Galvanic Corrosion of Ductile Cast Iron Coupled with Different Alloys in Synthetic Domestic Waste Water

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Waste water is an aggressive environment for transport pumps to treatment plants. The pumps used are generally, immersion pumps and are made of various elements like, rotor, stator, housing, screws, flanges, springs, seals, etc. The construction elements of the pumps are made of various metallic materials, such as nodular cast iron, gray cast iron, low alloy steel, stainless steel, aluminum, bronze, brass, copper, etc. When immersed in waste water, the metals form galvanic series. The paper presents the galvanic corrosion analysis of the above-mentioned metals in case the corrosive environment is waste water with various compositions.

Keywords: galvanic corrosion, nodular graphite cast iron, wastewater, galvanic coupler

The populated residential areas represent important and grave sources of water quality deterioration. The wastewater is first collected in a compact pumping station -such as a plastic sump -and is then pumped by a wastewater pump to a gravity sewer or to another pumping station. There are certain locations where it is possible to convey sewage by gravity to a central treatment facility or storm water is conveyed up to disposal point entirely by gravity. Whereas, in case of large area being served with flat ground, localities at lower elevation or widely undulating topography it may be essential to employ pumping station for conveyance of sewage to central treatment plant. Sewage and storm water is required to be lifted up from a lower level to a higher level at various places in a sewerages system.

Pumping stations are often required for pumping of untreated domestic wastewater, storm water, combined domestic wastewater and storm water, sludge at a wastewater treatment plant, and treated domestic wastewater. Pumping of sewage is also generally required at the sewage treatment plant.

Several types of pumps are used in the sewerage system for pumping of sewage, sewage sludge, grit matter, etc. as radial-flow centrifugal pumps, axial-flow and mixed-flow centrifugal pumps, diaphragm pumps, rotary screw pumps or pneumatic ejectors.

For pumping of water using radial-flow centrifugals and axial-flow and mixed-flow centrifugal type pumps normally bronze impellers, bronze or steel bearings, stainless or carbon steel shafts, and cast iron housing is used. For domestic wastewater pumping using radial-flow centrifugals and axial-flow and mixed-flow centrifugal type pumps similar material is used except that they are often made from cast iron, ductile cast iron or stainless steel impellers. Pumping of sewage is different than common water pumping due to polluted nature of the wastewater containing suspended solids and floating solids, which may clog the pumps. The dissolved organic and inorganic matter present in the sewage may chemically react with the pump and pipe material and can cause corrosion. Domestic wastewater consists of relatively weak solutions of non aggressive contaminant chemicals. The types and concentrations of contaminants in raw wastewater from domestic sources are fats, oils, greases, soaps, organic matter, dirt, human waste, food waste and anorganic compounds.

From a corrosion perspective, the sewage is no more corrosive than ordinary water, i.e., water that presents a pH near the neutrality. Wastewater is aerated in most parts of the wastewater system, at least where the biological reactions do not consume all the dissolved oxygen and produces much more corrosive conditions for many metals. The most common chemical contaminants in domestic wastewater are chlorides, nitrogen compounds and a wide variety of organic compounds. Sulfate and phosphate ions are present. The pH of domestic wastewater typically is between 6 and 7, running slightly on the alkaline side of neutral where there is higher use of soaps and household cleansing materials, most of which are mildly alkaline to increase their detergent effectiveness. Used water from manufacturing plants and factories can have a wider range of contaminants - some of which may significantly affect the corrosiveness of the wastewater. Accidentally, wastewaters can achieve low pH (acidic waters) or high pH (alkaline waters) which brings a corrosion accentuation [1-6].

Carbon steel and ductile cast iron both corrode slowly in aerated wastewaters. Corrosion rates in the normal aerated wastewater depend on the amount of aeration and to a lesser degree on the temperature. They seldom exceed 0.25 mm/y. This is relatively slow, but is high enough that carbon steel requires continual maintenance to achieve the long service life normally expected from pipes and other wastewater equipment, especially inside wastewater treatment plants. Corrosion rates of carbon steel and cast iron in wastewater can be accelerated 5 to 10 fold by local acidic conditions produced by

microbiological action or by accidentally contaminations. Furthermore, pipes and other structure made from carbon steel and ductile cast iron can be externally corroded by the surrounding soil. In some situations it is likely that they will be in contact with more traditional materials as mixed systems where galvanic forces can interfere with the corrosion resistance of the individual metals adding a supplementary corrosiveness [7-21].

When a metal is immersed in a conducting liquid it takes up an electrode potential (also known as the corrosion potential). This is determined by the equilibrium between the anodic and cathode reactions occurring on the surface and it is usually measured with reference to a standard electrode such as the saturated calomel electrode (SCE) [1-3].

Galvanic corrosion is an electrochemical process in which one metal corrodes preferentially when is in electrical contact with a different type of metal and both metals are immersed in an electrolyte [1-6]. When two or more different type of metal come into contact in the presence of an electrolyte a galvanic couple is set up as different metals have different electrode potentials. The electrolyte provides a means for ion migration whereby metallic ions can move from the anode to the cathode. This leads to the anodic metal corroding more quickly than it otherwise would; the corrosion of the cathode metal is retarded even to the point of stopping. The presence of electrolyte and a conducting path between the metals may cause corrosion where otherwise neither metal alone would have corroded. Even a single type of metal may corrode galvanic ally if the electrolyte varies in composition, forming a concentration cell.

The reactions which occur are similar to those that occur on single, uncoupled metal, but the corrosion rate is appreciable increased. The effect of coupling the two metals together increases the corrosion rate of the anode and reduces or even suppresses corrosion of the cathode.

When a metal is corroding two processes occur. One is the dissolution of metal at the anode. In the case of ferrous alloys Fe is dissolving metal, as:

$$Fe \rightarrow Fe_2^+ + 2e^-$$
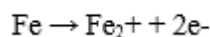
This must be balanced by a cathode reaction. Most practical cases of bimetallic corrosion occur in solutions containing dissolved oxygen and in most neutral and alkaline liquids the primary cathode reaction is the reduction of dissolved oxygen:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$
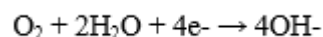
In acidic liquids the cathode reaction is often the reduction of hydrogen ions to hydrogen gas:

$$2H^+ + 2e^- \rightarrow H_2 (g)$$
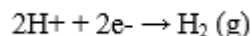
In deaerated environments other cathode reactions can occur, as reduction of partially oxidized sulphureous species. Under uncoupled corrosion the anodic and cathodic reactions occur at small, local areas on the metal. In a bimetallic couple the cathodic reaction is more, or totally, on the electropositive member of the couple and the anodic reaction is mostly, or totally, on the electronegative component of the couple.

Many factors can influence the corrosion in a coupled pair of different metals, i.e. couple potential (E_{couple}) and current density of couple (j_{couple}). Among these on can evidences: the difference in electrode potentials of the individual partner of the couple, the quality of the electrical connection between the metals, the conductivity of the electrolyte, area ratio of the two electrodes, their configuration (i.e., the distance between the dissimilar metals), aeration, metallurgical composition and stifling effects due to the diminishing rate of diffusion of oxygen through the electrolyte and through films of corrosion product to cathode regions. Similar studies were performed on different type of materials, according to their use [21-32].

This investigation was aimed to study the effect of coupling the ductile cast iron (nodular cast iron) with different alloys in three type of synthetic wastewater.

Experimental part

The ductile cast iron was coupled cu different alloys wherewith can come into contact in pumping stations. The compositions of the ductile cast iron and those of the other alloys used in this study are presented in table 1. These compositions were determined by optical emission

Table 1
THE COMPOSITIONS OF THE USED ALLOYS

Alloy	Abr.	Concentration, %
Ductile cast iron	DCI	Fe-78.1; C-4.5; Si-2.28; Ni-0.12; W-2.29; P-0.05; Cr-0.02;Pb-0.350; Mo-0.200; Mn-0.09; S-0.150
Cast metal care	CI	Fe-92.78; C-3.97; S-2.87; Mn-0.25; P-0.06; S-0.07; other-1.02
High strength low-alloyed steel	HSLA	Fe-97.1; C-0.16; Si-0.21; Mn-1.34; P-0.02; S-0.08; other-1.19
Bronze	BRZ	Cu-85,62; Sn-11,2; Pb-1,0; Zn-1,39; other-0.79
Brass	BRS	Cu-62,8; Zn-26,8; Al-6,03 ; Pb-0,91; Sn-0,57; Fe-0,97; Ni-0,46; Co-0,46; other-1.46
Stainless steel	SS	Fe-71.58; Cr-17.12; Ni-9.03; Ti-0.02; C-0.05; Si-0.45; Mn-0.0; P-0.03; S-0.01
Aluminium	AL	99.9%

Chemical Components	mg/l	Alimentary Components	Mg / l	Metal Traces	Mg /l
NH₄Cl	15	Milk powder	118	Cr(NO₃)₃.9H₂O	0.10
CH₃COONa.3H₂O	142	Yeast	54	CuCl₂.2H₂O	0.20
MgSO₄.7H₂O	32	Starch	122	MnCl₂	0.05
CaHPO₄	20	Soy oil	15	NiSO₄.7H₂O	0.08
K₂HPO₄.3H₂O	56			PbCl₂	0.07
FeSO₄.7H₂O	14				
Urea	98				
Peptone	15				

Table 2
BASIC COMPOSITION OF THE SYNTHETIC WASTEWATER (DWW-1)

spectroscopy (Foundry-Master emission spectrometer, WAS Company).

Synthetic test waters were prepared according with the Boeije [7] studies concerning the mean composition of the settled water from the sewage of the municipal sewerages. The constituent selection of the synthetic solutions is based on the expected composition of domestic waters exhaust. Some changes were made in the Boeije composition, regarding the ratio between inorganic constituents especially. The composition of the basic synthetic wastewater, denoted DWW-1, is presented in table 2. The inorganic components are respondent for the corroding properties of the solution, while the alimentary components behave as corrosion inhibitor or protector. This solution has a pH closed to neutrality: pH=6.5.

Towards analyze the pH influence regarding corrosion behavior, the pH of the base solution (DWW-1) was modified by adding hydrochloric acid and sodium hydroxide respectively. Thus were obtained the alternative solutions: DWW-2, with pH=3.0, by titration of basic solution with 0.1 M HCl solution; DWW-3, having a pH=11.0, by titration of basic solution with 0.1 M NaOH solution.

To evaluate the galvanic corrosion parameters, galvanic potential - E_{couple} and galvanic current - j_{couple}, the Evans method and a commercial potentiostat/galvanostat were used. All measurements were performed with the VoltaLab 21 (PGP201) potentiostat (Radiometer Analytical SAS - France), equipped with the acquisition and processing data software VoltaMaster 4 [33-37]. A special three electrodes electrochemical cell was used. This cell is presented in (fig.1). Ductile cast iron was mounted as work electrode, while the other materials were mounted as auxiliary electrode. A saturated calomel electrode (SCE) was used as a reference. All electrodes were realized as cylindrical disks (10 mm diameter and 2 mm thickness), and were screwed at cell connectors.

The free surface of the connector was covered with acrylic glass. In these conditions, all electrodes present the same surface: 2.76 cm².

Each specimen was polished with SiC paper, gradually, down up 2000 grit specification, degreased with acetone, washed in distilled water, and maintained in working solution for a determined period of time, up to constant temperature. The measurements were performed in fresh natural aerated solutions at 23°C.

The measurements were performed according to Evans method using the facilities offered by VoltaLab 21 potentiostat and VoltaMaster 4 acquisition software, using Evans test sequence (Coupled Corrosion - Evans) respectively. Briefly, an imposed current is applied gradually to the two electrodes and the voltammetric curves are registered, namely: potential of the working electrode E_{work} versus current and potential of the auxiliary electrode (E_{aux}) versus the same current.

Both potentials are measured versus reference electrode. The measurement stops when E_{work} - E_{aux} potential sign reverses. The intersection of the two curves determine the corrosion current and mixed potential (named and rest potential). As an example, in figure 2 is illustrated a typical diagram for ductile cast iron-stainless steel couple in DWW-1. To compare the data obtained in different situations, instead of the corrosion current (I) the corrosion current density (j = I/S) is calculated.

Results and discussions

Four or six successive measurements were performed for each pair of coupled alloys. The mixed potential and the couple current densities are presented in tables 3, 4 an
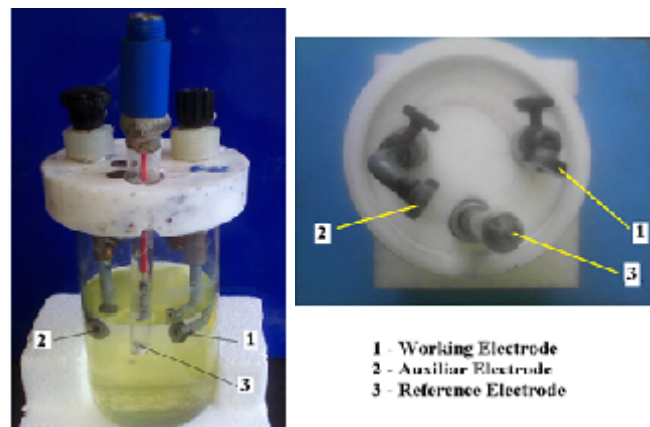

Fig.1. Three-electrodes electrochemical cell

1 - Working Electrode
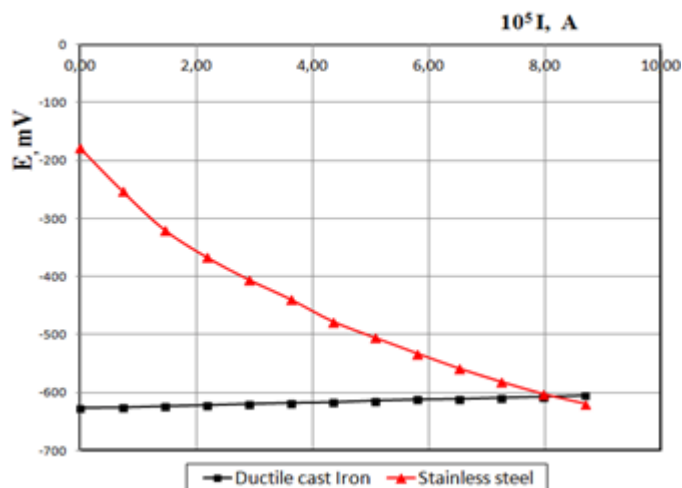2 - Auxiliar Electrode
3 - Reference Electrode

Fig.2. Evans curves for Ductile cast iron/Stainless steel pair in DWW-1 corrosion medium

5, dependent on corrosion medium and elapsed-time from the measurement starting. In all measurements the aria ratio of the anode and cathode were strictly equal with unity and the system configuration was unchanged, so that these parameters no influence actual results.

Very different results were obtained depending on nature of coupled alloys and corrosion medium pH. Some conclusions are presented forwards.

In the case of Ductile Cast iron/Stainless steel couple, the corrosion potential for the couple increase slightly with immersion time in all three synthetic waters and tend to a constant value. In alkaline water the corrosion potential is moved towards more negative value. Current densities of the couple have little and constant values in quasi neutral waste water (DWW-1) and are of approximately eight times higher in acidic waters (DWW-2). In acidic water the couple current density decrease in time, due to the appreciable increase of the corrosion products layer at high value of couple current. In alkaline waste water (DWW-3) the couple current density is of only two times higher than in neutral waters and increase with time.

The couple Ductile cast iron/Bronze behaves approximately likewise in the three corrosion media, the current density of couple being comprised between 60 and 80 µA/cm², saving that in DWW-1 the current density decrease from 60 µA/cm² till 45 µA/cm² in 45 min. The corrosion potential for couple also increase slightly in time, a more pronounced increase being evidenced in neutral water.

In all the three corrosion media, for *Ductile cast iron/ Brass* couple the current densities decrease with time immersion, the decrease being also more pronounced in DWW-1. In acidic and basic media the current densities

Table 3
GALVANIC COUPLES IN DWW-1

Ductile cast iron – Stainless steel						
τ, min	5	10	15	20	25	30
E_{couple}, mV	-591	-598	-603	-605	-607	
J_{couple}, µA/cm²	24	24	24	24	22	
Ductile cast iron – Bronze						
τ, min	5	10	15	20	25	30
E_{couple}, mV	-538	-548	-556	-559	-565	-567
J_{couple}, µA/cm²	60	55	50	50	45	45
Ductile cast iron – Brass						
τ, min	6	13	20	28	36	
E_{couple}, mV	-577	-591	-600	-608	-613	
J_{couple}, µA/cm²	70	65	60	55	55	
Ductile cast iron – High strength low alloyed steel						
τ, min	16	20	23	26	31	
E_{couple}, mV	-583	-587	-588	-592	-596	
J_{couple}, µA/cm²	20	20	24	24	22	
Ductile cast iron – Cast metal care						
τ, min	4	7	10	12	14	16
E_{couple}, mV	-636	-647	-651	-657	-662	-662
J_{couple}, µA/cm²	22	18	14	12	12	10
Ductile cast iron – Aluminium						
τ, min	2	4	6	8		
E_{couple}, mV	-634	-634	-634	-634		
J_{couple}, µA/cm²	6	6	6	6		

are neighbor of 80-90 µA/cm², while in neutral water the values decrease from 70 to 55 µA/cm² in 35 min. The corrosion potentials increase with immersion time. The decrease on current densities and the increase of the couple potentials can be explained by the decrease on corrosion intensity as a result of the surface coating with corrosion products, process assured by relative high values of the corrosion current.

The *Ductile cast iron/High strength low alloyed steel* coupling shows a similar behaviour as the Ductile *Cast iron/Stainless steel couple* in DWW-1, both for corrosion density and corrosion potential. In acidic media the current density is of four times lower than the for Ductile *Cast iron/ Stainless steel couple and decrease very fast with immersion time (from 70* µA/cm² to 35 µA/cm² after 12

min). This behavior indicate a fastness passivating of the Ductile cast iron. In basic solution (DWW-3) the corrosion behavior is practically similar with coupling of Ductile cast iron with Stainless Steel and with High strength low alloyed steel.

The coupling of Ductile cast iron with Cast metal care is less unfavourable in the three corrosion media; in DWW-1 the corrosion density decrease rapidly from 22 to 10 µA/cm² (16 min), in DWW-2 the corrosion density increase from 20 µA/cm² to 30 µA/cm² (14 min) and in DWW-3, the corrosion density is practically equal with 6 µA/cm² (the most advantageous couple). The increase of corrosion current in acidic media is probable due to the solubility of the corrosion products.

Table 4
GALVANIC COUPLE IN DWW-2

Ductile cast iron – Stainless steel						
τ, min	10	20	45	55	60	65
E_{couple}, mV	-573	-580	-589	-589	-587	-589
J_{couple}, µA/cm²	205	205	196	190	190	180
Ductile cast iron – Bronze						
τ, min	6	10	14	17	20	23
E_{couple}, mV	-598	-599	-601	-604	-604	-605
J_{couple}, µA/cm²	70	70	60	60	60	60
Ductile cast iron – Brass						
τ, min	4	7	11	15	19	
E_{couple}, mV	-602	-607	-609	-613	-612	
J_{couple}, µA/cm²	90	80	80	70	80	
Ductile cast iron – High strength low alloyed steel						
τ, min	2	4	6	8	10	12
E_{couple}, mV	-604	-611	-614	-619	-620	-620
J_{couple}, µA/cm²	70	50	40	30	30	35
Ductile cast iron – Cast metal care						
τ, min	1	2	6	10	12	14
E_{couple}, mV	-608	-610	-614	-616	-617	-618
J_{couple}, µA/cm²	20	25	32	30	30	30
Ductile cast iron – Aluminium						
τ, min	3	6	9	12	14	
E_{couple}, mV	-628	-630	-625	-635	-638	
J_{couple}, µA/cm²	-35	-35	-20	-30	-27	

Ductile cast iron – Stainless steel						
τ, min	14	20	24	28	34	
E_{couple}, mV	-670	-674	-675	-677	-682	
J_{couple}, $\mu A/cm^2$	50	55	60	60	55	
Ductile cast iron – Bronze						
τ, min	9	14	19	24	27	
E_{couple}, mV	-657	-666	-671	-675	-679	
J_{couple}, $\mu A/cm^2$	80	80	80	80	75	
Ductile cast iron – Brass						
τ, min	10	15	20	25	29	
E_{couple}, mV	-650	-659	-663	-668	-668	
J_{couple}, $\mu A/cm^2$	100	90	90	80	90	
Ductile cast iron – High strength low alloyed steel						
τ, min	3	7	11	15	18	
E_{couple}, mV	-662	-673	-676	-683	-682	
J_{couple}, $\mu A/cm^2$	75	60	60	50	60	
Ductile cast iron – Cast metal care						
τ, min	1	2	3	4	5	
E_{couple}, mV	-665	-682	-687	-691	-693	
J_{couple}, $\mu A/cm^2$	10	5	6	6	6	
Ductile cast iron – Aluminium						
τ, min	3	6	9	12	15	
E_{couple}, mV	-675	-683	-688	-691	-694	
J_{couple}, $\mu A/cm^2$	12	10	10	10	10	

Table 5
GALVANIC COUPLE IN DWW-3

The Ductile cast iron/Aluminium couple shows a different behavior. Thus, in neutral and basic waters the current densities are very small and constant (6 $\mu A/cm^2$ in DWW-1 and 10 $\mu A/cm^2$ in DWW-2), this couple being harmless. In these couplings Aluminium is more noble partner and Ductile cast iron the less noble partner. In acidic medium (DWW-2) Ductile cast iron is more noble partner while Aluminium corrodes with enough high speed.

Conclusions

In the galvanic couples performed between Ductile cast iron (DCI) and other alloys as: Stainless steel (SS), Bronze (BRZ), Brass (BRS), High strength low alloyed steel (HSLA), Cast metal care (Cast iron) (CI) and Aluminium (AL), Ductile cast iron appear as corrodible material in synthetic domestic waste water neutral (DWW-1; $pH=6.5$), acidic (DWW-2; $pH=3.0$) and basic (DWW-3; $pH=11.0$). An exception is the couple Ductile cast iron/Aluminium in acidic waste water, where Aluminium appears as corrodible material.

Taking into consideration only the initial values (at t=0 min) of the couple current density, the following galvanic series can be determined:

Least noble – anodic   Most noble - cathodic
In DWW-1: DCI < AQL < HSLA < CI < SS < BRZ < BRS
In DWW-2: AL < DCI < CI < HSLA < BRZ < BRS < SS
In DWW-3: DCI < CI < AL < SS < HSLA < BRZ < BRS

Thus, the coupling of Ductile cast iron with Brass, Bronze or Stainless steel appear to be the most disadvantageous arrangement.

Acidic waste water enhances the galvanic corrosion of the analyzed of alloy pairs.

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