Analysis of Contact Angle for Metallic Materials in Wastewater Pumps

CRISTIAN SAVIN[1], CARMEN NEJNERU[1]*, CATALIN ANDREI TUGUI[1], MANUELA CRISTINA PERJU[1,2]*, ANDREI VICTOR SANDU[1,2], COSTICA BEJINARIU[1]

[1]Gheorghe Asachi Technical University of Iasi, Faculty of Materials Science and Engineering, 67 Dimitrie Mangeron Str., 700050, Iasi, Romania

[2] Centre of Excellence Geopolymer& Green Technology (CEGeoTech), School of Materials Engineering, Universiti Malaysia Perlis, Kompleks Pengajian Jejawi 2, 02600 Arau, Perlis

Immersed wastewater pumps work in aggressive corrosive environments and physicochemical phenomena of corrosion and erosion take place at the liquid-solid interface. Due to the type of interaction between the two media when the basic metallic material is hydrophobic, corrosion phenomena can occur with the erosion due to the movement of the solid particles in the liquid. If the liquid is exposed to the hydrophilic base material, the corrosion phenomena occur in a laminar layer, having partial protection role. In this paper, the contact angle between the metals forming the pump components and the different corrosive media with different composition and pH was measured.

Keywords: boundary layer, contact angle, erosion, hydrophobic, hydrophilic, surface tension

Wetting is important because it accompanies all processes that occur at gas-liquid-solid interfaces for both moving elements and static protection elements. The wetting degree is influenced by processes occurring in the liquid at: thermal treatments such as quenching in oil baths, water or salt baths; temperature variation at which the studied system operates; all moving parts that work with lubrication; transformer oil; hydroelectric pumps; wastewater or drinking water pumps; water as a cooling or heating agent [1].

It is possible to analyze: connection of the interfaces - liquid-solid-gas; wetting by a certain liquid (water, oil, solutions of various concentrations and compositions) on surfaces of different nature (metal, glass, polymer, textile etc.); the influence of surface treatment on the adhesion of the liquid (thin layers deposited on metal, glass, textile-specific treatment); wetting on the same surface type with liquids of various composition (waste waters with different *p*H and compositions, various oils types and different grades of wear); paint protections; wetting on surfaces with different roughness [2].

The paper includes a study on the influence of the contact angle on the dynamic corrosion resistance of the metallic materials used in the fabrication of the immersed wastewater pumps. The contact angle (the surface tension of the liquid on a flat surface) reflects the possibility of forming a boundary layer adhering to the active surface of the pump working area [3-5]. The limit layer (where the liquid has null speed) forms a relative protection zone for both erosion and corrosion. Because the boundary layer acts favorably by increasing corrosion and erosion resistance it is important to study the possibilities of its formation by analyzing the contact angle [6-12]. At a small contact angle - the liquid adheres to the surface forming a protective layer, while at a large contact angle - the surface rejects the liquid.

Experimental part

The opportunity of the work

When a liquid flowing on a surface, besides dynamic erosion phenomena, boundary layer phenomena occurs. If the surface tension of the liquid on the metal surface is low, the liquid adheres to the surface and forms a chemically and physically stable compact film that acts as a protective film against the liquid stream moving without any erosion that can occur in case of turbulence or high velocity of the fluid [13].

The formed film also depends on the viscosity characteristics of the liquid, and the cohesion between the molecules of the film is high. The film is stable and relatively static or has a specific laminar behavior, not turbulent. If the surface tension of the liquid on the metal surface is high and the fluid contact angle is large, the liquid does not form a film adhering to the surface of the metal no matter what speed it is moving (even at low speeds), so that solid surfaces are exposed to both phenomena corrosion and erosion. The layer, depending on its thickness, protects the metal walls from blows caused by solid particles that move along with the stream and also protects against all types of dynamic aggressions.

Depending on the nature of the liquid (its chemical composition), corrosion phenomena may occur but will be less intense than when combined with erosion phenomena. Waste water (domestic and industrial) immersed pumps have metal components made of various types of metals - aluminum, bronze, brass, stainless steel, gray cast iron (cast iron), nodular cast iron (rotor), low alloyed steels (screws), etc.

During operation, they create the prerequisites for galvanic corrosion, because they form a galvanic series depending on the type of liquid (content in sulfur compounds, pH, concentration of suspension elements, etc.), decomposing biological substances, bacteria, fungi, etc.

The corrosion of the elements that form the pump is also accentuated by the mechanical erosion that occurs by hitting the pump elements with sand, sludge and suspended particles (may also be metallic microparticles). A high influence is also the type of liquid flow - laminar or turbulent. In both cases, either physical or chemical aggression can be diminished if the liquid in which it is immersed adheres to the metal surfaces, forms a protective layer against corrosion due the suspensions [14].

Corrosion occurs also in the boundary layer but is reduced than in the absence of the boundary layer. If the contact angle between the metal parts of the pump and

* *email: nejnerucarmen@yahoo.com; mcperju@tuiasi.ro*

the liquid (wastewater) is large, the liquid humidifies the surface to form a protective layer, and if the contact angle is low, the liquid slides over the metal and boundary layer is not formed. An influence on the surface tension represented by the angle of contact is also the thermal or thermochemical treatment of the surface.

Phosphating is the enrichment of the superficial phosphorus layer, forming stable compounds of the $FePO_4$ (iron phosphate) type, $Fe_3(PO_4)_2$, $Zn_2Fe(PO_4)_2 \cdot 4H_2O$ (Phosphophilite Hydrate) [15, 16]. The surface has a specific structure, generally porous, which leads to an increased wetting capacity of the liquids. A special influence also has the quality of the surface, implicitly roughness [17].

Chemical-structural characterization of the metallic materials used

The metallic materials which have been chosen as the basis for measuring the contact angle of the various types of wasted liquids are materials from which the components of the immersed pumps are constructed, namely: low alloyed steel, bronze, brass, aluminum alloy, lamellar graphite cast iron, nodular cast iron, phosphated nodular cast iron.

The chemical compositions of all samples were determined using a FOUNDRY-MASTER - World Wide Analytical Systems AG emission spectrophotometer. The microstructure of these alloys was analyzed by optical microscopy, according to standard procedures [18], after attack of the polished surface with a solution of 2% nitric acid in ethyl alcohol. An Optika B383 MET metallographic microscope was used.

The samples, from the above-mentioned metallic materials were prepared for metallographically evaluation being attacked with Nital 4% for ferrous materials, with ferric chloride ($FeCl_3$) for Cu-alloys and weakly concentrated nitric acid (HNO_3) for aluminum alloys.

Chemical analysis of support metal materials used in the experiment

Contact angle experiments will be performed using liquid-solid angle measurement using wastewater with different *p*H (neutral, acidic and basic) as the liquid, and as a support - the metallic materials from which the elements of immersed pumps are made, the chemical composition being shown in table 1.

Samples from the above-mentioned metallic materials were prepared metallographically and attacked with Nital 4% for ferrous materials, Cu-alloys with ferric chloride ($FeCl_3$) and weakly concentrated nitric acid (HNO_3) for aluminum alloys.

In figure 1 a where the microstructure of the low alloy steel sample is shown, a hypo eutectoid structure is observed, where the light portions of polygonal, equiaxial grains are ferrite (Fα) and the dark areas are perlite (a mechanical mixture containing 88% ferrite and 12% cementite). On the lamellar graphite cast iron it is possible to distinguish the shape of the fine graphite lamellas on the background of the ferrite-perlite mass figure 1 b.

Table 1
CHEMICAL COMPOSITION OF METALLIC MATERIALS, %

sample	Fe	C	Si	Mn	P	S	Cr	Ni	Al	Cu	Ti	W	AE
Low alloyed steel	98.5	0.26	0.11	0.42	0.02	0.05	0.09	0.07	0.02	0.32	0.02	0.02	0.1
sample	Fe	C	Si	Mn	P	S	Cr	Ni	Ti	AE	-	-	-
Stainless steel	71.5	0.05	0.45	1.16	0.03	0.006	17.1	9.03	0.55	0.02	-	-	-
sample	Fe	C	Si	Mn	P	S	Cr	Ni	Cu	Mo	Sn	Ti	AE
Gray cast iron	91.7	4.5	1.54	1.03	0.62	0.14	0.09	0.05	0.15	0.01	0.02	0.03	0.06
sample	Fe	C	Si	Ni	Mg	Mn	P	S	Cr	Ti	Al	Cu	AE
Nodular cast iron	92.7	4.50	2.28	0.12	0.10	0.09	0.05	0.04	0.02	0.02	0.01	0.01	0.01
sample	Cu	Sn	Pb	Zn	Fe	Al	Ni	Si	AE	-	-	-	-
Bronze	85.6	11.2	1.05	1.39	0.40	0.02	0.29	0.02	0.01	-	-	-	-
sample	Cu	Zn	Al	Pb	Sn	Mn	Fe	Si	Ni	Co	Ag	-	-
Brass	58.4	39.4	0.03	1.06	0.07	0.03	0.11	0.06	0.12	0.02	0.006	-	-
sample	Al	Zn	Mg	Cu	Fe	Cr	Mn	Ti	V	Zr	Ga	Co	AE
Al alloy (7075)	90.3	5.41	2.26	1.50	0.17	0.22	0.04	0.03	0.01	0.01	0.007	0.003	0.04

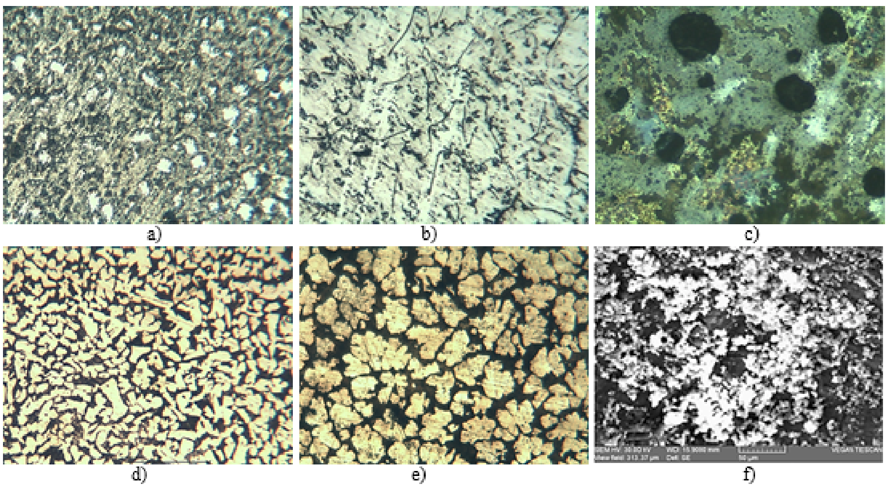

Fig.1. Microstructure of the samples used at various magnification powers: a) low alloyed steel sample 200x; b) gray cast iron sample with lamellar graphite 200x; c) cast iron sample with nodular graphite 200x; d) bronze sample 200x; e) 100x brass sample; f) duralumin sample 500x.

Nodular cast iron is a cast iron with spheroidal graphite. Due to the nodular aspect of the graphite, the rejection effect is minimized and thus high value of strength to elongation and failure are obtained, figure 1 c. The cast bronze sample has the main Sn alloying element. It has a biphasic structure, $\alpha + \beta$, specific to cast alloys, figure 1 d. In figure 1 e a biphasic metallographic casting structure is observed. Brass containing more than 37% Zn has in addition to the solid solution α and an intermetallic phase β. These brasses are hard and fragile and can be processed by hot plastic deformation. Thermal treatments can also be applied to obtain better technological or mechanical properties. Aluminum alloys in the Cu-Al-Mg system, also called Dural, have important mechanical strength, refractoriness and shock resistance properties and are mainly used in the naval and aeronautical industries. The structure is one of relatively small and uniform grain casting, figure 1f.

Sample analysis of phosphated nodular iron

The rotor of the immersed pump is heavily stressed both to erosion due to the presence of suspension microparticles in waste water as well as to corrosion due to aggressive chemical agents such as sulphides or acids.

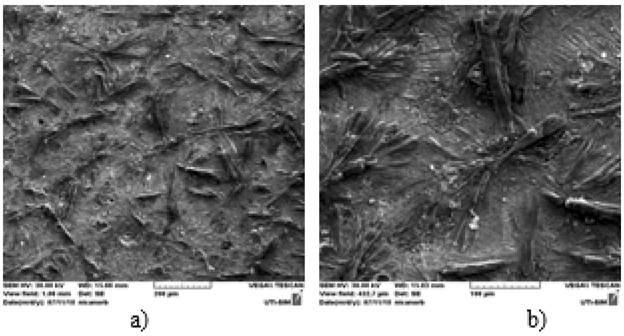

Fig.2. Phosphate nodule iron microstructure: a) 200x; b) 500x.

In order to improve the surface quality of the material from which the pump rotor is made, a thermo-chemical enrichment of the surface layer with phosphate, i.e. phosphating, is carried out, obtaining the substance $Zn_2Fe(PO_4)_2 \cdot 4H_2O$ (phosphophilite hydrate) [19, 20].

Synthetic wastewater composition

Synthetic test waters were prepared according to the Boeije [21] studies on the average composition of sedimentary water in municipal sewage.

The composition of synthetic base waste water, called DWW-1 (Domestic Waste Water) is:

-Chemical components: NH_4Cl 15 mg/L, $CH_3COONa \cdot 3H_2O$ 142 mg/L, $MgSO_4 \cdot 7H_2O$ 32 mg/L, $CaHPO_4$ 20 mg/L, $K_2HPO_4 \cdot 3H_2O$ 56 mg/L, $FeSO_4 \cdot 7H_2O$ 14 mg/L, Urea 98 mg/L, Peptone 15 mg/L (Peptone - mixture of water-soluble peptides obtained by the hydrolysis of proteins under the action of pepsin).

-Food components: 118 mg / L powder, 54 mg / L brewer's yeast, 122 mg / L starch, 15 mg / L soybean oil.

-Metal artifacts: $Cr(NO_3)_3 \cdot 9H_2O$ 0.10 mg metal/L; $CuCl_2 \cdot 2H_2O$ 0.20 mg metal/L, $MnCl_2$ 0.05 mg metal/L, $NiSO_4 \cdot 7H_2O$ 0.08 mg metal/L, $PbCl_2$ 0,07.

Inorganic components are respondents for the corroded properties of the solution, while the food components behave as a corrosion inhibitor or protector. This solution has a *p*H close to neutrality: *p*H = 6.5.

In order to analyze the influence of *p*H on corrosion behavior, the *p*H of the basic solution (DWW-1) was modified by addition of hydrochloric acid and sodium hydroxide. Thus, alternative solutions were obtained: DWW-2, *p*H = 3.0, by titration of the basic solution with 0.1 M HCl solution; DWW-3, having a *p*H of 11.0 by titrating the basic solution with 0.1 M NaOH solution.

The choice and characterization of the working method consisting in measuring the angle of contact with the goniometer

The contact angle measurement gives indications of the surface tension at the solid-liquid-gas interface [22]. In the case of the immersion pump studied, the contact angle measured for each combination of metal and liquid shows corrosion and erosion possibilities with or without protective film. To carry out these measurements, a Kruss type goniometer has been used to measure the values of contact angles and superficial tension [23].

The experiments were performed in accordance with the occupational health and safety laws and regulations [24, 25].

Results and discussions

The contact angle provides indications of hydrophobic or hydrophilic character of a solid-liquid combination. In this case, studying the contact angle is important for characterizing the zone of the liquid medium that causes corrosion and erosion in the immersed pump. If the metal is combined with a liquid and there is a hydroscopic phenomenon, there is a tendency to form a liquid protective layer that adheres physically to the surface of the metal. The protective boundary layer is relatively stable when motion of stream is either slow or turbulent in the environment and has some elasticity that makes it remove the suspended particles moving with the liquid, decreasing the possibility of wall erosion. The protection also refers to the decrease of the corrosion intensity in the boundary layer area, which leads to a longer operation and to keeping the working dimensions longer in functional parameters. Three types of different *p*H (neutral, acidic and basic *p*H) waste water were used to measure the metal-liquid contact angle and distilled water for comparison. The waste water used for the measurements has been filtered with filter paper to avoid problems in the gauge, to avoid the clogging of the droplet release valve. This does not essentially influence the result because the presence of suspension particles relatively little affects the hydrophilic or hydrophobic character of the metallic material.

The results of the measurements were recorded in table 2, based on the liquid, where the mean values and the maximum deviations were calculated.

Five measurements were made for each coupling, waste or distilled water - metal support, to see how a repeatability of the results occurs. The values in 8th column represent the average of the results obtained for the contact angle measured with the Kruss goniometer.

For all metal surfaces, apart from phosphated nodular cast iron, there are no differences greater than 10^{o}, regardless of the type of droplet. One exception occurs in bronze with acidic water where a difference of 14^{o} is encountered.

Several researches have been carried due to the contact surface accuracy, which, even if was sanded and polished, can interfere with the air suspension that can influence the measurements. All surfaces, except for phosphate and bronze, are hydrophilic, both for distilled water and different wastewaters with different *p*Hs.

The angle of contact is between 92.1° (nodular cast iron with acidic water) and 103.3° (brass with distilled water), relatively close values indicating the impossibility of forming the protective film in almost all cases and the

Table 2

RESULTS OF CONTACT ANGLE MEASUREMENTS FOR METALLIC MATERIALS AND WASTED LIQUIDS

Metallic materials and liquids	Contact angle measurements					mean value	deviation
	U.C. (degree)	U.C. (degree)	U.C. (degree)	U.C. (degree)	U.C. (degree)	U.C. (degree)	U.C. (degree)
bronze ad	104.1	105.4	102.9	97.9	99.8	102.0	3.1
low alloyed steel ad	103.9	98.5	96.3	100.2	97.2	99.2	3.0
brass ad	104.8	106.3	108.0	99.6	100.9	103.9	3.6
stainless steel ad	97.9	96.4	96.2	98.0	96.5	97.0	0.9
aluminum ad	99.2	100.0	101.4	102.2	102.0	101.0	1.3
gray cast iron ad	96.5	98.0	98.8	96.5	98.6	97.7	1.1
n.c.i phosphated ad	39.1	50.7	49.6	68.0	50.8	51.6	10.4
nodular cast iron ad	101.8	101.5	101.4	101.1	104.2	102.0	1.3
bronze dww1	99.6	99.8	99.2	99.0	99.5	99.4	0.3
low alloyed steel dww1	97.2	97.6	97.0	97.4	98.1	97.5	0.4
brass dww1	102.0	100.9	102.7	100.5	100.4	101.3	1.0
stainless steel dww1	95.3	94.1	95.3	95.6	93.0	94.7	1.1
aluminum dww1	97.6	99.6	102.1	98.8	100.7	99.8	1.7
gray cast iron dww1	96.9	95.5	93.4	95.6	94.1	95.1	1.4
n.c.i phosphated dww1	36.0	48.3	51.0	-	-	45.1	8.0
nodular cast iron dww1	99.4	100.3	99.1	97.2	94.9	98.2	2.2
bronze dww2	98.3	102.4	97.6	94.6	96.7	97.9	2.9
low alloyed steel dww2	96.8	97.0	97.1	98.8	98.0	97.5	0.8
brass dww2	101.3	102.0	100.9	101.6	100.9	101.3	0.5
stainless steel dww2	92.1	93.8	93.8	94.6	95.1	93.9	1.1
aluminum dww2	101.4	100.0	100.9	99.7	100.5	100.5	0.7
gray cast iron dww2	99.9	102.1	98.6	96.1	98.6	99.1	2.2
n.c.i phosphated dww2	65.9	60.8	44.9	40.4	-	53.0	12.3
nodular cast iron dww2	95.3	98.7	95.8	97.2	98.3	97.1	1.5
bronze dww3	82.8	88.7	74.7	80.5	80.6	81.5	5.0
low alloyed steel dww3	96.8	94.3	94.8	94.6	96.6	95.4	1.2
brass dww3	99.2	101.6	100.5	100.5	98.9	100.1	1.1
stainless steel dww3	101.3	96.9	96.3	95.3	96.1	97.2	2.4
aluminum dww3	98.2	100.3	100.0	99.2	101.0	99.7	1.1
gray cast iron dww3	98.7	98.1	98.3	97.8	97.1	98.0	0.6
n.c.i phosphated dww3	68.1	60.9	61.1	48.4	38.1	54.4	11.0
nodular cast iron dww3	95.1	93.5	96.7	92.1	93.7	94.2	1.7

ad – distilled water; dww – domestic waste water; U.C. – contact angle; n.c.i - nodular cast iron

occurrence of dynamic erosion and corrosion simultaneously.

At bronze with acidic water there is the possibility of a protective layer of lamellar protective film at low speeds having a contact angle of less than 90° but greater than 74.7°. In the case of phosphated nodular iron, the contact angle shows a highly hydrophilic surface in all types of liquids with the possibility of forming the protective layer. However, there is also a strong non-uniformity in the measurement of contact angle values due to the strong porosity of the adhering layer which leads to the anchoring of the protective layer and its stability even under the high velocity of the liquid in the pump. Droplets photos (selection) are shown in figures 3 to 10.

The solid bronze surface, on which different pH drops were used to measure the contact angle

Bronze as the base material for distilled water and waste water is a relatively hydrophobic surface, the contact angle ranging between 97.6 and 102.9° (mean values) and slightly hydrophilic to acidic water with a contact angle of 80.6°. This shows that no protective coating is formed on the bronze plates and the erosion due to solids suspensions and particles (sand, mud, etc.) is relatively high (fig. 3).

Bronze being a material resistant to marine water (high salinity water) and wastewater, chemical corrosion is not too high (so it is not a strong destructive factor). It can be noticed that the acidic wastewater (*p*H - 11) has a lower contact angle (80.6°) and lower surface tension, which

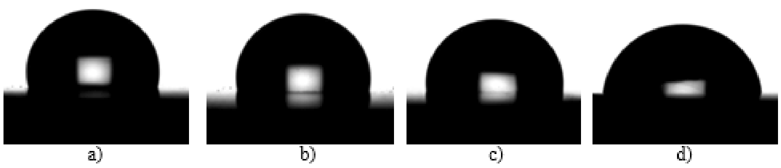

Fig.3. Contact angle for bronze metal surface with: a) distilled water (contact angle: 102.9°); b) neutral *p*H (6.5) - dww1 (contact angle: 99.5°); c) basic *p*H water (3.0) - dww2 (contact angle: 97.6°); d) wastewater with acid *p*H (11.0) - dww3 (contact angle: 80.6°).

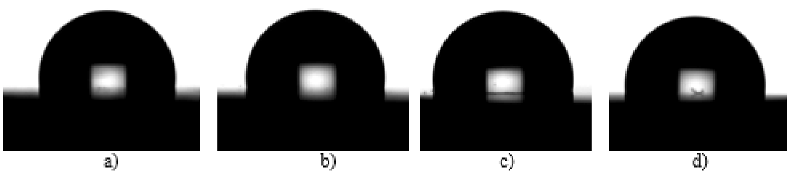

Fig.4. Contact angle for the low alloyed steel surface with: a) distilled water (contact angle: 98.5°); b) neutral *p*H (6.5) - dww1 (contact angle: 97.6°); c) wastewater with basic *p*H (3.0) - dww2 (contact angle: 97.1°); d) wastewater with acid *p*H (11.0) - dww3 (contact angle: 94.8°)

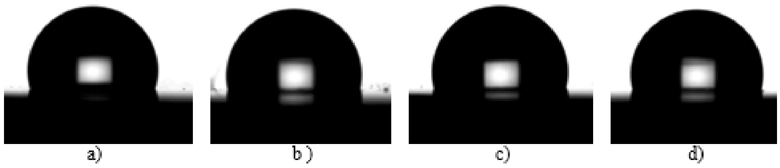

Fig.5. The contact angle for the brass metal surface with: a) distilled water (contact angle: 104.8°); b) neutral *p*H (6.5) - dww1 (contact angle: 100.9°); c) basic *p*H water (3.0) - dww2 (contact angle: 101.6 °); d) wastewater with acid *p*H (11.0) - dww3 (contact angle: 100.5°)

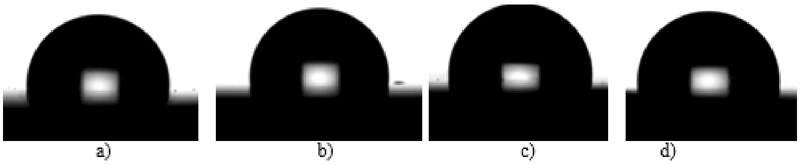

Fig.6. Contact angle for stainless steel surface with: a) distilled water (contact angle: 96.5°); b) neutral *p*H (6.5) - dww1 (contact angle: 95.3°); c) basic *p*H water (3.0) - dww2 (contact angle: 93.8°); d) wastewater with acid *p*H (11.0) - dww3 (contact angle: 96.9 °)

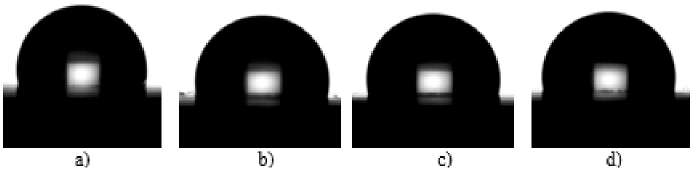

Fig.7. Aluminum metal surface contact angle with: a) distilled water (contact angle: 101.4°); b) neutral *p*H (6.5) - dww1 (contact angle: 99.6°); c) basic *p*H water (3.0) - dww2 (contact angle: 100.5°); d) wastewater with acid *p*H (11.0) - dww3 (contact angle: 100.0°)

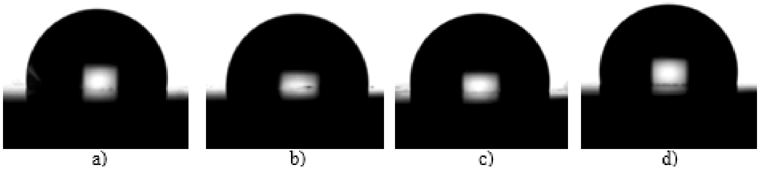

Fig.8. Contact angle for the cast iron gray metallic surface with: a) distilled water (contact angle: 98.0 °); b) neutral *p*H (6.5) - dww1 (contact angle: 95.1°); c) wastewater with basic *p*H (3.0) - dww2 (contact angle: 98.6°); d) wastewater with acidic *p*H (11.0) - dww3 (contact angle: 98.1°)

means that at low velocities of the liquid on bronze surfaces, cannot form low-thickness protection layers.

Solid surface, low-alloyed steel, with different pH drops for measuring the contact angle

Low alloy steel has a relatively uniform, hydrophobic surface, whether distilled water or waste water, with contact angles ranging from 98.5 to 94.8° (mean values) (fig. 4).

This indicates that no protective coating is formed on the surfaces, the corrosion and dynamic erosion being high and depend less on neutrality, acidity or water baseness, and more on the velocity of the stream and on the presence and size of the waste particles in the water.

The solid brass surface, which has been used to measure the contact angle, drops of wastewater with different pH

The Cu-Zn (brass) alloy has hydrophobic characteristics for both distilled water and wastewater, with contact angles ranging from 100.5 to 104.8°(mean values) (fig. 5).

It can be seen that distilled water has a slightly higher contact angle on brass compared to wastewater irrespective of *p*H. This is due to the influence of homogeneous molecule corrosion compared to the heterogeneous molecules encountered in the wastewater, when dissolved in water modifies the physical and chemical characteristics of the liquid. Waste water has a very close contact angle on brass, which shows that the acidity or basicity of the waste water does not influence the adhesion of water to the surface.

Solid surface, stainless steel, which has been used to measure the contact angle, drops of wastewater with different pH

The contact angle of distilled and wasted water on the stainless steel surface is closed as value regardless of the *p*H of the water and indicates a hydrophobic water surface(fig. 6).

A slightly lower value is for *p*H 3 (basic) water on stainless steel and is 93.8° . The other values range between 95.3° (neutral pH wasted water) and 96.9° (acidified *p*H wasted water). The stainless steel is resistant to corrosion in aggressive environments, but it is a soft steel, which can cause problems with microparticle erosion, because on its surface there are no protective films adhering to the surface of stainless-steel parts.

Solid surface, aluminum, on which different pH drops of water were used to measure the contact angle

Aluminum is a hydrophobic surface for both distilled water and wastewater irrespective of its *p*H and contact angle values varying between 99.6° (neutral *p*H water) and 101.4° (distilled water) (mean values) (fig. 7).

Because the values are very close, it can be concluded that aluminum does not form protective adhering film on the surface of the parts. Aluminum and its alloys have the property of forming compact aluminum oxides with similar characteristics (water-repellent) to the surface. If the surface had been freshly ground, the absence of aluminum oxide could have given a different value for the contact angle.

The solid, lamellar gray cast iron surface, on which different pH drops of water were applied to measure the contact angle

Gray lamellar cast iron has a hydrophobic surface for distilled water and waste water, with a contact angle varying slightly between 95.1° (neutral *p*H water) and 98.6° (baseline *p*H) (fig. 8).

Gray lamellar cast iron is usually used in the execution of the pump housing so that during operation, the mechanical and dynamic stresses are relatively low so that the lack of the protective layer does not greatly affect the reliability of the gray cast iron parts.

The solid surface, gray nodular cast iron, which has been used to measure the contact angle, drops of wastewater with different pH

The angle of contact for water droplets on the nodular cast iron support is greater than 90° in all situations, ranging from 93.7° (for water with *p*H 11) and 101.8° (for distilled water), (mean values) (fig. 9).

Under these conditions, the surface is hydrophilic, not allowing formation of the laminar protective layer.

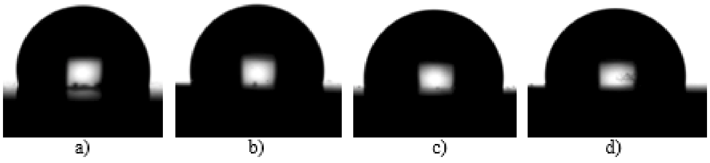

Fig.9. The contact angle for the nodular cast iron metal surface with: a) distilled water (contact angle: 101.8°); b) neutral *p*H (6.5) - dww1 (contact angle: 99.1°); c) basic *p*H water (3.0) - dww2 (contact angle: 97.2°); d) wastewater with acid *p*H (11.0) - dww3 (contact angle: 93.7°)

Fig.10. The contact angle for the phosphorous nodular cast iron metal surface with: a) distilled water (contact angle: 50.8°); b) neutral *p*H (6.5) - dww1 (contact angle: 48.3°); c) basic *p*H water (3.0) - dww2 (contact angle: 44.9°) d) wastewater with acid *p*H (11.0) - dww3 (contact angle: 48.4°)

Solid surface, phosphated nodular gray cast iron, to which different pH drops of water were used to measure the contact angle

Nodular cast iron is the material from which the rotor of the immersed wastewater pump is made and which has the purpose of gathering domestic and industrial wastewater towards treatment plant for cleaning toxic chemical elements, heavy metal particles, decomposing food waste, etc. (fig. 10)

Since the rotor is subjected to multiple dynamic aggressions (mechanical erosion) and static (chemical corrosion), a thermo-chemical phosphate treatment has been carried out on its surface, which influences both the corrosion behavior and the character of the contact angle.

The contact angle for phosphated cast iron is between 44.9° for basic water and 50.8° for distilled water. This indicates that the distilled water and the waste water adhere to the surface, which has a hydrophilic character, forming laminar protective coatings on the surface.

This protective layer limits erosion of rotor walls in dynamic regime, erosion due to the presence of suspension particles, metallic particles, sludge or sand. The protective effect of the lamellar layer is all the more important as the speed of use of the rotor is higher. Due to this type of deposition that is porous, the contact angle is nonuniform value, but it reflects the hydrophilic nature of the surface.

Conclusions

It is noted that the three (waste) water with acidic, basic and neutral pH, but also distilled water react in terms of the contact angle, which is relatively similar. The contact angle has similar values for low alloyed steel or stainless steel, brass, aluminum and gray lamellar or nodular gray cast iron, the surfaces being hydrophobic. The only exception is bronze for basic pH water when the surface becomes hydrophilic with contact angle values between 74.7° and 88.7°.

Thermal or thermal-chemical treatment of surfaces strongly influences the contact angle. In the studied case it is observed that the phosphated nodular iron has contact angles between 38.1 and 68.1° indicating a hydrophilic surface. It is also noticed the particularly high degree of unevenness of the measured values, which indicates a roughness with high values and a high porosity of the phosphate layer.

In the case of hydrophobic surfaces (almost all the metal surfaces studied), the liquid that comes in contact with immersed pump parts hits the surfaces directly, the corrosion and the dynamic erosion occurring directly. In the case of hydrophilic surfaces, there is an adherent limiting layer on the surface of the metal to protect the erosion of suspended particles, as well as sand, grease or heavy metal micrograins that would hit the walls of the pumps. The lamellar layer on the pump walls is stationary or has a slight laminar flow compared to the dynamic turbulent flow of the liquid stream formed by dirty water. Due to this, the particles bounce on the protective layer avoiding destruction.

References

1. CHEN, L., BONACCURSO, E., GAMBARYAN-ROISMAN, T., STAROV, V., KOURSARI, N., ZHAO, Y., Static and dynamic wetting of soft substrates, Current Opinion in Colloid & Interface Science **36**, 2018, 46–57.
2. BORMASHENKO, E., Apparent contact angles for reactive wetting of smooth, rough, and heterogeneous surfaces calculated from the variational principles, Journal of Colloid and Interface Science **537**, 2019, 597–603.
3. HERNANDEZ-SANDOVAL, J., GONZALEZ-LOPEZ, R., HERNANDEZ-RODRIGUEZ, M.A.L., GUZMÁN, A.M., Localized corrosion in an electrical submergible pump (ESP), Engineering Failure Analysis **53**, 2015, 124–131.
4. SMITH P., KRAENZLER, T., Reducing effects of corrosion and erosion, World Pumps, **2017**(2), 2017, 38-41.
5. ESCOBAR, J.A., ROMERO, A.F., LOBO-GUERRERO J., Failure analysis of submersible pump system collapse caused by assembly bolt crack propagation by stress corrosion cracking, Engineering Failure Analysis **60**, 2016, 1–8.
6. PARK, J., KIM, D., LEE C., Contact angle control of sessile drops on a tensioned web, Applied Surface Science **437**, 2018, 329–335.
7. KARIM, A.M., ROTHSTEIN, J.P., PIROUZ KAVEHPOUR, H., Experimental study of dynamic contact angles on rough hydrophobic surfaces, Journal of Colloid and Interface Science **513**, 2018, 658–665.
8. CHEN, Y., XIA, W., XIE, G., Contact angle and induction time of air bubble on flat coal surface of different roughness, Fuel **222**, 2018, 35–41.
9. REMER, M., PSARSKI, M., GUMOWSKI, K., ROKICKI, J., SOBIERAJ, G., KALIUSH, M., PAWLAK, D., CELICHOWSKI, G., Dynamic water contact angle during initial phases of droplet impingement, Colloids and Surfaces A: Physicochem. Eng. Aspects **508**, 2016, 57–69.
10. AMREI, M.M., DAVOUDI, M., CHASE, G.G., VAHEDI TAFRESHI, H., Effects of roughness on droplet apparent contact angles on a fiber, Separation and Purification Technology **180**, 2017, 107–113.
11. GU, H., WANG, C., GONG, S., MEI, Y., LI, H., MA, W., Investigation on contact angle measurement methods and wettability transition of porous surfaces, Surface & Coatings Technology **292**, 2016, 72–77.
12. WU, D., WANG, P., WU, P., YANG, Q., LIU, F., HAN, Y., XU, F., WANG L., Determination of contact angle of droplet on convex and concave spherical surfaces, Chemical Physics **457**, 2015, 63–69.
13. ANGELA MUNTEAN, DUMITRU ION ARSENIE, Probleme generale ale mecanicii fluidelor, Editura Matrixrom, 2014.
14. SAVIN, C., NEJNERU, C., PERJU, M.C., BEJINARIU, C., BURDUHOS-NERGIS, D., SANDU A.V., Galvanic Corrosion of Ductile Cast Iron Coupled with Different Alloys in Synthetic Domestic Waste Water, Rev. Chim.(Bucharest) **70**, no. 2, 2019, p. 506-511.

15. SANDU, A.V., BEJINARIU, C, SANDU, I.G., ABDULLAH, M.M.A., Modern Technologies of Thin Films Deposition: Chemical Phosphatation, Materials Research Foundations, **39**, 2018, 1-149.
16. SANDU, A.V., BEJINARIU, C, SANDU, I.G., ABDULLAH, M.M.A., Thin Phosphate Film Characterization Methods and Techniques, Materials Research Foundations, **39**, 2018, 54-85.
17. HEIB, F., HEMPELMANN, R., MUNIEF, W.M., INGEBRANDT, S., FUG, F., POSSART, W., GROß, K., SCHMITT, M., High-precision drop shape analysis (HPDSA) of quasistaticcontact angles on silanizedsilicon wafers with different surface topographies during inclining-plate measurements: Influence of the surface roughness on the contact line dynamics, Applied Surface Science, **342**, 2015, 11-25.
18. BUEHLER SUM-MET, The Science Behind Material Preparation, A Guide to Materials Preparation and Analysis, Buehlet LTD, 2004.
19. SANDU, A.V., BEJINARIU, C, SANDU, I.G., ABDULLAH, M.M.A., Characterization of Thin Phosphate Films, Materials Research Foundations, **39**, 2018, 86-131.
20. LAZAR, P., BEJINARIU, C., SANDU, A.V., CAZAC, A.M., CORBU, O., SANDU, I.G., PERJU, M.C., Corrosion Evaluation of Some Phosphated Thin Layers on Reinforcing Steel, IOP Conference Series-Materials Science and Engineering, **209,** 2017, 012025.
21. BOEIJE, H., Chemical fate prediction for use in geo-referenced environmental exposure assessment, PhD. Thesis.Faculty of Agricultural and Applied Biological Sciences. Ghent University, p. 225, 1999.
22. YILDIRIM ERBIL, H., The debate on the dependence of apparent contact angles on drop contact area or three-phase contact line: A review, Surface Science Reports, **69**(4), 2014, 325-365.
23.*** Standard Practice for Surface Wettability of Coatings, Substrates and Pigments by Advancing Contact Angle Measurement, ASTM D7334-08 (2013) -http://www.astm.org/Standards/D7334.htm.
24. BEJINARIU, C., DARABONT, D.C., BACIU, E.R., IONITA, I., SAVA, M.A.B., BACIU, C., Considerations on the Method for Self Assessment of Safety at Work. Environ. Eng. Manag. J., **16**, 2017, pp. 1395–1400.
25. BEJINARIU, C., DARABONT, D.-C., BACIU, E.-R., GEORGESCU, I.-S., BERNEVIG-SAVA, M.-A., BACIU, C., Considerations on Applying the Method for Assessing the Level of Safety at Work. Sustainability, **9**, 2017, p. 1263.

Manuscript received: 9.01.2019