

Aqueous Erosion of Polymeric Materials Used in Water Supply Systems

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Abstract. Elements of water supply systems such as pipes, elbows, tee connections, ...etc., are made of polymeric materials. They are subjected to erosion by streams of water and contaminants. The objective of this work is to investigate the erosion resistance of the polymers that are locally used to produce such components. Three materials were examined, namely: High pressure PVC (HP-PVC), Low pressure PVC (LP-PVC), and Polypropylene (PP). Four types of water were used to erode the polymeric specimens: Distilled water (DiW), Desalinated water (DeW), Sea water (SW), and untreated deep ground (Well) water (WW). The effects of water stream velocity and eroding time on the erosion wear behaviour of the polymers were examined. The work was conducted under controlled environment of 23 °C temperature and 40% humidity. Results show that erosive wear of all materials increases with the increase in stream velocity and/or eroding time. It also indicates that at certain values of velocity and/or eroding time the increase in rate was more pronounced. In addition the presence of water contaminants has drastic effects on the erosion volume. Results also show that HP-PVC has the highest erosion resistance.

Keywords: erosive wear of polymers; erosive wear in water supply systems.

1. Introduction

In spite of the negative side of their properties such as low strength, low modulus of elasticity, limited service temperature, and degradation when they are subjected to sun light, polymeric materials are facing higher performance requirements and increasingly greater use in aerospace, automobile, marines and many other applications. This is due to the positive side of their properties such as high strength-to-weight ratio, relatively low friction coefficient, self lubrication, ease and cheap manufacturing, and good machinability^[1-5]. This encouraged researchers to spend more effort to improve the properties of this new generation of engineering materials. Selective examples are given in references^[6-15]. However, the published work on mechanical and tribological properties of polymers and composites are somewhat limited.

Wear of polymers as an unwanted phenomenon that depends on many factors including applied load, sliding speed, sliding distance, temperature, thermal, mechanical, and chemical properties, has been classified into mild and severe wear^[16-17]. It is considered as one of the big disadvantages that restrict the use of polymers. Researchers named some mechanisms including adhesive, abrasive, fatigue, corrosive, erosive wear^[9, 10, 17].

Erosive wear was defined by the American Society for Testing and Materials as “progressive loss of original material from a solid surface due to the mechanical interaction between that surface and a fluid, a multi component fluid, or impinging liquid or solid particles”^[18]. Research work on erosive wear by liquids is very rare^[19-25]. Studies were concerned mostly with erosion by solid particles^[26-38]. The erosion rate (ER) of a material depends on several factors, including target material properties, and erosion test conditions such as impinging angle, velocity, temperature, particle flux, and erodent^[39]. Erosion rate has been shown to follow the following empirical velocity equation^[40-43]:

$$ER = kV^n \quad (1)$$

Where:

V = the erodent velocity.

k = constant.

n = power factor which has a range of values (2 – 6.5).

Published works show that the value of (n) depends on target material, impinging particle kinetic energy and shape, temperature, and testing conditions^[44]. An (n) of (2) is expected based on impacting particle kinetic energy ($mV^2/2$). No satisfactory explanation for deviation of (n) from the value of (2) is given in the literature, nor has the cause of (n) being varied from one test apparatus to another for same target material has been addressed^[39]. Values of (n) less than (2) have not been found to date in solid particle erosion, although values as low as (0.8) have been found in erosion-corrosion tests^[24].

2. Experimental Details

2.1 Erosion Wear Machine

A specially designed erosion wear testing machine was employed during this course of erosion wear tests. Figure 1 shows a schematic diagram of the machine. It was designed and constructed as quoted in reference^[45]. Full details are given there. However, some relevant details will be given herein after.

The eroded specimen is held in specimen seat (5), which is mechanically connected to a special diaphragm of pressure measuring unit (not shown) seated on seat (6). This unit reads the water pressure impinging the eroded specimen. The pump (12) pumps the water stream from the container (10) through the water jet (3).

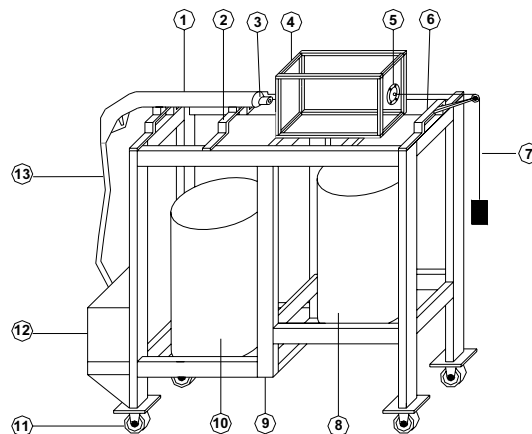


Fig. 1. Schematic diagram of erosion wear testing machine.

1- Water gun, 2- Gun seat, 3- Jet, 4- Protection box, 5- Specimen seat, 6- Pressure unit seat, 7- Calibration unit, 8- Waste water, 9- Frame, 10- Water container, 11- Wheel, 12- Pump, 13- Hose.

2.2 Timer

To set the time of the test at a preselected value, the machine is loaded with an electrical timer (not shown on the schematic diagram). The required time is pre-set on the timer before starting the machine. The machine stops automatically when the time is up. To ensure a simultaneous start and stop for both machine and timer, they are connected to the same start push-button.

2.3 Balance

Electrical balance type (Toledo – AB104) supplied by (Mettler of Denmark) was employed to obtain the material loss by erosion. The specimen was weighed before and after run. Consequently, the wear volume was derived from the difference in weight. The balance accuracy is (± 0.1 mg) as indicated by the manufacturer.

2.4 Microscopy and Camera

A microscope type (Ferox, 051594), supplied by the (CETI of Belgium) was also employed in this research work. It was mainly used to examine the eroded surface before and after run. In addition, a (Kodak Easy Share V610) digital camera, supplied by (Eastman Kodak Company – USA), was attached to the microscope and computer for taking the required shots.

2.5 Materials of Wear Samples

Three polymeric materials, locally manufactured and supplied by two local manufacturers in (Jeddah, and Riyadh, Saudi Arabia), were examined in the as-received condition through this project. They are: the High Pressure Polyvinylchloride (HP-PVC), Low Pressure Polyvinylchloride (LP-PVC), and Polypropylene (PP). The manufacturer properties of those three materials are tabulated in Table 1. They have been selected for their wide local use in manufacturing different components for the hot and cold water supply systems including pipes, elbows, junctions, etc. The examined samples were cut to the required cylindrical size of (30 mm) diameter and 10 mm length, using center lathe machine. To ensure similar surface topographical properties for all samples, constant values of cutting speed, depth of cut, and feeding speed, were used on the lathe. Moreover, distilled water was used as a coolant during the cutting processes to cool down the cutting area.

Table 1. Manufacturer properties of the examined polymers.

Property	Units	LP - PVC	HP-PVC	Polypropylene
Density	g/cm ³	0.90	1.34	0.895
W. absorp.	%	0.32	0.2	< 0.3
Tensile str.	N/mm ²	38	48	21
Tensile mod.	N/mm ²	2800	3500	--
Shear str.	N/mm ²	----	--	--
Impact str.	KJ/m ²	----	--	No break
Elongation	%	----	120	10 – 15
Flex. str.	N/mm ²	104	125	-
Flex. modulus	N/mm ²	---	--	1150
Hardness	Rock.		R105	R90-95
Melt point	°C	80	80	140-150
Max service temp. in air:				
-short period ⁽¹⁾		70	70	90
- continuous ⁽²⁾		--	--	70
Minimum	°C	-25	-25	--
Thermal con.	W/K.m	0.14	0.14	0.2

(1) Only few hours, with little or no load applied.

(2) For 20000 hr. After those periods, mechanical properties reduced by 50 %.

2.6 Eroding Substances

Water supply systems are locally used for the transmission of four types of waters, namely: distilled water, desalinated water, sea water, and untreated deep ground (well) water. Accordingly, these four types of water were selected to be used separately as erodents for the three polymeric materials. Distilled water was supplied by (Al-hadara Factory, Riyadh, Saudi Arabia), desalinated drinking water was supplied by (Local desalination plant, Jeddah, Saudi Arabia), sea water was brought from the red sea at about 3 km off Jeddah shore, and well water was obtained from the local wells in the province of Makkah, Saudi Arabia.

2.7 Erosion Wear Calculation

The erosion wear volume (EV) for each run was obtained from the difference in sample weights before (W_1) and after the run (W_2), the density (ρ) of the examined material, and the adsorbed water weight (W_w):

$$EV = (W_1 - W_2 - W_w) / \rho \quad (2)$$

2.8 Parameters and Conditions

The effects of water stream velocity, erosion time, and water contaminants on the erosive wear behaviour of the three polymers were examined in this work. Other parameter were kept at constant values of: eroding angle (90°), water temperature (20 °C), laboratory temperature (23 °C), and laboratory humidity (%40).

3. Test Procedures

Experimental procedures were devised and strictly followed during the courses of all experiments. To avoid any spurious or unwanted results, all other parameters were kept at constant values, and the machine was calibrated

3.1 Steps for Water Stream Velocity

The water stream velocity was varied in the range of (2-14 m/s) in (2 m/s) increment at a time. The eroding time was kept at constant value of (15 hr). For accuracy purposes: (a) each run was repeated three times and average values were calculated; (b) to evaluate the amount of adsorbed water by test specimen, a similar sample was weighed, dropped into a bath of same erodent, and left there for the running time of each test. The amount of adsorbed water, then deducted from erosion wear volume as indicated in equation (2). Steps for each test were:

- 1- Prior to each run, the sample was washed by warm water, cleaned by cloth, left (30 minutes) to dry; then weighed.
- 2- The sample was then, firmly seated in place.
- 3- The velocity and pressure gauges were adjusted.
- 4- The timer was set to zero.
- 5- The second similar sample was dropped into the erodent bath and simultaneously, the machine started.
- 6- At the end of the test, the machine was stopped; both samples were removed, cleaned and dried by cotton clothe.
- 7- The samples were weighed again and the weights were recorded.
- 8- The test was restarted following the same steps.

3.2 Steps for Eroding Time

To examine the effects of eroding time, the same steps were followed except for the water stream velocity, which was kept at constant value of (8 m/s). The eroding time was varied in the range of (5-30 hr) with an increment of (5 hr) at a time.

3.3 Steps for Water Contaminants

No special tests were conducted to measure the effects of additional water contaminants. However, the effects of the contaminants were derived from the all above mentioned tests which used water of different contaminants.

4. Results and Discussion

4.1 Velocity Effects

4.1.1 Eroders

Figures 2-4 show the variation of erosion wear volume for each of the examined polymers with the velocity of erodent. They illustrate that: (a) the erosion wear volume increases in a non linear trend with increasing erodent velocity for all four types of water erodents; (b) the increase in wear volume tends to be sharper and of higher level for the well water erodent, then comes sea water, desalinated water and lastly distilled water.

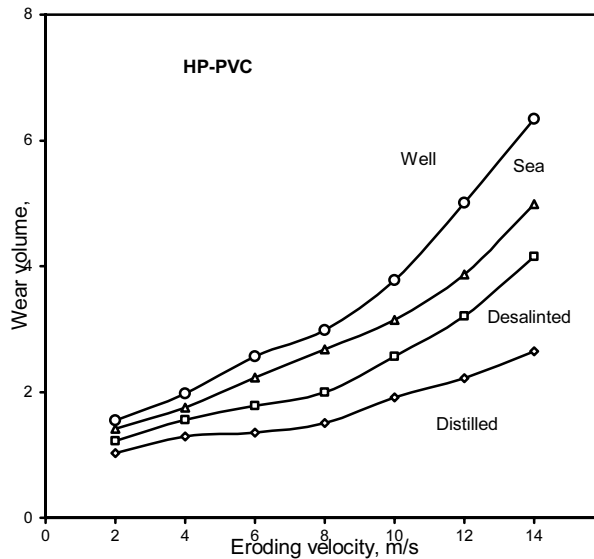


Fig. 2. Variation of erosion volume with velocity - High Pressure PVC.

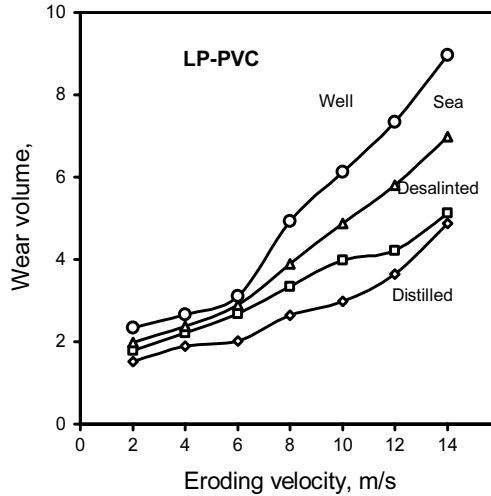


Fig. 3. Variation of erosion volume with velocity - Low pressure PVC.

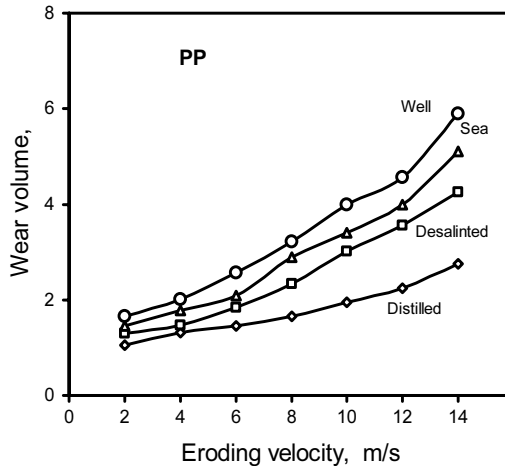


Fig. 4. Variation of erosion volume with velocity - Polypropylene.

Reasons for such behaviour would be related to: (a) the pressure applied by erodent on the material exceeds its yield pressure, this leads to plastic deformation or fracture, hence detachment of materials fibrils (photos 3-4); (b) increasing the velocity to higher values increases the pressure on materials, hence increasing the detachment of eroded fibrils. This can be noticed for velocity values greater than (6 m/s). This is the case of erosion by all erodents; However, (c) at velocity values less than (6 m/s) the surface topography of sample seems to deviate the water stream from being normal to the eroded surface, hence keeping the erod-

ing wear volume low, (photos 1-4); (d) the presence of some solid contaminants in desalinated, sea, and well waters drastically raises the wear volume of the polymers. This is because two types of erosion processes are encountered, erosion by water and erosion by solid particles and/or other contaminants. Indeed, the solid contaminants are the main cause of this drastic rise in erosion wear rate. This is expected, and it is based on impacting particle kinetic energy, which is given by $(mV^2/2)$. The rate of erosion wear is believed to be proportional to an (n) powered velocity, where (n) is greater than (2) for solid or slurry erodent. However, values of (n) less than (2) have not been found to date in solid particle erosion, although values as low as (0.8) have been found in erosion-corrosion tests^[24]. However, the non linearity in the curves could be related to the following: the actual erodent–target impact velocities in the cases of well, desalinated, and sea waters are less than the impingement velocity due to particle rebound shielding effects, fluid dynamic effect, and the damping effect of water which prevents most of the erodent particles from penetrating the tested material^[19-21], and to the damping effect of the examined polymers.

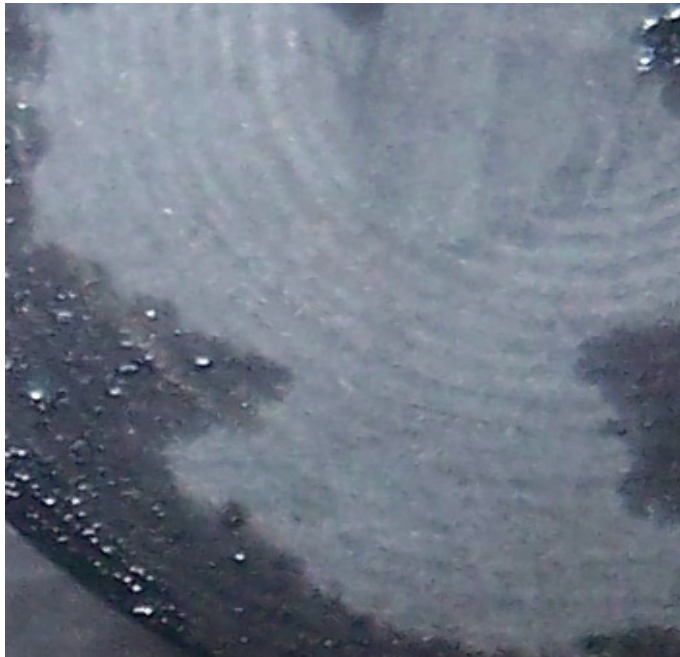


Photo 1: Samples surface topography before erosion. X20



Photo 2: Surface topography after 4 hrs of continuous erosion. X20

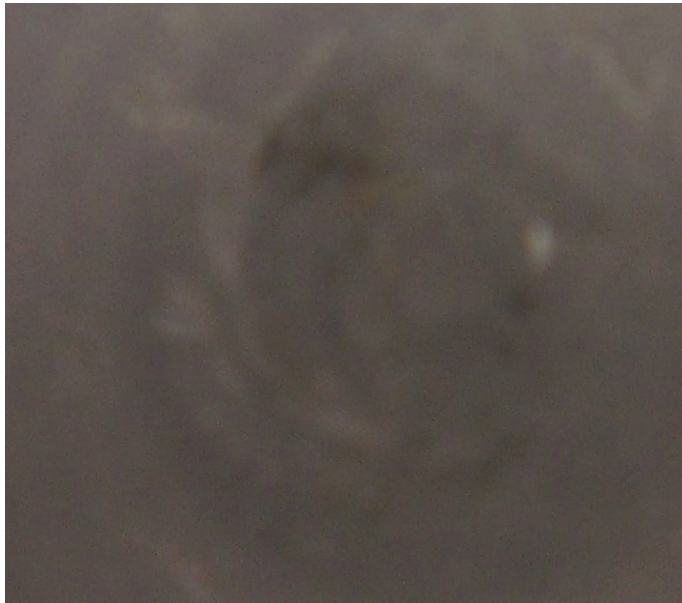


Photo 3: Eroded area of sample. X20.

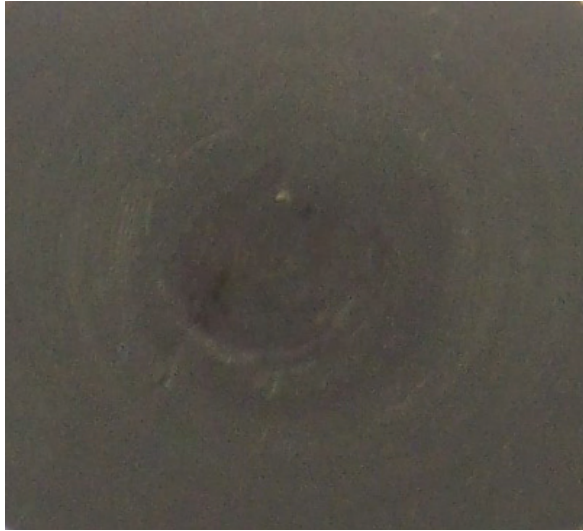


Photo 4: Eroded area of sample. X20

4.1.2 Comparison

Figures 5-8 compare the results of erosion by the four erodents. It is shown that (PVC) has the highest aqueous erosion resistance, and then comes PP, and lastly LP-PVC. This could be related to the following: (a) the hardness of HP-PVC (see Table 1). The erosion wear rate is inversely proportional to the hardness of the material; (b) the damping effect of the polymers which varies from one material to another depending on the elasticity and plasticity of the material; (c) other mechanical properties of the materials (Table 1) such as impact, tensile, and flexural strength, fatigue resistance, and ductility^[24, 39].

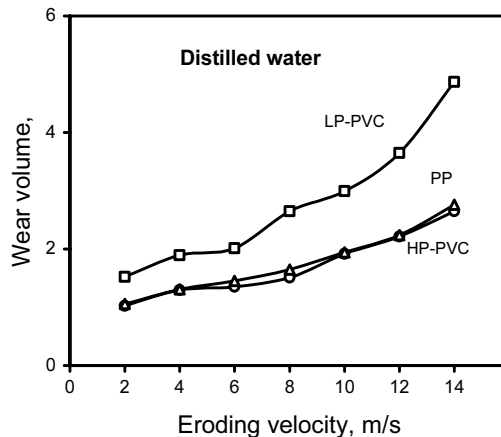


Fig. 5. Erosion by distilled water.

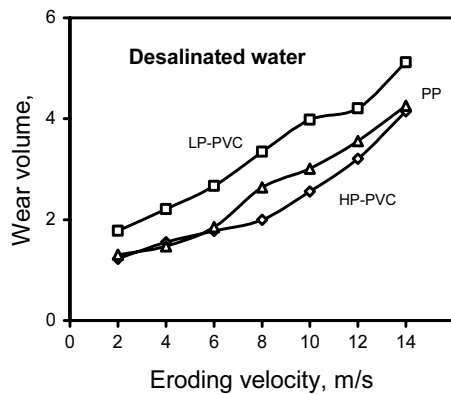


Fig. 6. Erosion by desalinated water.

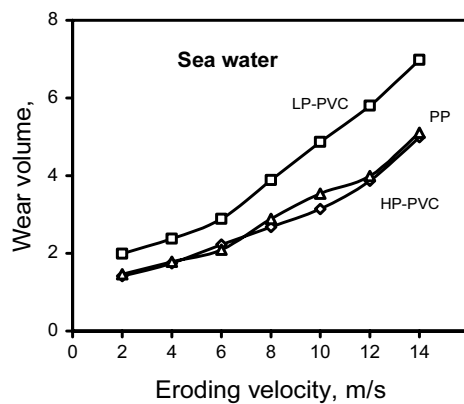


Fig. 7. Erosion by sea water.

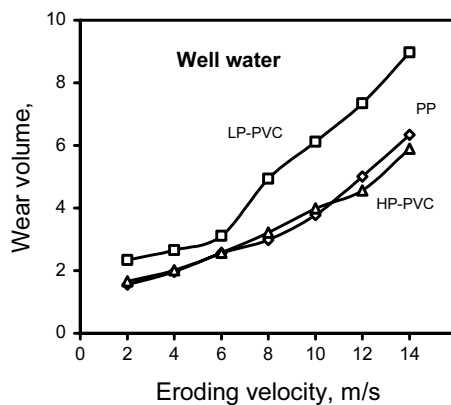


Fig. 8. Erosion by well water.

4.2 Time of Erosion

4.2.1 Eroders

Figures 9-11 show the variation of erosion wear volume for each polymeric material with the erosion time (hours). They illustrate that: (a) the erosion wear volume increases in a non linear trend with the increasing erosion time for all three polymers and for all types of the aqueous erodents; (b) the increase in erosion volume tends to be sharper and of higher level for the well water erodent, then comes the sea water, the desalinated, and lastly the distilled water; (c) sharp change in the trends of all curves as the eroding time exceeds the value of (15) hours.

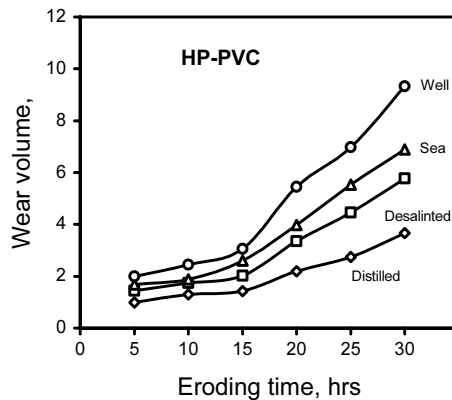


Fig. 9. Variation of erosion wear volume with time for HP-PVC.

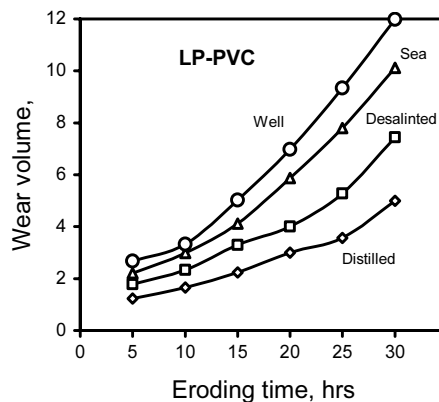


Fig. 10. Variation of erosion volume with time for LP- PVC.

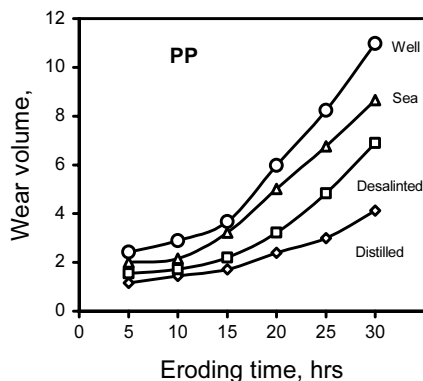


Fig. 11. Variation of erosion with time for Polypropylene.

The reasons for such behaviour are thought to be related to the following: (a) as previously indicated for the case of velocity of erodents; (b) to the accumulation of the mechanical damages such as fatigue, cracks, and deformation into the materials fibrils, which reduces the erosion resistance of the polymeric material, hence, the detachment of the eroded fibrils from the bulk of the material becomes faster and greater in values. This is the case for the eroding time value greater than (15 hr).

4.2.2 Comparison

Figures 12-15 compare the results of erosion wear volume for the three polymers eroded by the four aqueous erodents. It has the same trend as the results which were previously obtained for the case of velocity of erodents. The figures also show that the (HP-PVC) has the highest aqueous erosion resistance, then closely comes (PP), and lastly the (LP-PVC). It is believed that the same preceding interpretation is still valid here.

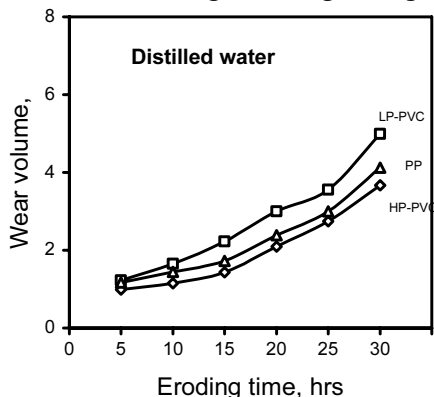


Fig. 12. Erosion by distilled water.

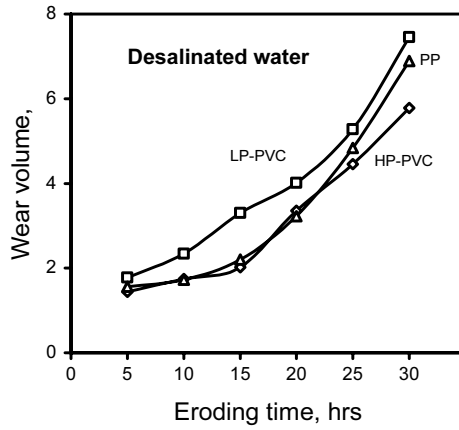


Fig. 13. Erosion by desalinated water.

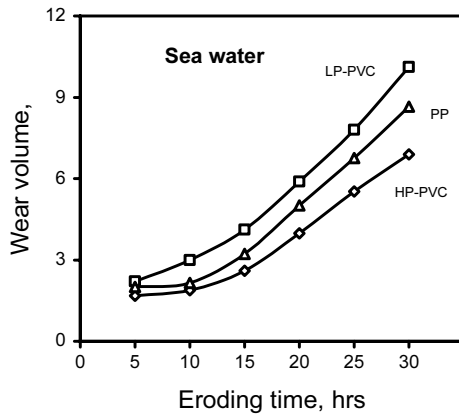


Fig. 14. Erosion by sea water.

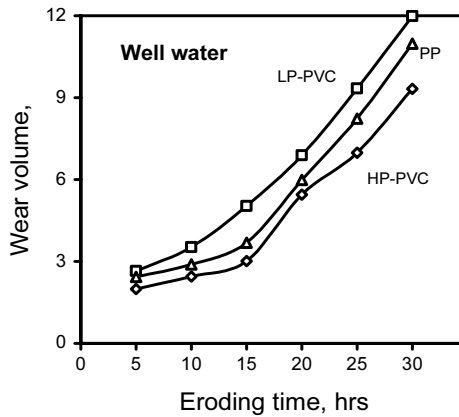


Fig. 15. Erosion by well water.

5. Conclusions

The erosive wear volume for all three polymers increases with the increasing erodent velocity and/or eroding time. As the velocity and / or eroding times exceed certain values, the increase in erosion wear became severe. This is for all four erodents. Furthermore, the presence of contaminants in desalinated, sea, and well waters (solid particles, diluted salt, and ... etc) doubles or, in some cases, triples the wear volume in comparison with the distilled water. However, comparing these results to the results of erosion by solid particles show that the presence of water greatly reduces the level of erosion wear due to particle rebound shielding effects, fluid dynamic effect, and the damping effect of water which prevents most of these erodent particles from penetrating the material, and also to the damping effect of the examined materials. Photos 3-4 show some white colored solid particles of well water penetrated and captured by the damping polymeric samples. It is also concluded that the HP-PVC has the highest erosion resistance, and then closely comes the PP, and lastly the LP-PVC.

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تآكل المواد اللدنة المستخدمة في أنظمة نقل المياه بآلية الاقتلاع (الحت) بالسوائل المائية

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المستخلص. تصنع عناصر أنظمة نقل المياه مثل الأنابيب،
والأكواع، والوصلات المختلفة من مواد اللدائن. وبسبب طبيعة
عملها تتعرض هذه العناصر للتآكل بآلية الاقتلاع أو الحت
(Erosion) نتيجة صدمها بتيارات الماء وما يحتويه من مواد علفة
صلبة أو ذائبة. يهدف هذا البحث لدراسة مقاومة هذه العناصر
للتآكل بآلية الاقتلاع.

وقد تم اختيار ثلاثة أنواع من المواد اللدنة تستخدم غالباً في
انتاج العناصر المذكورة وهي: (بي في سي PVC) عالي الضغط
و (بي في سي PVC) منخفض الضغط و بولي بروبايلين (PP).
كما استخدمت أربعة أنواع من المياه المختلفة كوسائط اقتلاع وهي:
الماء المقطر (Distilled water)، الماء المالح (Desalinated
water)، ماء البحر (Sea water)، وماء الآبار (Well water).
وقد تمت دراسة تأثيرات كل من سرعة تيار الماء وزمن استمرار
الاقتلاع على سلوك تآكل هذه المواد المذكورة.

أُجريت جميع التجارب المعملية اللازمة في وسط معايير عند درجة حرارة (٢٣°) ونسبة رطوبة قدرها (٤٠٪). وقد بينت التجارب أن تآكل جميع المواد اللدنة المختبرة يزداد مع زيادة كل من سرعة التيار وزمن الاقتلاع أو كليهما معاً، كما بينت أن التآكل يزداد بشكل كبير عند قيم معينة للسرعة والزمن أو لأحدهما. وبينت التجارب أيضاً أن وجود بعض الشوائب في المياه له تأثير كبير على تآكل المواد، وأن مادة (بي في سي PVC) عالية الضغط هي الأعلى مقاومة للتآكل بآلية الاقتلاع (الحت Erosion) بين المواد المختبرة.