RESEARCH ARTICLE OPEN ACCESS

Study the Effect of Speed, Impinging Angle and Slurry Concentration on Erosion of Stainless Steel -316L

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ABSTRACT
The main aim of the present research work is focused on the influence of key parameters, such as; impinging angle, rotational speed, and concentration of sand in water on the behavior and characterization of erosion process of stainless steel-type 316L. In the current study, special erosion testing machine has been designed and constructed locally conforming to standard specifications. It was observed that, at a given impinging angle, concentration, and rotational speed, the variation of volume loss with accumulative distance is generally linear and the erosion rate has been determined from the least square fit of the variation of erosion volume loss with accumulative distance. It was found that increasing the impinging angle increases initially the extent of erosion rate and reach maximum rate at angle of 60o. However, at higher impinging angle, there is a significant decrease in the erosion rate. The erosion rate increases considerably with increasing rotational speed from 550 r.p.m. to 1520 r.p.m. . It was also observed that increasing the concentration of sand particles to about 30 wt.%, increases the erosion rate. In all cases, the erosion rate is near a double after inserting the flow baffles compared to those cases without baffles, and has been attributed to increase of particles rotation and vortices in the flow.

Keywords: erosion; impinging; concentration; vortices.

Date of Submission: 02-04-2024 Date of acceptance: 13-04-2024

I. Introduction:

The process of erosion can be defined as the removal of material due to successive loss from the surface of solid material. Erosion can occur under four different conditions: firstly, due to mechanical interaction between the surface and the fluid containing particles with higher hardness than the material; secondly, due to the impact of liquid droplets on the material surface; thirdly, as a result of the flow of hot gases over the material surface; fourthly, due to cavitations occurring on the material surface. Erosion is a serious problem facing industrial advancement, occurring in both ferrous and non-ferrous metals. Carbon steel is more susceptible to erosion than other metals due to its numerous engineering applications and industrial uses, making it susceptible to various environments. Erosion occurs, for example, in automobiles, machinery, and equipment, or it may occur in metal pipes used in pipe manufacturing, bends, and tanks. It also occurs in turbine blades for gas, steam, and water turbines, pipelines, industrial fuel processors, chemical industries, cement manufacturing facilities, power plants, mill parts, compressor pump parts, and coal ash dischargers. Consequently, researchers have focused on studying the loss occurring on metal surfaces to prevent it or at least attempt to reduce it and preserve metals from erosion damage. There are several techniques for measuring erosion rate, including the use of optical microscopy, photography, observation of surface changes, and reliance on knowing its response to erosion behavior, volume loss method, and weight loss method. Researchers who have focused on studying this area include Dasgupta and his colleagues who studied the effect of sand concentration in water on the erosion rate of steel. The study examined two types of steel differing in chemical composition in terms of carbon content and other components and thus differing in hardness and other properties. The mixture used in the experiment consisted of water and sand, and the study was conducted for two types of steel that differed in chemical composition in terms of carbon content and other components, and thus differed in hardness and other properties. The mixture used in the experiment consisted of water and sand, and the study was conducted for two types of steel that differed in chemical composition in terms of carbon content and other components, and thus differed in hardness and other properties. The study concluded that the highest erosion rate occurs at a speed of 111 rpm, and that the higher the sand content, the lower the erosion rate. Additionally, Jha and colleagues studied the effect of impact angle and rotational speed on erosion behavior for aluminum alloy (Grade 1900). Samples were taken from the alloy with dimensions of 3 mm thickness, 25 mm width, and 25 mm length. A device for measuring erosion was used, consisting of a container and sample holder at different angles, and a motor to rotate the samples at different speeds. The samples were fixed at different angles and immersed in sand and water in the device's container. The selected angles in the experiment were 90°, 45°, 30°, and 0° for the direction of rotation speed, and the samples were rotated at different speeds of 011, 111, 511, and 011 rpm. The weight loss method was used to measure the erosion rate, and quartz sand with a hardness of HV 911 was chosen for the experiment, with particle sizes ranging from 300-200 μm and a sand concentration in water of approximately 40 wt.%. Surface changes of the alloy were observed using scanning electron microscopy. The researchers concluded that the erosion rate of this aluminum alloy increases with increasing mounting angle, showing a direct relationship between them, while the erosion rate increases logarithmically with increasing rotational speed. Moreover, Deng and colleagues studied the effect of particle rotation on erosion rate for two types of particles, the first being spherical glass beads and the second being angular glass powder. The study compared their effects on the erosion of heat-treated EN 24 steel. They observed that angular particles give a higher erosion rate than spherical particles, and the sample area was 0.5 mm2 with a thickness of 0.5 mm. The collision speed of the particles with the surface was 25 m/s at drop angles of 62.5°, 45°, 32.5°, and 20°. Additionally, researcher Roger Francis studied the erosion behavior of four alloys: 316L stainless steel, 22Cr Duplex, Alloy 105, and Zeron 100 stainless steel. Using weight loss technique, the amount of sand in the water was approximately 10 mg/l, and the speed was 30 m/s. The researcher concluded that the highest weight loss was for 316L S.S. alloy, followed by 22Cr Duplex alloy and Alloy 105, while the lowest weight loss was for Zeron 100 alloy. This study investigated the nature and behavior of erosion for 316L stainless steel and determined its response to erosion and the effects of the variables involved in the research topic, including impact angle, rotational speed of the models, and concentration of the mixture in the erosion rate. Additionally, an initial study was conducted on the effect of flow nature and vortices resulting from introducing obstacles in the basin on the erosion rate of this alloy.

Practical Aspect:

This part of the research includes four stages of practical procedures necessary to determine the erosion rate of stainless steel through laboratory experiments. It involves designing and manufacturing a special device for rotating models in the medium consisting of water and sand to induce erosion, preparing the specific environment in which erosion will occur for this type of stainless steel, preparing the alloy and cutting it into the required shapes and dimensions, and taking measurements specific to the experiments to determine the erosion rate. This device, as shown in Figure 1, consists of a model holder, which is a circular disc made of Teflon material with holders for two models made of aluminum alloy, as depicted in Figure 2, designed and manufactured to hold and secure the models at different angles.

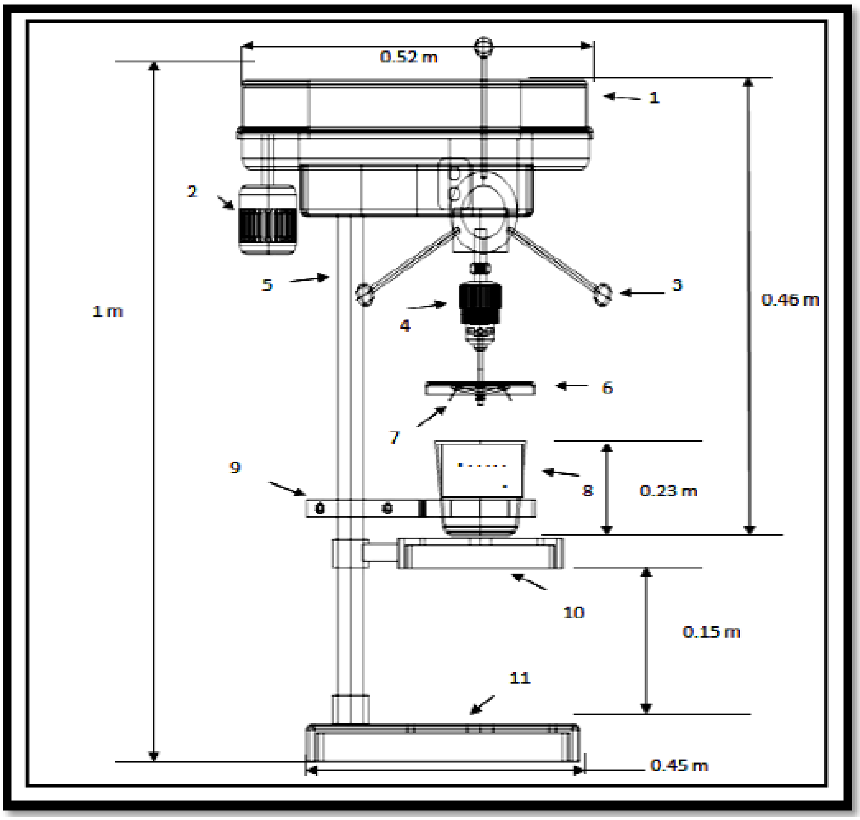

Figure 1: A schematic diagram of the erosion study device designed in the current research; 1 speed conveyor cover, 2 electric motor, 3 rotating shaft arm, 4 rotating shaft, 5 mounting shaft, 6 model holder, 7 model, 8 glass basin, 9 basin incubator, 10 basin base, 11 device base.

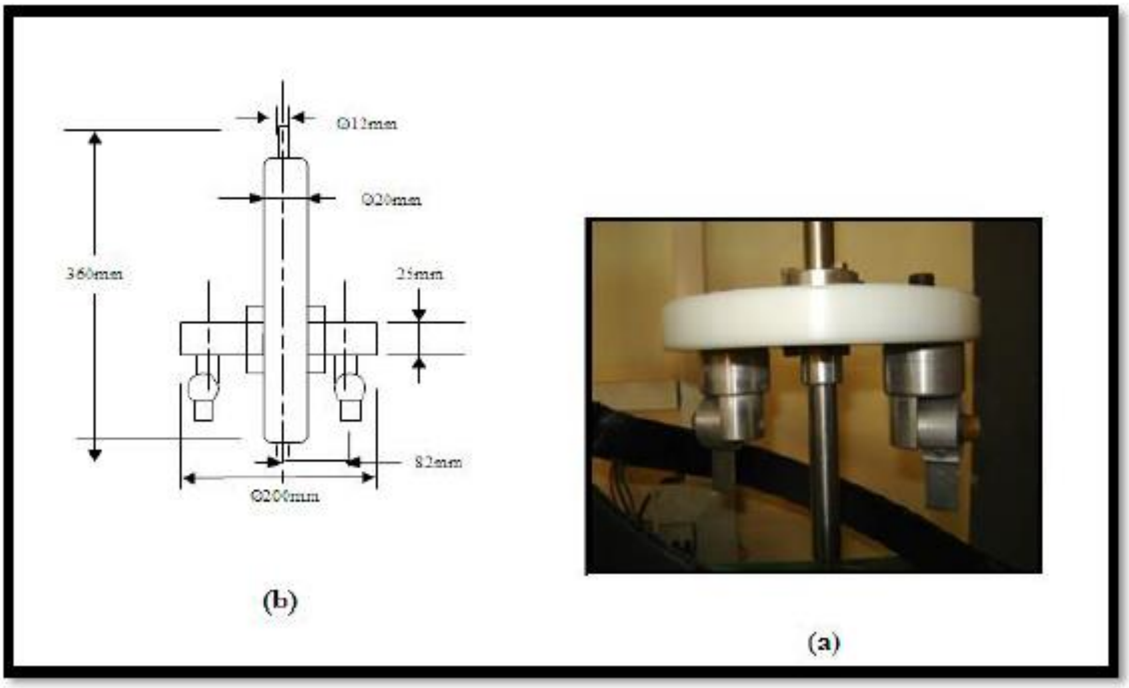

Figure 2: Model holder used in the current research (a) a photograph of the model holder (b) a schematic diagram of the model holder.

This model holder disc was mounted in a variable speed drill and rotated at different speeds. The other part of the device is the basin containing the erosion medium, made of heat and shock-resistant glass (Pyrex) with specific dimensions. The basin was also secured by a steel incubator to prevent movement during the experiment, and obstacle barriers were manufactured and installed in the basin.

As for the erosion medium, it consists of sand and distilled water. Water was taken from a distillation apparatus, and sand was obtained from civil engineering laboratories and sifted using special sieves to obtain the desired particle size. After obtaining the sand of the desired size, it was washed, purified from impurities and dust, dried, and examined under a light microscope, as shown in Figure 3. It was then tested in civil engineering laboratories to determine its specific weight, which was found to be 2.66, and to ensure its sulfate-free nature. Chemical analysis was also performed using X-ray diffraction to determine its basic components, as shown in Table 8

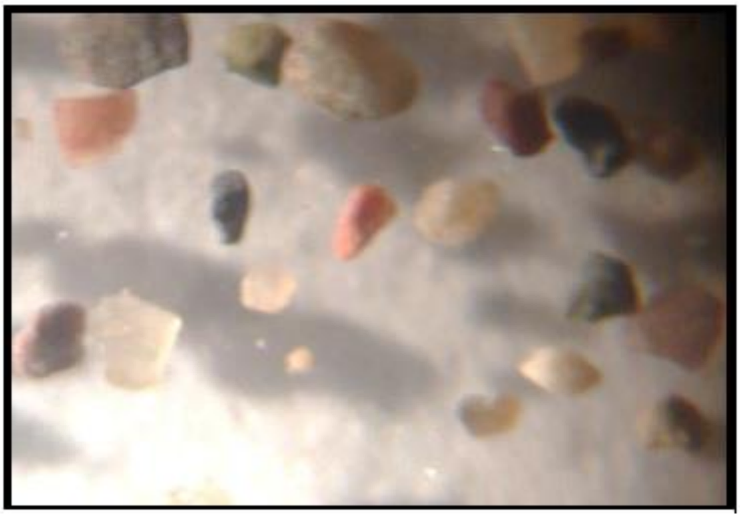

Fig (3) Microscopic images of the erosion sand used in the current research.

sand used in the current research. The selected material is stainless steel type 316L. The chemical composition of the alloy was examined to determine the proportion of common elements in its composition, as well as to observe its microstructure. It is known that this type of steel has a low carbon content (%1.138). The rest of the elements are indicated in
Its hardness was also tested using a hardness measuring device (Karl Kolb, Germany), and its value was found to be HV=209.

Subsequently, specific readings were taken using the weight loss method to determine the volume loss. This involved weighing the models after preparation and cutting to the mentioned dimensions, washing them with water, then using a special brush to wash them with acetone, and drying them using a model dryer. Then, they were weighed using a sensitive balance with a capacity of 0.081 g and an accuracy of 0.1 mg. All models were weighed and numbered before conducting the experiment. The models were then fixed in the erosion measurement device, and the experiment was conducted by operating the device for a certain period. Afterward, the models were removed, washed using the same method, dried, and weighed again to determine the weight loss, which is used to calculate the erosion rate. This erosion rate is influenced by several variables, including the solution concentration, temperature, impact angle, particle size, geometric shape of the model, rotation speed, properties of the particles, and model material properties, among others. In our research, we focused on four variables: impact angle, model rotation speed, slurry concentration, and barrier effects.

II. Results and Discussion:

To calculate the erosion rate, ten experiments were conducted for each of the mentioned variables (impact angle, slurry concentration, and rotation speed) and for both cases (with and without barriers) on two models from the specimens, with each experiment covering a distance of 5 km (approximately two hours and 50 minutes). The weight loss rate was calculated for each experiment, then divided by the density of the alloy, which was 7.99 gm/cm^3, to obtain the volume loss rate. A graph was plotted with the cumulative distance traveled, and the erosion rate was calculated by fitting the closest straight line representing the erosion rate. The experiments were conducted with an impact angle of 30°, a concentration of 20 wt.%, and a rotation speed of 550 rpm. Then, one of these three variables was changed while the others were kept constant to assess the effect of each variable individually, and ten experiments were conducted on the models to calculate the erosion rate.

The erosion rate obtained for the models without barriers was determined by considering the three variables to calculate the weight loss of the models, namely the angle of model fixation, slurry concentration, and model rotation speed. The experiments were conducted with an impact angle of 30°, a concentration of 20 wt.%, and a rotation speed of 550 rpm.

Effect of Impact Angle: Ten experiments were conducted at other angles (45°, 60°, 90°), and the weight loss rate was calculated. From this, the volume loss rate was calculated, as previously explained. These results were then represented in a graph shown in Figure (4).

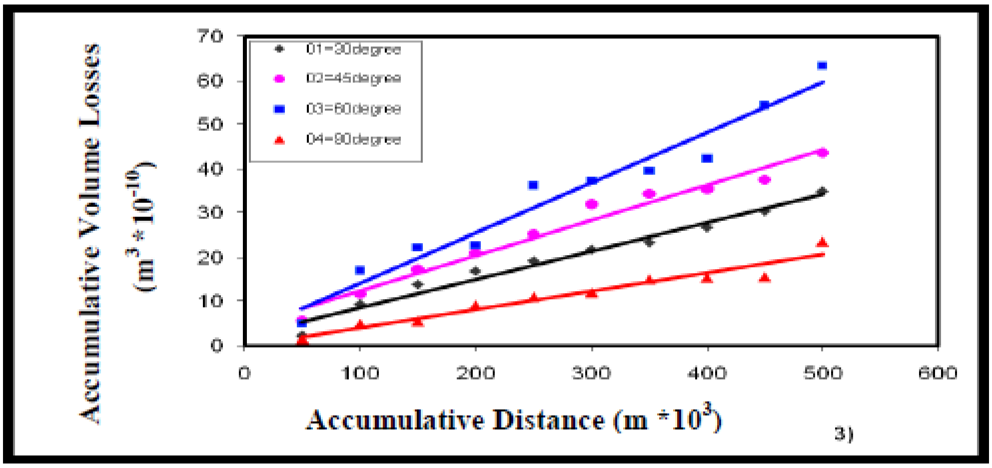

Figure (4) illustrates the variation in the volume loss with the distance traveled for four impact angles without barriers (concentration 20 wt.% and rotation speed 550 r.p.m.)

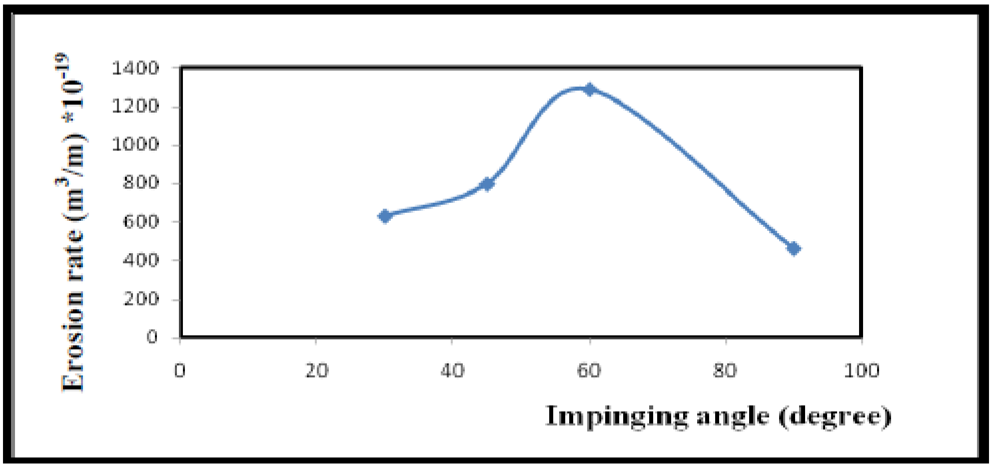

Figure (5) shows the variation in the erosion rate with the impact angle without barriers (concentration 20 wt.% and rotation speed 550 r.p.m).

As observed from the figure, the volume loss rate gradually and linearly increases with the cumulative overlapping distance at a 90° impact angle. The same trend is observed for the other three angles (30°, 45°, 60°), with a noticeable divergence of the drawn lines as the overlapping distance increases. The erosion rate was calculated from the compatibility value with the closest straight line for each selected angle, representing the erosion rate. Figure (5) illustrates the effect of changing the impact angle on the erosion rate without barriers, showing that the erosion rate begins to increase when changing the angle from 30° to 60°, then decreases at a 90° angle.

Effect of Concentrations: To investigate the effect of slurry concentration on the erosion rate, ten experiments were conducted at other concentrations (25 wt.%, 30 wt.%, 35 wt.%, 40 wt.%), and the weight loss rate was calculated. Similarly, the erosion rate was calculated from the compatibility value with the closest straight line for each selected concentration, representing the erosion rate. Figure (6) shows the effect of changing the concentration on the erosion rate without barriers. It illustrates that the erosion rate increases when changing the concentration from 20 wt.% to 30 wt.%, then decreases at the other concentrations of 35 wt.% and 40 wt.%, but with higher erosion rates than those without barriers.

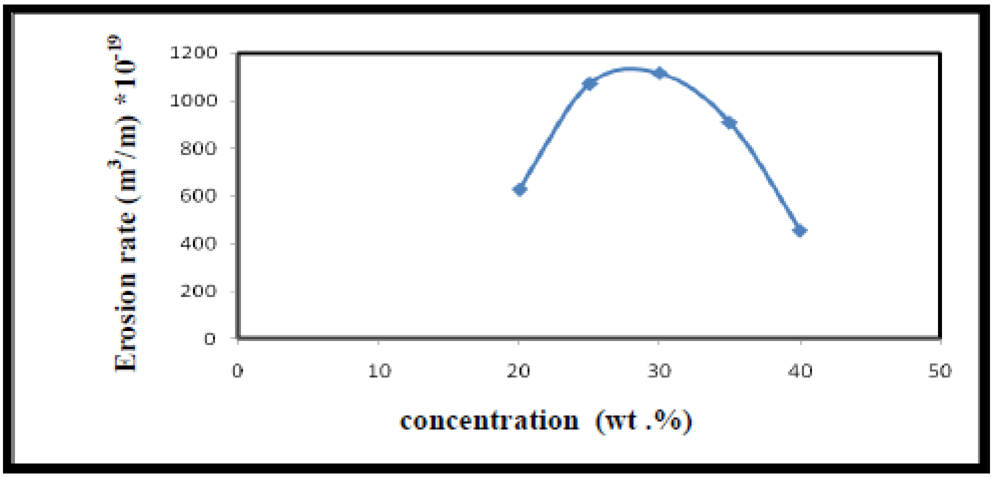

Figure (6) illustrates the change in the erosion rate with the rotation speed of the models without barriers (impact angle 30o and concentration 20 wt.%)

Effect of Model Rotation Speed: To investigate the effect of model rotation speed on the erosion rate, ten experiments were conducted at other speeds (910 r.p.m., 1520 r.p.m.), and the weight loss rate was calculated. Similarly, the erosion rate was calculated from the compatibility value with the closest straight line for each selected speed, representing the erosion rate. Figure (7) illustrates the effect of model rotation speed on the erosion rate without barriers, showing that the erosion rate increases with increasing rotation speed.

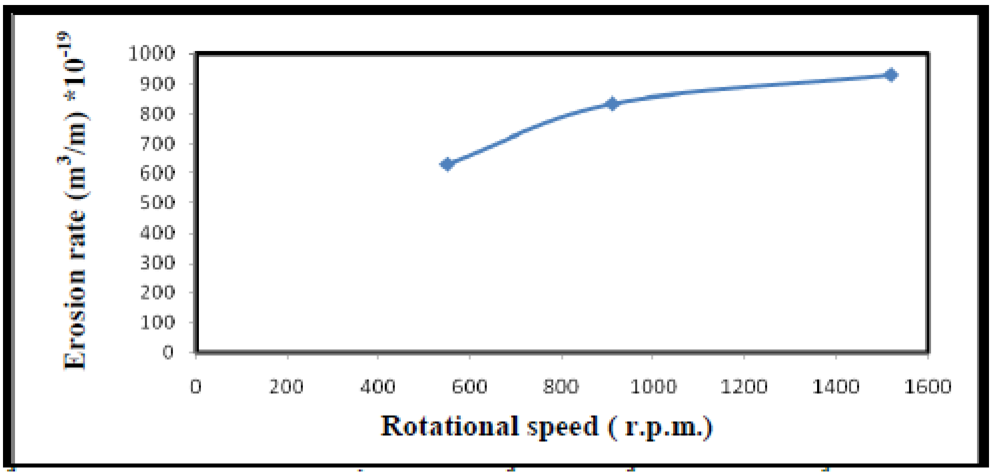

Figure (7) illustrates the variation in the erosion rate with the rotation speed of the models in the absence of barriers (impact angle 30° and concentration 20 wt.%)

Erosion Rate with Barriers: To study the effect of barriers on the erosion rate, the previous experiments (in the absence of barriers) were repeated with the presence of barriers, considering the same three variables for calculating the weight loss rate (angle of model fixation, slurry concentration, model rotation speed). The experiments were conducted with an impact angle of 30°, a concentration of 20 wt.%, and a rotation speed of 550 r.p.m.

Effect of Impact Angles: Figure (8) illustrates the effect of changing the impact angle on the erosion rate with barriers, showing that the erosion rate begins to increase when changing the angle from 30° to 45°, then to 60°, and decreases at a 90° angle, but with erosion rates greater than those without barriers.

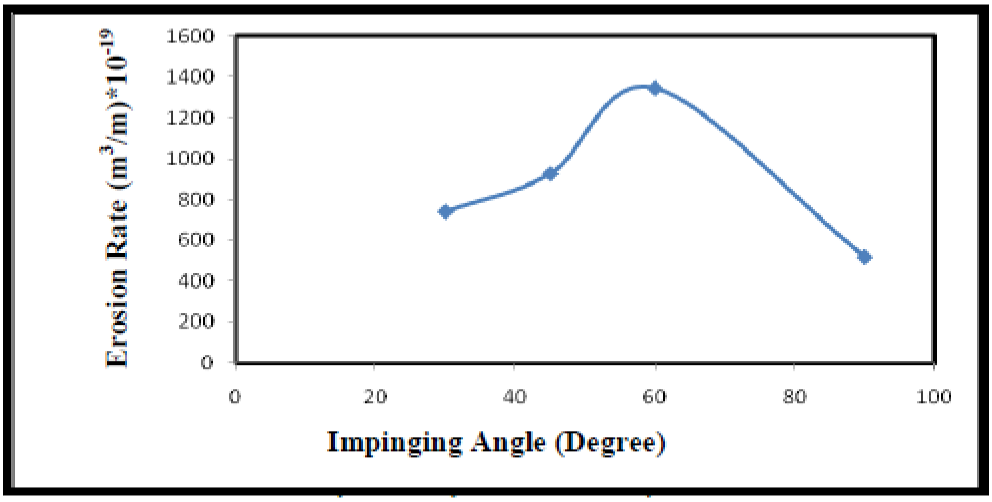

Figure (8) shows the change in the erosion rate with the impact angle in the presence of barriers (concentration 20 wt.% and rotation speed 550 r.p.m.).

Effect of Concentrations: Figure (9) shows the effect of changing the concentration on the erosion rate with barriers, indicating that the erosion rate increases when changing the concentration from 20 wt.% to 25 wt.% to 30 wt.%, then decreases at the other concentrations of 35 wt.% and 40 wt.%, but with erosion rates higher than those without barriers.

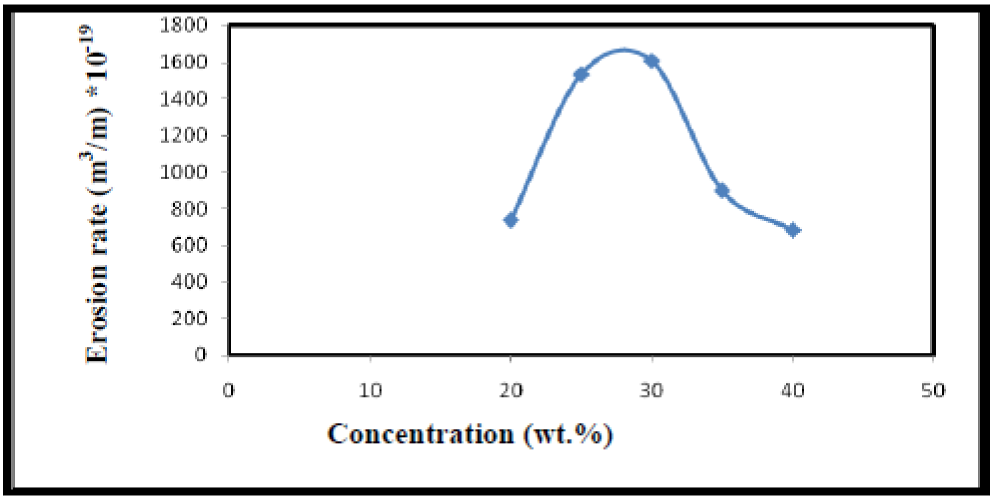

Figure (9): Illustrates the variation of the erosion rate with slurry concentration in the presence of barriers (impact angle 30° and rotation speed 550 r.p.m.).

1-2-3: Effect of Model Rotation Speed: Figure (10) demonstrates the impact of model rotation speed on the erosion rate with barriers, indicating that the erosion rate increases with increasing rotation speed, with erosion rates higher than those without barriers.

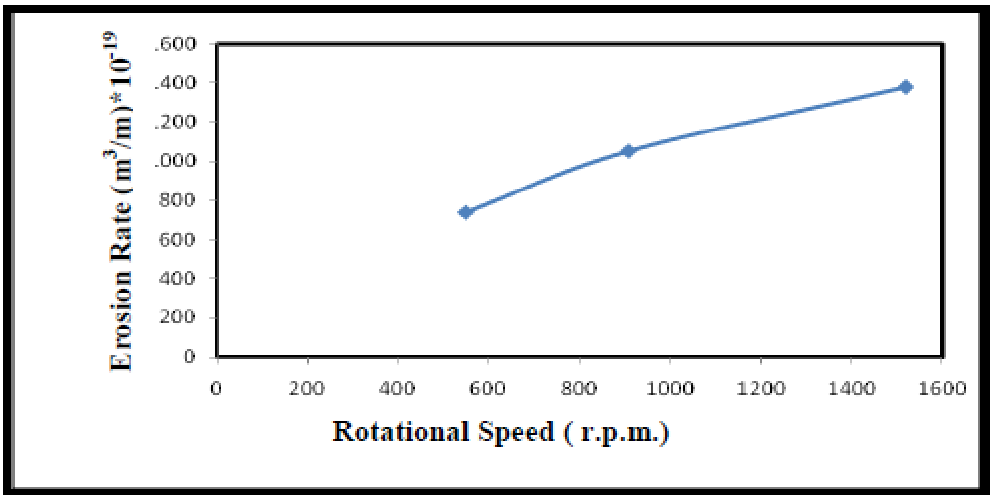

Figure (10): Shows the variation of the erosion rate with model rotation speed in the presence of barriers (impact angle 30° and concentration 20 wt.%).

From the foregoing, it is evident that an important part of the results obtained in this research confirms the relationship between the factors studied in this research (impact angle, slurry concentration, model rotation speed), as well as the barriers, and the erosion rate relied upon in studying the erosion behavior of Stainless Steel Type 316L, especially the main part of the research that illustrates the differences between the two conditions (with and without barriers) and their effect on the erosion rate. It has been found that the erosion rate is affected by changes in the impact angle, slurry concentration, and model rotation speed. Additionally, it was found that the erosion rate increased to its maximum value at an impact angle of 60°, then decreased at a 90° angle. This may be attributed to the orientation of the model relative to the sand particles, as when it is perpendicular, the erosion mechanism differs from when the model orientation is horizontal relative to the direction of particle movement. Furthermore, erosion mechanism at an impact angle close to 90° leads to the formation of metal ridges at the impact area resembling a lip, somewhat similar to the friction mechanism between two contacting surfaces when the impact angle is close to zero, which may lead to variations in weight loss and thus in the erosion rate.

Moreover, it was found that the erosion rate began to increase with an increase in sand concentration in the slurry and reached its maximum value at a concentration of 30 wt.%, then started to decrease to its lowest value at a concentration of 40 wt.%. The reason for this decrease in the erosion rate may be attributed to the increase in random collision of erosion particles with each other, leading to the dissipation of some kinetic energy of the particles.

Regarding the model rotation speed, it was found that the erosion rate increased with an increase in rotation speed. The reason for this increase may be attributed to the increase in kinetic energy of the particles, which directly depends on their speed.

In general, the comparison between the two conditions (with and without barriers) showed that the presence of barriers led to an increase in the erosion rate, which may be due to the increased rotation of particles around themselves, as indicated by the researcher (Deng) [4], or it may indicate that the barriers exposed the models to sand to a greater extent than in the case where these barriers are absent.

These results may serve as a warning to specialists in design and production engineering dealing with Stainless Steel Type 316L under conditions where resistance to erosion is crucial, which must be considered and taken into account in this field.

Furthermore, the existence of such a phenomenon enables stakeholders to determine the strength and weakness of the resistance of Stainless Steel Type 316L to this phenomenon, which in turn encourages attention to the relationship between these factors and their effect on the alloy's resistance to erosion and the possibility of adopting a feasible method in some cases to control the erosion phenomenon.

III. Conclusions:

In light of the results obtained, the following conclusions can be drawn:

1. The device designed and manufactured in the current research can be used to study the erosion process and its characteristics for this type

of stainless steel, as well as the possibility of using it to study the erosion behavior of other materials.

2. The erosion behavior of Stainless Steel Type 316L depends on the impact angle, as it was observed that the erosion rate increased to its maximum value at an impact angle of 60°, then decreased at an impact angle of 90°.

3. The erosion rate of Stainless Steel Type 316L varies with changes in slurry concentration. It was noted that the erosion rate began to increase with an increase in sand concentration in the slurry, reaching its maximum value at a concentration of 30 wt.%, then started to decrease to its lowest value at a concentration of 40 wt.%.

4. The erosion rate is directly dependent on the rotation speed of the models. It was found to increase with increasing rotation speed, ranging from 551 r.p.m. to 1520 r.p.m.

5. The addition of barriers significantly alters the erosion rate, as their addition led to an approximately twofold increase in erosion rates compared to the condition without these barriers.

References:

[1]. Nam P.S.,"Tribophysics" Practice Hall Inc. New Jersey USA, 1986.

[2]. Jha A. K., Batham R., Ahmed M., Majumder A. K., Modi O. P., Chaturvedi S., Gupta A. K., " Effect of impinging angle and rotating speed on erosion behavior of aluminum" ,Trans. Nonferrous Met. Soc. China,Vol.21, pp.(32-38) , 2011.

[3]. Dasgupta R., Prasad B.K., Jha A.K., Modi O.P., "Effects of Sand Concentration on Slurry Erosion of Steels" Materials Transaction, JIM,Vol.39, No.12,pp. (1185 - 1190) , 1998.

[4]. Fang C.K.,Chuang T.H., "The effect of humidity on the erosive wear of 6063 Al alloy" , Wear , Vol.236,pp.(144-152) , 1999.

[5]. Chui K.Y., Cheng F.T., Man H. C., "Cavitation Erosion Resistance of AISI 316L Stainless Steel Laser Surface-modified with NiTi", Materials Science and Engineering , A 392, pp. (348- 358), 2005.

[6]. Francis R., "The Erosion Corrosion Resistance Of Zeron 100", Corrosion Services Manager, Rolled Alloys, No. TN781, (2008

[7]. Hazim M.M., "Effect of Speed, Impinging Angle and Slurry Concentration of Water and sand on Erosion of Stainless Steel - 316L ", M. Sc. Thesis, University of Mosul, Mosul, 2012.

[8]. htt//: www.aksteel.com , product data sheet ,316 L Stainless Steel.