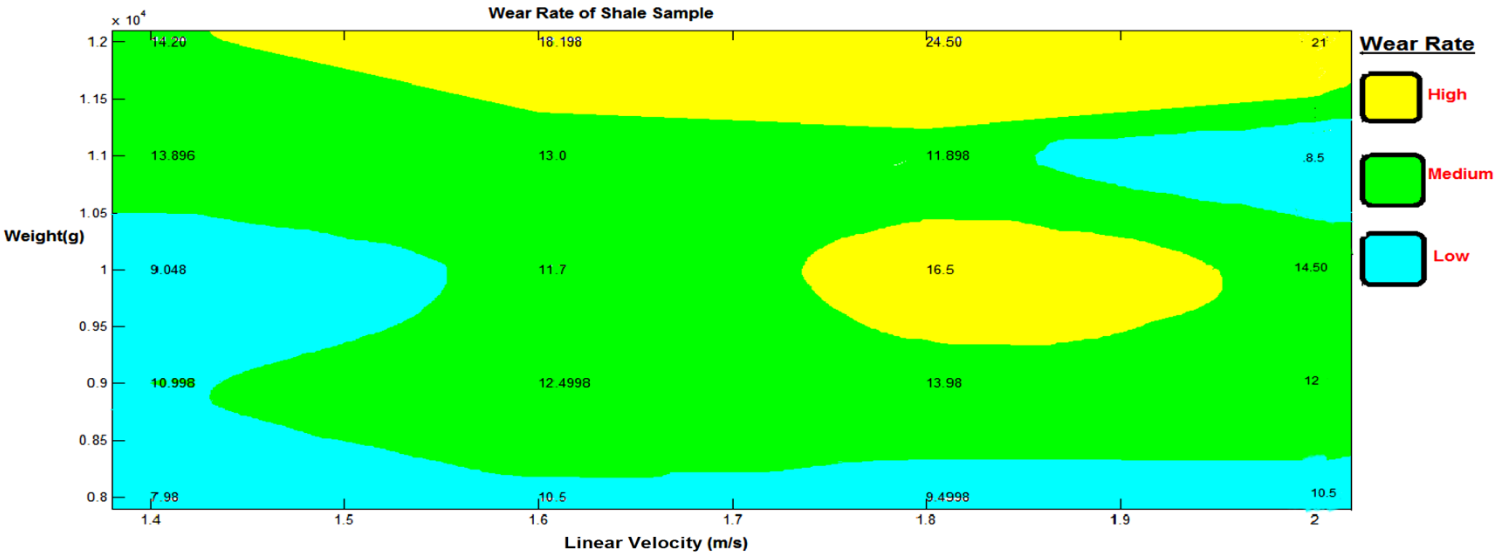
Similarly if cost and tool life are important then we should select conditions of linear velocity and weight on bit for medium range of rock wear and minimum wear in tool.
Conditions for Medium range of rock wear & Minimum Wear of tool:

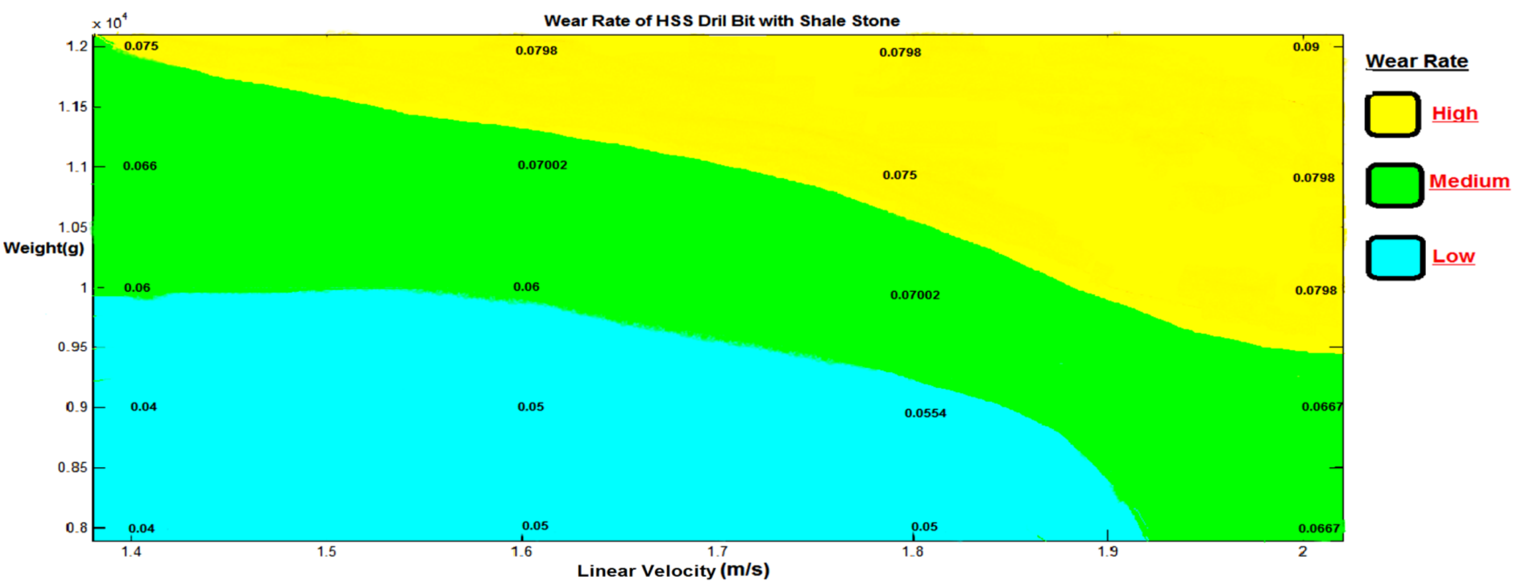
Linear Velocity (ms^{-1})	**Weight(g) on HSS pin**
1.4-1.9	6000-8200

Table 30 : Optimized Conditions for limestone with HSS pin for minimum wear in tool

6.2 Optimization for Shale & HSS pin:

As in drilling operations desired conditions are maximum rate of penetration and minimum wear in drill bit. Based on experimental results and wear maps of shale and HSS pin we can select conditions of linear velocity and weight on bit to get our desired conditions of maximum rate of penetration and minimum wear rate in drill bit.





If time is important and we want to drill well in less time than conditions for maximum rate of penetration are selected. As above mentioned wear maps show that region for maximum wear in rock corresponds to medium range of wear in tool. So conditions for maximum rate of penetration with medium range of wear in tool are:

Linear Velocity (ms^{-1})	**Weight(g) on HSS pin**
1.73-1.95	9400-10500

Table 31: Optimized conditions for shale with HSS pin for maximum RoP

Similarly if tool life and cost is major factor and we want to keep our tool save then we select conditions where tool wear is minimum therefore comparing wear maps we see that minimum wear in tool corresponds to medium range of wear in rock. So conditions for minimum wear in tool and medium range of wear in rock.

Linear Velocity (ms^{-1})	**Weight(g) on HSS pin**
1.5-1.9	8300-9300
1.55-1.75	9300-10000

Table 32 : Optimized conditions for shale with HSS pin for minimum tool wear

CONCLUSION AND RECOMMENDATIONS

Purpose of this research was to solve the petroleum drilling problems. Thus with the help of results drilling problem such as Drill bit wear and finding conditions for maximum rate of penetration can be solved as we have wear maps for rock samples of limestone and shale now we can see which conditions of linear velocity and weight on bit give maximum rate of penetration to reduce time for drilling. It will also save money similarly we have wear maps for HSS pin from which we can select the conditions for minimum wear in drill bit. It also helps to save the money and time because operating drill bit on most optimized conditions will drill the oil & gas well in less time and money. As there is always a compromise between rate of penetration and wear in bit so it depends upon factor either time is important or cost and life of tool is important therefore operating optimized condition give maximum results.

Using this technology we can find wear maps of other rocks and drill bits that are used in petroleum industry. As this method is determination of wear in dry conditions but in real conditions they use lubricants so there is scope of finding wear in wet conditions and find wear maps of both rocks and drill bit. So it will give us more realistic and accurate results. Similarly there is scope of finding a way to determine wear in drill bit while in operation because so far this is not possible and a method or technique should be devised to determine wear in tool while it is under the hole. It will help to save time because we will have accurate time of changing the tool which will ultimately save cost.

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[5] **ASTM.** Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus. *Annual Book of ASTM Standards.* 2005

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[7] http://www.tribometers.com/

APPENDIX

Matlab code for plotting wear maps:

```
weight = [ 8000 9000 10000 11000 12000 ];
speed  = [ 1.4 1.6 1.8 2.0];
wear   = [7.98     10.5   9.4998      10.5 ;
10.998      12.4998     13.98         12 ;
9.048       11.7         16.5       14.50 ;
13.896      13.0        11.898      8.5;
14.20      18.198        24.50      21];

 low = 5 : 0.01 : 10 ;
 medium = 10 : 0.01: 15;
 high = 15 : 0.01: 25 ;


[SPEED,WEIGHT] = meshgrid(speed,weight);
contour(SPEED,WEIGHT,wear,low,'cyan')
hold on;
contour(SPEED,WEIGHT,wear,medium,'green')
hold on;
contour(SPEED,WEIGHT,wear,high,'yellow')
text(1.4,8000 , '7.98')
text(1.6,8000 , '10.5')
text(1.8,8000 , '9.4998')
text(2.0,8000 , '10.5')
text(1.4,9000 , '10.998')
text(1.6,9000 , '12.4998')
text(1.8,9000 , '13.98')
text(2.0,9000 , '12')
text(1.4,10000 , '9.048')
text(1.6,10000 , '11.7')
text(1.8,10000 , '16.5')
text(2.0,10000 , '14.50')
text(1.4,11000 , '13.896')
text(1.6,11000 , '13.0')
text(1.8,11000 , '11.898')
text(2.0,11000 , '8.5')
text(1.4,12000 , '14.20')
text(1.6,12000 , '18.198')
text(1.8,12000 , '24.50')
text(2.0,12000 , '21')
```