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# Design and manufacture of the cooling system of JUPITER reactor

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# Design and manufacture of the cooling system of JUPITER reactor

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**Abstract.** The experimental investigations carried out in the Plasma laboratory of the Universidad Industrial de Santander, on superficial modification of metallic materials by hybrid discharges of high-voltage and electric arc at low pressures are carried out in the joint universal plasma and ion technologies experimental reactor. The cooling system of the reactor is by water, which means that it is directly connected to the water supply line of the building, which creates a dependence on the system. Additionally, the water supply line is often filled with particles that accumulate in the cooling system, disfavoring the transfer of energy between the water, the vacuum system and the cathode, which can lead to overheating of the reactor and melt the elements that make up the electric power system. In accordance with the above, the present research work consists of designing, building and implementing an efficient cooling system totally independent from the water supply line of the building, which allows to recirculate and minimize water consumption in order to take care of the natural resource.

## 1. Introduction

The technologies of surface modification of materials, such as the joint universal plasma and ion technologies experimental reactor (JUPITER) [1-4], implemented in the research group in Physics and Technology of Plasma and Corrosion (FITEK) of the Universidad Industrial de Santander (UIS), uses water as a means of cooling their system, thus preventing overheating and consequently possible equipment failures, which are not convenient in such expensive systems. The JUPITER reactor is used for the modification of surfaces of metallic materials by means of hybrid discharges of high voltage pulsed and electric arc discharges at low pressures (implantation and surface deposition of metallic and non-metallic species) [5-9].

The JUPITER reactor is based on pulsed hybrid high voltage and electric arc discharges at low pressures, the which allows the development of an alternative technique for an advanced surface treatment called three-dimensional ion implantation (3DII). The equipment has the pulse parameters: duration up to 2.5ms, repetition frequency up to 60Hz and voltage up to 60kV [10]. The above parameters guarantee the implantation of quasi-monoenergetic ions with an angle of incidence perpendicular to the surface of the materials to be treating; in addition, a high dose of implanted atoms are achieved in short treatment times (for example a dose of $1 * 10^{17}\ \mathrm{iones/cm^2}$ with energy of $30\mathrm{keV}$ are made in a discharge of 30 minutes) [ 11-13]. These doses are enough to improve tribological properties of carbon steels such as increased resistance to corrosion, increased microhardness, and decreased hydrogen permeation, among other physicochemical properties [10,14-20].

However, the current cooling system of the JUPITER reactor is open, which does not allow the recirculation and reuse of water. Therefore, its processes are dependent on the fact that they are subject to the availability of water supplied by the line of the facilities where is located. Consequently, heat exchangers are thermal machines that extract energy from the working fluid, lowering the temperature and providing the possibility of returning the fluid to the circuit [21-25].

By the above, the present research work consists of designing, constructing and implementing an effective, efficient and independent cooling system to the water supply line, which allows recirculating the cooling fluid over and over again with the objective of minimizing resources and costs.

## 2. Experimental setup

In a superficial modification process, the electrode (cathode) where the substrates are located reaches high temperatures. For this reason, it must have a system electrically isolated with a cooling capacity equal to 7kW. Additionally, it must be considered that the maximum temperature of the water, at the exit of the reactor, must be 60°C, and the temperature interval between the outlet and the water inlet should not be higher than 15°C. Figure 1 shows the current cooling system of the JUPITER reactor.

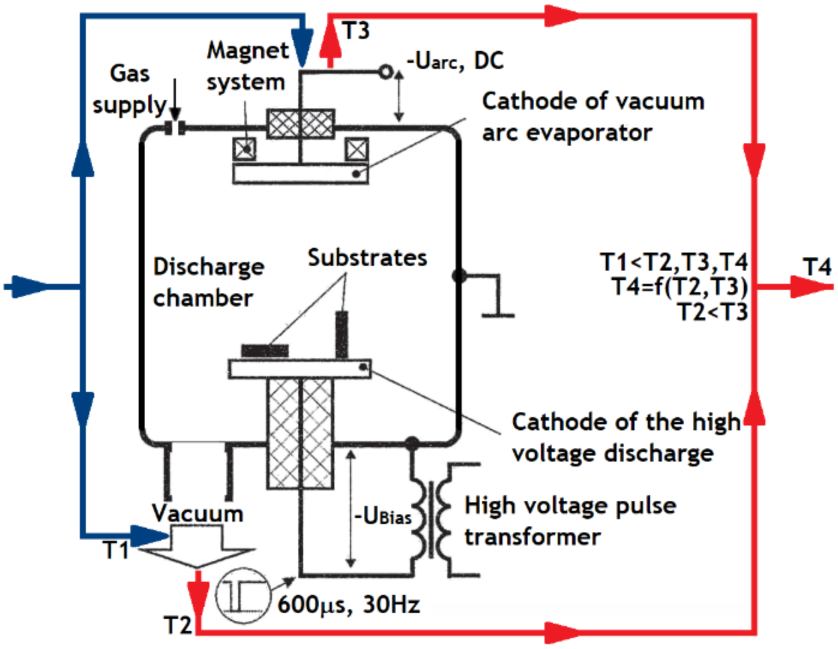

**Figure 1.** The current cooling system of JUPITER reactor.

The heat transfer process of the JUPITER reactor in operation (defined by the different powers supplied by the vacuum system and the electric arc, which are controlled by the variation of the voltage and current) was carried out by the water temperature at the inlet and the output with a J type thermocouple adapted to a FieldPoint FP-1601 module. In Figure 1, the temperatures T1, T2, T3 and T4 represent the temperatures recorded by the thermocouple; where the blue color represents the water before gaining energy supplied by the turbo molecular pump and the electric arc, and the red color symbolizes the water of exit. The temperature values registered were analyzed using the National Instruments Measurement & Automation Explorer software. The output flow was measured with the 4L flow meter and a stopwatch with a resolution of 0.001s. Accordingly, the heat gain of the water was determined by the heat transfer equation (see Equation (1)) [21-25].

$$Q = m_w * C_{pw} * (T_{wo} - T_{wi}) \tag{1}$$

where, $m_w$ is the water mass flow, $C_{pw}$ is the specific heat of the water, $T_{wo}$ is the water temperature at the output, measured with the thermocouple, and $T_{wi}$ is the water temperature at the inlet, recorded with the thermocouple.

According to the above, we determined that the JUPITER reactor supplies the water, in the normal operating range, with a power of approximately 4.12kW. Then, as is expected that the reactor will work with a maximum power of 6kW, a safety factor of the cooling system of 7kW is established.

Figure 2 shows the design of an air-water heat exchanger (radiator), which according to the operating conditions of the JUPITER reactor, is the best option to protect the system from overheating and maintain the water temperature in an acceptable range of operation. The function of this type of heat exchanger is to remove the heat that the reactor supplies to the water, through an integrated radiator with two fans that make the air at room temperature flow transversely through the fins, dissipating the heat that the water brings with it after passing through the reactor (see Figure 3).

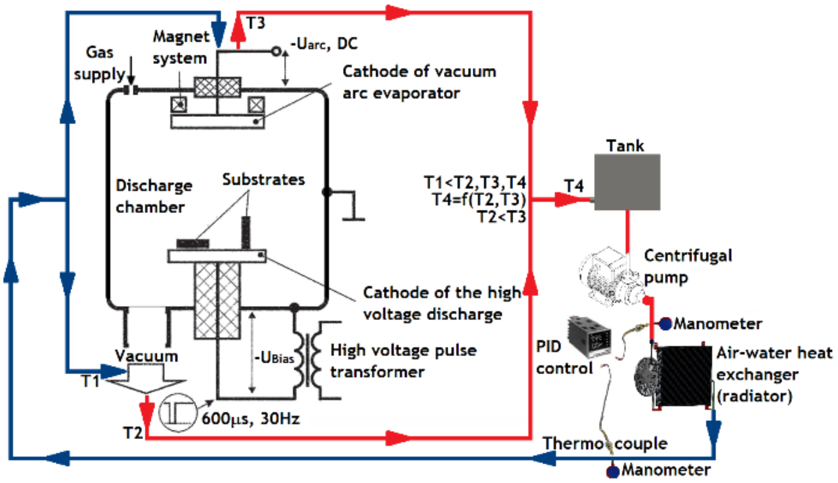

**Figure 2.** The cooling system for JUPITER reactor proposed.

The radiator temperature range (Figure 3) we determined by reference to the input parameters and the heat transfer area necessary to dissipate the heat supplied by the reactor subsystems. These parameters are indispensable to finding the heat transfer coefficients of water, air, and efficiency of the exchanger fins used to find the global heat transfer coefficient U.

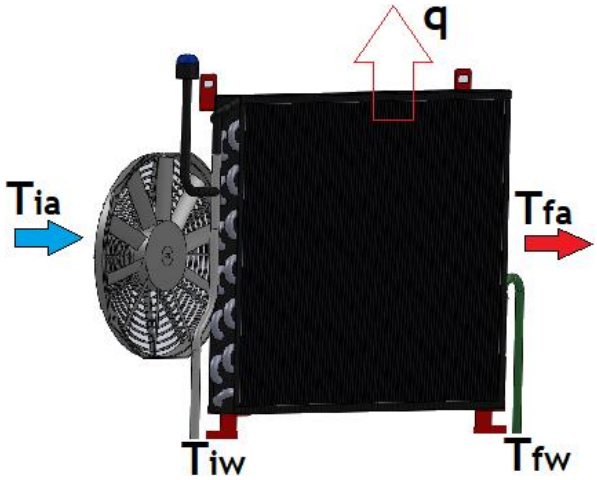

**Figure 3.** air-water heat exchanger (radiator).

The parameters assumed in the design, which determine the approximate calculation of the temperatures that provide the balance in the process of heat transfer, are established having as reference a critical ambient temperature of 28°C (temperature at which inlet air), the water flow ($\dot{V}_w = 5\text{gpm}$), air velocity ($V_{air} = 5\,\text{m/s}$) and heat to be dissipated by the radiator $Q = 7\text{kW}$). Accordingly, the energy that the water gains when going through the reactor is the same that dissipates the air. Equation (2) describes the energy balance of the proposed system,

$$\frac{1}{U_f} = \frac{1}{h_f} + \frac{1}{h_i * (A_i/A_f)} \tag{2}$$

where, $h_o$ is the outside heat transfer coefficient, $h_i$ is the inside heat transfer coefficient, $A_i$ is the inside transfer area, $A_f$ is the outside transfer area, and $U_f$ is the el heat transfer global coefficient by the air side. Then, the following values we are obtained from the operating parameters of the JUPITER device: $h_f = 101.6\,\text{W}/(\text{m}^2 - \text{K})$, $h_i = 13730\,\text{W}/(\text{m}^2 - \text{K})$, $A_f = 5.262\text{m}^2$, $A_i = 0.3589\text{m}^2$, and $U_f = 91.65\,\text{W}/(\text{m}^2 - \text{K})$.

The number of transfer units (NTU) method is used to iterate until the area found coincides with the external area of the exchanger $A_t = A_f$ (see Table 1) because we used the heat transfer global coefficient by the air side ($U_f$). The efficiency of this exchanger type is given by Equation (3),

$$\varepsilon = \frac{T_{f,a} - T_{i,a}}{T_{i,w} - T_{i,a}} \tag{3}$$

and the NTU is related to the exchange area through the Equation (4).

$$\text{NTU} = \frac{U_f * A_f}{C_{min}} \tag{4}$$

where, $C_{min}$ is determined with the Equation (5).

$$C_{air} = \dot{m}_{air} * Cp_{air} = 1.049\,\text{Kj}/(\text{k} - \text{s}) = C_{min} \tag{5}$$

where, $Cp_{air}$ is the specific heat of the air and $\dot{m}_{air}$ is the mass flow of air in the exchanger. The Equation 6 describe the effectiveness in a heat exchanger cross flow (are not mixed both torrents).

$$\varepsilon = 1 - \exp\left[\frac{1}{k * \text{NTU}^{-0,22}} * (\exp(-\text{NTU} * k * \text{NTU}^{-0,22}) - 1)\right] \tag{6}$$

Table 1 reports the values that determine the energy balance of the system, which we obtained from the iteration process, varying the temperature $T_{fw}$.

The energy balance of the system we then determined from the values obtained from the iteration process, varying the temperature $T_{fw}$, the which occurs when $A_t \cong A_f$ (the external area of the radiator is equal to the outer area found by the balance).

In row 12 of Table 1, it is observed that $A_t \cong A_0$, which means that at this point all the calculated and assumed data are valid because the analysis we performed with a previously known exchanger geometry. Where we have: $T_{fw} = 44.11$°C, $T_{iw} = 49.48$°C and $T_{f,a} = 34.68$°C. Also, of the factors that intervene in the analysis, such as: $\text{NTU} = 0.454$ and $\varepsilon = 0.308$.

**Table 1.** System energy balance.

| | $T_{(f,a)}$ (°C) | $T_{(i,a)}$ (°C) | $T_{fw}$ (°C) | $T_{iw}$ (°C) | $A_t$ ($m^2$) | $A_f$ ($m^2$) |
|---|---|---|---|---|---|---|
| 1 | 34.68 | 28 | 44.00 | 49.37 | 5.262 | 5.301 |
| 2 | 34.68 | 28 | 44.01 | 49.38 | 5.262 | 5.297 |
| 3 | 34.68 | 28 | 44.02 | 49.39 | 5.262 | 5.293 |
| 4 | 34.68 | 28 | 44.03 | 49.40 | 5.262 | 5.290 |
| 5 | 34.68 | 28 | 44.04 | 49.41 | 5.262 | 5.286 |
| 6 | 34.68 | 28 | 44.05 | 49.42 | 5.262 | 5.283 |
| 7 | 34.68 | 28 | 44.06 | 49.43 | 5.262 | 5.279 |
| 8 | 34.68 | 28 | 44.07 | 49.44 | 5.262 | 5.275 |
| 9 | 34.68 | 28 | 44.08 | 49.45 | 5.262 | 5.272 |
| 10 | 34.68 | 28 | 44.09 | 49.46 | 5.262 | 5.268 |
| 11 | 34.68 | 28 | 44.10 | 49.47 | 5.262 | 5.265 |
| 12 | 34.68 | 28 | 44.11 | 49.48 | 5.262 | 5.261 |
| 13 | 34.68 | 28 | 44.12 | 49.49 | 5.262 | 5.257 |
| 14 | 34.68 | 28 | 44.13 | 49.50 | 5.262 | 5.254 |
| 15 | 34.68 | 28 | 44.14 | 49.51 | 5.262 | 5.250 |
| 16 | 34.68 | 28 | 44.15 | 49.52 | 5.262 | 5.247 |
| 17 | 34.68 | 28 | 44.16 | 49.53 | 5.262 | 5.243 |
| 18 | 34.68 | 28 | 44.17 | 49.54 | 5.262 | 5.240 |
| 19 | 34.68 | 28 | 44.18 | 49.55 | 5.262 | 5.236 |
| 20 | 34.68 | 28 | 44.19 | 49.56 | 5.262 | 5.233 |
| 21 | 34.68 | 28 | 44.20 | 49.57 | 5.262 | 5.229 |
| 22 | 34.68 | 28 | 44.21 | 49.58 | 5.262 | 5.225 |
| 23 | 34.68 | 28 | 44.22 | 49.59 | 5.262 | 5.222 |
| 24 | 34.68 | 28 | 44.23 | 49.60 | 5.262 | 5.218 |
| 25 | 34.68 | 28 | 44.24 | 49.61 | 5.262 | 5.215 |
| 26 | 34.68 | 28 | 44.25 | 49.62 | 5.262 | 5.211 |

## 3. Results

Figure 4 shows scheme the air-water cooling system (radiator), which we coupled at the JUPITER reactor.

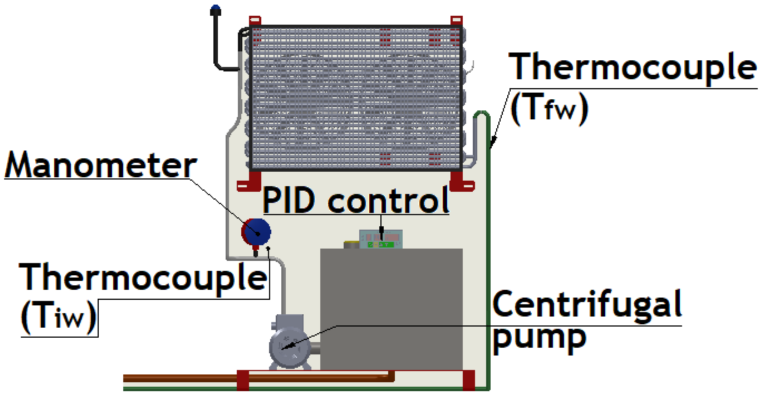

**Figure 4.** Scheme of the air-water heat exchanger (radiator).

The point of operation of the centrifugal pump, of the heat exchanger, we established by measuring its outlet pressure. The results obtained from the pressure, flow and temperature measurement tests of the cooling system carried out at an ambient temperature of 20°C are reported in Table 2 and Table 3 respectively. In Table 2, it is observed that the pressure is approximately 20PSI and the flow rate we obtained is 7gpm.

**Table 2.** Test of pressure and caudal in the centrifugal pump.

| P (PSI) | V (ml) | t (s) |
|---|---|---|
| 20 | 4000 | 9 |
| 18 | 4000 | 10 |
| 20 | 4000 | 11 |
| 19 | 4000 | 9 |
| 20 | 4000 | 9 |

**Table 3.** Temperature test.

| $T_{amb}$ (°C) | $V_{air}$ (m/s) | Q (gpm) | $T_{iw}$ (°C) | $T_{fw}$ (°C) |
|---|---|---|---|---|
| 20 | 5 | 7 | 32 | 30 |
| 20 | 6 | 7 | 32 | 30 |
| 20 | 8 | 7 | 30 | 27 |
| 20 | 10 | 7 | 28 | 26 |
| 20 | 12 | 7 | 28 | 25 |

## 4. Conclusion

An air-water cooling system (radiator) was designed and built, which allows the JUPITER reactor to operate in the range of permissible temperatures in the process. Then, it changed from an open cooling system, where the water was wasted, to a closed cooling system where the water recirculates, making it an environmentally friendly method. Besides, A control system we implemented, which maintains the air-water cooling system (radiator), operating in the permissible temperature range of the process.

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## References

[1] V I Khvesyuk, P A Tsygankov 1997 The use high-voltage discharge low pressure 3D ion implantation *Surface & Coatings Technology* **96** 68-74
[2] Dougar-Jabon V D, Dulce Moreno H J, Tsygankov P A 2003 Implantación iónica *Revista Respuestas* **8** 19-30
[3] Dougar V, Dulcé J, Tsygankov P A 2002 High voltage pulse discharge for ion treatment of metals *Review of Scientific Instruments* **73(2)** 828
[4] Dougar-Jabon V D, Castro B J, Dulce Moreno H J, Tsygankov P A 1999 Device JÚPITER for ion implantation *Revista Colombiana de Física* **31(2)** 181-184
[5] Dugar-Zhabon Valeriy Dondokovich, Dulcé Moreno Hector Jaime, Garnica Villamizar Hernán Alfonso, Valbuena Niño Ely Dannier 2012 A new method for surface modifications of carbon steels and alloys *Materials Research* **15(6)** 969-973
[6] V Niño Ely Dannier, Dulce Moreno Jaime, Garnica Hernán Alfonso, Dugar-zhabon Valeriy, Peña Rodríguez Gabriel y Tsygankov Petr 2012 Aplicación de descargas simultáneas de alto voltaje y arco eléctrico para el tratamiento superficial avanzado de metales *Revista Iteckne* **9(1)** 14-20
[7] H J Dulce-Moreno, P A Tsygankov, V Dugar-Zhabon, E D V-Niño, F F Parada-Becerra 2011 Estudio de los haces electrónicos en la descarga eléctrica de alto voltaje a bajas presiones *Puente Revista Científica* **5(2)** 21
[8] Dulce H J 2015 Descargas eléctricas y sus aplicaciones *Eco. Mat.* **6(1)** 6-21
[9] P A Tsygankov, F F Parada Becerra, V D Dugar-Zhabon, A Plata and E D V-Niño 2016 Artificially modulated hard coatings produced with a vacuum arc evaporator *Journal of Physics: Conference Series* **687** 012005 1-4
[10] Valbuena Niño E D and Dugar-Zhabon V 2006 Comportamiento del acero SAE-4140 implantado con iones de nitrógeno en ambientes hidrogenados *Revista Colombiana de Física* **38(1)** 61

[11] F H Vera-Rivera, B R Pérez Gutiérrez, H J Dulce-Moreno, F Duran-Flórez, and E D V-Niño 2016 Estimate of the concentration of implanted ions in solid substrates using a web application *Journal of Physics: Conference Series* **743** 012016 1-5

[12] F H Vera-Rivera, V D Dugar-Zhabon, H J Dulce-Moreno, and E D V-Niño 2016 Development of a web application for estimate the total charge in an electric discharge *Journal of Physics: Conference Series* **687** 012058 1-4

[13] B R P Gutiérrez, F H Vera-Rivera, and E. D V-Niño 2017 Design and implementation of a web application to estimate the surface density of implanted ions in solid substrates *Journal of Physics: Conference Series* **786** 012015 1-6

[14] Ely Dannier V Niño, Hernán Garnica, Veleriy Dugar-Zhabon and Genis Castillo 2014 Behavior of AISI SAE 1020 steel implanted by titanium and exposed to bacteria sulphate deoxidizer *Journal of Physics Conference Series* **511** 012080 1-5

[15] J J Castro-Maldonado, H J Dulcé-Moreno and E D V-Niño 2013 Nitrogen implantation into steel wire coated with zinc used as reinforcement in power transmission conductors *Journal of Physics: Conference Series* **466** 012005 1-3

[16] E D V-Niño, V Dugar-Zhabon, H A Garnica 2011 Tecnología del plasma aplicada a problemáticas en el sector hidrocarburos en colombia *Revista Iteckne* **8(1)** 37-41

[17] Ely Dannier V. Niño, Deicy Viviana Salinas, Darío Y. Peña, Luisa fernanda Chinchilla 2011 Modificación superficial de un acero AISI SAE 1045 mediante la implantación de iones de nitrógeno y titanio *Revista Iteckne* **8(1)** 31-36

[18] H Jaime Dulce M, Valeri Dougar J and Carlos R Cabrera 2003 *Revista Colombiana de Física* **35(2)** 332

[19] J.E. Caballero, E.D. V-Niño 2017 Wear evaluation of flank in burins of high speed steel modified with titanium ions *Journal of Physics: Conference Series* **935** 012024 1-5

[20] Ely Dannier V-Niño, Jorge Enrique Caballero, Jesús Eduardo Contreras Naranjo 2016 Evaluación del desgaste de flanco en buriles de acero rápido implantado con iones de titanio y nitrógeno *Universidad, Ciencia y Tecnología* **20(80)** 106-113

[21] Yunus A Cengel 2004 *Transferencia de calor*, segunda edición (México: McGraw Hill Interamericana)

[22] J. P. Holman 1998 *Transferencia de calor*, 8a edición (España: McGraw Hill Interamericana)

[23] Frank P. Incropera, Davis P. Dewitt 1999 *Fundamentos de transferencia de calor*, cuarta edición (México: Prentice Hall Hispanoamericana S.A.)

[24] Donald Q. Kern 1999 *Procesos de transferencia de calor* (México: Compañía Editorial Continental S.A.)

[25] Faye C. McQuiston, Jerald D. Parker, Jeffrey D. Spitler 2005 *Heating, ventilating and air conditioning. Analysis and design*, sixth edition (USA: John Wiley & Sons Inc.)