FRICTION POWER APPROACH FOR THE EVALUATION OF WEAR IN CENTRIFUGAL SLURRY PUMPS

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ABSTRACT:

An approach for the prediction of erosive wear in centrifugal pump impeller handling dense slurries is presented in this paper. In this particular case of high slurry concentration flow, the mechanism of wear by friction is assumed to be a predominate mechanism. The model neglects the effect of wear by particles impingement,also it is assumed a uniform velocity pattern and constant concentration. An order of magnitude calculation is presented in this stage of research.

The erosion rate is measured in a centrifugal slurry pump impeller. Two different impellers were considered. The erosion is measured by the reduction in the impeller wall thickness. The ultrasonic technique was used in the wall thickness measurement. The tests were run with constant concentration 30% by volume and constant speed.

The results show that an order of magnitude of wear may be predicted from the friction power model. The erosion rate is not uniform, and dependent on the velocity pattern inside an impeller channel. The results show also that in order to present a more accurate prediction of wear propagation in the centrifugal slurry pump impeller, the deformed velocity pattern must be considered in the calculation.

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INTRODUCTION:

The erosive wear in hydraulic machinery handling slurries is of a great importance, due to its practical application in areas such as, derdging, hydraulic transportation of solid materials by pipe lines. A literature review of abrasive wear in hydraulic machinery is presented by Truscott [1]. It show that most of the work is covering the wear tests on materials properties and some service experience on hydraulic machinery.

The expression of abrasive power is presented by Bovet[2], considering the wear is mainly due to the velocity acting on the particle in a liquid flow. This is resulted in wear of scouring type. Recently Roco et al [3] have presented a theoritical model attributed the wear to the combination of three different mechanisms; random, directional impingement and wear by friction(supported load). Tuzson [4] has prsented a model for dense slurry assuming a sliding bed type of flow pattern and neglects the effect of turbulent diffusion of slurry particles. In fact the modeling effort is hurt by the complex nature of this type of flow which is non-newtonian, and Bingham plastic at high concentration.

different groups; the first is concerned with the study of the flow hydrodynamic and the resulted erosion mechanism, the second is concerned with the materials properties and failure mechanisms(5). Both research groups are interdependent, since the failure mechanism is a result of the erosion mechanism.

The experimental investigation on model slurry pumps are rare. The few experimental results show that the wear is influenced by concentration, solid particle shape and velocity.

There are two methods used currently in evaluating wear experimentally; the first is the weight loss method, the second is the depth of penetration method. The first method gives a global view of erosion. The second method gives the detailed pattern of erosion. Both methods are long and time consuming since for every point the machine should be dismatelled and the impeller inspected then re-installed. To avoid this difficulty, the ultrasonic wall-thickness meter is proved to be adequate [6] in measuring absolute values of wear in centrifugal pumps.

The objectives of this investigation are to present experimental results concerning the wear in centrifugal slurry pump impeller, then to present a model to predict an-order of magnitude value of wear propagation using the friction power approach.

FRICTION POWER CONCEPT:

The concept of energy has motivated many researchers[2],[3] ,[5] for the under-standing of the erosion process. A part of the energy dissipated in the process during solid particle impingement is manifested by weight loss of materials. Many theories and methods have been proposed to explain the erosion process. The erosion process in hydraulic machinery is connected to both, the characteristics of flow as velocity, concentration, and physical characteristics of eroded material as hardeness, tensile strength... The volume loss mechanism is dependent on the erosion mechanism, which is directly connected to the hydrodyamic flow characteristics. The erosion mechanism may be presented as:

a- Scouring (Wear by friction).

b- Directional, random impingement.

One of the various mechanisms proposed for the material removal is the wear by deformation and cutting, which may be siutable to explain the wear by friction. The wear due to directional and random impingement may be resulted from the following processes:

a- Plastic flow and lip formation.

b- Extrusion of material and melting.

In high concentration, the mechanism of erosion due to friction is more likely to appear; in medium low concentration, both mechanisms are present. In directional and random impingement the damage is considered as a results of the impinging particles kinetic energy, which is partially absorbed by the materials surface. This leads to the concept of materials energy absorption property, which is presented by Rao et al [5].

Bovet [2] has presented the abrasive power concept to evaluate the wear in hydraulic machinery. This relation may be written on the following form:

$$\text{Abrasive power} = \mu \frac{V_p}{D} (\rho_p - \rho_f)\, w^3 \qquad (1)$$

Where :

μ Couloumbs friction coefficient, sand-metal.

V_p Solid particle volume

ρ Density.

D Raduis of curvature.

W Soild particle velocity.

Relation (1) may be modified after reference [7] to include the effect of concentration, and to overcome the difficulty of measuring the particle velocity. This modified expression may be written on the following form:

$$\text{Abrasive power} = \mu \frac{V_p}{2 R_2} (\rho_d - \rho_f)\, C_{r1} \qquad (2)$$

The expression of equation (2) relates the erosion to the characteristics of the particle, as volume and shape.

In the following analysis the erosion will be treated as a results of scouring mechanism, which is more likely to appear in high concentration [5]. Figure (2) presents the forces envolved in the process. The friction force is considered to be the predominate force, It is assumed that no pressure forces are present, also assume that the flow fills the entire impeller passages, the velocity is uniformly distributed and consequently the concentration. Consider the elementary volume as in figure (2), the volume can be written on the following form:

$$dv = R\, d\theta\, H\, dR \qquad (3)$$

The mass of the elementary volume dV may be written on the following form:

$$dM = R\, d\theta\, H\, dR\, \rho_d \qquad (4)$$

With

$$\rho_d = C\, \rho_s + \rho_f\, (1-C) \qquad (5)$$

The friction force is obtained by multiplying the mass of slurry particles contained in the elementary volume dV, by the radial component of the acceleration and the coefficient of friction. Thus the friction force may be written on the following form:

$$\Delta F = dV\, \rho_d\, a_r\, \mu \qquad (6)$$

With

$$a_r = \frac{d^2 R}{dt^2} - R\left[\frac{d\theta}{dt}\right]^2 \qquad (7)$$

The total power dissipated from friction force is obtained by multyplying equation (6) by the mixture velocity Cr_1^1:

The friction power $\Delta \varphi = dV\, \rho_d\, a_r\, \mu\, C_r$ (8)

Then total power may be obtained by integrating equation (7), A double integration with respect to R and O may be performed on the following form:

$$\varphi = \int_0^{2\pi} \int_{R_1}^{R_2} R\, \rho_d\, C_r \frac{d^2 R}{dt^2}\, R\omega^2 \qquad (9)$$

The term $d^2 R/dt^2$ may be neglected compared to $R\omega^2$, since the through velocity is approximately constant. The continuity equation may be written on the following form:

$$R_1\, d\theta\, H\, C_{r1} = R\, d\theta\, H\, C_r \qquad (10)$$

Substitute equation (10) in (9), then performing the integration with the following assumptions: neglect $\omega^2 R1$ with reference to $\omega^2 R_2$, and considering both sides of the impeller, the friction power dissipated is written on the following form:

$$\varphi = 2\pi \; R_1 \; H \; C_{r1} \; \rho_d \; U^2_2 \mu \; \text{N.m/s} \tag{11}$$

In the derivation of the above expression, the concentration is considered homogeneous and constant through out the impeller passage. In this stage of research an order of magnitude is only required. To go deeper inside, the concentration distribution connected to the actual velocity pattern may be considered.

EXPERIMENTAL APPARATUS AND INSTRUMENTATION:

The experiments of this part of research program were under taken using the hydraulic circuit of paderborn university in Meschede. The circuit consists of 125 mm inside diameter loop 25m total length. A model dredge pump is connected to the circuit. The pump is equipped with a highly wear resistant housing to concentrate the wear on the impeller and to avoid change of the pump characteristics due to the volute wear.

The pump is driven by a speed controlled direct current motor of 55 KW. The data are collected using a multi-channel processing system with printer. A magnitic flow meter is used to measure the flow rate. The concentration is measured by radiometric density meter. A differential pressure transducer is used to measure the pump pressure.

The ultrasonic wall thickness meter is used in measuring the depth of penetration. This technique has been developed in Paderborn University hydraulic laboratory [6]. It is proved to be a simple and quick, it provides absolute wall thickness measurements from 0 to 70 mm. The solid material is sand of 0,990 mm mean diameter.

The pump is dismantelled every five hours of continuous operation. The impeller is weighed and then re-installed. The thickness of vanes are measured at 8 points per vane. A total number of 32 measurement points in the impeller disc and shroud were performed, 16 points on the disc and the rest on the cover, also half of the measuring points were located at impeller inlet, the rest were located at impeller exit. The impeller is equipped with four vanes. The pump was running at constant speed of 700 RPM, The concentration were ket constant at 30% by volume.

RESULTS:

The presented results are preliminary results, since the work is still going on. In this stage of research it is intended to test the friction model validity, so that the follow up research may be continued. Only one concentration was considered at constant running speed. Two diffrent impellers of different materials were used.

The pump characteristics at different operating speeds and 30% concentration by volume are presented in figure (4). The weight loss results are presented in figures (5), (6). Figure (5) presents the cumulative weight loss (CWL) versus the continuous operating time. Figure (6) presents the weight loss rate versus the continuous operating time, the weight loss rate is defined as follows:

$$WLR = \frac{\Delta WL}{\Delta t} \qquad (12)$$

The depth of penetration is presented in figure (7). These measurements were performed using ultrasonic wall thickness meter on both walls of the impellers parts; disc, shroud, vanes, only representatives measurements are presented. The presented measurements cover the vanes pressure side and suction side. The points are located on the disc inlet and exit.

The relation between the abrasive power as presented in equation (2) is presented in figure (8). The abrasive power in N.m/s and the wear rate in grammes per hour. Figure (9) shows the relation between the friction power expression as presented in equation (11) in kN. m/s and the erosion rate in grammes per hour.

DISCUSSION:

Since there are many factors involved in the erosion process it is convenient to keep some of these factors constant in order to permit the evaluation of the rest. In order to consider the wear by friction it is important to run the tests at high concentration. This is to reduce the effect of erosion by solid particle impingements. Two impellers of different materials were tested. Since the objective was not to study the material erosion properties, all the experimental points were put together on the same curves. This may explain why the experimental points of figures (8), (9) are scattered. The reason of testing two impellers is to check the repeatability of the characteristics of CWL versus, time curve and WLR versus time curve. Figure (5) shows a typical characteristics of weight loss curve characterized by an incubation period. Figure (6) shows also a typical characteristics of erosion curve characterized by an incubation period then a period of reduced or constant wear rate. It may be noticed that this nature of erosion wear which has been observed by other investigators [7] may attribute the material removal mechanism to low cycle fatigue type failure. Figure (7) confirms the nature of erosion curves of figures (5), (6), it has the same characteristics as incubation period followed by an increased erosion rate and constant erosion rate. Two observations may be drawn from figure (7):

a- There is a noticeable difference in erosion between inlet and exit, the inlet part exhibits a high erosion rate compared to the exit. This may be attributed to the change of direction encountered in the impeller eye from axial to radial direction. Also in an impeller passage occurs a decelerating flow resulted in a relatively higher flow velocity at inlet than exit.

b- The erosion in suction side of the vanes is larger than the erosion in the pressure side of the vane.

The above mentioned results indicate the importance of considering the jet-wake flow pattern in the evaluation of velocity distribution. The suction side is corresponding to the wake region of high relative velocity compared to pressure side. The difference in erosion between the two sides may be attributed to this nature of flow which exhibits a difference in the velocity between the passages side walls. This change will also provoke a change in local concentration distribution, Since in this part it was intended only to test the friction model, a global values of erosion were taken. An accurate prediction of wear sbould include the actual velocity distribution and the corresponding concentration distribution.

The concept of friction energy is presented in figures (8), (9). To be precise it is the solid particle energy which is presented in the abrasive power expression of equation (2). In equation (11), it is the the energy of the solid mixture moving in the impeller channel. Since an order of magnitude is only required in this stage, the vane erosion is omitted due to its small surface area compared to the passage area. The inclusion of vane's erosion in equation (11) will result in an additional constant quantity. Figures (8), (9) also show that both expressions of abrasive power and friction power are similar in characteristics since both attributed the erosion to be of a scouring type.

The advantage of friction power expression is its relation with WLR which is of a linear form.

CONCLUSION

Based on this investigation the following conclusions and recommendations are offered:

1- The ultrasonic wall-thickness meter is a precise and simple method which gives direct and absolute measures of wear.

2- The erosion in an impeller channel is not uniform, in the inlet the erosion is higher than exit, also suction side has higher wear rate than pressure side. This may be explained by the deformed velocity distribution pattern inside the the impeller channel.

3- The friction power approach is adequate for the prediction of an order of magnitude value of wear rate in centrifugal slurry pump impeller.

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NOMENCLATURE

a	mixture acceleration	m/s^2
C	mixture transport concentration	
C_r	mixture velocity (radial component)	m/s
d	soild particle diameter	m
D	Radius of curvature	m
H	impellers height	m
F	friction force	N
m	mass	Kg
R	impellers radius	m
t	time	s

U	tangential velocity	m/s
V	volume	m^3
W	soild particle velocity	m/s

Greek letters

	friction power dissipated	N.m/s
	angular displacement	
	couloumbs friction coefficient, sand-metal	
	angular velocity	

Subscripts

d	mixture
f	fluid
r	radial component
o	tangential component
p	solid particles
1	inlet
2	exit

REFERENCES

1. Truscott, G.F., " A Literature Survey on Abrasive Wear in Hydraulic Machinery". Wear vol. 2o, 1972 pp.2 9650.
2. Bovet, T., "Contribution to the Study of the phenomenon of abrasive erosion in the Realm of Hydraulic Turbines". Bull. Tech. Suisse Romande 84(3')1958 pp.3749
3. Tuzson, J.J. "Laboratory Slurry Erosion Tests and Pump Wear Rate Calculations", J. Fluid Engineering Trans ASME Vol. 1o6, June 1984 pp. 135-140.
4. Roco, M.C., Nair, P.,Addie, G.R., and Dennis, J., "Erosion of concentrated Slurries in Trubulent Flow".J.of Pipe lines Vol.4, pp.213-221 ,1984.
5. Rao,P.V. and Buckly, D.H., "Solid impingement Erosion Resistance fo ductile Metals". Liquid Solid Flows and Erosion Wear in Industrial Equipment, Pub. ASME, FED vol. 13: pp 50-62 1984.

6. Wiedenroth, W. "The Evaluation of Wear of Pipes Elbows and Centrifugal Pump components". Liquid Soild Flows and Erosion Wear in Industrial Equipment, Pub. ASME, FED 13: Vol. 13:, pp 78-83, 1984.

7. Rayan, M.A., and Shawky, M., The evaluation of Wear in Centrifugal Slurry Pump Impeller" International Symposium Workshop on Particulate and Multi-Phase process, Miami Florida, April 1985.

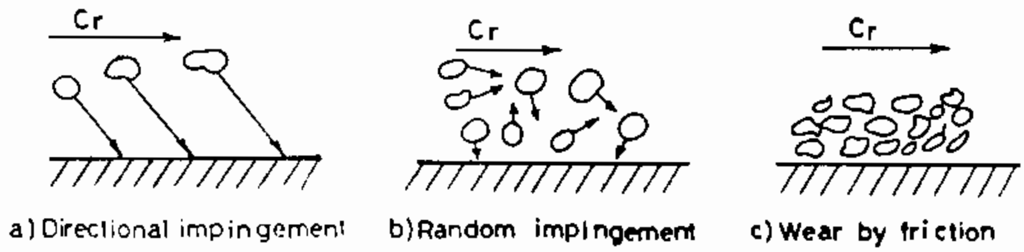

Figure 1. The different mechanisms which causes erosion.

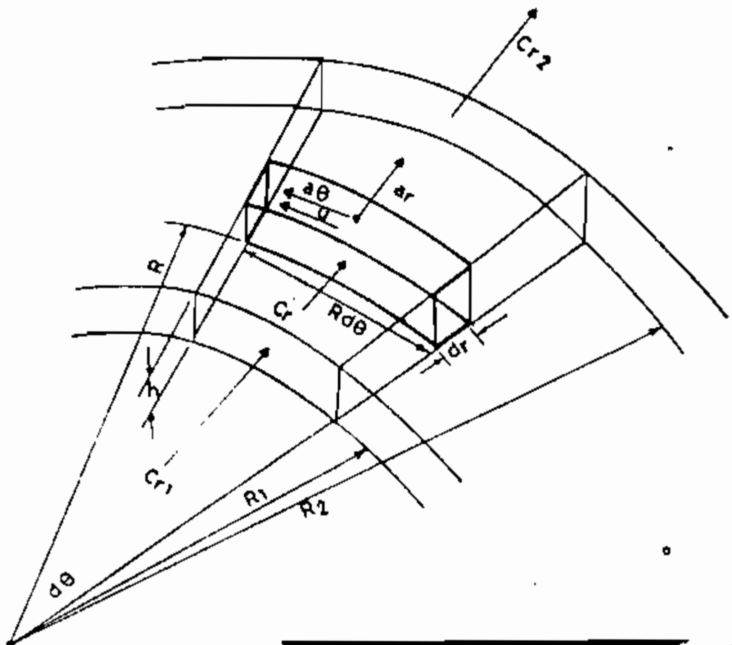

Figure 2. Schema of velocities and accelerations involved in the friction model.

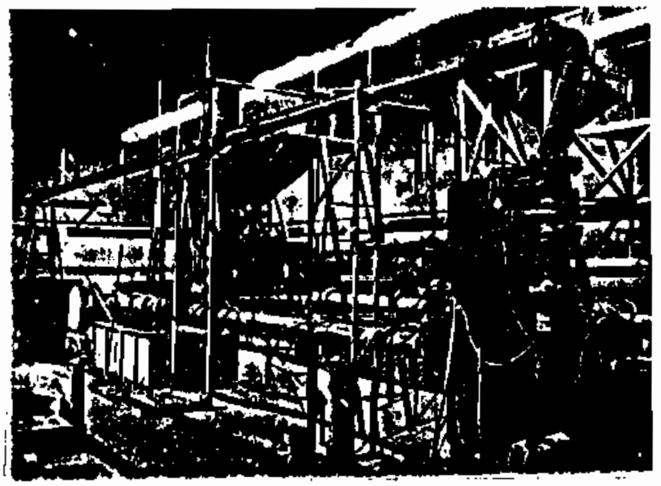

Figure 3. The test loop in Meschede.

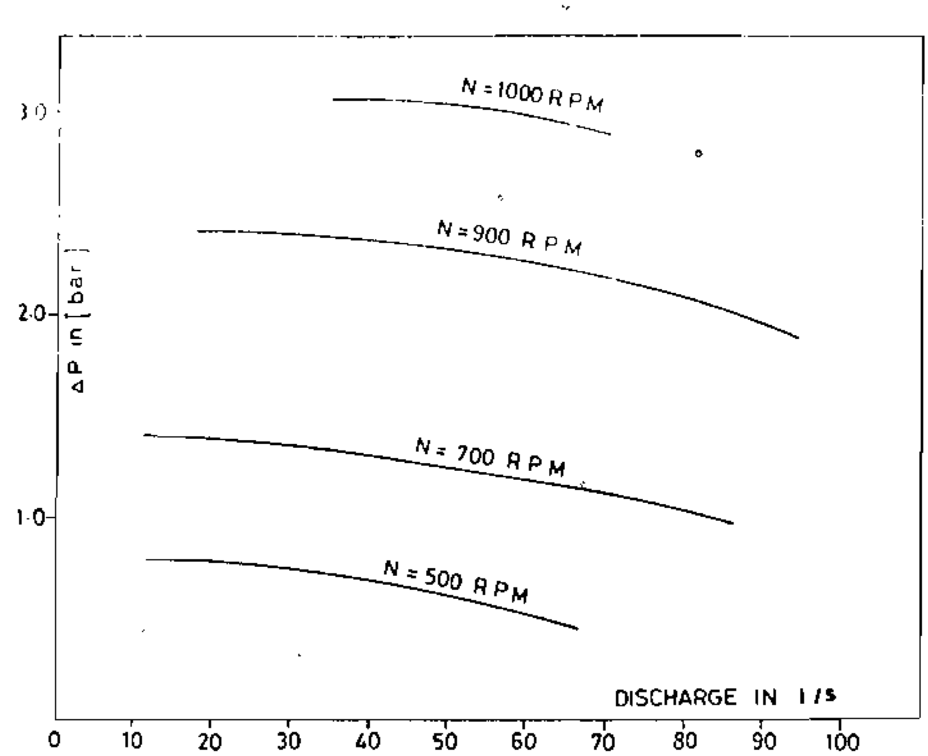

Figure 4. Pump characteristics at 30 % concentration .

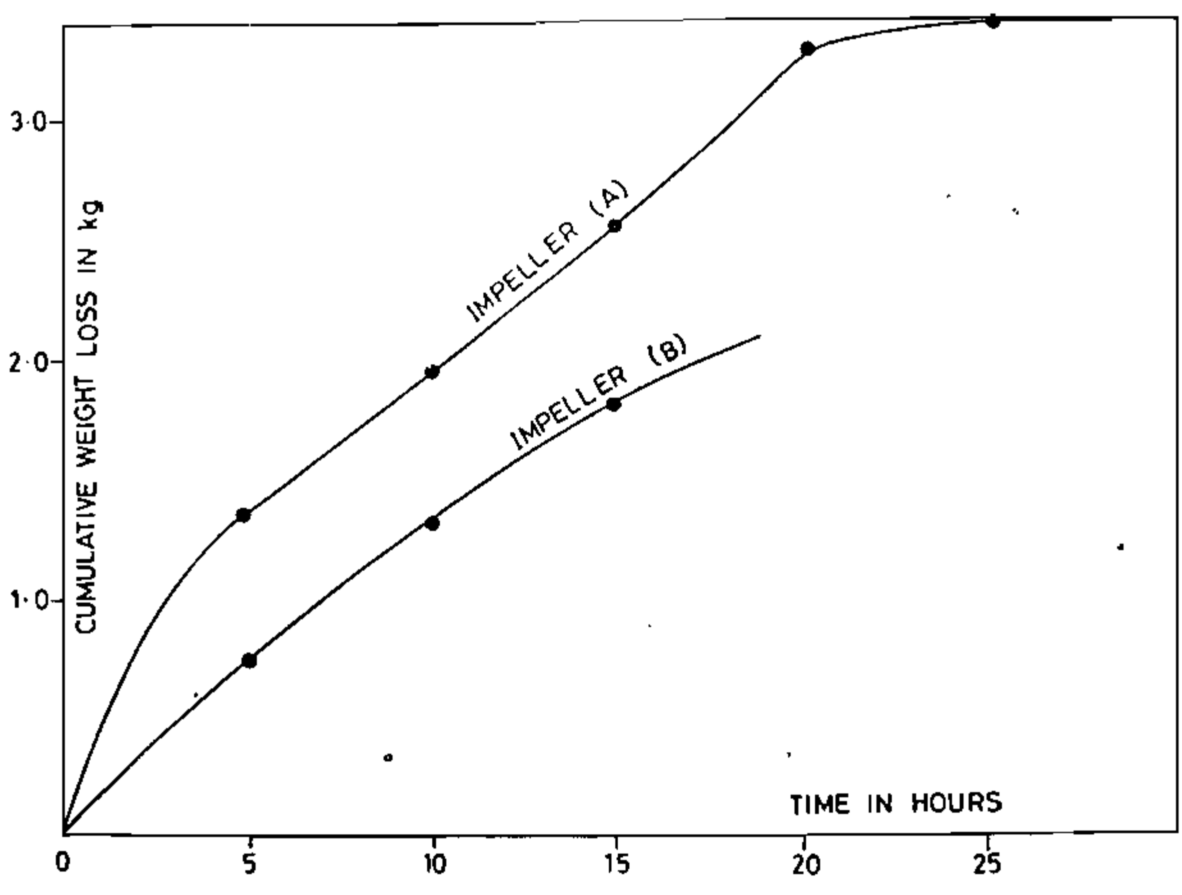

Figure 5. Cumulative weight loss (CWL) versus time.

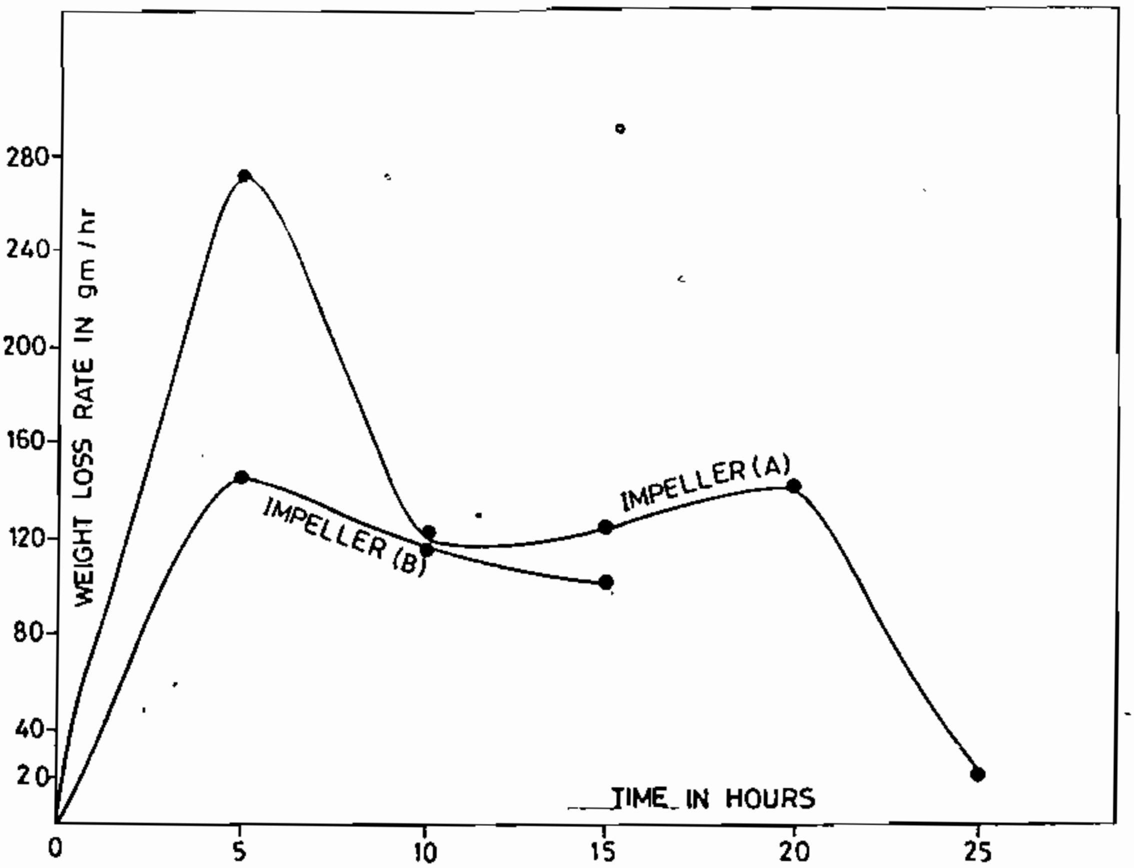

Figure 6. Weight loss rate (WLR) versus time.

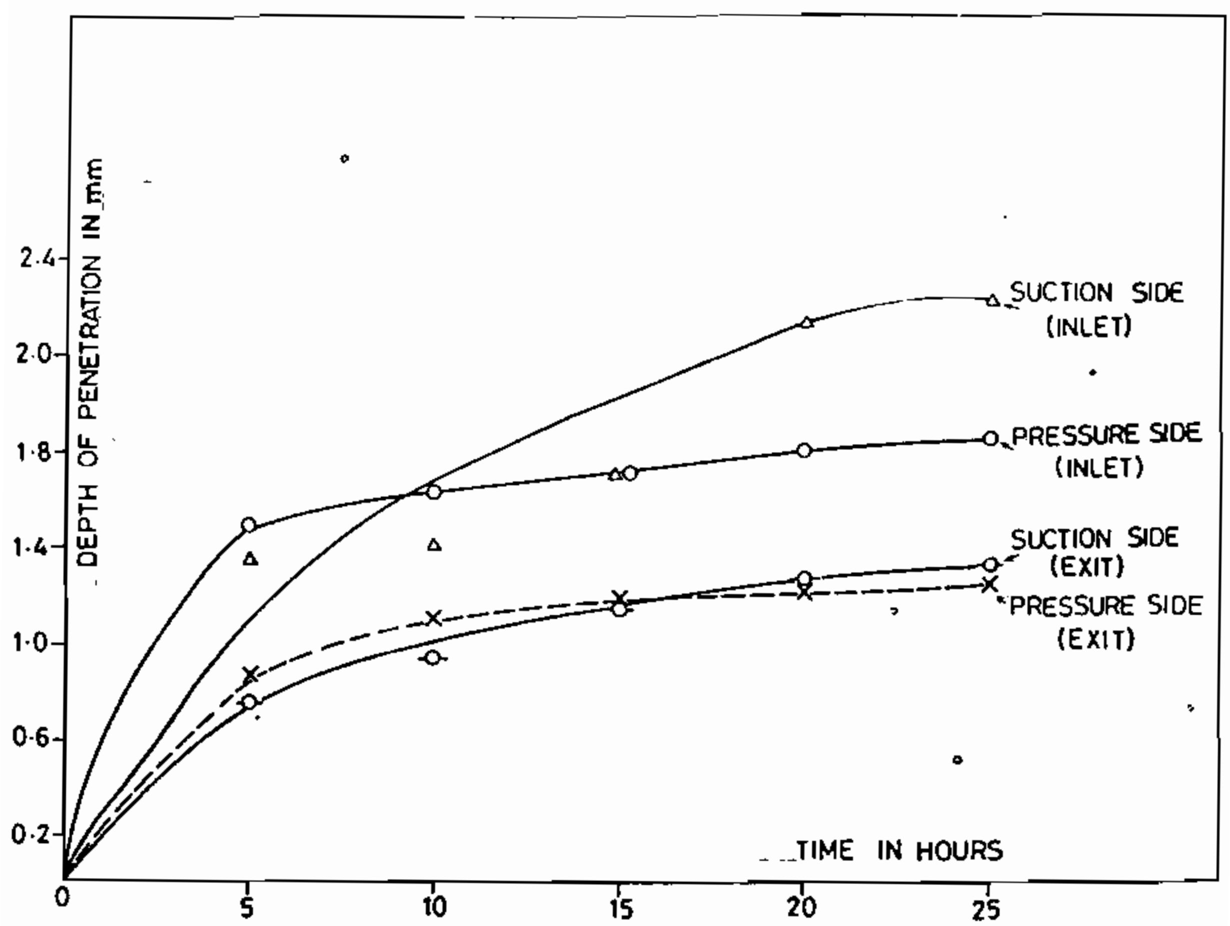

Figure 7. Depth of Penetration versus time

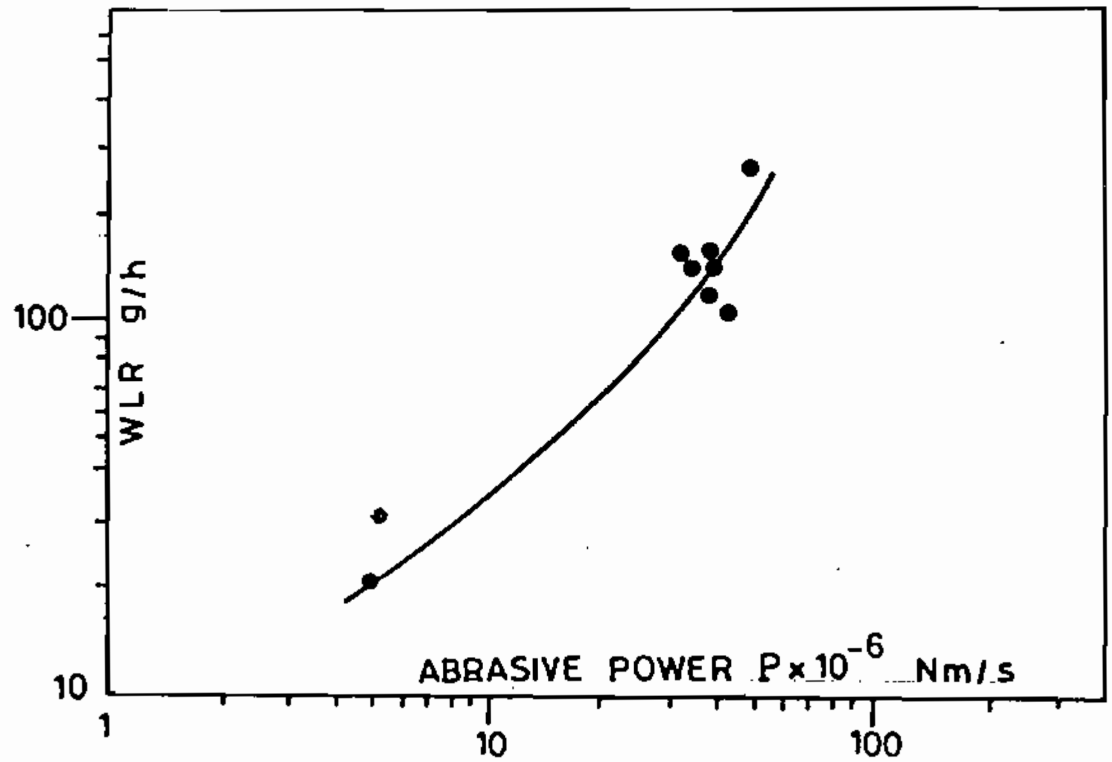

Figure 8. Abrasive power versus weight loss rate(WLR).

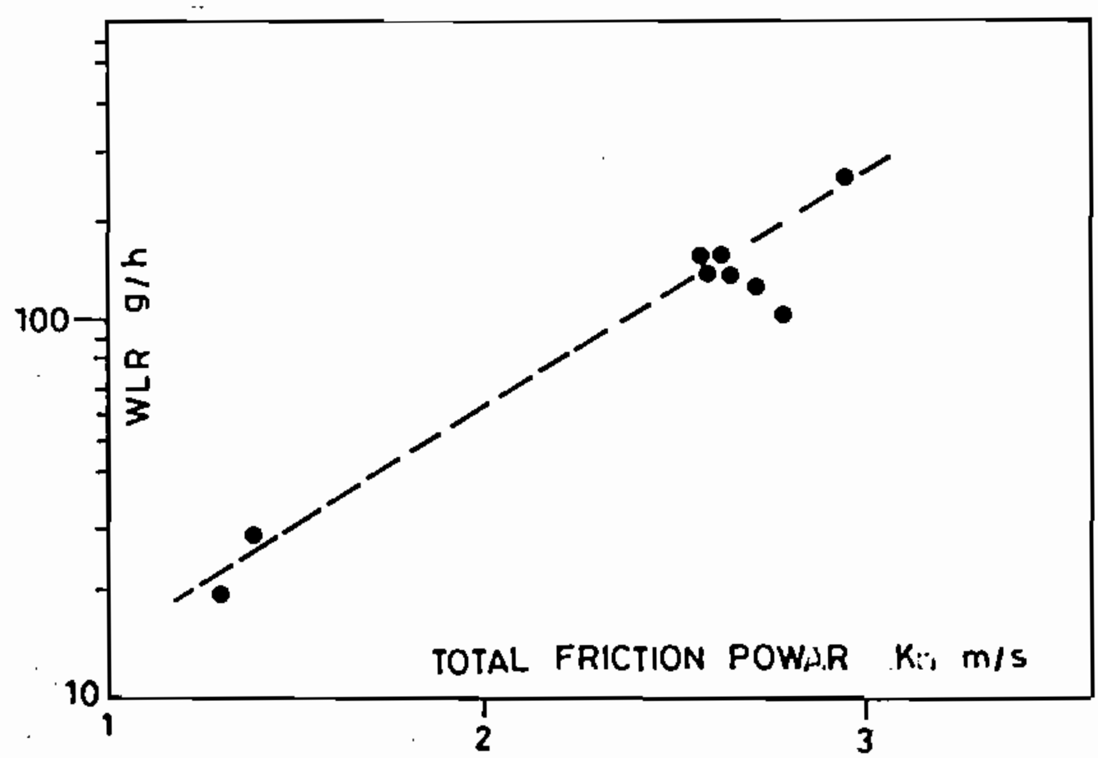

Figure 9. Friction power versus weight loss rate (WLR).