217

THE EFFECT OF CHEMICAL ADDITIVES ON CUTTING FORCES AND RATE OF WEAR OF NATURAL DIAMONDS

by

BOKKA NARASIMHA RAO

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KANSAS STATE UNIVERSITY
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Approved By:

F. C. Appl

Major Professor

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

NOMENCLATURE

a	Radius of Diamond
A_w	Wear Area of Diamond
H_w	Depth of Diamond Wear
λ_w	Diamond Wear Angle
X	Axial Cutting Force
Y	Tangential Cutting Force
Z	Normal Cutting Force
F	Resultant Normal Cutting Force
F_T	Tangential Cutting Force

CHAPTER I

INTRODUCTION

The projected total expenditure for drilling and tunneling in the US during the next decade runs as high as \$100 billion (19). Considering the increased demands for improved environmental quality, underground excavation and tunneling through hard rock, drilling for oil and exploration for minerals, any modest improvement in the efficiency of comminution processes would drastically reduce the high cost of operation. One important issue in achieving reduced costs in hard rock drilling is improved bit performance. It is therefore necessary to obtain a better understanding of rock fracture mechanisms, so that more effective bits can be designed.

Another potentially important alternative, is to modify the mechanical behavior of rock by chemical means so as to enhance drilling efficiency. During recent years researchers have attempted to increase drilling efficiency by adding chemical additives to the flushing medium (1), (2), (4), (5). The physical as well as the chemical nature of the environment is found to influence significantly the performance of comminution operations (10).

If the comminution involves primarily the creation of new surfaces, then the basic principle is that reduction in surface free energy of the solid being fragmented results in an increase of the effective efficiency of the operation. Also the physical properties of the flushing fluid such as density, viscosity and the heat transfer coefficient 'h' between the bit and the fluid have an effect on the efficiency of comminution processes (10).

Many investigators have studied the effects of chemicals added to the flushing medium on rock properties and drill bit penetration rate, and explanatory theories have been advanced (1), (2), (4), (5), (7), (9), (12), (13), (15), (19). Basically two major theories were proposed to explain these effects. The first by Rehbinder, et. al. is based on surface energy reductions owing to the adsorption of chemical reagents and observed changes in penetration rates during drilling (20). The second theory was postulated by Westwood, et. al. and is based on the adsorption-induced alterations in the movement of dislocations at the surface of the solids (19).

Several workers have reported increased penetration rates by chemical additives but the explanation of these effects remain somewhat obscure (9), (19). Some conflicting results have been published by the US Bureau of Mines (2) indicating that there is no significant effect on drilling rate, by surface active chemicals in drilling microcline or serpentine.

In 1975 Cooper and Berlie (1) showed that there is no significant increase in drilling rate for marble and granite, but the rate of diamond wear is significantly affected when drilled with surface active chemicals.

The identification of the true mechanisms and their relative importance in the overall comminution process together with a clear explanation of the observed effects in drilling with surface active chemicals has not been found. This can only be established by careful experimentation and systematic control of all the system variables such as ionic strength, adsorption capacity of the solid, pH value, chemical composition of the solution etc. But, no clearly understood theory exists today to explain what occurs at the mineral-solution interface, and the reason for large variations in the results of mineral hardness research.

CHAPTER II

RESEARCH OBJECTIVES

In view of the recently published results on the effect of surface active chemicals in hard rock diamond drilling, there does not appear significant increase in penetration rate, but the distinct promise of extending the bit life is very encouraging (2).

The investigations in this field were carried out using different types of diamond bits such as diamond-impregnated core drills (2), surface-set diamond coring bits (4), and hemispherical diamond-impregnated bits (9). This means that the experimental results obtained by drilling tests represent the combined effects of many individual diamonds cutting under widely varying conditions. Due to many variables such as chip removal, diamond wear, matrix wear, cutting force on diamonds and complex interrelationships between them, it is not possible to understand and correlate the effects of chemicals on drilling.

Essentially the many individual diamonds protruding from the surface may be regarded as individual cutting tools. In the particular case of drilling with surface set diamond bits a theoritical model has been developed by first considering the cutting action of a single diamond and then properly combining the effects of all the individual diamonds on the bit face (21), (22), (23). Accordingly, a single point diamond tool was chosen for the present research to measure and study the controversial yet interesting chemically induced effects of surface active chemicals on cutting rock. Using a single diamond to cut rock is a more direct approach and the complications which arise in the case of drilling with diamond bits are avoided. The chief objective of this investigation is to study the rate of wear of the diamond while cutting granite rock using different concentrations of a cationic surfactant solution.

CHAPTER III

EXPERIMENTAL PROCEDURE

The test material used in the investigation was a cylindrical specimen of Georgia granite. The cylindrical rock was 9 inches in diameter and 10 inches long and mounted on a steel mandrel between the centers of a Reed-Prentice lathe. The cutting parameters such as the speed of the lathe (94.8 rpm), the feed rate (0.0025 inches per revolution), and the depth of cut (0.003 inches) were held constant throughout the investigation.

The cutting tool was a single spherically shaped natural diamond. The diamond as shown in Figure 1 was 0.092 inch in diameter and held in a metal matrix. The tool was mounted in a three-component force dynamometer as shown in Figure 2. This allowed continuous recording of the force components acting on the diamond during the cutting process. The dynamometer had a range of 100 pounds in the normal direction and 50 pounds in the axial and tangential directions. Two channels of a Sanborn recorder were used to record the normal and tangential forces, whereas the axial force was recorded on a second Sanborn recorder. Each component of the dynamometer was initially calibrated to a known force on the corresponding channels of the recorders.

The liquid environments consisted of cationic aqueous Aluminum Chloride, deionized distilled water, and tap water.

The selection of the surfactant and the concentration levels was guided by the experimental results relating to the specific damping of the pendulum, published by the US Bureau of Mines (14). A stock solution of this reagent was made 0.1 Molar with deionized distilled water and then diluted to the required concentration levels. Five concentration levels were used in the cutting experiments. In view of the extremely low concentration levels of Aluminum Chloride used, distilled water was deionized before using for diluting the stock solution. This was done to eliminate the presence of any traces of Chloride ions in the distilled water. Sufficient cutting fluid for one complete cut across the rock was mixed and stored before each cut. To avoid difficulties of filtering the fluid was discarded and new fluid used for each cut.

The entire storage and pumping system was made of plastic to avoid any possible contamination of the chemical fluid used. The solution was stored in a graduated plastic tank and through a plastic nozzle on to the rock just ahead of the cutting tool. The pipe-line contains a pressure gauge and a needle valve, and by controlling the needle valve, the pressure of the flushing medium can be regulated. Thus the rate of flow of the fluid was held essentially constant for all the cuts. The complete experimental set-up is shown in Figure 3.

A continuous cut was taken with each concentration level of the surfactant and the forces continuously recorded on the

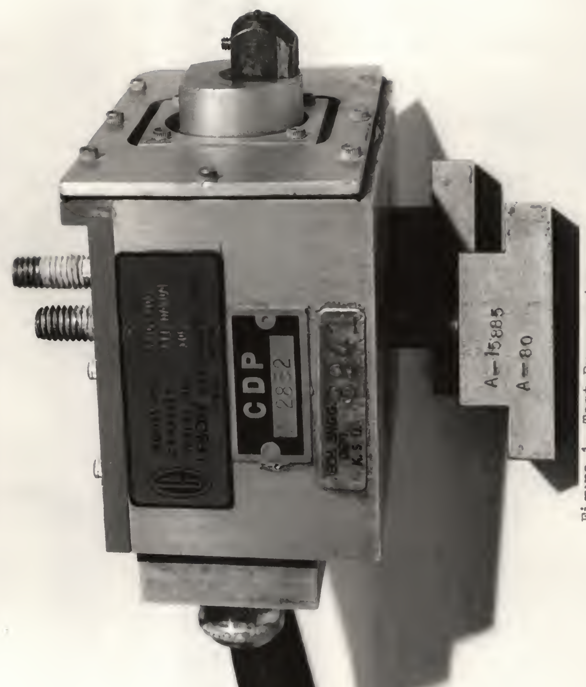


Figure 1. Test Dynamometer

Figure 2. Test Diamond in Holder

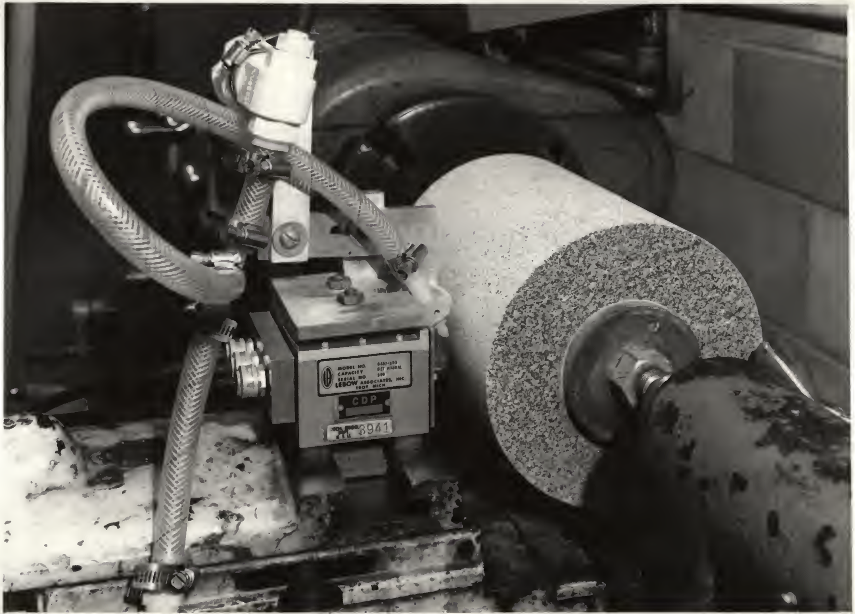


Figure 3. Test Set-Up

Sanborn recorders. From the charts of the recorders, the readings for the forces were taken at twenty equidistant points along the entire length of the rock.

Each concentration level was used once for an entire cut and the diamond was removed from the dynamometer at the end of the cut and photographed through a microscope. The area of the wear flat was determined from these photographs and the wear volume computed. Also the diameter of the rock was measured after every cut.

Deionized distilled water and ordinary tap water were also used during the investigation as flushing mediums in addition to the different concentration levels of the surfactant for comparison. Typical photographs of the worn diamond are shown in Appendix 3.

CHAPTER IV

ANALYSIS OF EXPERIMENTAL DATA

The photographs of the diamond taken at the end of each run were used to determine the amount of diamond wear. The area of the wear flat A_w was obtained using a planimeter. This wear area was approximated to an equivalent circle to get the depth of diamond wear H_w.

$$H_w = a\,(1 - \text{Cos}\,\lambda_w), \quad \ldots\ldots\ldots\ldots\ 1.$$

Where, $$\lambda_w = \text{Sin}^{-1}\,\frac{1}{a}\,\left(\frac{A_w}{\pi}\right)^{\frac{1}{2}}, \quad \ldots\ldots\ldots\ 2.$$

The volume of diamond worn was then computed using the equation

$$\text{Wear volume} = \pi\left(aH_w^2 - \frac{H_w^3}{3}\right), \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 3.$$

The volume of rock removed for every cut was also computed.

From the experimental data obtained, graphs between the resultant normal force and the volume of rock removed were plotted as shown in Figure 4. Because of the inherent inhomogeneities of the granite rock the average slopes $\left(\frac{dF}{dV_r}\right)$ for each run were obtained from these graphs as shown in Figure 4. The ratio between the average normal force and the wear area $\left(\frac{dF}{dA_d}\right)$ for each cut was calculated using the relation given by,

$$\left(\frac{dF}{dA_d}\right) = \left(\frac{dF}{dV_r}\right)\left(\frac{dV_r}{dA_d}\right), \quad \ldots\ldots\ldots\ldots\ldots\ 4.$$

The ratio between the volume of diamond worn and the volume

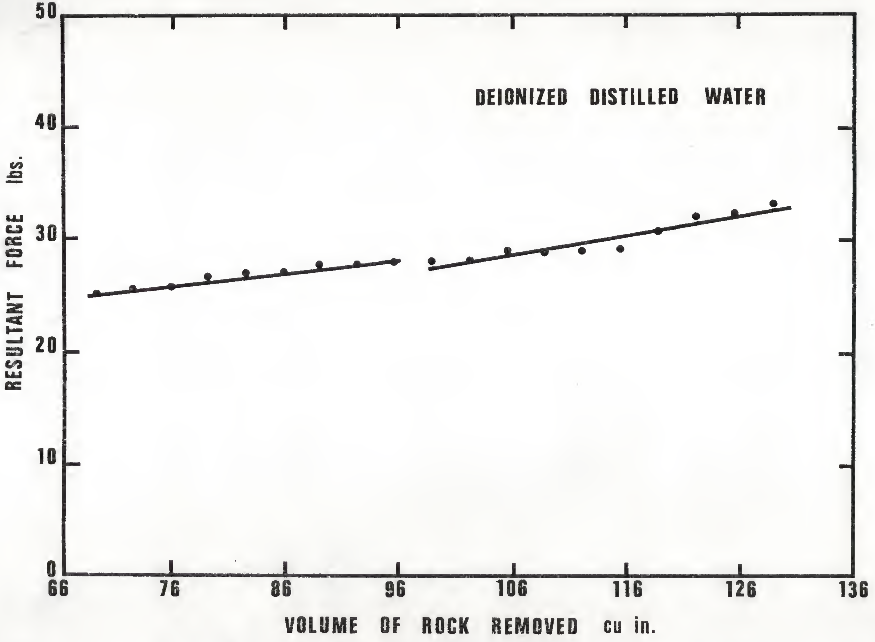


Figure 4 (a). Normal Force vs. Volume of Rock Removed.

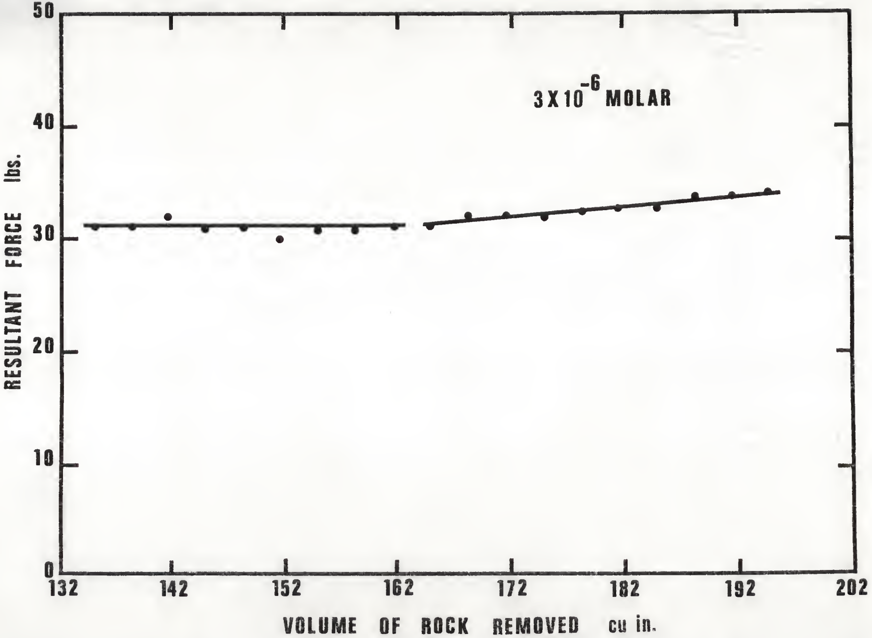


Figure 4 (b). Normal Force vs. Volume of Rock Removed.

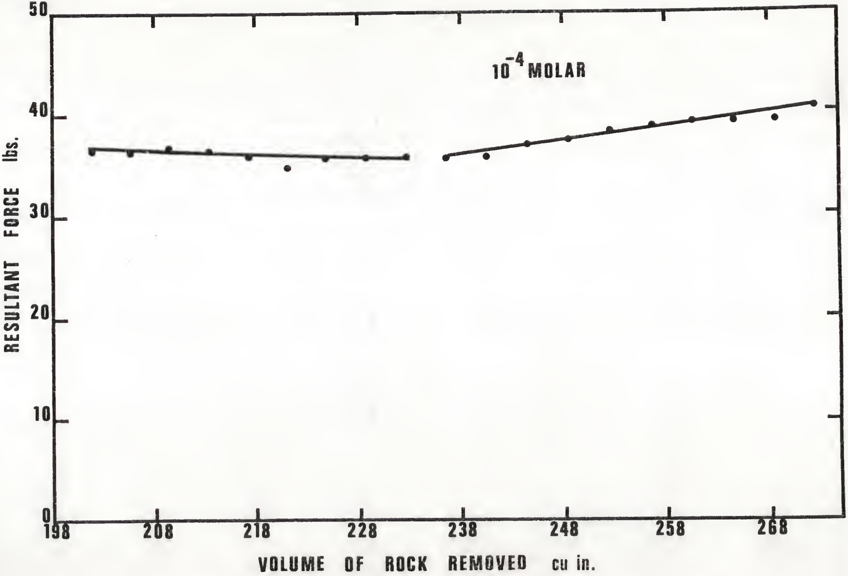


Figure 4 (c). Normal Force vs. Volume of Rock Removed.

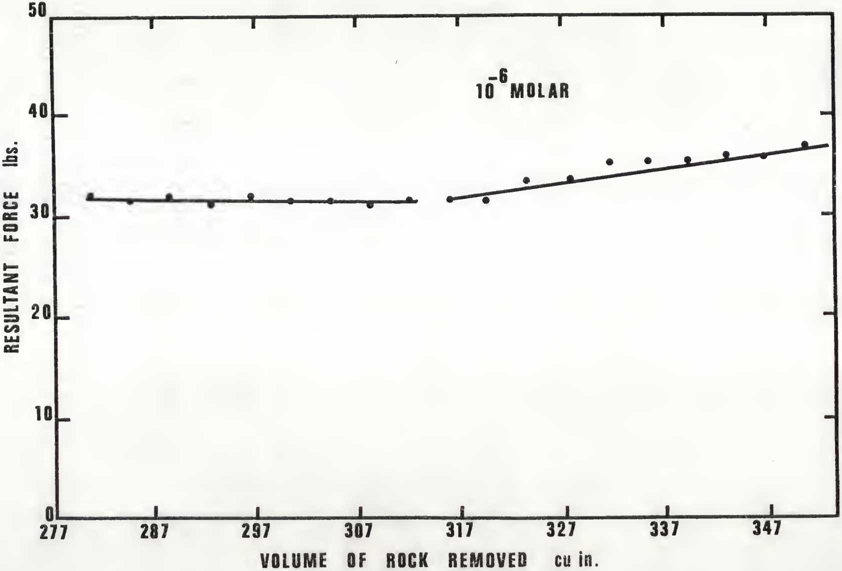


Figure 4 (d). Normal Force vs. Volume of Rock Removed.

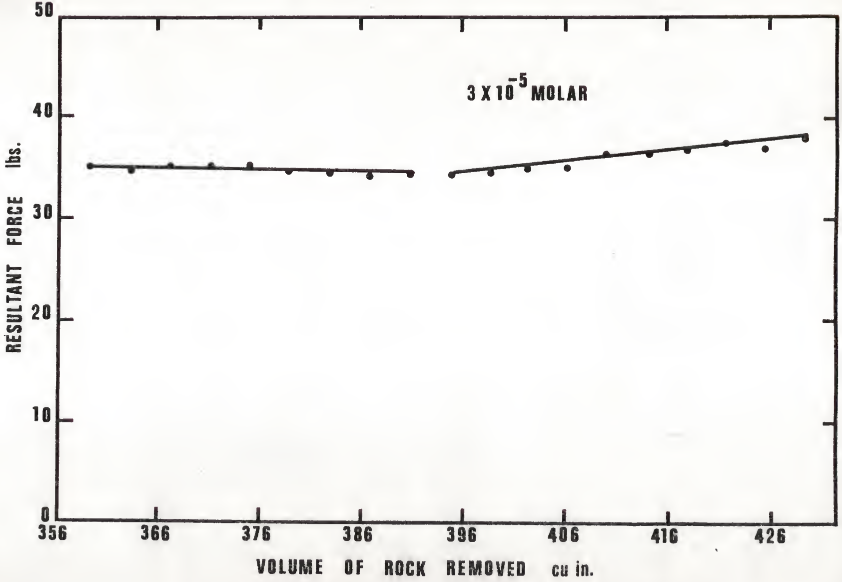


Figure 4 (e). Normal Force vs. Volume of Rock Removed.

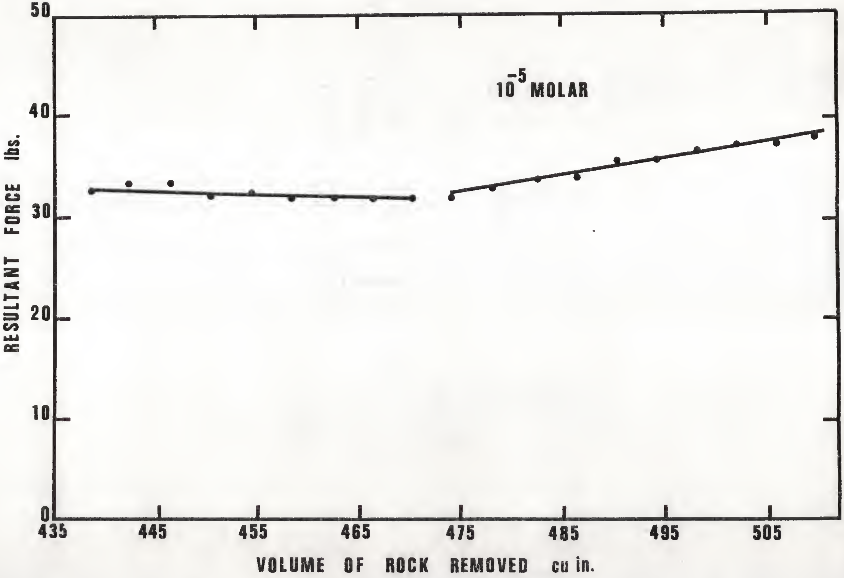


Figure 4 (f). Normal Force vs. Volume of Rock Removed.

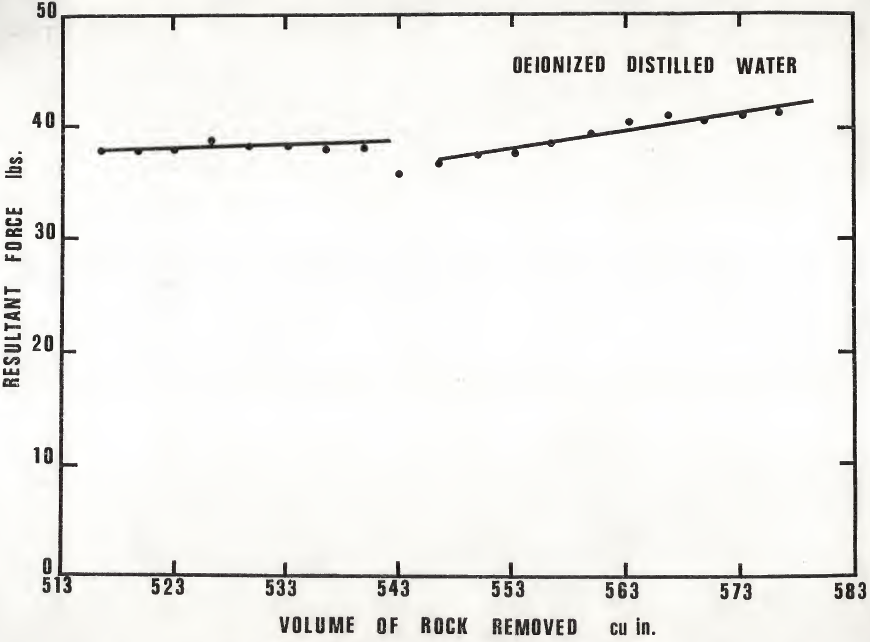


Figure 4 (g). Normal Force vs. Volume of Rock Removed.

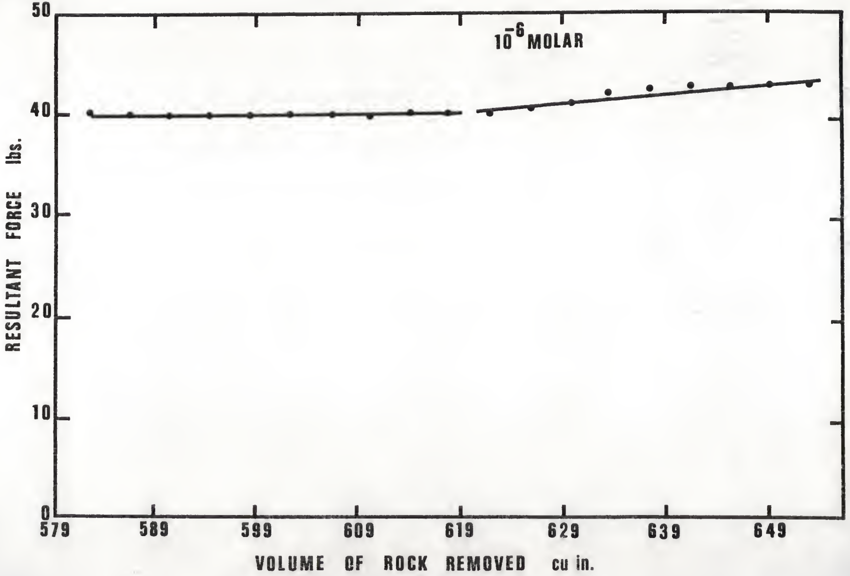


Figure 4 (h). Normal Force vs. Volume of Rock Removed.

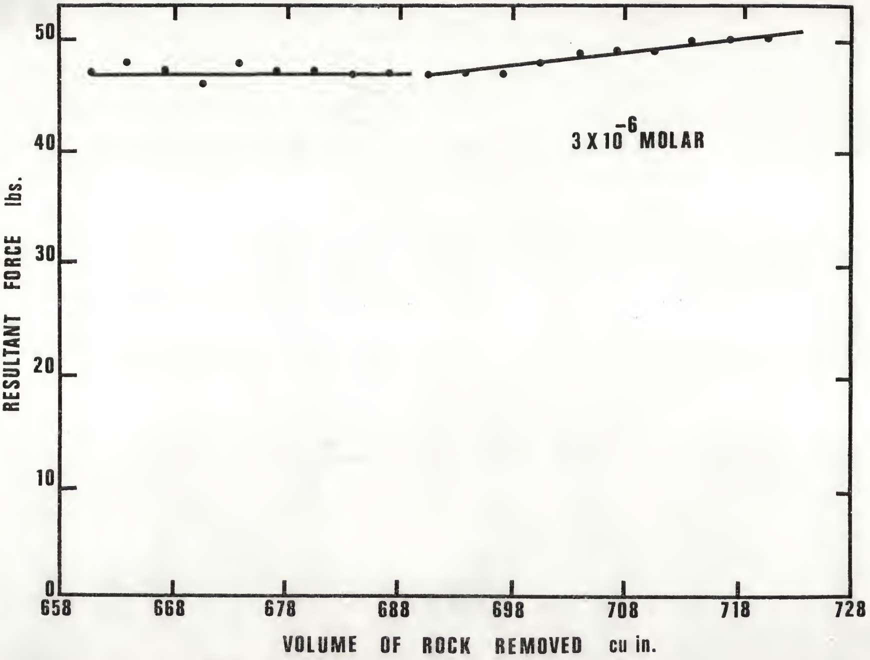


Figure 4 (i). Normal Force vs. Volume of Rock Removed.

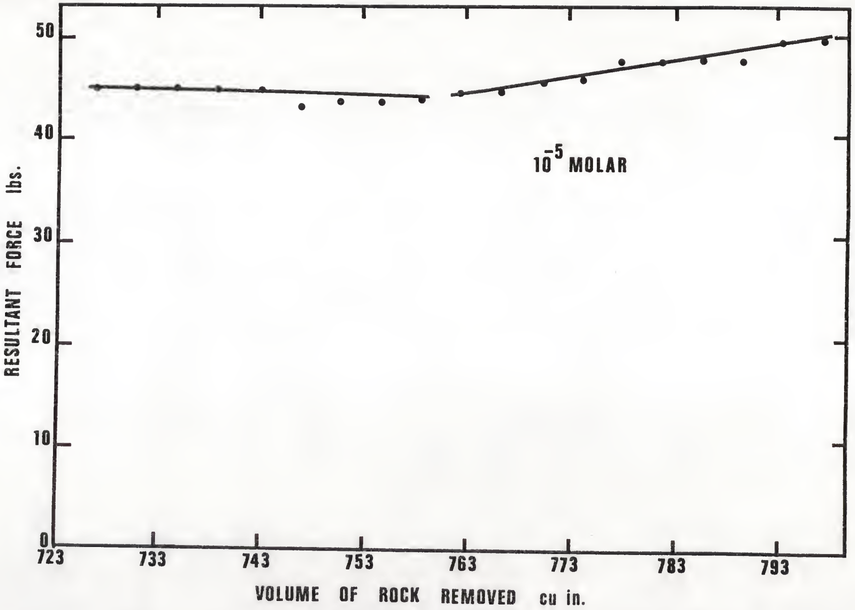


Figure 4 (j). Normal Force vs. Volume of Rock Removed.

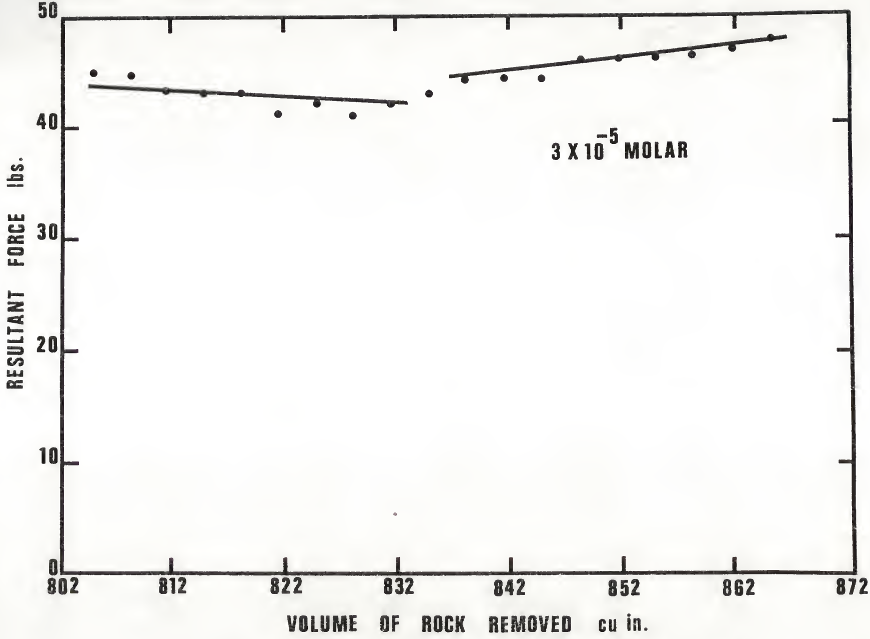


Figure 4 (k). Normal Force vs. Volume of Rock Removed.

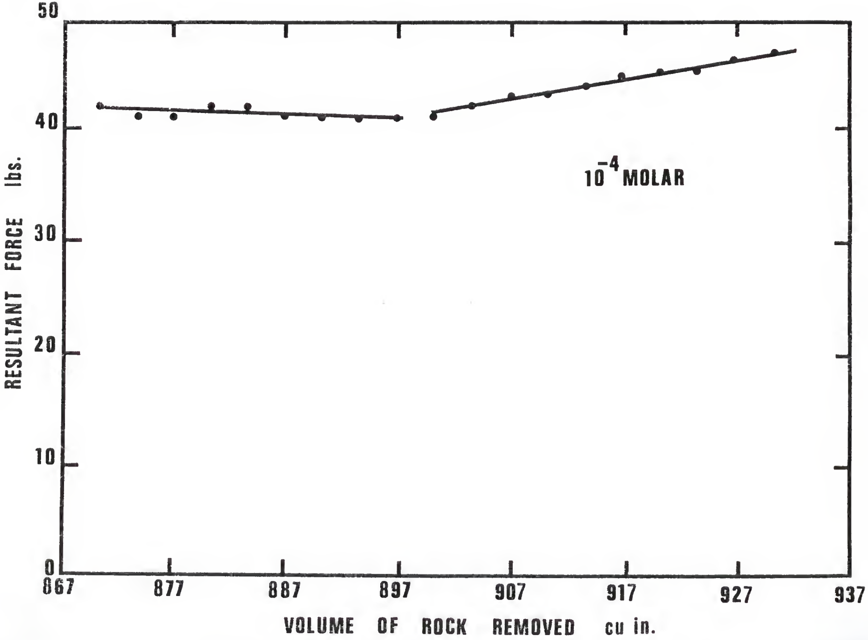


Figure 4 (1). Normal Force vs. Volume of Rock Removed.

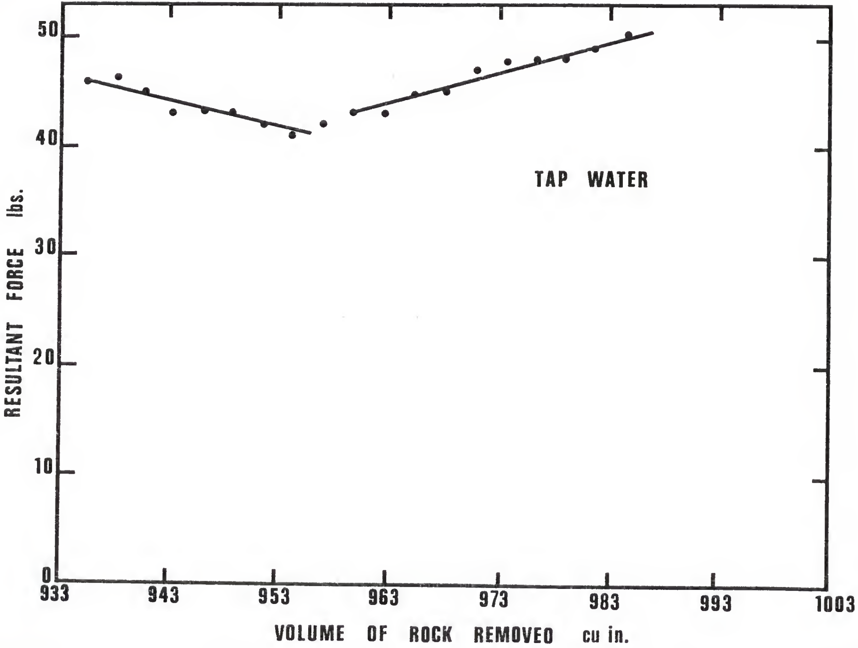


Figure 4 (m). Normal Force vs. Volume of Rock Removed.

of rock removed was also computed for all the cuts. These results were summarized in Tables 1 and 2 respectively.

Graphs were plotted for the diamond wear rate $(\frac{dV_d}{dV_r})$ versus the logarithm of concentration and for the effective cutting hardness $(\frac{dF}{dA_d})$ versus the logarithm of concentration as shown in Figures 5 and 6 respectively. The corresponding values for deionized distilled water and tap water are also given in these graphs for comparison. Computer programs for the volume of diamond worn and the volume of rock removed are given in Appendix 1. The cutting hardness $(\frac{dF_T}{dA_d})$ from the data for tangential cutting force was obtained similar to $(\frac{dF}{dA_d})$. Graph plotted for the cutting hardness $(\frac{dF_T}{dA_d})$ versus the logarithm of concentration is shown in Figure 8.

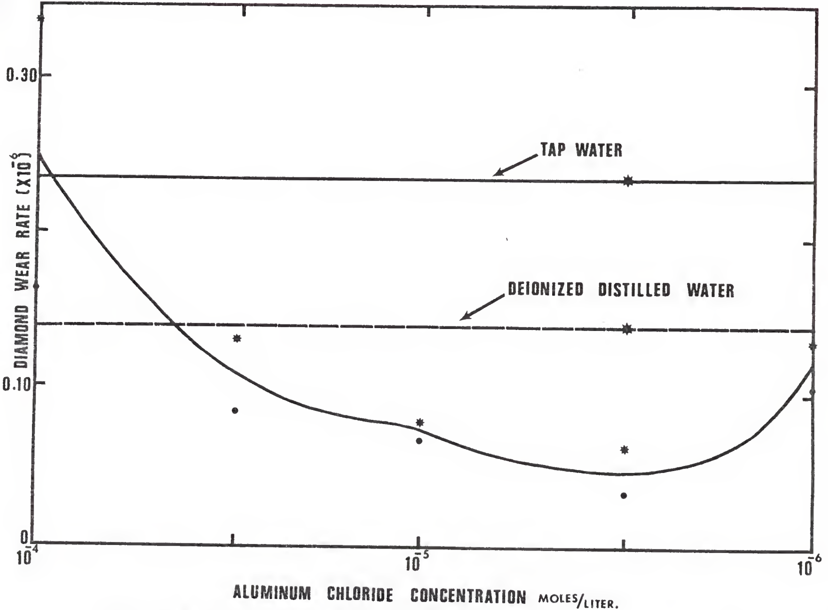
DISCUSSION OF THE RESULTS

Results for Single Point Cutting

The rate of diamond wear $(\frac{dV_d}{dV_r})$ and the cutting hardness $(\frac{dF}{dA_d})$ and $(\frac{dF_T}{dA_d})$ have been plotted as functions of the logarithm of concentration in Figures 5, 6 and 7 respectively. It is clear from the graph that the minimum diamond wear rate occurs at the concentration level 3×10^{-6} Molar. For comparison, the diamond wear rate with deionized distilled water and tap water are shown as level lines on the graph. From the graphs plotted between $(\frac{dF}{dA_d})$ versus the logarithm of concentration and $(\frac{dF_T}{dA_d})$ versus the logarithm of concentration level, it appears that the cutting hardness is maximum at approximately 3×10^{-6} Molar concentration. It was also found that the diamond wear rate correlates with the hardness determined by the Pendulum Sclerometer as published by the Bureau of Mines (14). This is shown in Figure 8.

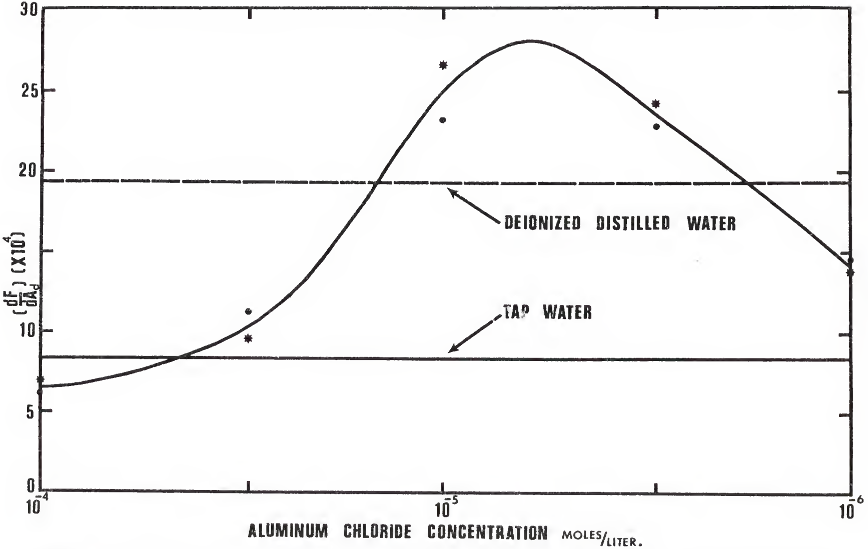
Expected Results for Drilling with Diamond Bits

The single diamond cutting tests were performed with essentially constant rock removal rate. Under these conditions the cutting forces were maximum when the diamond wear rate was minimum. It is therefore believed that when drilling with constant weight on a diamond bit, the penetration rate will be minimum at 3×10^{-6} Molar concentration. The diamond wear rate will also be minimum at this concentration level. To improve the drilling performance of a bit, it is desired to increase the penetration rate and to decrease the wear rate. But, from the results obtained, it is expected that both the objectives, namely minimum wear rate



Diamond Wear Rate vs. the Logarithm of Concentration of Surfactant

Figure 5



Effective Cutting Hardness vs. the Logarithm of Concentration of the Surfactant

Figure 6

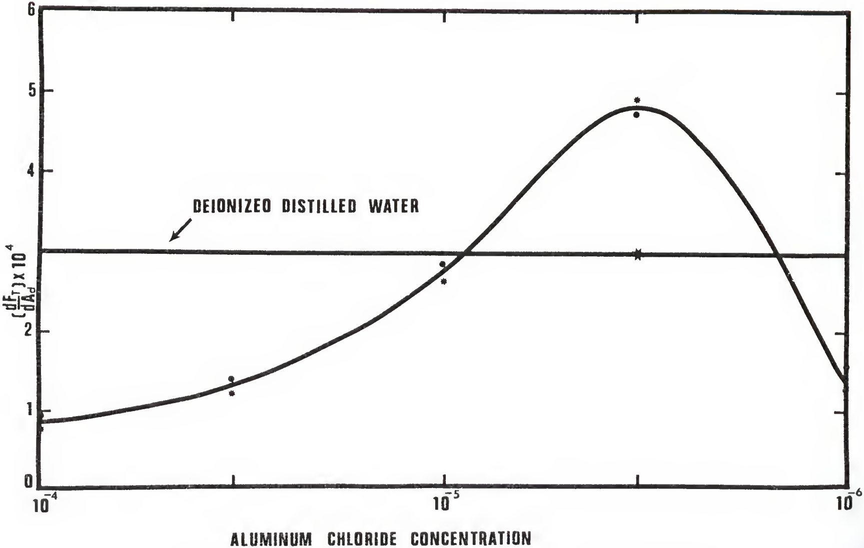


Figure 7. (dF_T/ dA_d) vs the Logarithm of Concentration of the Surfactant

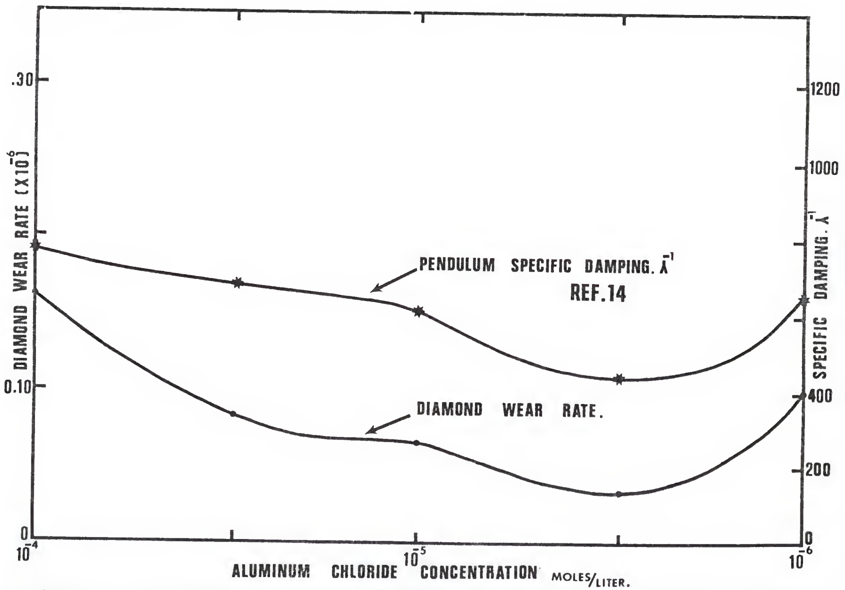


Figure 8. Comparison of Diamond Wear Rate with Bureau of Mines Specific Damping

and maximum penetration rate cannot be achieved at the same time.

Agreement with former Results

The experimental results, that the diamond wear rate is minimum and the cutting hardness is maximum at the concentration level 3 X 10^{-6} Molar, are in agreement with results published by Westwood, et al (9) and Selim, et al (12). Westwood states that microhardness is maximum at the isoelectric point which should be in the vicinity of 3 X 10^{-6} Molar concentration. Selim found that the additives simultaneously increased the energy consumption (corresponding to increased tangential cutting force) while the diamond wear rate was decreased.

Disagreement with former Results

The results published by Engelmann and Terichow of the Bureau of Mines (14) however don't appear to agree with our results. The hardness determined by the Pendulum Sclerometer was minimum at the isoelectric point.

Aspects of the Results which are not understood

Several aspects of the results are not presently understood. These are:

1. Why the diamond wear rate is minimum when the cutting hardness is maximum.
2. Why the Pendulum hardness is minimum when the cutting hardness is maximum.
3. Why the diamond wear rate correlates with the Pendulum hardness.

The reason that wear rate is decreased when cutting hardness is increased may be that although the rock becomes stronger the mode of failure becomes more brittle in nature.

CONCLUSIONS

It is clear that there are still many unanswered questions regarding the effects of chemical additives on the cutting action and wear rate of diamond cutting tools. Based on the single diamond cutting tests in granite rock, it can be concluded that:

1. The cutting forces are increased by the Aluminum Chloride solution.
2. The diamond wear rate is decreased by the Aluminum Chloride solution.

It therefore appears that "optimum" drilling performance must be some compromise between decreased penetration rate and increased bit life.

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TABLE 1

VALUES OF THE RATIO $(\frac{dv_d}{dv_r})$ FOR DIFFERENT CONCENTRATION LEVELS OF THE SURFACTANT

I SET		II SET	
1. Deionized Distilled Water	: 0.103×10^{-6}	7. Deionized Distilled Water	: 0.177×10^{-6}
2. 3×10^{-6} Molar	: 0.037×10^{-6}	8. 1×10^{-6} Molar	: 0.134×10^{-6}
3. 1×10^{-4} Molar	: 0.163×10^{-6}	9. 3×10^{-6} MOlar	: 0.066×10^{-6}
4. 1×10^{-6} Molar	: 0.104×10^{-6}	10. 1×10^{-5} Molar	: 0.078×10^{-6}
5. 3×10^{-5} MOlar	: 0.085×10^{-6}	11. 3×10^{-5} Molar	: 0.132×10^{-6}
6. 1×10^{-5} Molar	: 0.068×10^{-6}	12. 1×10^{-4} MOlar	: 0.338×10^{-6}
		13. Tap Water	: 0.236×10^{-6}

TABLE 2

VALUES OF THE RATIO $(\frac{dF}{dA_d})$ FOR DIFFERENT CONCENTRATION LEVELS OF THE SURFACTANT

I SET	II SET
1. Deionized Distilled Water : 19.69×10^4	7. Deionized Distilled Water : 18.58×10^4
2. 3×10^{-6} Molar : 22.21×10^4	8. 1×10^{-6} Molar : 13.46×10^4
3. 1×10^{-4} Molar : 6.21×10^4	9. 3×10^{-6} Molar : 24.19×10^4
4. 1×10^{-6} Molar : 14.28×10^4	10. 1×10^{-5} Molar : 26.72×10^4
5. 3×10^{-5} Molar : 11.05×10^4	11. 3×10^{-5} Molar : 9.47×10^4
6. 1×10^{-5} Molar : 23.14×10^4	12. 1×10^{-4} Molar : 6.83×10^4
	13. Tap Water : 8.16×10^4

```
$JOB
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  100 FORMAT('1',40X,'ANALYSIS OF PLANIMETER DATA FOR DIAMCND NO.8'/'-',
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     XOF',18X,'VOLUME'/' ',15X,'AREA',16X,'OF DIAMOND',17X,'WEAR AREA',1
     X5X,'DIAMCND WEAR',17X,'WORN'/)
  101 FORMAT(10X,120('*')/)
  102 FORMAT(' ',I2,2X,D23.16,2X,D23.16,2X,D23.16,2X,D23.16,2X,D23.16/)
  103 FORMAT(10X,120('*')/'1')
      PRINT 100
      PRINT 101
      PI=3.14159265358979300
      R=0.046D0
      X1=59.D0
      N=14
      READ (5,99) (PA(I),I=1,N)
      DO 104 I=1,N
      AR(I) = PA(I)/(X1**2.)
  104 CCNTINUE
      DO 105 I=1,N
      REQ(I) = (PA(I)/(PI*(X1**2.)))**0.5
  105 CCNTINUE
      DO 106 I=1,N
      HWD(I) = R-((R**2.-REQ(I)**2.)**0.5)
      VW(I)=(PI/3.D0)*(HWD(I)**2.)*((3.D0*R)-HWD(I))
      PRINT 102,I,PA(I),AR(I),REQ(I),HWD(I),VW(I)
  106 CCNTINUE
      PRINT 103
      STOP
      END

$ENTRY
```

Computer Program

Appendix 1

```
C$JOB            ,TIME=(,20),PAGES=100
       DOUBLE PRECISION D,SPD,DIS,DIST,VOL,VOLT,WID,FD,RPM
       DIMENSION D(300),SPD(300),DIS(300),DIST(300),VOL(300),VOLT(300)
    99 FORMAT(9D8.3)
   100 FORMAT('1',40X,'ANALYSIS OF CUTTING DATA FOR DIAMOND NO.8'/'-',15X
      X,'DIAMETER',13X,'DISTANCE',18X,'TOTAL DISTANCE',15X,'VOLUME',15X,'
      XTOTAL VOLUME'/' ',14X,'BEFORE CUT',13X,'TRAVELED',21X,'TRAVELED',1
      X5X,'REMOVED',15X,'REMOVED'/)
   101 FORMAT(8X,120('*')/)
   102 FORMAT(' ',I3,2X,D23.16,2X,D23.16,2X,D23.16,2X,D23.16,2X,D23.16/)
   104 FORMAT(8X,120('*')/'1')
       PI=3.14159265358979D0
       WID=0.5D0
       FD=0.0025D0
       RPM=94.8D0
       DIST(1)=0.D0
       VOLT(1)=0.D0
       M=280
       N=300
       READ (5,99) (D(I),I=1,N)
       PRINT 100
       PRINT 101
       DO 105 I=1,M
       SPD(I)=(PI*D(I)*RPM)/12.D0
       DIS(I) = ((((PI*D(I))**2.)+(FD**2.))**0.5)*WID/(FD*12.D0)
       VOL(I) = (PI/4.)*((D(I)**2.)-(D(I+20)**2.))*WID
       DIST(I+1) = DIST(I)+DIS(I)
       VOLT(I+1) = VOLT(I)+VOL(I)
   105 PRINT 102,I,D(I),DIS(I),DIST(I+1),VOL(I),VOLT(I+1)
       PRINT 104
       STOP
       END

$ENTRY
```

ANALYSIS OF PLANIMETER DATA FOR DIAMOND NO.8

```
            PLANIMETER                 ACTUAL WEAR AREA              RADIUS OF                  DEPTHOF                   VOLUME
               AREA                      OF DIAMOND                  WEAR AREA               DIAMOND WEAR                  WORN

            ***************************************************************************************************************************

  1   0.1228000000000000D 01   0.3527721918588796D-03   0.1059673894422896D-01   0.1237190394839357D-02   0.2192147191308394D-06
  2   0.1403000000000000D 01   0.4030451019821850D-03   0.1132666060844435D-01   0.1416294911020281D-02   0.2869028727815482D-06
  3   0.1460000000000000D 01   0.4194197069807526D-03   0.1155445538276392D-01   0.1474787358085330D-02   0.3109569672168425D-06
  4   0.1733000000000000D 01   0.4978454467107153D-03   0.1258845214788563D-01   0.1756007497962004D-02   0.4399453295862074D-06
  5   0.1885000000000000D 01   0.5415110600402183D-03   0.1312891175568888D-01   0.1913361705485697D-02   0.5217209293300063D-06
  6   0.2000000000000000D 01   0.5745475438692502D-03   0.1352346713225196D-01   0.2032786798309564D-02   0.5883645223475969D-06
  7   0.2088000000000000D 01   0.5998276357368572D-03   0.1381775080812152D-01   0.2124392499491137D-02   0.6421546557341045D-06
  8   0.2266000000000000D 01   0.6509623671358805D-03   0.1439471281384082D-01   0.2310273026636487D-02   0.7584067710695099D-06
  9   0.2416000000000000D 01   0.6940534329215742D-03   0.1486351470005448D-01   0.2467530155511905D-02   0.8641654688172738D-06
 10   0.2475000000000000D 01   0.7110025854639471D-03   0.1504390747297423D-01   0.2529540513762794D-02   0.9077296071994042D-06
 11   0.2556000000000000D 01   0.7342717605882216D-03   0.1528809866098896D-01   0.2614817744627744D-02   0.9693544289638651D-06
 12   0.2665000000000000D 01   0.7655846021258259D-03   0.1561067415478058D-01   0.2729838775048844D-02   0.1055612737913624D-05
 13   0.2925000000000000D 01   0.8402757828210285D-03   0.1635445165062886D-01   0.3005443237460354D-02   0.1276914843145446D-05
 14   0.3060000000000000D 01   0.8790577420281528D-03   0.1672760502325307D-01   0.3149244695267747D-02   0.1400537733810219D-05

            ***************************************************************************************************************************
```

APPENDIX 2

Cut Number 1 : Deionized Distilled Water

Diameter of Rock Before Cut : 8.393 inches

Diameter of Rock After Cut : 8.388 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	3.0	4.4	25.0	25.18
2.	3.0	4.6	25.5	25.67
3.	3.1	4.6	25.5	25.69
4.	3.2	4.6	26.5	26.69
5.	3.2	4.6	27.0	27.19
6.	3.3	4.6	27.0	27.20
7.	3.4	4.7	27.5	27.70
8.	3.4	4.7	27.5	27.70
9.	3.4	5.0	28.0	28.21
10.	3.4	5.0	28.0	28.21
11.	3.4	5.0	28.0	28.21
12.	3.5	5.1	29.0	29.21
13.	3.5	5.0	28.5	28.71
14.	3.5	5.1	28.5	28.71
15.	3.6	5.2	29.0	29.22
16.	3.7	5.5	30.5	30.72
17.	3.9	5.7	32.0	32.24
18.	4.0	5.7	32.0	32.25
19.	4.0	5.8	33.0	33.24
20.	4.0	5.8	33.0	33.24

EXPERIMENTAL DATA

Cut Number 2 : Aluminum Chloride Solution (3 x 10^{-6} Molar)

Diameter of Rock Before Cut : 8.388 inches

Diameter of Rock After Cut : 8.383 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	3.4	5.0	31.0	31.19
2.	3.5	5.4	31.0	31.20
3.	3.6	5.4	32.0	32.20
4.	3.6	5.1	31.0	31.21
5.	3.6	5.1	31.0	31.21
6.	3.6	5.1	30.0	30.22
7.	3.6	5.3	30.5	30.71
8.	3.6	5.3	30.5	30.71
9.	3.6	5.3	31.0	31.21
10.	3.5	5.3	31.0	31.20
11.	3.6	5.4	32.0	32.20
12.	3.6	5.4	32.0	32.20
13.	3.6	5.3	31.5	31.71
14.	3.6	5.5	32.0	32.20
15.	3.6	5.6	32.5	32.70
16.	3.6	5.6	32.5	32.70
17.	3.6	5.8	33.5	33.70
18.	3.6	5.7	33.5	33.70
19.	3.6	5.7	34.0	34.19
20.	3.6	5.7	34.0	34.19

EXPERIMENTAL DATA

Cut Number 3 : Aluminum Chloride Solution (1 x 10^{-4} Molar)

Diameter of Rock Before Cut : 8.383 inches

Diameter of Rock After Cut : 8.377 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	4.4	6.0	37.0	37.26
2.	4.4	6.1	36.5	36.76
3.	4.4	6.0	37.0	37.26
4.	4.4	5.9	36.5	36.76
5.	4.3	5.8	36.0	36.26
6.	4.2	5.8	35.0	35.25
7.	4.4	5.8	36.0	36.27
8.	4.3	5.9	36.0	36.26
9.	4.3	5.9	36.0	36.26
10.	4.4	5.9	36.0	36.27
11.	4.3	5.9	36.0	36.26
12.	4.4	6.1	37.0	37.26
13.	4.5	6.1	37.5	37.77
14.	4.6	6.3	38.5	38.77
15.	5.1	6.2	38.5	38.84
16.	5.3	6.3	39.0	39.36
17.	5.2	6.4	39.0	39.35
18.	5.2	6.3	39.0	39.35
19.	5.2	6.4	40.0	40.34
20.	5.2	6.4	40.0	40.34

Cut Number 4 : Aluminum Chloride Solution (1×10^{-6} Molar)

Diameter of Rock Before Cut : 8.377 inches

Diameter of Rock After Cut : 8.371 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	3.1	5.0	32.0	32.15
2.	3.0	5.0	31.5	31.64
3.	3.1	5.1	32.0	32.15
4.	3.1	5.2	31.0	31.15
5.	3.1	5.0	32.0	32.15
6.	3.0	5.0	31.5	31.64
7.	3.0	5.0	31.5	31.64
8.	2.9	5.0	31.0	31.14
9.	3.0	5.2	31.5	31.64
10.	3.0	5.0	31.5	31.64
11.	2.9	5.0	31.5	31.63
12.	3.1	5.4	33.5	33.64
13.	3.2	5.3	33.5	33.65
14.	3.3	5.5	35.0	35.16
15.	3.3	5.4	35.0	35.16
16.	3.3	5.5	35.0	35.16
17.	3.3	5.5	35.5	35.65
18.	3.2	5.4	35.5	35.64
19.	3.3	5.6	36.5	36.65
20.	3.3	5.6	36.5	36.65

EXPERIMENTAL DATA

Cut Number 5 : Aluminum Chloride Solution (3 x 10^{-5} Molar)

Diameter of Rock Before Cut : 8.371 inches

Diameter of Rock After Cut : 8.365 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	3.1	5.1	35.0	35.14
2.	3.1	5.3	34.5	34.64
3.	3.2	5.4	35.0	35.17
4.	3.2	5.4	35.0	35.17
5.	3.2	5.4	35.0	35.17
6.	3.2	5.3	34.5	34.65
7.	3.2	5.4	34.5	34.65
8.	3.2	5.5	34.0	34.15
9.	3.2	5.5	34.5	34.65
10.	3.2	5.6	34.5	34.65
11.	3.2	5.6	34.5	34.65
12.	3.1	5.6	35.0	35.14
13.	3.2	5.5	35.0	35.15
14.	3.3	5.6	36.5	36.65
15.	3.3	5.6	36.5	36.65
16.	3.4	5.8	37.0	37.16
17.	3.4	5.8	37.5	37.65
18.	3.3	5.6	37.0	37.15
19.	3.3	5.8	38.0	38.14
20.	3.3	5.8	38.0	38.14

EXPERIMENTAL DATA

Cut Number 6 : Aluminum Chloride Solution (1 x 10^{-5} Molar)

Diameter of Rock Before Cut : 8.365 inches

Diameter of Rock After Cut : 8.359 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	2.7	4.6	32.5	32.61
2.	2.7	4.8	33.5	33.61
3.	2.7	4.8	33.5	33.61
4.	2.7	4.6	32.0	32.11
5.	2.6	4.7	32.5	32.60
6.	2.6	4.5	32.0	32.11
7.	2.6	4.6	32.0	32.11
8.	2.6	4.6	32.0	32.11
9.	2.6	4.7	32.0	32.11
10.	2.6	4.8	32.0	32.11
11.	2.7	5.0	33.0	33.11
12.	2.8	5.0	34.0	34.11
13.	2.8	4.9	34.0	34.11
14.	3.0	5.2	36.0	36.12
15.	3.0	5.2	36.0	36.12
16.	3.0	5.3	37.0	37.12
17.	3.0	5.3	37.5	37.62
18.	2.9	5.3	37.5	37.61
19.	3.0	5.4	38.0	38.12
20.	3.0	5.4	38.0	38.12

EXPERIMENTAL DATA

Cut Number 7 : Deionized Distilled Water

Diameter of Rock Before Cut : 8.359 inches

Diameter of Rock After Cut : 8.354 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	3.0	5.2	38.0	38.12
2.	3.0	5.2	38.0	38.12
3.	3.0	5.3	38.0	38.12
4.	3.1	5.4	39.0	39.12
5.	3.0	5.2	38.5	38.62
6.	3.0	5.2	38.5	38.62
7.	3.0	5.2	38.5	38.11
8.	2.9	5.1	38.0	38.61
9.	2.9	5.3	38.5	36.11
10.	2.9	5.0	36.0	37.12
11.	2.9	5.0	36.0	38.12
12.	3.0	5.2	37.0	38.12
13.	3.0	5.3	38.0	39.12
14.	3.0	5.6	40.0	40.11
15.	3.2	5.7	41.0	41.12
16.	3.2	5.8	41.5	41.62
17.	3.2	5.8	41.0	41.12
18.	3.2	5.8	41.5	41.62
19.	3.2	5.8	41.5	41.62
20.	3.2	5.8	41.5	41.62

EXPERIMENTAL DATA

Cut Number 8 : Aluminum Chloride Solution (1 x 10^{-6} Molar)

Diameter of Rock Before Cut : 8.354 inches

Diameter of Rock After Cut : 8.348 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	3.1	5.4	40.5	40.62
2.	3.2	5.4	40.5	40.63
3.	3.3	5.4	40.0	40.14
4.	3.3	5.4	40.0	40.14
5.	3.3	5.4	40.0	40.14
6.	3.3	5.3	40.0	40.14
7.	3.3	5.4	40.0	40.14
8.	3.3	5.4	40.0	40.14
9.	3.3	5.4	40.5	40.63
10.	3.3	5.4	40.5	40.63
11.	3.3	5.6	40.5	40.63
12.	3.3	5.7	41.0	41.13
13.	3.3	5.8	41.5	41.63
14.	3.4	5.8	42.5	42.64
15.	3.4	5.9	43.0	43.13
16.	3.4	6.0	43.0	43.13
17.	3.4	6.0	43.0	43.13
18.	3.4	6.0	43.0	43.13
19.	3.4	6.0	43.0	43.13
20.	3.4	6.0	43.0	43.13

EXPERIMENTAL DATA

Cut Number 9 : Aluminum Chloride Solution (3 x 10^{-6} Molar)

Diameter of Rock Before Cut : 8.348 inches

Diameter of Rock After Cut : 8.343 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	2.2	6.3	47.0	47.05
2.	2.2	6.4	48.0	48.05
3.	2.2	6.4	47.5	47.55
4.	2.2	6.2	46.0	46.05
5.	2.2	6.4	48.0	48.05
6.	2.2	6.2	47.5	47.55
7.	2.2	6.2	47.5	47.55
8.	2.2	6.2	47.0	47.05
9.	2.2	6.3	47.0	47.05
10.	2.2	6.4	47.0	47.05
11.	2.2	6.3	47.0	47.05
12.	2.2	6.4	47.0	47.05
13.	2.2	6.4	48.0	48.05
14.	2.4	6.5	49.0	49.06
15.	2.4	6.5	49.0	49.06
16.	2.4	6.6	49.0	49.06
17.	2.4	6.8	50.0	50.06
18.	2.4	6.8	50.0	50.06
19.	2.4	6.8	50.0	50.06
20.	2.4	6.8	50.0	50.06

EXPERIMENTAL DATA

Cut Number 10 : Aluminum Chloride Solution (1 x 10^{-5} Molar)

Diameter of Rock Before Cut : 8.343 inches

Diameter of Rock After Cut : 8.337 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	3.2	6.4	45.0	45.11
2.	3.4	6.5	45.0	45.13
3.	3.4	6.6	45.0	45.13
4.	3.4	6.5	45.0	45.13
5.	3.5	6.5	45.0	45.14
6.	3.4	6.3	43.5	43.63
7.	3.4	6.4	44.0	44.13
8.	3.4	6.5	44.0	44.13
9.	3.4	6.4	44.0	44.13
10.	3.5	6.5	45.0	45.14
11.	3.5	6.6	45.0	45.14
12.	3.5	6.6	46.0	46.13
13.	3.6	6.7	46.0	46.14
14.	3.6	6.8	48.0	48.13
15.	3.7	6.8	48.0	48.14
16.	3.6	6.8	48.0	48.13
17.	3.7	6.8	48.0	48.14
18.	3.7	6.9	50.0	50.14
19.	3.8	7.0	50.0	50.14
20.	3.8	7.0	50.0	50.14

EXPERIMENTAL DATA

Cut Number 11 : Aluminum Chloride Solution (3×10^{-5} Molar)

Diameter of Rock Before Cut : 8.337 inches

Diameter of Rock After Cut : 8.332 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	2.8	6.2	45.0	45.09
2.	2.9	6.3	45.0	45.09
3.	3.0	6.0	43.0	43.10
4.	3.0	6.0	43.0	43.10
5.	3.0	6.1	43.0	43.10
6.	3.0	5.8	41.0	41.11
7.	3.0	6.2	42.0	42.11
8.	3.0	6.0	41.0	41.11
9.	3.0	6.2	42.0	42.11
10.	3.0	6.2	43.0	43.10
11.	3.1	6.3	44.0	44.11
12.	3.0	6.3	44.0	44.10
13.	3.1	6.3	44.0	44.11
14.	3.2	6.6	46.0	46.11
15.	3.2	6.5	46.0	46.11
16.	3.2	6.5	46.0	46.11
17.	3.2	6.5	46.0	46.11
18.	3.2	6.5	47.0	47.11
19.	3.2	6.6	48.0	48.10
20.	3.2	6.6	48.0	48.10

EXPERIMENTAL DATA

Cut Number 12 : Aluminum Chloride Solution (1 x 10^{-4} Molar)

Diameter of Rock Before Cut : 8.332 inches

Diameter of Rock After Cut : 8.327 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	2.3	6.1	42.0	42.06
2.	2.3	6.0	41.0	41.06
3.	2.3	6.0	41.0	41.06
4.	2.4	6.1	42.0	42.06
5.	2.5	6.1	42.0	42.07
6.	2.4	5.9	41.0	41.07
7.	2.5	5.9	41.0	41.08
8.	2.4	5.9	41.0	41.07
9.	2.5	5.8	41.0	41.08
10.	2.5	5.8	41.0	41.08
11.	2.6	5.9	42.0	42.08
12.	2.6	6.0	43.0	43.08
13.	2.6	5.9	43.0	43.08
14.	2.6	6.1	44.0	44.08
15.	2.6	6.2	45.0	45.08
16.	2.6	6.2	45.0	45.08
17.	2.6	6.2	45.0	45.08
18.	2.6	6.3	46.0	46.07
19.	2.6	6.4	47.0	47.07
20.	2.6	6.4	47.0	47.07

EXPERIMENTAL DATA

Cut Number 13 : Tap Water

Diameter of Rock Before Cut : 8.327 inches

Diameter of Rock After Cut : 8.323 inches

	X (Lbs)	Y (Lbs)	Z (Lbs)	F_N (Lbs)
1.	3.3	6.1	46.0	46.12
2.	3.5	6.3	46.0	46.13
3.	3.4	6.2	45.0	45.13
4.	3.4	6.0	43.0	43.13
5.	3.5	6.0	43.0	43.14
6.	3.5	6.1	43.0	43.14
7.	3.6	6.0	42.0	42.15
8.	3.6	5.9	41.0	41.16
9.	3.6	6.0	42.0	42.15
10.	3.6	6.0	43.0	43.15
11.	3.5	6.0	43.0	43.14
12.	3.5	6.3	45.0	45.14
13.	3.5	6.3	45.0	45.14
14.	3.4	6.4	47.0	47.12
15.	3.5	6.5	48.0	48.13
16.	3.6	6.6	48.0	48.14
17.	3.6	6.6	48.0	48.14
18.	3.6	6.6	49.0	49.13
19.	3.6	6.8	50.5	50.63
20.	3.6	6.8	50.5	50.63

APPENDIX III

PHOTOGRAPHS OF THE WORN DIAMOND

PLAN

PROFILE

MAGNIFICATION FACTOR 59X

Photographs of Worn Diamond After Second Run

PLAN **PROFILE**

MAGNIFICATION FACTOR 59X

Photographs of Worn Diamond After Twelfth Run

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VITA

BOKKA NARASIMHA RAO

Candidate for the Degree

MASTER OF SCIENCE

THESIS: The Effect of Chemical Additives on Cutting Forces and Rate of Wear of Natural Diamonds.

MAJOR FIELD: Mechanical Engineering

BIOGRAPHICAL:

Personal Data: Born June 13, 1952 at Secunderabad, Andhra Pradesh, India.

Education: Graduated from Nagarjuna sagar Engineering College, Osmania University. Hyderabad, India. Received a B.E. Degree in Mechanical Engineering from Osmania University in 1974. Completed requirements for the M.S. Degree in Mechanical Engineering in January 1978.

THE EFFECT OF CHEMICAL ADDITIVES ON CUTTING FORCES AND RATE OF WEAR OF NATURAL DIAMONDS

by

BOKKA NARASIMHA RAO

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ABSTRACT

The effects of surfactant solution Aluminum Chloride on diamond wear rate while cutting granite rock were investigated. The cutting forces were recorded continuously on a specially built dynamometer.

The experimental results revealed that the diamond wear rate attains a minimum and the cutting hardness a maximum at the Aluminum Chloride concentration level of 3×10^{-6} Molar. It has been concluded that both the objectives, minimum wear rate and maximum penetration rate cannot be achieved at the same time, and hence some compromise should be sought between these two objectives which will optimize the total drilling operation.