Design and Construction of an Educational Corrosion Monitor System for Students at High Schools and Universities

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***Abstract*—This study aims to design an educational corrosion monitor system. The developed system gives the students the ability to study metal corrosion in an acidic media by following the emitted Hydrogen gas is produced from the acid that reacted with the metal. A Hydrogen gas sensor was used to measure the quantity of gas emitted. This sensor was connected to an Arduino-UNO microcontroller to convert the sensor's signal to digital values. The monitoring of the corrosion process can be followed by software programmed as Macro Unit and installed on Microsoft Excel. The Affected factors studied include the exposure time of metal in acid media, the producibility, and the system's response to the acceleration of emitted gas. The results indicate that the system has high accuracy. Also, this system is characterized as cheap (25$) to construct and is small, portable, and easy to operate, which gives the ability to study metal corrosion in education for high schools and universities.**

Keywords—Corrosion, Arduino, Hydrogen, 3d printer

I. INTRODUCTION

Metal corrosion [1] is considered as a natural phenomenon, and this phenomenon caused changes in the physical and chemical properties and deterioration of the metals[2]. The corrosion phenomenon is the decay of the metal by touching it with a solution like acid[3], base, or salt solution. The direct contact between the metals and the electrolyte solution led to an oxidation-reduction reaction[4]. There are many problems that arise from this phenomenon, such as changes in the dimension and mechanical properties of the corrected body, deformed appearance, and reduction of safety[5].

To detect the possibility of the occurrence of corrosion, there are many ways such as virtual inspection[6], loss of weight, frequency current resistance[7], and following the concertation of the emitted hydrogen gas. The corrosion rate study through the following of the concertation [8,9] of gas in the acidic media is very good because it has high accuracy and it doesn't need a long time[10]. The aim of this study is to develop a new system to study corrosion rate and to be used by students at high schools and universities to get a deep understanding of the corrosion phenomenon.

II. EXPERIMENTATION AND MATERIAL USED

To design this system we used electronic components and chemical materials as follows:

1. Arduino tablet type UNO.
2. Hydrogen Gas Sensor type QM-8.
3. 3D printer.
4. Pieces of metals like small nat.
5. Sulphuric acid.

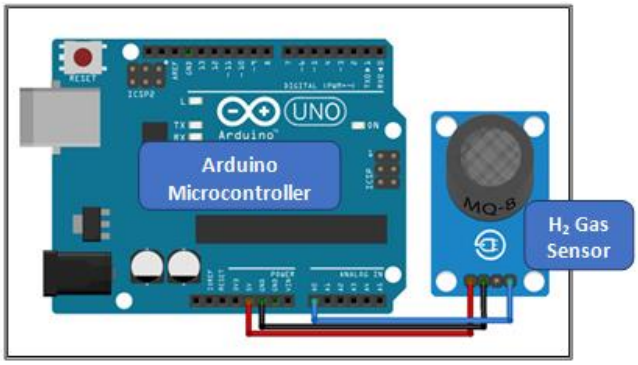

Fig. 1-A. Assembly method of an Arduino with hydrogen sensor

This system consists of an Arduino tablet joined with a Hydrogen gas sensor. The hydrogen sensor was placed in a plastic container that was printed by a 3D printer type Anet 8. The analog port on the Arduino tablet (A0) was joined with a gas sensor Fig. 1-A . The Macro unit in Microsoft Excell was used to program an application called Corrosion to Peak Fig. 1-B . This application was used to show the results a lively on a laptop by receiving data from an Arduino.

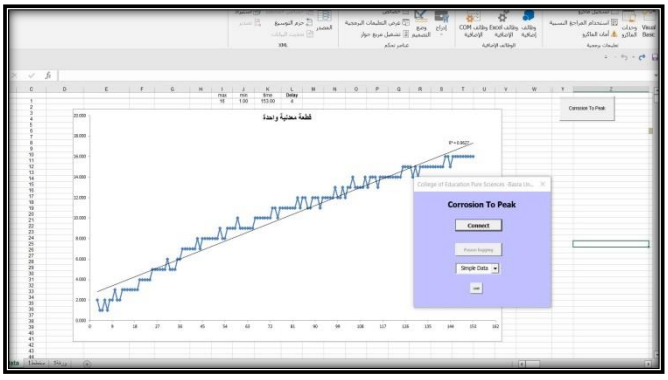

Fig. 1-B. Interface for programmed software (Corrosion to peak)

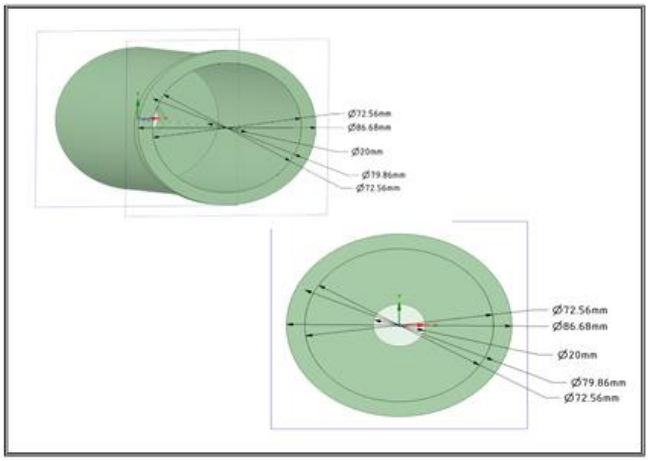

Fig. 2. The 3D Design for Hydrogen Container.

The Surface area of the nuts was calculated by using design spark Mechanical V4.0 Fig.8. The affecting factors for studying Corrosion are starting by taking 25 ml. of 5% Sulfuric acid in a beaker, then putting the metal pieces (nut) inside the beaker. After that, placed the container above the beaker, then click Connect from the software. When Hydrogen gas start emitting from the beaker, it will accumulate inside the container and the gas sensor start to sense the Hydrogen gas gradually.

Several factors were studied such as Producibility[11], effect time[12], concentration of acid [13], and Signal to ration[14] to check the ability of the designed system to be used in the corrosion rate study.

III. DISSECTION

A. *Mechanism of working of the corrosion monitor device*

When the nuts were put in the Sulfuric acid solution, they will emit hydrogen gas because the metal will react with the acid media[15]. After that, the beaker was covered by the container of the hydrogen sensor directly fig. 2 Through the designed software, click on the connection button. The software will start drawing a curve between the Voltage of the Hydrogen gas sensor and time and the Voltage proportionality with the volume of emitted gas. Fig.3 shows the steps flow for running the designed corrosion monitor.

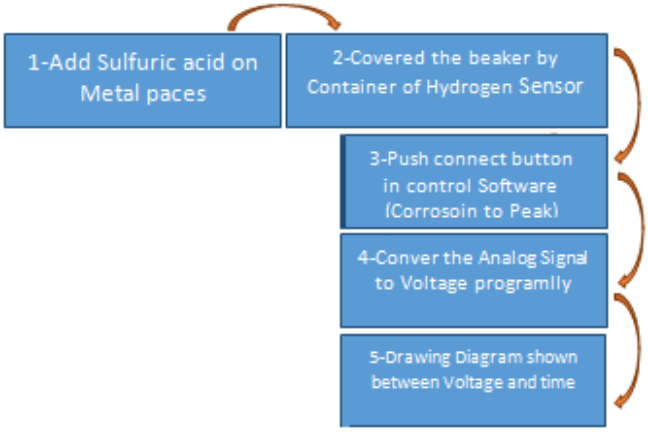

Fig.3: The Steps flow for using the Designed system monitor.

B. *Effect of Time on Corrosion [16]*

When corrosion started, the sensitivity of the Hydrogen gas sensor will be taking a linear relationship during the first 31 seconds. However after some time, the relationship deviated, it becomes non-linear because the sensor of gases was becomes saturated with high concertation of hydrogen gas that accumulated inside the container, and it has no ability to distinguish between the different concertation of gases. From Fig. 4, it can be deduced that the best time to study corrosion by the designed system is the first 31 Seconds.

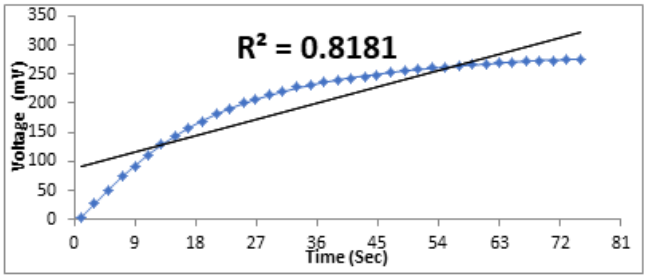

Fig. 4. Effect of time on corrosion

C. *Producibility :*

The study of the producibility [17] is essential Fig. 5 A, B, C and Table I to get confident results from the designed system in the same conditions. Meanwhile, if the producibility was studied three times, the results indicated that the system has a good producibility value, where the RSD is 2.51 %. This indicates the validity to use the system to study the corrosion phenomenon in our laboratories.

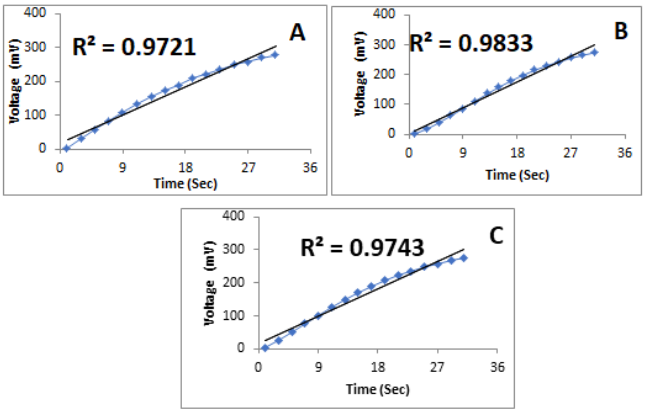

Fig. 5 -A, B, and C. Producibility of the system

TABLE I. THE SD AND RSD % OF THE PRODUCIBILITY OF THE

Time	$Peak_A$	$Peak_B$	$Peak_C$	Main Peak	SD	RSD%
31	277	276	274	271.6	6.896	2.51

IV. DESIGNED SYSTEM

A. *The stability of the corrosion monitoring system[18]:*

The stability of the present device is very important to give confident results. The stability study was done by running the

monitor system without any source of hydrogen. Figs. 6-A,B, and C and Table II showed that this system has good stability and can be trusted in the study of the corrosion Phenomenon with full understanding.

TABLE II. SHOWING THE DIFFERENCE BETWEEN THE LOWER AND HIGHER PEAK.

Time	ΔPeakA	ΔPeakB	ΔPeakC	Main Peak
31	1.5	2	2	1.8

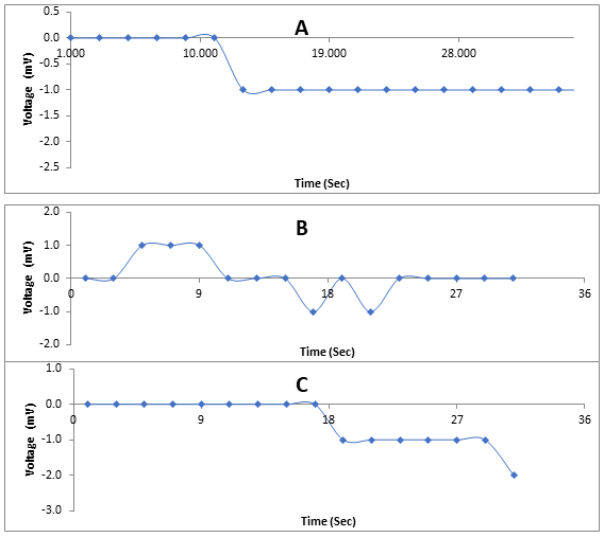

Fig 6 (A, B, C). The stability of the corrosion monitor system

B. *Effect of the acidity concertation of the media[19,20]:*

The acidity of the medium has a direct effect on the corrosion process. Therefore the use of three different concentrations of Sulfuric acid [21]solution (5%,10%, and 20 %) were used. Fig. 7 A,B, and C and Table III showed that the concertation 20% can not use because this acidity generates turbulent Hydrogen gas bubbles that affect the sensitivity of the Hydrogen Gas Fig. 7-C . As for the second concentration (10%), it gave lower voltage values because of the formation layer of a ferric oxide which prevents contact between the metal and acid solution[22]. So the 5% concentration of Sulfuric is the best and preferred to be used in the next experiments.

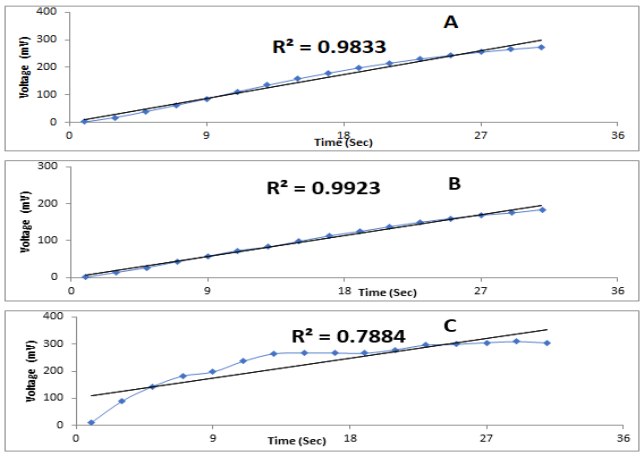

Figure 7-A,B, C: Effect of acidity concertation of the media

TABLE III SHOWING THE EFFECT OF ACIDITY CONCERTATION. OF THE MEDIA

	Peak Conc. 5%	Peak Conc. 10%	Peak Conc. 20%
	277	184	309
R^2	0.9833	0.9923	0.7884

C. *Application of the designed corrosion monitor*

After the optimum conditions found for using the designed system, Now studying the corrosion of metal in acid media by using the designed corrosion monitor designed possible. To calculate the Corrosion rate[23] was used the below equation was used.

Corrosion Rate = Conductivity / time*Surface Area

To calculate the surface area [24] for metal paces (nut) used design mechanical spark program to calculate the small and unregular shape fig. 8. The surface area calculated is (125.46mm2). [25]

Fig. 9. Shows the corrosion process and Table IV shows the corrosion rate.

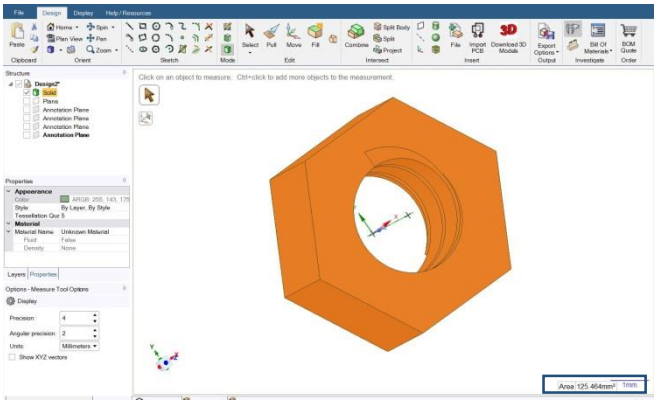

Fig. 8. Design spark mechanical program that is used for the calculation of surface area.

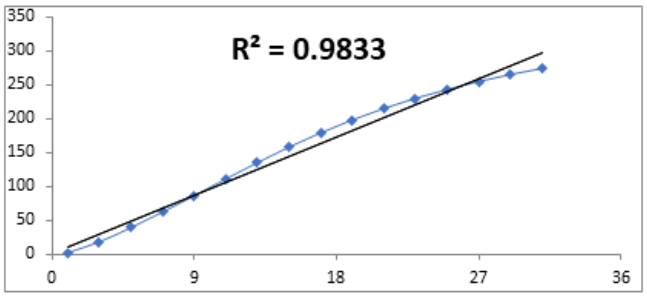

Fig. 9. Design spark mechanical program that is used for the calculation of surface area.

TABLE IV. SHOWN SURFACE AREA AND CORROSION RATE.

Time	Peak of Cond.	Surface Area	CR
31	272 mV	125.464mm^2	0.0699 mV /Sec.mm2

V. CONCLUSION

The designed corrosion monitoring device was designed using cheap materials available in the local market. The Arduino microcontroller was used to process the signals and the 3D printer was used to manufacture the assembly container. A special program was also programmed to control the device and display the results, called Corrosion t Peak. The designed device can be used by students in Universities and secondary schools to study the phenomenon of corrosion, the optimum conditions for the study of corrosion were studied in sulfuric acid medium, and the manufactured device is characterized by its cheap construction price (25$), in addition to the accuracy of its results, and this makes it possible to use it in educational and research laboratories.

REFERENCES

[1] J. Latif, ZA. Khan and MH. Nazir, K. Stokes and J. Plummer, "Condition monitoring and predictive modelling of coating delamination applied to remote stationary and mobile assets". Structural Health Monitoring, 2018.

[2] M.M. Benjamin, H. Sontheimer and P. Leroy, "Corrosion of iron and steel. In Internal Corrosion of Water Distribution Systems". Cooperative Research Report, AWWA Research Foundation, Denver, CO,1996.

[3] S. Sim, I. S. Cole, Y. Choi and S. Birbilis," N. A review of the protection strategies against internal corrosion for the sate transport of supercritical CO2 via steel pipelines for CCS purposes" . Int. J. Greenhouse Gas Control 2014.

[4] B. P. McGrail , H. T. Schaef , V. A. Glezakou, L. X. Dang and A. T. Owen," Water reactivity in the liquid and supercritical CO2 phase: has half the story been neglected". Energy Procedia 2009.

[5] J. Olsson, M. Snis," Duplex - A new generation of stainless steels for desalination plants". Desalination 2007, 205.

[6] ASTM G59, in Standard Test Method for Conducting Potentiodynamic Polarization Resistance Measurements. 97(2014).

[7] D. D. Macdonald, C. English, "Development of anodes for aluminium/air batteries – solution phase inhibition of corrosion", J. Appl. Electrochem. 20 (1990).

[8] M. A. Amin, S. S. Abd El-Rehim , E. El-Sherbini and R. S. Bayoumi, "inhibition of low carbon steel corrosion in hydrochloric acid solutions by succinic acid: Part i. Weight loss", polarization, EIS, PZC, EDX and SEM studies. Electrochim. Acta 52, 3588–3600 (2007).

[9] G. Bailey, J. Brian and C. Champion ,"An investigation into the impact of sealed wooden and acrylic showcases and storage cases on the corrosion of lead objects during long term storage and display". AICCM Bull. 2017, 38, 43–50.

[10] S.N. Raicheva, B.V. Aleksiev and E. Sokolova, "The effect of the chemical structure of some nitrogen- and sulphur-containing organic compounds on their corrosion inhibiting action", Corros. Sci. 34 (1993).

[11] E. Light, B. Little, M. Barclay, B. Manis, R. Gay and J. Bailey ,"Measuring the Corrosivity of Indoor Air". In Proceedings of the Indoor Air 2011, Austin, TX, USA, 5–10 June 2011.

[12] Arduino, (2018). "Arduino official online store". [online] Available at: https://store.arduino.cc/arduino-unorev3 [Accessed 30 Apr. 2018].

[13] S.M. Moon, S.I. Pyun, "The corrosion of pure aluminium during cathodic polarization in aqueous solutions" , Corros. Sci. 39 (1997).

[14] S.S. Abdel Rehim, O.A. Hazzazi, M.A. Amin and K.F. Khaled," On the corrosion inhibition of low carbon steel in concentrated sulphuric acid solutions. Part I: Chemical and electrochemical (AC and DC) studies", Corros. Sci. 50 (2008).

[15] A.J. Bard, R. Parsons and J. Jordan, " in: Standard Potentials in Aqueous Solution, Marcel Dekker" , Inc., New York, 1985, p. 566

[16] W. Luo, Y Xu, Q. Wang, P. Shi, M. Yan, Corr. Sci., 52 (2010) 3509-3513.

[17] http://www.idnext.com/bookradio/ (accessed,August,2009).

[18] F. Mansfeld, "Tafel slopes and corrosion rates obtained in the pre-Tafel region of polarization curves", Corros. Sci. 47 (2005).

[19] R.R. Hartwell. "Certain Aspects of Internal Corrosion in Tin Plate Containers" . 1951, 327-383.

[20] AV Radhamani, Hon Chung Lau and S. Ramakrishna , " Nanocomposite coatings on steel for enhancing the corrosion resistance: A review" . Journal of Composite Materials 2020,

[21] J. Aljourani, K. Raeissi and M. A. Golozar, "Benzimidazole and its derivatives as corrosion inhibitors for mild steel in 1M HCl solution" ,Corros. Sci. 2009,51, 1836– 1843, DOI: 10.1016/j.corsci.2009.05.011

[22] C. Li , X. Y. Guo , S. Shen, P. Song, T. Xu, Y. Wen, H.F. Yang," Adsorption and corrosion inhibition of phytic acid calcium on the copper surface in 3 wt% NaCl solution" . Corros. Sci. 2014.

[23] F. Witte, H. Ulrich, M. Rudert and E.Willbold, "Biodegradable magnesium scaffolds: Part I: Appropriate inflammatory response" . J. Biomed. Mater. Res., Part A 2007.

[24] Y. Pan, C. Chen, R. Feng, H. Cui, B. Gong, T. Zheng and Y. Ji, "Effect of calcium on the microstructure and corrosion behavior of microarc oxidized Mg-xCa alloys" . Biointerphases 2018.

[25] J. Tang, J. Wang, X. Xie, P. Zhang, Y. Lai, Y. Li and L. Qin, "Surface coating reduces degradation rate of magnesium alloy developed for orthopaedic applications" . J. Orthop. Transl. 2013.