

ASSEMBLING OF EROSION TEST APPARATUS AND THE INFLUENCE OF IMPACT ANGLE ON SLURRY EROSION RATE

MAHDI KHIDER SADAN

Dept. of Mechanical, College of Engineering, University of Duhok, Kurdistan Region-Iraq

(Received: November 6, 2022; Accepted for Publication: May 3, 2023)

ABSTRACT

A Jet erosion tester is designed and assembling then used to study the relative erosion behavior of high density polyethylene (HDPE) with specific concentration of silica sand as an abrasive material, during varying impingement angles and specific size of abrasive particles. The water flow was turbulent. The test samples were mounted on sample holder and which has a provision to move in different angular positions to find out the erosion wear for different angles. The experiments were carried out using silica sand as erodent with a particle size range of (500-599) μm . Were used varying impact angles (90° , 60° , 45° and 30°) and solid abrasives of (2% wt.) concentrations have been used as fixed parameter for 20 hours. The concentration of slurries can vary from (2% to 50%) depending upon the type of slurry. Three samples were taken for each angle and the average was taken to obtain accurate results and was evaluated. The results which have been obtained shows that the erosion rate of (HDPE) was maximum at impact angle (45°) and minimum at (30°).

KEYWORD: Slurry erosion, Impact angle, Jet erosion tester, High-density polyethylene (HDPE), Erosion resistance.

1. INTRODUCTION

The polymer used in this search was high density polyethylene (HDPE) because it is widely used in many applications such as water pips transportation, oil pipes, systems, turbines, nozzles, oil field mechanical equipment, sewage which deals with slurry due to it is high erosion resistance characteristics etc.. Slurry

erosion is a type of erosive wear which takes place when a stream of liquid hits a solid body and results erosion in this body surface. Slurry erosion is caused by wall shear of the slurry flow through a pipe with particle impacts. These type of erosion influence the pipes with a reduced lifetime. Connected through the flow field that will affect the performance and efficiency of the parts may be causing the parts failure. (Clark, 1992). Slurry erosion has always been a real problem for the industries; including pipe line, hoses, pumps (Pearce, 2002), because it is considered one of the major sources of failure in slurry transportation pipelines. For this, there is important to solve such a problem or reduce its damage. The slurry erosion is a complex phenomenon, because it depends on many parameters, which operate at same time. These factors include impact angle, sample material

properties, silica sand size, erodent partials velocity, standoff distance, and duration. Among these factors, the impact angle and microstructure of the specimen material play a necessary role on slurry erosion process (B.D. Nandre et al., 2018). The target surface characteristics include toughness, hardness, ductility, and strength. Fluid characteristics include the viscosity and density of the fluid. All these factors greatly affect the slurry erosion rate. (T.Frosell et al., 2015). The characteristics real have a greatly effect on the slurry erosion of slurry. The mass loss occurs of sample due to erosion higher for higher kinetic energy of the articles impacting at the target surface.

2. PARAMETERS AFFECTING SLURRY EROSION

2.1. Related to the Test Piece

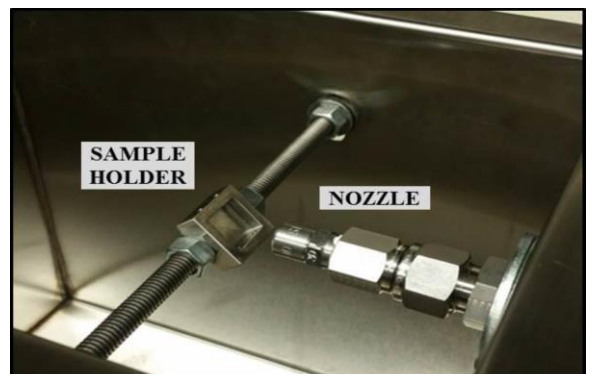
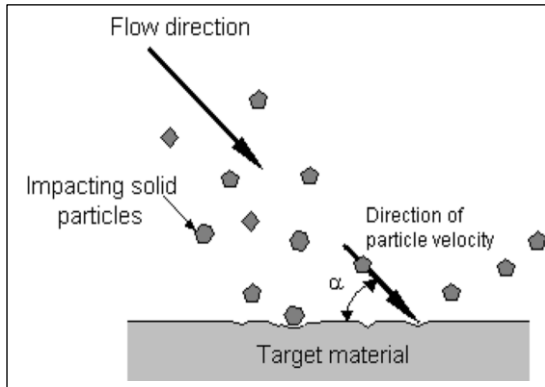
Table (2) show used parameters in our tests. The following are the most important factors related to fluid flow conditions.

2.1.1 Impact angle:

Impact angle is defined as the angle between the target surface and the direction of striking velocity of the solid particle as in figure (1). The variation of erosion wear with the impact angle depends on the characteristics of the target

surface material namely brittle or ductile type (Clark, H. M. 2002a). The effect of impact angle is different in the cases of brittle and ductile material. The maximum erosion rate of HDPE

takes place at impact angles (40° - 50°) and The minimum erosion rate takes place at impact angles (90° and 30°) (Ahmed M. et al.,2021).



2.1.2 Hardness:

Is defined as the resistance of a material to permanent deformation. Surface hardness as well as hardness of solid particles has profound effect on the erosion wear mechanism. Hardness ratio has been defined as the ratio of hardness of target material to the hardness of erodent material (Wang et al., 2011).

2.2. Related to the Slurry:

2.2.1 Erodent shape and size:

Particle shape and size influences erosion rate. Many researchers have considered erodent particle shape and size necessary to erosion rate. Increase the erosion rate with large size solid particulates with sharp irregular edges

(Thakur et al., 2015). The influences of erodent particle shape on the erosion rate have not been well elucidated due to difficulties in determining different shape attributes (Wang et al., 2011). In general, roundness factor is taken into account (Thakur et al., 2015). The percentage of each particle in the granule is graded with respect to the particle size. For the size range particles sand, sieve standard analysis performed to determine the particle size distribution. From Grade II of (IS 650) Indian standard, the medium particle size of 550 sand μm . In this research

was collected as the suspended particles between the two sieves of 500 μm and 599 μm sizes. Figure (2) and table (1) shows the silica sand.

2.2.2 Impact Velocity:

Velocity of solid particle strongly affects the erosion wear. The impact velocity has dominant effect on the material removal rate. As particle velocity increases there is significant increase in erosion rate. (Thakur et al., 2015).

2.2.3 Concentration of solid Particles:

Is actual volume (weight) of the solid particles in known volume (weight) of slurry multiplied by 100. When the concentration of particle increases more particles hit the surface of specimen material, causing the increase the erosion rate (Desale et al., 2009). The slurry particle concentration effect on the erosion rate of tool components

is a critical factor in the design and maintenance of industrial equipment (Frosell T. et al., 2015). The slurry concentration can be changed from (2% to 50%) depending on the type of slurry. However, when the concentration is greatly increased, the particle interaction increases and this reduce the hitting velocity of sand particle on the surface of target material (Sharma et al., 2008).

2.2.4 Slurry

Slurries are mixture of water-solids particles. The combination of type, size, shape and quantity of the solid erodent particles together with the water nature determine the fine properties and flow of characteristics of the mixture.

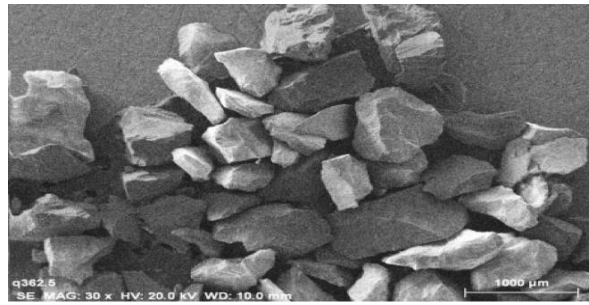


Fig. (2): SEM picture of silica sand.

Table (1): Erodent particle Physical properties.

Erodent	Chemical symbol	Color	Sp. Gravity(Kg/m ³)	Hardness (V)	Shape of Particle
Silica sand	SiO ₂	Gray	2652	1100	Angular Sub

Table (2): Experimentation parameters:

Dimensions of specimen (mm)	(50x50x4)
Pressure gauge (bare)	0.65
Test temperature (C°)	25
Volumetric flow rate (m ³ /sec)	2×10 ⁻⁴
Jet velocity (m/sec)	11.227125
Impingement Angle (°)	30, 45 , 60 , and 90
Sand concentration by weight (%)	2
Nominal silica sand size (micron)	(500-600)
Nozzle diameter (mm)	4.7625
Standoff distance (mm)	20
Duration (minutes).	120

3. DESCRIPTION OF THE APPARATUS

3.1. Parts of apparatus.

The picture and schematic drawing for the apparatus are shown in Figure (3) and Figure (4); the primary subsystems consist of the motor and pump, reservoir and plumbing, stirring mechanism, sample holder, flow

meter, valves and the nozzle enters the front of the reservoir through a bulkhead fitting. This apparatus was designed and manufactured in accordance with the test apparatus explained in American standard (ASTM G73). Each of these subsections will be discussed in detail.

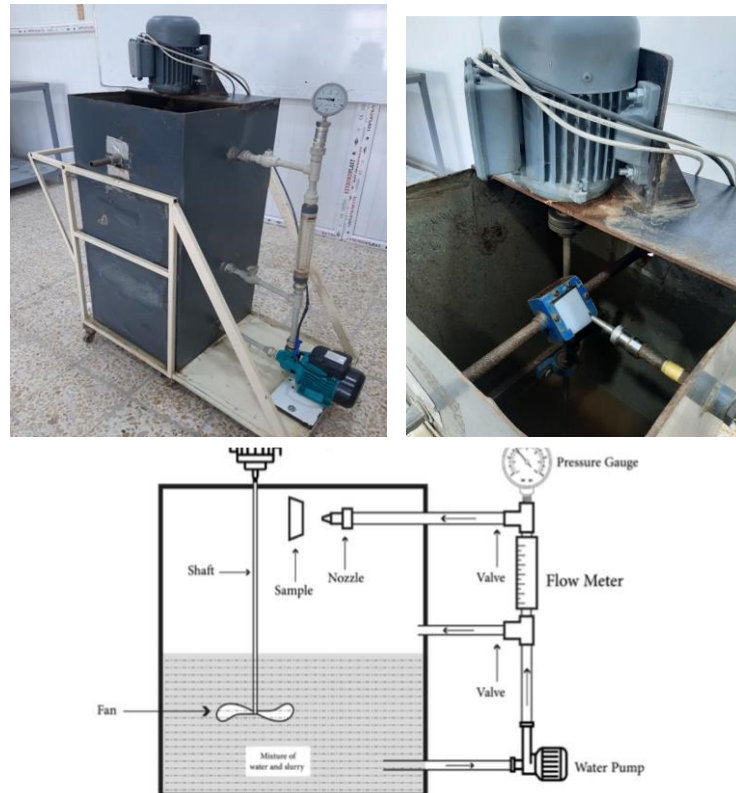


Fig. (4): Schematic representation of the test device.

1. Frame of base:

Which is considered the major part of the apparatus; it holds the whole assembly and motor of stirrer. The material used for this purpose is mild steel hollow square bar with a dimensions of (2x2) cm and dimensions of frame (LxWxH) = (100x50x85) cm.

2. Rectangular tank (reservoir): This reservoir has 75-liter capacity to fill 30 cm height. The function of this pot is to prepare homogeneous mixture of sand and water for different particle sizes of silica sand and 2% wt. concentrations of silica sand as an abrasive. The reservoir was constructed from mild steel, in the shape of square funnel with dimensions of approximately (50x50x100) cm.

3. Stirring Mechanism:

For the preparation the mixtures of homogeneous of particles sand-water different aggregates the tank contains a stirrer that is driven by an A.C. motor with a maximum speed of 1420 rpm. The test setup was originally designed to use a stirrer in order to keep the particles suspended in the water. A motor drives the propeller, connected by a shaft. The propeller pushes water down towards the bottom of the reservoir to induce a significant turbulent effect throughout the entire volume of slurry. Testing of this stirring mechanism further revealed that

particle settling in the reservoir did not occur. Vibration was found not to be an issue as well.

4. Sample Holder

It also has a specimen holder (Fixture), The specimen holder could be fixed at any angle between 0° to 90° . A sample holder was placed within the reservoir and was positioned such that approximately (20 mm) of space lies between the surface of the sample and the nozzle exit.

Water Pump:

This Apparatus test also contains a centrifugal pump china factory QB80 of (0.75 Kw), electric irrigation water pumps Certificate. This pump is used for the purpose of sucks the slurry from slurry pot to the test sample for the erosion purpose

5. Pipes, fitting and valves.

To control the slurry flow rate there is two control valve used with help bypass between delivery side and nozzle. With dimensions (12.7mm). It is used for the purpose of transferring slurry as a medium through (PVC) pipe. It's so smooth, which means there is no loss of velocity flow or pressure of water because of friction. Finally, dose not react chemically with water, also there is little rust risk or corrosion.

6. Flow meter (Rota meters):

Rota meters Z-4003 series is used, "A device used to measure flow rates of fluids in a closed system" in unit flow rate (volume/time). Rota meters are a the variable area principle. Particular kind of flow meter, based on based on the variable area principle. This ariable area principle consists of three basic elements: A uniformly tapered flow tube, a float, and a measurement scale.

8. Burdon Gauge:

The working of bourdon tube pressure gauge is simple and does not need any skilled labor for operating. The whole working process will depend upon the C-shaped Bourdon Tube. The C-Shaped tube will be formed round 250 degrees. The bourbon pressure gauge is attached or fixed to the fluid flow pipe or to the storage tank.

9. Nozzle:

A nozzle is used which is has orifice diameter of (4.7625) mm, Inlet diameter of (12.7) mm, which is 63.5 mm long. The standoff distance between the nozzle and sample can be change from (20-70) mm. It's designed to control the direction of a fluid flow and increase velocity as it exits (or enters) an enclosed pipe. It's placed at top of pot against the sample test.

3.3. Erosive Wear Testing

Erosion wear test was carried out as per ASTM G76 (Pearce, J. T. H 2002). At room temperature. Target Material Is High Density polyethylene (HDPE-Sabic) is a high molecular weight High Density Polyethylene with high erosion resistance property. It has broad molecular distribution and high density combine successfully to give strength and rigidity. The material contains an antioxidant. Erosive wear

samples were cut with dimensions of (50×50×3.5) mm. grinder used to clear the surface of each sample. Sample wight loss was measured with an electronic scale having resolution of 0.01mg. A mixture of silica sand–water was prepared by mixing concentration of particles 2% wt. .The sand was sifted into successive sieves with range (500-559) µm. A predetermined mass of sand was poured first in the tank at the rate of 2% and then a known quantity of water at the rate of 98% was poured through the top of the tank to the rectangular tank to a height of 30 cm.

The stirrer is rotated with the help of driven electric motor it has maximum speed of 1420 rpm for the purpose of homogeneous distribution of particles sand in water. The samples have been fixed on the sample holder of the erosion

apparatus exposed through the nozzle to a jet of the slurry pumped from the tank.

3.4. Design of Flow control system:

Since the slurry consists of solid particles suspended in a liquid, the properties of a slurry mixture will depend upon those of the constituents.

3.4.1 Density of slurry

Density of a slurry is affected by the density of the carrier liquid, density of the solid particles and the concentration of the solid particles. The concentration of the solid particles is often given in percent by weight, as it is more convenient when calculating pipeline throughput tonnages. However, slurry properties in pipeline flow are more related to the volume of solids. The currently used slurry consists of silica particles of (500-599) µm and of 1497 kg/m³ density. To determine the density of the whole slurry consisting of silica sand and water, equation (1) can be used. (Wasp et al., 1977).

$$\rho_m = 100 / [(C_w / \rho_s) + ((100 - C_w) / \rho_L)] \dots (1)$$

Where (ρ_m) is density of slurry mixture (kg/m³), (C_w) is solids concentration by weight in slurry (%), (ρ_s) is density of the solids (kg/m³) and (ρ_L) is density of liquid without solids (kg/m³).
 $\rho_m = 100 / [(2 / 1497) + (100 - 2) / 997] = 1003.7 \text{ kg/m}^3$ at concentration by weight (C_w = 2 %).

3.4.2 Viscosity of slurry

To calculate viscosity of slurry mixture the fractional volume concentration of solids equation (2) and the ratio between viscosity mixture of slurry and viscosity of water should be calculated (Gutmark, E. 2015).

Fractional volume concentration of solids (C_v):

$$C_v = (C_w \times \rho_m) / \rho_s \dots (2)$$

$$= 2 \times (1003.7 / 1497) = 1.341 \%$$

Ratio between viscosity mixtures of slurry:
 $\mu_m / \mu_L = 1 + 2.5 C_v + 10.05 C_v^2 + 0.0273 e^{(16.6 C_v)}$ (3)

Where (μ_m) is viscosity mixture of slurry, (μ_L) is viscosity of water in slurry mixture and (C_v) is fractional volume concentration of solids
 $\mu_m / \mu_L = 1 + 2.5 \times 0.01341 + 10.05 \times 0.01341^2 + 0.0273 e^{(16.6 \times 0.01341)} = 1.07$

Since dynamic viscosity of water is 8.90 × 10⁻⁴ kg/m.sec, the dynamic viscosity of mixture = 1.07 × 0.00089 = 9.5 × 10⁻⁴ kg/m.sec

3.4.3 Flow rate at nozzle

According to standard G76, Independent parameters, orifice diameter of nozzle, d = 4.7625 mm.

$$A_{\text{nozzle}} = \pi \cdot r^2 = \pi \cdot (2.38125)^2$$

$$=1.7814 \times 10^{-5} \text{ m}^2$$

And the water volume flow rate
($Q = 2 \times 10^{-4} \text{ m}^3/\text{sec}$).

Then the velocity at orifice (V_o):

$$V_o = Q / A \dots\dots\dots (4).$$

$$V_o = 11.227124 \text{ m/sec}.$$

3.4.4 Reynolds number:

Reynolds number (Re): The transition from laminar to turbulent flow depends on the geometry, surface roughness, flow velocity, surface temperature, and type of fluid, among other things. The flow regime depends mainly on the ratio of inertial forces to viscous forces in the fluid. This ratio is called the Reynolds number,

The flow in a circular pipe is

$$Re \leq 2300 \text{ laminar flow}$$

$$Re \leq 4000 \text{ transitional flow}$$

$$Re \geq 4000 \text{ turbulent flow}$$

$$Re = \frac{\text{Internal forces}}{\text{Viscous force}} = \frac{\rho L V_o D}{\mu}$$

Where:

(V_o) is velocity of slurry; d is pipe internal diameter, (ρ_L) is fluid density, (μ) is a dynamic viscosity of a mixture and Re is Reynolds number (dimensionless value) and is expressed for internal flow in a circular pipe water flowing in a PVC pipe smooth at temperature ($T=25^\circ\text{C}$).

$$Re = \frac{\rho L V_o D}{\mu} \dots\dots\dots (5).$$

$$Re = \frac{1003.7 \times 11.227124 \times 4.7625}{0.00095}$$

$$= 56491593$$

$$Re \geq 4000$$

Hence, the water flow is turbulent.

3.4.5 Erosion rate:

Slurry erosion is a type of wear phenomenon in which the erosion of the target material takes place due to impact of solid particles entrained in fluid medium. The samples mass weighed before to tests using a digital scale with an accuracy (0.01) g and weighed again after the

tests to calculate the rate of mass loss and erosion. Erosion rate of specimen (E) after (20 hour) can be obtain form the following equation (Sandip K. 2019):

$$E = W_b - W_a \dots\dots\dots (6).$$

Where:

E: Erosion rate (gm)

W_a: Weight of the specimen after erosion (gm).

W_b: weight of the specimen before erosion (gm).

3.4.6 Working procedure:

1. Cleaning the sample with acetone and emery paper.
2. Dry the specimen properly
3. Weighing the sample.
4. Installing the sample in the holder.
5. Adjusting the stand at the desired angle.
6. Weighting the required amount particles sand according to the slurry concentration.
7. Mixing the exact amount of water and grains of sand into the pot.
8. Turning on the pump.
9. Controlling the slurry flow rate to obtain desired value of velocity by flow meter and a bay-pass.
10. Unclamping the sample from the holder.
11. Cleaning sample with acetone and drying it.
12. Weighing the sample after experiment for measuring the mass loss with the same balance.
13. The steps repeated from 1 to 12 as needed.

4. Test results:

Experimental investigation of the slurry erosion rate and weight loss of (HDPE) has been carried out in the conditions listed in paragraph table (2) and results were recorded in the table (3) and figure (5). Three samples were taken for each angle and the average was taken to obtain accurate results.

Table (3): Results of slurry erosion rate of (HDPE) at duration (20 hours).

Specimen Material	velocity (m/sec)	Impingement Angle (°)	Weight Before Erosion (gm)	Weight After Erosion (gm)	Erosion (gm)
HDPE	11.227124	30	12.56	12.55	0.01
HDPE	11.227124	45	12.05	12	0.05
HDPE	11.227124	60	13.55	13.51	0.04
HDPE	11.227124	90	14.5	14.48	0.02

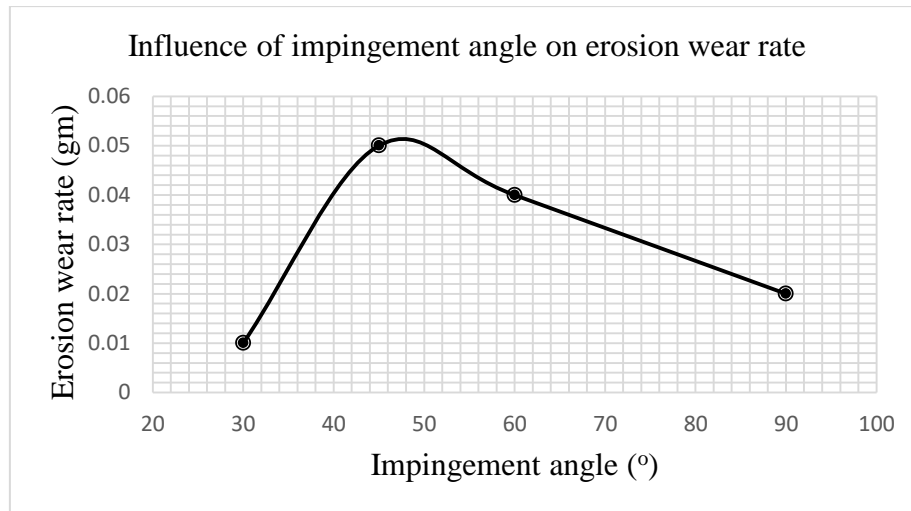


Fig. (5): The effect of impingement angle on erosion wear rate of HDPE.

5. RESULTS DISCUSSION

5.1. Influence of Impact angle.

In order to authenticate the working of the jet erosion tester, a high density polyethylene (HDPE-Sabic) was used to study the erosion wear pattern. It can be clearly seen from the figure that the impact angle has a great influence on erosion. Shows that the erosion rate is increase with the impact angle till the impact angle is about 48° and then starts to decrease with the impact angle. The maximum erosion rate occurs between impact angles 40° and 50° (B.D. Nandre et al. 2018).

6. CONCLUSION

Slurry erosion test rig on (HDPE) specimen have been used for 20 hours for each specimen. Silica sand particles with range (500-559) μm , Sand concentration (2 % wt), impact angles (90°, 65°, 40° and 30°) and orifice velocity 11.227165 m/sec.

B.D. Nandre , G.R.Desale, Study the Effect of Impact Angle on Slurry Erosion Wear of Four Different Ductile Materials, Materials Today: Proceedings 5 (2018) 7561-7570.

T.Frosell, M.Fripp , E.Gutmark, Investigation of slurry concentration effects on solid particle erosion rate for an impinging jet, Wear 342-343 (2015) 33-43.

Clark, H. M. (2002a). Particle and size effects in laboratory slurry erosion measurements. Tribology International, 35(10), 617-624.

Ahmed Mostafa¹, Tarek Mohamed Abd El-badia², Raafat Mahmoud Gad El-Rab³. (2021). Effect of impact angle and impact velocity on the

- Maximum measured erosion rate is 0.05 gm occurs at 45° impact angle and minimum at impact angle 30°.

- The results found the maximum mass loss of (HDPE) occurs from impact angles (40° to 50°).

- Comparison of these results with the mass loss rate behavior of elastic materials is acceptable.

- Through the results of this research, (HDPE) can be used in applications with Impact angles from (0° to 40°) and from (50° to 90°) as fluid transfer pipes taking into account the influence of velocity of impact.

- Impact angle has a significant effect on mass loss. For slurry pipe elbow it is preferred to design the elbow angle to avoid maximum erosion rate according to the ductile or brittle elbow materials and flow conditions.

REFERENCES

Clark, H. M. (1992b). The influence of the flow field in slurry erosion. Wear, 152(2), 223-240.

Pearce, J. T. H (2002). High chromium cast irons to resist abrasive wear. Foundry man, 95, 156-166.

slurry erosion behavior of high density polyethylene (HDPE).

Wang, Y., Zuo, M. J., and Fan, X. (2011). Design of an experimental system for wear assessment of slurry pumps. Proceedings of the Canadian engineering education association.

Thakur P.A., Khairnar H.S., Deore E.R., More S.R., Development of slurry jet erosion tester to simulate the erosion wear due to solid-liquid mixture. International Journal of Novel Research in Engineering and Science, 2 (2015) 14-20.

Desale, G. R., Paul, C. P., Gandhi, B. K., and Jain, S. C. (2009). Erosion wear behavior of laser clad

surfaces of low carbon austenitic steel. Wear, 266(9-10), 975-987.
Sharma, A. K. (2008). Numerical study of erosion wears on centrifugal slurry pump. MSc thesis, Thapar University, Patiala, India.
Wasp, E., J., Kenny, J., P., Gandhi, R., L., Solid-Liquid Flow – Slurry Pipeline Transport.

Series on Bulk Materials Handling Vol. 1 (1975/77) No. 4. Trans Tech Publications, Clausthal, Germany, 1977.

Sandip Karmokar Wear Rate Comparison of Different Impeller Materials for Pumping Various Types of Slurry Bangladesh May 2019.

كۆكردنه وهى ئامپىرى تاقىكردنه وهى رووخان و كارىگه رى گۆشه يى كدادان له سه رپژهى رووخان.

پوخته

تاقىكه ره وهى رووخان دىزايىن كراوه و دواتر به كار دىت بۆ لىكۆلپينه وه له هه لسوكه وتى رپژهى رووخان له پۆلى ئىپىلىن (HDPE) له گه ل چرى ديارىكراوى لمى سيلىكا وهك مادده يه كى توند، له كاتى گۆشه ي جياواز و قه باره ي ديارىكراوى ته نۆلكه ي تىژى. ئاوه كه شله ژاو بوو. نموونه كانى تاقىكردنه وه كه له سه ر هه لگرى نموونه دانراون و كه داينكردى هه يه بۆ جولاندن له شوپنى گۆشه يى جياواز بۆ دۆزپنه وهى پۆشپنى رووخان بۆ گۆشه ي جياواز. تاقىكردنه وه كان به به كار هپنانى لمى سيلىكا نه نجام دراون وهك رووخاندن له گه ل مه وداى قه باره ي ته نۆلكه كان (500-599) مىكروم. گۆشه ي كارىگه رى جياواز به كار هپنرا (90°، 60°، 45°، 30°) و تىژى رهق له چرى (2%) به كيش بۆ ماوه ي (20) كاتر مىر وهك پارامپته رى جىگىر به كار هاتوو. چرى شله ي له وان هه يه له (2% بۆ 50%) بگۆرپت به پى جۆرى شله. بۆ هه ر گۆشه يه ك سى نموونه وه رگىران و تىكراكه وه رگىرا بۆ به ده سه ته پنانى نه نجامى ورد و هه لسه نگاندىن. ئه و نه نجامانه ي كه به ده سه ت هاتوون ئه وه نيشان ده دن كه رپژهى دارمانى (HDPE) زۆر ترين بووه له گۆشه ي كارىگه رى (45°) و كه منرىن له (30°).

بناء جهاز اختبار تآكل الملاط النفات وتأثير زاوية التأثير على تآكل الملاط.

الخلاصة

كان البوليمر المستخدم في هذا البحث من البولي إيثيلين عالي الكثافة (HDPE) لأنه شائع الاستخدام في هذا المجال مثل أنابيب المياه والزيوت وانايب مياه الصرف الصحي التي تتعامل مع الملاط بسبب مقاومته العالية للتآكل. في هذا البحث ، تم استخدام آلة اختبار التآكل لاختبار التآكل النسبي للبولي إيثيلين عالي الكثافة في نطاق حجم رمل السيليكامادة كاشطة ، مع زوايا اصطدام مختلفة. تم استخدام خزان مستطيل للملاط (رمل السيليكامادة) يحتوي على مروحة تدور بواسطة المحرك بسرعة 1420 دورة في الدقيقة أعلى خزان الملاط من أجل التوزيع المتجانس. تم تثبيت العينات على حامل العينة والتي لديها ترتيب للتحرك في مواضع زوايا مختلفة لمعرفة التآكل. أجريت التجارب باستخدام الرمل كمتآكل بمدى حجم جسيمى (500-599) ميكرومتر. زاوية اصطدام (90 درجة ، 60 درجة ، 45 درجة ، 30 درجة) وتم الاحتفاظ بالجسيمات عند (2% بالوزن) استخدمت التركيزات كمعاملات ثابتة لمدة 20 ساعة. تم فحص عينة فقدان الوزن للعينة المتآكلة وتم تقييمها. تم قياس فقدان الوزن باستخدام ميزان بحساسية (0.01 غرام). بعد الحصول على النتائج تبين أن معدل فقدان الوزن أو معدل التآكل لـ (HDPE) كان بحد أقصى عند زاوية التأثير (45 درجة) وأقل عند (30 درجة).