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NUMERICAL ANALYSIS OF A SOLAR CHIMNEY SYSTEM FOR DESALINATION AND POWER GENERATION FOR BRUMADINHO, BRAZIL

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Abstract. Energy and water are essential for life. In the last decades, the energy demand has presented a high growth, stimulating the search for renewable sources of energy. At the same time, drinking water is also becoming a scarce resource. In this way, technologies that promote the preservation of these two resources are gaining worldwide prominence. Solar chimneys are devices that use solar energy to generate a flow of hot air, which can be used to movement wind turbines and produce energy. Recently, several studies have proposed the use of the heat generated for water desalination. This study proposes a mathematical model for a solar chimney for the production of energy and drinking water for the city of Brumadinho, Brazil. The results will be compared with literature data for the city of Dalian, China. The proposed solar chimney has as main components a solar collector, a tower, a wind turbine and a high efficiency condenser. The model will be defined based on three models in the literature. It is intended to evaluate the influence of the collector size, solar irradiation and the efficiency of the generator on the electrical power produced and on the overall efficiency of the system.

Keywords: Solar Chimney, Desalination, Power Generation, Brumadinho, MATLAB.

1. INTRODUCTION

The growing demand for water brought about by population growth; the burning of fossil fuels aggravating the greenhouse effect; the waste of water; the pollution of rivers caused by anthropogenic activities and the growing deforestation in recent years make the world face serious challenges related to both the availability of drinking water and energy supply (Campos, 2017).

According to Castro Silva (2014), added to all these factors, the last decades have been constantly marked by an increase in energy demand, which is proportional to the increase in the world population. Therefore, the demand for energy captured from fossil fuels on a large scale is a source of great concern for the environment.

Even in the middle 1980s, the concern related to energy capture with the environment became a global issue. Since then, the search for new energy sources has been growing steadily. According to the International Energy Outlook (U.S. Energy Information Administration, 2016), almost all of the increase in world energy demand comes from countries considered to be developing (like as Brazil). To solve the impacts caused by the increase in energy demand, renewable energy forms should represent around 30% of the world's total energy generation by the year 2040 (Castro Silva, 2018).

In numerical data, an estimated investment of 45 to 56 billion dollars, including public and private investment, is needed annually to reach the global goal of obtaining energy, projections conclude that these values should be maintained until the year 2030 (REN21, 2016). Therefore, global renewable energy investment and development play important roles in achieving sustainable development goals, financially reducing significant energy costs for many countries and mainly as an ally to tackle climate change (Gu and Zhou, 2020).

According to ANEEL (2021), in Brazil, approximately 83% of electricity is generated by renewable sources, of which almost 62% are hydroelectric energy and 21% are from other alternative sources. Hydroelectric energy is the main source of energy explored in Brazil. The high percentage coming from this generates a great dependence of the country on its energy matrix. Therefore, it is clear that the best application methodology for a country with as much diversity as Brazil results in the use of a widely diversified energy matrix. Therefore, an energy matrix based largely on hydroelectric plants, as seen in Brazil, is not relevant, since this type of matrix is completely hostage to rain, the climate, in addition to generating major impacts on the environment, especially in its implementation (Marinho Júnior et al., 2018).

Due to its geographic location, climatic characteristics, natural resources and biodiversity, Brazil has a wide range of resources to obtain several other energy sources. A large amount of sunlight, an extensive coastal territory (an excellent factor for the exploitation of wind and ocean energy), as well as a large food and livestock production (remarkable for bioenergy exploration) are common characteristics in the country.

Solar energy is the largest source of energy received by the Earth. The total amount of solar energy incident on the earth is vastly in excess of the world's current and projected energy needs. This source has the potential to satisfy all energy needs in the future (Castro Silva, 2018).

Solar radiation can be used directly as a source of thermal energy; based on the absorption of radiant energy by a surface. Another form of use is from the heating of fluids or environments, as well as the generation of mechanical or electrical power. The energy conversion of solar radiation can also be obtained indirectly through effects such as thermoelectric and photovoltaic, as well as chemical energy; with the photo-biochemical process (Castro Silva, 2018).

From another perspective, it is estimated that by 2050 approximately 1.8 billion people around the world will live in regions where drinking water will be scarce at least once a month. In 2020, UN data prove that more than 4.2 billion people live without access to basic sanitation. More than half of the world's population does not have treated sewage. About 40% of the world's population live without soap and water to wash their hands, which means that every day more than 800 children die from diseases such as diarrhea and other infections, which are caused by the lack of basic sanitation and contaminated water (ONU News, 2020).

The Brazilian Constitution of 1988 establishes that waters are commonweal, there are no private waters, and ownership (administrative and management responsibility) is sometimes of the states, sometimes of the Union. In other words, they are the domain of the Union "the lakes, rivers and any streams of water on land under its domain, or that bathe more than one state, serve as boundaries with other countries, or extend to or come from foreign territory, as well as marginal lands and river beaches"; "surface or underground, flowing, emerging and deposited waters are the domain of the States, except, in this case, in the form of the law, those resulting from works of the Union" (ANA, 2006 and Brazilian Constitution, 1988).

Meanwhile, mining is probably among the main water users in Brazil, the one with the greatest peculiarities. It ranges from complex projects with greater impacts, but at the same time with modern and efficient environmental controls on such impacts, including mitigation and compensation measures, even for small potters, miners or sand or gravel extractors, without any planning and environmental control and, often with the indulgence of the local community (ANA, 2006). Descendants of the mining process, environmental disasters involving mining tailings dams that result in the pollution of watercourses and that have occurred all over the world (Fletcher et al., 2006; Gelencsér et al., 2011), and unfortunately have become a recurrent problem in Brazil (Souza et al., 2021).

In November 2015, the Fundão tailings dam (District of Mariana, State of Minas Gerais, Brazil) collapsed, releasing more than 45 million m^3 of mud with traces of metals in the Doce River basin and the Atlantic Ocean, causing 19 deaths (Fernandes et al., 2016; Carmo et al., 2017; Souza et al., 2021). The most recent failure of the B1 tailings dam at Córrego do Feijão (Brumadinho District, Minas Gerais State, Brazil) on January 25, 2019 has released more than 12 million m^3 of ore tailings mining in the Paraopeba River and has been considered the most fatal disaster (260 deaths and 10 missing people) involving ore tailings worldwide, in addition to socioeconomic and environmental impacts (CPRM, 2019 and Souza et al., 2021). Water and sediments impacted by metals from the mining process can have harmful health effects on aquatic organisms and can also pose a risk to human health (Wu et al., 2016; Singh and Kumar, 2017; Shil and Singh, 2019; Teramoto et al., 2021). Thus, this emergency due to the need for drinking water should progressively increase its costs, making this resource increasingly less accessible, especially for the poorest and most marginalized (Eliasson, 2015).

One of the available solutions to these two problems is the use of solar energy in desalination processes for brackish waters and the sea. Desalination basically consists of removing or reducing the concentration of salts and dissolved solids from salt water (which may be sea or brackish) to obtain fresh water suitable for consumption. In addition to removing minerals, this process also removes other chemical, organic and biological components (Greenlee, 2009).

The use of this technology can overcome several problems present in traditional desalination processes, making this option more sustainable, as it uses a large amount of clean and renewable energy such as solar energy. In addition to this, this technology has a large scale of social relevance as it brings more economically viable options to more remote and often forgotten regions where water is considered unsuitable and/or brackish due to several possible factors for it, in the which human activities directly dependent on water stand out, such as the mining process, for example (Campos et al., 2017; Campos, 2017).

For the realization of the desalination process and the use of solar energy (either through photovoltaic or solar thermal energy) in order to improve the performance of this process and achieve economic viability, solar chimneys have been presented as promising devices (Yosif, 2014).

The principle of the solar chimney was invented in 1978 by the German professor Schlaich (Zou et al., 2011), its operation involves the combination and communication of three distinct devices: solar collectors, towers and turbines. During the day, part of the solar radiation incident during the day passes through the transparent chimney cover, thus promoting the natural heating of the soil. Once heated, the soil transfers heat to the mass of air available inside the collector. The air mass then flows upwards towards the tower due to buoyant forces from the temperature gradients within the device. Upon finding the tower, the heated air is then sucked out of the device (Castro Silva, 2018). At night, when the solar incidence ceases, the soil below the chimney releases part of the heat stored during the day into the air, generating a flow, allowing the device to continue to function (Marinho Júnior et al., 2020).

For this type of technology, a large number of pilot configurations have already been built and tested in various parts of the world (Zhou et al., 2009). The main drawback of solar chimneys is their efficiency. When compared to other forms

of technology for obtaining energy, it is very low. The overall performance of solar chimneys can be improved if water desalination and power generation processes are combined in a single system.

This work intends to numerically evaluate some of the main parameters of water desalination and electricity generation from an installation of a solar chimney for desalination in the city of Brumadinho, Minas Gerais, Brazil.

2. MATHEMATICAL MODELING

In this system, the chimney converts the saturated hot air flow into kinetic energy, which is directly determined by the increase in the collector exit air flow temperature and the height of the chimney (Zhou et al., 2008; Ming, 2016).

For this, the chimney can be defined as an ideal chimney, as long as it does not present an area change, internal obstructions, wall friction or additional losses in the system (Von Backstrom and Gannnon, 2000; Yosif, 2014).

To solve this problem, the one-dimensional compressible flux equations in the chimney will have the following equations governing the problem: mass conservation, linear momentum conservation and energy conservation equations, respectively described in Equations (1), (2) and (3). These equations are evaluated from Versteeg and Malalasekera (2007):

$$\frac{\partial \rho}{\partial t} + \nabla (\rho \cdot \vec{v}) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho \cdot \vec{v}) + \nabla (\rho \cdot \vec{v} \cdot \vec{v}) = -\nabla p + \nabla \left(\mu \left[(\nabla \vec{v} + \nabla \vec{v}^T) - \frac{2}{3} \nabla \cdot \vec{v} \, I \right] \right) + \rho \, \vec{g} \tag{2}$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\vec{v}(\rho E + p)) = \nabla \left(k_{eff} \nabla T - h \vec{J} + \left(\mu \left[(\nabla \vec{v} + \nabla \vec{v}^T) - \frac{2}{3} \nabla \cdot \vec{v} \, I \right] \cdot \vec{v} \right) \right) \tag{3}$$

Where t represents time, $\vec{v}$ the velocity vector, p the pressure, E the energy and $\vec{g}$ the acelration vector of gravity.

According to Duffie and Beckman (2006), various types of radiation calculations are most conveniently done using radiation levels, that is, the relationship between the radiation level and the theoretically possible radiation that would be available if there were no atmosphere. So we need a method of calculating extraterrestrial radiation. In this form, the solar radiation for a horizontal plane outside the atmosphere is the normal incident solar radiation that can be obtained from Equation 4:

$$G_o = G_{SC} \left(1 + 0.033 \frac{\cos 360n}{365} \right) \cos \theta_z \tag{4}$$

Where G_o is the extraterrestrial radiation, Gsc is the solar constant, n is the day of the year, θ_z is the zenith angle (Angle formed between direct radiation and a surface vertical to a local observer). Applying the value of the $\cos \theta_z$ for a horizontal surface ($\beta = 0$; where β is the inclination angle of a surface in relation to the horizontal surface) we obtain Equation 5:

$$G_o = G_{SC} \left(1 + 0.033 \frac{\cos 360n}{365} \right) (cos\emptyset cos\delta cos\omega + sen\emptyset sen\delta) \tag{5}$$

Where $\emptyset$ is the evaluated geographic latitude, δ is the solar declination ratio, which refers to the sun's angular position in relation to the Equador and ω is the hourly angle, which refers to sun's angular displacement from midday, east or west in relation to the local meridian that happens due to the Earth's rotation.

Also according to Duffie e Beckman (2006), for the case applied to the solar chimney of this study will be necessary for the calculation of daily solar radiation to have the system integrated daily extraterrestrial radiation on a horizontal surface (H_0). This is obtained integrating the Equation 5 along sunrise to the sunset period. For Gsc in Watts per square meter, the value of H_0 in daily Joule per square meter will be expressed by Equation 6:

$$H_0 = \frac{24 * 3600 G_{SC}}{\pi} \left[1 + 0.033 \cos \left(\frac{360º \, n}{365} \right) \right] \left(cos\emptyset cos\delta cos\omega + \frac{\pi \omega_S}{180º} sen\emptyset sen\delta \right) \tag{6}$$

Where ωs is the angle of the sunset time od the studied place (in this study by Brumadinho).

In turn, to obtain the value of total production of energy made by system is necessary to obtain the values of energy production by wind turbine disposed in the center of chimney, as well as by the water generator disposed outside the chimney. In this form, studies by Zhou e outros (2010) and Yosif (2014) proved that, for the wind turbine inside the chimney the value of n (turbine pressure drop factor - useful life - of the integrated plant system) is considered 0.9 (constant), this being a reduced depression factor in the turbine. The θ represents the total pressure loss coefficient involving the chimney wall friction factor, which factor has the value of f = 0.008428 determined from the studies by Zhou et al. (2008).

This form, to determine the loss coefficients related to the effectiveness of the high power condenser, the values determined by Zhou et al. (2008) were used, where it was assumed that the angle of the inlet guide vane and the height of the collector roof are, respectively, 22.5° and 0.356°, so the kinetic energy output loss coefficient εout becomes 1.058 and the kinect energy input coefficient εin becomes 0.056.

Since the energy produced by the air turbine can be calculated by Equation 7:

$$\dot{W}_{at} = \eta_{at}.n.A_{ch}.u_1.\Delta P \tag{7}$$

Where $\dot{W}_{at}$ is the energy produced of the air turbine, η_{at} is the efficiency of the air turbine, n is the factor of turbine pressure drop (lifetime) of the integrated plant system, A_{ch} is the chimney area, u_1 is the speed of air operation at the chimney inlet and ΔP is the difference produced by pressurebetween ambient air and the base of the chimney.

For this study, the values of Schlaich (1995) were assumed, where he assumed the efficiency of the air turbine generator (ηat) as 80%.

In turn, according to Zhou et al. (2010) the power of the water generator is estimated by Equation 8:

$$\dot{W}_{ag} = \eta_{ag}.\dot{m}_{agua2}.g.H \tag{8}$$

Where $\dot{W}_{ag}$ is the power of the water generator, $\dot{m}_{água2}$ is the mass flow rate of condensed vapor in the condenser, g is the gravitational acceleration, H is the height of the chimney. Basing the study on the data obtained by experimental means of Schlaich (1995) it is determined that the efficiency of the water generator ηwg can reach 90%.

Thus, the total electrical energy of the system ($\dot{W}_{total}$) is equal to the sum of the energy generated from the turbine generator ($\dot{W}_{at}$) and the energy generated from the water generator ($\dot{W}_{ag}$), which can then be expressed as Equation 9 (Zhou et al., 2010; Yosif, 2014):

$$\dot{W}_{total} = \dot{W}_{at} + \dot{W}_{ag} \tag{9}$$

Finally, according to Zhou et al. (2010) the total energy conversion efficiency of the solar chimney system (η can be expressed as the total electrical energy of the system ($\dot{W}_{total}$) by the proportion of solar radiation radiated into the collector (S) multiplied by its area (A_{coll}):

$$\eta = \frac{\dot{W}_{total}}{A_{coll}.S} \tag{10}$$

Based on the model elaborated, a calculation is made to predict and analyze the system.

3. METHODOLOGY

For the extraterrestrial radiation data proposed for the city of Brumadinho, the referential values for H_0 (Daily extraterrestrial radiation in the horizontal surface) were calculated based on the average day of each month proposed by Duffie and Beckman (2006) disposed in the Figure 1:
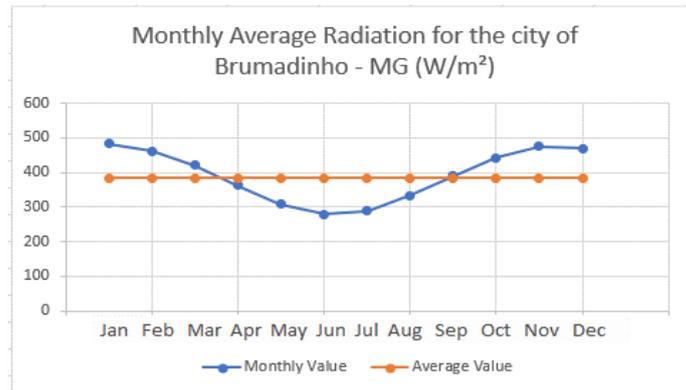
Figure 1. Daily extraterrestrial radiation in na horizontal surface based on the monthly average day of each month of the year x Average value of the daily extraterrestrial radiation calculated for the city of Brumadinho.

Therefore, for better chimney behavioral applicability in the whole year, the value of H_0 assumed for this papper became the referential value of the annual average of the calculated values for the city of Brumadinho, this value being the result in 384W/m².

Once the values for extraterrestrial radiation for the city of Brumadinho were defined, it was assumed that

for this article, the literary dimensions for the chimney studied by Zhou et al. (2010) and Yosif (2014) will be taken, since they applied experimental values made in the city of Dalain in China, thus assuming a numerical and behavioral validation of the same. Thus, this paper is based on a 500m high energy theoretical solar chimney with an internal diameter of 160m in a location where the typical atmospheric condition is around 91.5kPa (according to Castro Silva, 2018) for the city of Belo Horizon (which by geographic location is not far from Brumadinho).

The increase in the air temperature at the exit of the collector where the turbines are under load is 23.9 ºC, the assumed wind speed at sea level comes from calculations available in the literature by Castro Silva (2018) for the city of Belo Horizonte, from these, the value of 10m/s is assumed. In Table 1 shows the study parameters for a mathematical model for a combined solar chimney system for desalination and obtaining electrical energy. The output power provided is for the proposed plant to be active 24 hours a day for a period of a full calendar year at a location with an average global solar radiation of 384W/m² received by the collector for one day.

Table 1. Study parameters of the combined solar chimney system for desalination and obtaining electrical energy

Parameters	Value
Collector diameter, m	6000
Chimney height, m	500
Chimney radius, m	80
Collector outlet airflow temperature, ºC	38.9
Collector outlet airflow velocity, ms⁻¹	7.58
Total mass flow rate of vapor contained in chimney inlet airflow, ms⁻¹	7398.8
Air mass flow rate at the chimney inlet, kgs⁻¹	167941
Condensed steam mass flow rate in the chimney, kgs⁻¹	1162.15
Atmospheric pressure at the chimney outlet, KPa	95.44
Airflow velocity at the chimney outlet, ms⁻¹	7.66
Air mass flow rate at the chimney outlet, kgs⁻¹	162805.9
Condenser Diameter, m	80
Condenser Effectiveness, %	90
Ambient air temperature at the condenser inlet, ºC	11.75
Ambient air mass flow rate at the condenser inlet, kgs⁻¹	116670.6
Mass flow rate of condensed steam in the condenser, kgs⁻¹	3378.22
Atmospheric pressure at the condenser outlet, kPa	94.54
Efficiency, %	38.5

4. ANALYSIS OF RESULTS

For this analysis, it is important to emphasize that the results obtained for the city of Brumadinho have as their main theoretical foundation the geometric dimensions already studied and made possible by the literature. The relevance of this work is therefore primarily based on its applicability to this city, since the exemplified input data used for it is determined by its geographic location and its radiation numbers.

Thus, the first analysis of this article gives the relations referring to variations in values for the radius of the collector. For this, the radius of the solar collector was varied between 2000-4500m. According to the current literature, for this work the analytical models of the solar collector presented by Schlaich (1995), Backström and Gannon (2000), Zhou et al. (2010) and Yosif (2014) were studied.

From these studies and researches for the solar collector it was concluded that the total energy production obtained for the solar chimney increases significantly as the radius of the collector radius increases (Figure 2), reaching a minimum power of approximately 1.8GW for when the collector radius reaches 2000 meters and a maximum power output of 9GW for when the collector radius reaches 4500 meters.
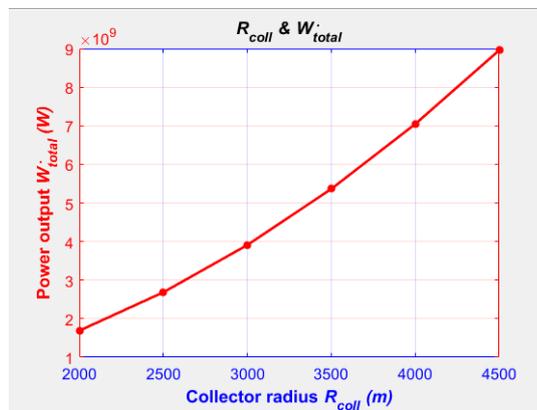

Figure 2 – Power Output x Collector Radius

For the case of the total values of electric energy production, these are directly dependent on the area of the solar collector as well as on the atmospheric solar radiation, values that dominate the relation of the efficiency of the chimney. Therefore, increasing the radius of the solar collector directly affects the efficiency of the integrated system. Thus, the efficiency values of this system vary between approximately 19% for the radius value of 4500 meters and approximately 92% for the value of 2000 meters as shown in (Figure 3):
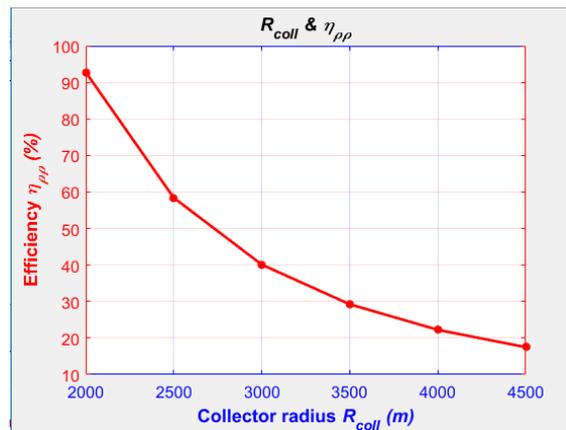

Figure 3: Efficiency x solar collector radius.

Since efficiency is directly related to the capacity that a system has to be effective, the relationship of a smaller radius size for the system still achieves large values of output power, as is the case in the studied system (see which happens in Figure 2) causes that, by increasing the size of the collector radius, the efficiency of the system as a whole drops (Figure 3), it is more interesting for this case to use a collector radius of smaller values, which consequently will also result in lower costs for the system.

The atmospheric solar radiation taken for this study obtained the calculated value for the annual average of the city of Brumadinho the value of 384W/m^2. To understand how this factor is directly related to the energy production in this

system, it was varied from 200W/m^2 to 600W/m^2, thus varying on the conditions of best to worst solar radiation available for the city of Brumadinho (such variations that can be submitted throughout the year).

In its functioning, the solar radiation component is collected by the solar collector and transferred by heat convection to the operating air under the collector. The water to be desalinated in the process, in turn, located under the surface of the collector is then heated, thus transferring the steam radially, which steam flows upwards towards the outside of the chimney.

Thus, the increase in solar radiation also leads to an increase in the total electrical energy, thus leading to a further increase in the fresh water production of the power plant made through the solar chimney. This example is shown in Figure 3, where in a hypothetical situation of daily extraterrestrial radiation of 600W/m^2 as a daily average would reach approximately 6.1GW of power produced by the plant, in turn a daily extraterrestrial radiation obtaining the minimum value of 200W/m^2 would obtain approximate values at 2GW of power. Finally, based on the average extraterrestrial radiation for the city of Brumadinho (384W/m^2), the approximate value of 3.8GW of output power in the system was reached.
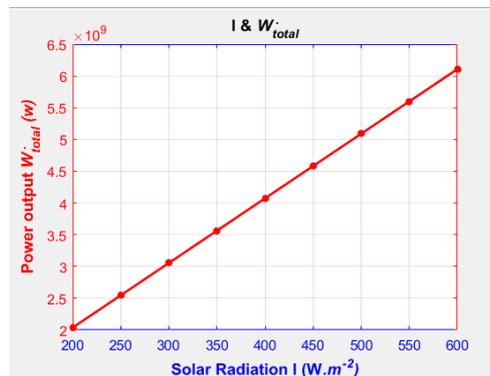

Figure 4: Power Output x atmospheric solar radiation.

A study by Yosif (2014) states that for the plant to operate fully, the area of the solar collector and the atmospheric solar radiation directly dominate the value of its efficiency. Everything is due to its operation since the short and long wave solar radiation component is collected by the solar collector and transferred by heat convection to the operating air under the collector. The sea surface under the roof has heated up and then transfers the steam radially, which in turn flows from outside to the chimney. Therefore, the increase in solar radiation leads to an increase in the total electrical energy, leading to an additional increase in both the production of fresh water and the obtainment of energy produced by the solar chimney. Thus, it is concluded that the increase in solar radiation directly affects the efficiency of the integrated system, this estimate is proven from Figure 5 where at its best radiation (daily extraterrestrial radiation of 600W/m^2) a system efficiency is obtained. of approximately 27% and, at its worst radiation (daily extraterrestrial radiation of 200W/m^2), a system efficiency of approximately 78% is obtained.
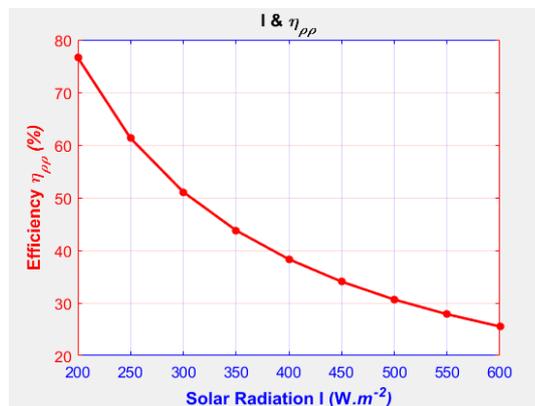

Figure 5: Efficiency x atmospheric solar radiation.

Thus, from the determination of the efficiency of the system it is possible to find that, for the case studied where the solar radiation was assumed for the city of Brumadinho having the value of 384W/m^2, the efficiency of this calculated system obtains an annual average value of 40 %.

It is important to note that the efficiency values fall as described in the graph because when varying only the radiation values for the system, considering the fixed values of total work, output heat available in the condenser and collector area,

it is in fact expected that the efficiency values fall; because it is as if this system received more radiation and still could not take advantage of it, that is, the system is less efficient.

From the literature it is assumed that the efficiency of water generators is considered to be 90% (Schlaich, 1995). Thus, the increase in the total electrical energy produced by the system is also directly dependent on the increase in the efficiency of the water generator. From Figure 6, it is possible to observe that the total electrical energy and plant efficiency varies linearly with the efficiency of the water generator.
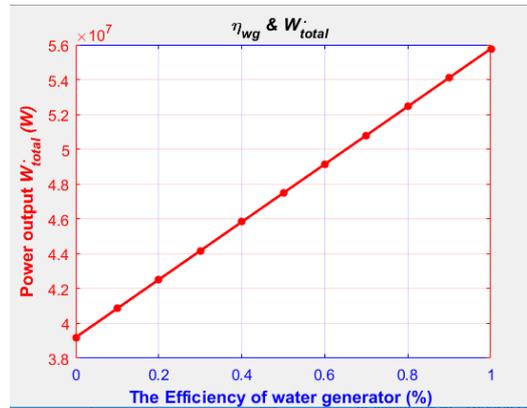

Figure 6: Power Output x Efficiency.

Thus, from Figure 6 it is possible to notice that the system efficiency considered by Schlaich's (1995) literature of 90%, the system output power obtains the total value of 5.40MW.

5. CONCLUSIONS

The solar chimney system for desalination of brackish water and obtaining electricity is a relatively new system, based on a set of new principles that operate simultaneously for the production of fresh water and electricity. To obtain the optimal capacity, a mathematical model of some parameters considered critical by the available literature was developed. For this model changes are possible within the large number of variables in the system to facilitate solutions for it to work at the highest possible performance level, thus improving the process as a whole. Thus, the following conclusions were reached for this system based on a mathematical analysis and availability of current literature:

1- From this system, the feasibility and possibility of producing electricity and desalination of sea water at the same time was proven, which is why it is considered a production system with multiple outputs.

2- To make this system viable, it must be installed on vacant land near the river or sea to be desalinated. In the case studied, it is feasible that its installation be close to the Paraopeba River. In this way, large investments or structures would not be necessary for the water to be desalinated to reach the destination of the system.

3- According to the results of the variations of the parameters estimated by the mathematical method made, the performance of the system increases with most parameters, having for this large variations in the output power when the values referring to the collector radius, extraterrestrial radiation are increased as well as the quality of the water generator – these results are in agreement with the extensive literature review carried out for this work. In this case, it is necessary to carry out a more in-depth study on the costs and feasibility of this project for large dimensions, since the larger the project means more expenses. For the initial thought of the project, with the radiation values of the city of Brumadinho and the specific dimensions of the water generator described by Schlaich (1995) as well as the project dimensions equal to the project described in Manzanares in Spain, the system proved to be viable and competitive. Analyzing each parameter separately, the calculated values of 4GW of power are obtained from the average solar radiation of 384W/m² for the city of Brumadinho, 1.8GW of generated power for the dimension of 200m of collector radius and 5.50MW of power generated from the water generator.

4 – With the installation of these systems, the supply of energy and drinking water will increase in the affected areas and will revitalize the water disposed of in the Paraopeba River, water that today is still loaded with ore tailings. Thus, directly, it will have a special benefit for populated areas previously denied these benefits.

5 - Another advantage of this system does not need direct sunlight and can operate successfully in weather conditions that receive only diffused or reflected sunlight because of partially or totally cloudy skies.

6 - About the relationship of this system to the environment in general terms, the construction of such a system is relatively simple because the materials needed for the construction process are readily available. The construction technology is widely known and operation and maintenance costs are at the lowest possible levels, in addition to the fact that it does not have any major negative impact on the environment, does not destroy natural resources, does not cause migration problems to the environment. man or for animals, operates only in vacant spaces of land (or completely infertile

as it would be the case), improves the environment, reduces the problem of lack of water and increases the rate of agricultural production.

7 – On the other hand, for these systems, the limitation of investigation into their functioning is still the result of the short term for putting into operation of plants of this type, the number of sites installed, the results derived from experiments or theoretical studies available in the literature, the presence of such projects and the high price required to configure them. However, this field is still open for broader research, experiments, theoretical and economic analyses.

6. ACKNOWLEDGEMENTS

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