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IMPACT OF COVID-19 ON THE THERMODYNAMIC PERFORMANCE OF THE HUMAN BODY.

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Abstract. *The application of exergetic analysis in human beings can be obtained through the Idea of entropy generation, which is intensified in situations where there are pathologies and abnormalities. The human body throughout its life starts from a place of high levels of disorder to another place of even bigger disorder, that is, the entropy of biological systems tends to a state of balance with the environment where its entropy would be maximum. The present study proposes to develop an approach to the impact caused by COVID- 19 about the perspective of termofluid sciences, which specifically enjoys the first and second laws of thermodynamics relating concepts discussed by the theorems, with the effect occasioned by the pathology in question. Therefore, the ending of this study has by objective obtain an exergetic model of a body affected by the Sars-CoV-2 virus, from a careful analysis based on the laws mentioned above; and at the same time, also show a modeling about the presents subsystems in the human body as: cardiovascular, respiratory and metabolic systems. It is worth noting that this study intends to use numerical simulations, modelings and interactive methods to reach the expected results.*

Keywords: *Covid-19, mathematical modeling, Second Law of Thermidynamics, exergetic analysis, entropy*

1. INTRODUCTION

Exergetic analysis is a well-established tool for evaluating the quality of energy conversion processes and has been applied to a wide range of industrial systems. By allowing the identification of irreversible phenomena that cause entropy generation and, therefore, exergy losses - also called irreversibilities. These irreversibilities can be evaluated based on parameters related to both the system to be analyzed and its surroundings.

The structure of the thermodynamic model is based on the so-called conceptual energy balance equation, together with empirical correlations for thermoregulatory heat transfer rates which, when considered separately, result in a total irreversibility rate more responsive to heat transfers influenced by convection or radiation, with exergy losses becoming smaller if the body is able to transfer more heat (to the environment) by convection. In this sense, the first and second laws of thermodynamics can be properly combined to improve the efficiency of the process. Resulting from this combination, exergy, which is a property that can be interpreted as the useful energy available to a system Mady (2018)

In recent years, some authors have applied exergetic analysis to the human body to understand its exergetic behavior, ultimately aiming to collaborate with the medical field in the diagnosis and treatment of pathologies. Uniquely, the arteries in particular can be compared to common pipes, being also susceptible to local pressure drops that can occur due to narrowing of the artery at some point, which is called stenosis. At these points, as there is a slight obstruction of the channel and soon after the release again, in some cases we can assume that it behaves like a convergent-divergent nozzle. Henriques (2018)

This phenomenon is taken as a singularity in the blood flow that leads to a localized loss of load and, consequently, irreversibilities. Considering that the exergy destruction in a given artery due to a stenosis is determined as a function of the diameter reduction - considering the exergy variation of the inflow and outflow, caused by distributed and localized head losses. Henriques *et al.* (2013)

In addition, several other studies demonstrate that pathologies can be associated with a difference in the exergetic balance of the human body, given that there will be a greater demand on the body to fight the pathology. In this sense, the present work seeks to contribute to the understanding of the impacts of COVID 19 on the exergetic behavior of the human body, considering that one of the main causes of mortality of the infected individual is the failures in the respiratory system, directly affecting the cardiac system. Thus, it is expected that this will provide some effective results to help diagnose and treat diseases related to complications related to the cardiorespiratory system. Mady (2018)

2. METHODOLOGY

From a thermodynamic perspective, it is evident that there are a series of processes that effect the conversion of energy in the human body, especially the conversion of chemical and fuel energy into several other forms of energy. One of the main sources of energy for the body is the ingestion of food, which is subsequently metabolized and provides adequate maintenance for vital functions, ensuring the execution of movements and adjustment of body temperature. Henriques (2018), Rabi *et al.* (2012)

In view of this, the understanding of the physical principles of the body's performance can be carried out from a careful understanding of the processes carried out separately by Organs vital organs and their subsystems, taking into account factors that may reduce or impair the efficiency of their functioning.Henriques (2018)

The circulatory system has as its main attribution to practice the transport of nutrients, gases, hormones, waste and energy in the form of heat by convection in the human body, which happens through the blood, allowing this process to be more effective than if it were carried out through diffusion. In this way, blood circulation occurs fundamentally through a fluid transport system, in which blood vessels act as if they were a kind of pipes and the heart can be modeled as a pumping mechanism. Mady (2018)

As stated earlier, the heart operates as a pump responsible for ensuring that there is sufficient propulsive power to transport blood to the organs, tissues and cells of the body. Henriques (2018)

The exergetic analysis has been constantly applied in concepts related to the well-being of an individual, such as: thermal comfort, performance in physical activities, aging and pathologies. Studies indicate that both physical exercise and hypertension considerably attenuate the rate of exergy destruction in the heart, since there is an increase in blood pressure and consequent increase in pumping power and metabolism exergy. Henriques *et al.* (2013)

Hypertension is a pathology that can be associated with the accumulation of fat in the walls of the arteries, which can contribute to the appearance of arterial stenosis. Stenosis is a narrowing located in an artery, which similarly can be observed in industrial pipes where there is a loss of load related to this reduction in area. Henriques *et al.* (2013)

It is also noted that the COVID-19 pandemic has directly affected the global social dynamics, at the same time that there has been an incessant search for vaccines, treatment, medications and methods of preventing this terrible disease. In view of this, researchers observed that patients who already had a pre-clinical condition of aortic stenosis had a high rate of morbidity, thus demonstrating the need for special care and management of this profile of patients. Tanguturi *et al.* (2020)

Arteries are responsible for ensuring that the transport of oxygenated blood occurs correctly from the blood to the heart, and similarly in the pipes seen in large industries, where there is movement of fluids and consequently loss of load, blood flow is also subject to this phenomenon. and thus the losses due to irreversibilities become evident. Henriques *et al.* (2013)

The percentage reduction in the diameter of a given artery, as seen above, is characterized by being a zone of stenosis and can be generated through fat deposits, arterial coarctation and even calcification. Its degree of severity is measured from this percentage of reduction in the blood flow area, which causes localized head loss. Henriques *et al.* (2013)

The equation given by Bernoulli can be obtained from the First Law of Thermodynamics in situations where the working fluid is inviscid, and thus its viscous effects can be neglected and consequently friction is also disregarded. On the other hand, it is known that in a real case this hypothesis does not apply, so it becomes imperative to take into account head losses present in a real flow, and the equation proposed by Bernoulli can be corrected by adding the terms H_f and H_l. The term Hf represents the head loss due to friction between the fluid and the wall, and H_l the head loss due to abrupt changes in the flow velocity vector. Henriques (2018)

2.1 Mathematical model of Stenosis

Based on what was previously presented, atherosclerosis is a set of diseases in which the accumulation of fat in the wall of blood vessels is noticed, thus providing a loss of elasticity and reduction of area for the passage of blood. Henriques (2018)

Thus, the modeling will be done by approaching the narrowing region with a divergent convergent nozzle, as can be seen in the following figure:

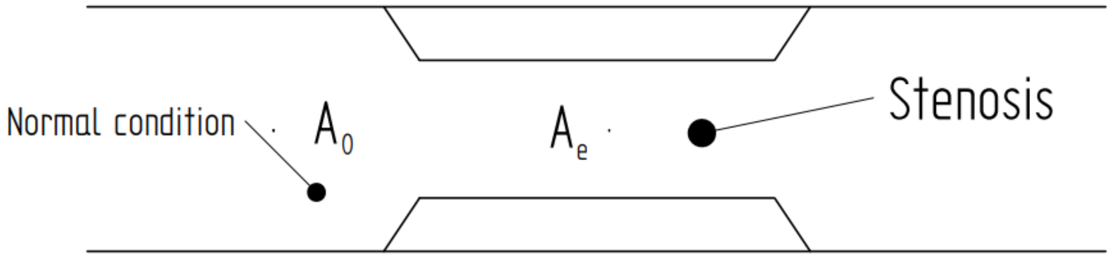

Figure 1. Stenosis zone. Source: Authors.

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$$\frac{P_1}{g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{g} + \frac{V_2^2}{2g} + Z_2 + H_f + H_l \tag{1}$$

In addition, the pressure losses existing in the flow can be considered a type of irreversibilities in the blood flow, thus increasing the rate of exergy destruction, which is also aggravated by the coronavirus infection. Therefore, considering that the difference between the specific exergy flow (b) between the upstream (1) and downstream (2) points is given by:

$$b_1 - b_2 = -b_q + w + b_d \tag{2}$$

Where w represents the specific work, b_d the specific exergy destroyed and b_q the exergy transfer associated with heat exchange between the artery and its adjacent vein. Also assuming that initially the control volume does not include the heart, that is, in this first analysis the control volume is constituted only by the artery, the specific work will be null. So: Henriques (2018)

$$b_d = b_1 - b_2 + b_q \tag{3}$$

Considering the specific enthalpy given by h , and applying the assumptions that the working fluid is incompressible and there are no changes in its chemical composition along the flow, it will be possible to simplify the previous equation. For this, the exergy terms related to heat transfer between an artery and its corresponding vein were also defined, as well as the entropy variation in the system, with ϕ the entropy generation term representing:

$$b_q = q\left(1 - \frac{T_0}{T}\right) \tag{4}$$

$$s_1 - s_2 = -\left(\frac{q}{T} + \phi\right) \tag{5}$$

Gouy-Stodola Theorem where the exergy destroyed is given by the product between the entropy generation and the temperature at the boundary surface, that is:

$$b_d = \phi T_0 \tag{6}$$

For the case where there is no heat exchange between the arteries and its adjacent vein ($q = 0$) and knowing that there are head losses related to impeding factors that affect its development, such as friction between fluid and surface and localized head losses along the flow. due to regions of vessel narrowing (stenosis), the following simplification will be performed:

$$\frac{P_1 - P_2}{\rho} + \frac{V_1^2 + V_2^2}{2} + g(Z_1 - Z_2) = g(H_f + H_l) \tag{7}$$

Henriques (2018) says that regardless of the system temperatures and heat transfer rates involved, the mathematical modeling for exergy destruction is exclusively a function of irreversibilities due to head loss.

$$B_d = \left(\frac{\dot{m}gT_0}{T}\right) H_f + \left(\frac{\dot{m}gT_0}{T}\right) H_l \tag{8}$$

2.2 Energy expenditure of the human body

Considering that the energy demand of the body's metabolic functions comes from food consumption, it is urgent to include the calculation of the basal metabolic rate (BMR), which corresponds to the minimum level of energy necessary to sustain vital functions. It is measured at complete rest, in a neutral temperature environment, in a fasted state, and measured by heat production or oxygen consumption per unit of time and expressed as calories released per kilogram of body weight or per square of body surface per hour. Kumagai and Yahagi (2020)
Making a correlation, since the metabolic changes caused by the acute disease make nutritional assessment a difficult clinical exercise, these patients are characterized by increased resting energy expenditure and negative nitrogen balance, both of which are correlated with the severity of the disease or extension of the disease. trauma. Thus, it is possible to calculate the resting energy expenditure (REE) through the Harris-Benedict equation. Coletto *et al.* (2003)
For men:

$$GER_{M-B} = 66.473 + (13.7516 \cdot Weight) + (5.0033 \cdot Height) - (6.755 \cdot Age) \tag{9}$$

For woman:

$$GER_{W-B} = 655.0955 + (9.5634 \cdot Weight) + (1.8496 \cdot Height) - (4.6756 \cdot Age) \tag{10}$$

Resting energy expenditure is increased in situations in which the patient has a certain pathology present in his body. Knowing that the coronavirus is an inflammatory process that seriously harms the health of the infected, it was considered an injury correction factor given by FI in case SarS-CoV2 affects the energy performance of the human body through sepsis. Coletto *et al.* (2003)

$$GER_{CALC} = GER_{CI} \cdot FI \tag{11}$$

2.3 Loss of Load

The head loss for fluid dynamics can be classified as major losses, which are generally caused by the effects of friction in the flow, and minor losses, which arise due to the existence of inlets, fittings or changes in area along the tubular section. Fox *et al.* (2006)
As previously mentioned, in situations where changes in area along a particular artery are noticed, they also cause changes in blood flow, which can thus cause serious damage to the individual's health. This reduction is called the zone of stenosis and originates from fat deposits, arterial coarctation or even calcification. Henriques *et al.* (2013)
This narrowing provides a localized pressure drop in the flow and can be calculated using the following equation:

$$H_l = \frac{K_s u^2}{2g} \tag{12}$$

The factor K_s is usually obtained through conventional tables that provide numerical values according to the geometry and type of instrument used. However, for the analysis of the effects caused by stenosis, the coefficient is calculated as a function of the severity of the stenosis (θ), which varies from 15% to 90%. Thus, the term . Henriques (2018)

$$K_s = 1.65514\theta - 0.2125 \tag{13}$$

The distributed head loss is considered the mechanical energy converted into thermal energy due to the effects of friction between the fluid and the rough surface of the tubular section in which the flow occurs, and can be calculated using the Darcy- Weisbach equation. Fox *et al.* (2006)

$$H_f = f\left(\frac{L}{D}\right)\left(\frac{u^2}{2g}\right) \tag{14}$$

Where f gives us the friction factor as a function, L the arterial length, D diameter of the artery and the flow velocity. The friction factor f is determined by experimental means and represented graphically through the Moody diagram and will be obtained as a function of the Reynolds number of the flow.Considering a laminar flow. Fox *et al.* (2006)

$$f = \frac{64}{Re} \tag{15}$$

By the continuity equation it is possible to determine an expression that relates the flow velocity at the point of stenosis as a function of the section area under normal conditions and the area in the stenosis region, so that it R_0 indicates the radius of the tubular section under normal conditions and R_e the radius in the narrowing. Fox *et al.* (2006)

$$\frac{\partial}{\partial t}\int_{VC} \rho dV + \int_{SC} \rho(\vec{V} \cdot \vec{n})dA = 0 \tag{16}$$

Solving the Continuity Equation, it is possible to find an expression for the velocity at the Stenosis point:

$$V_e = V_0 \left(\frac{R_0}{R_e}\right)^2 \tag{17}$$

Based on equation (1) an expression for the pressure gradient was determined:

$$P_0 - P_e = \Delta P = \left(\frac{Re \cdot \mu}{D_0}\right)^2 \frac{1}{2\rho}\left[(1+K_S)\left(\frac{R_0}{R_e}\right)^4 + \left(\frac{64}{Re}\right)\left(\frac{L}{D_0}\right) - 1\right] \tag{18}$$

3. RESULTS

3.1 Effects of area reduction on runoff

Considering the following physical characteristics taken from Feijó (2007): $\rho = 1050\,Kg/m^3$, $\mu = 4{\times}10^{-3}Kg/m{\cdot}s$, $Re = 2000$, $D = 2,55\ cm$, $L = 25\ cm$, of an abdominal aorta artery, it was possible to obtain the flow velocity before the region of narrowing, as well as other parameters such as velocity at the point of stenosis, pressure gradient and relate graphically as a function of severity.

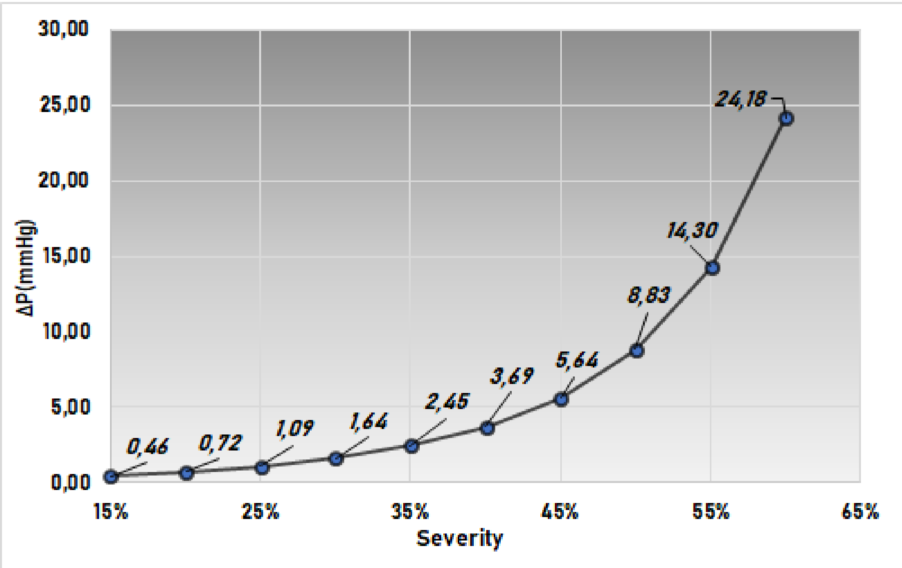

Figure 2. Relationship between pressure gradient and severity. Source: Authors.

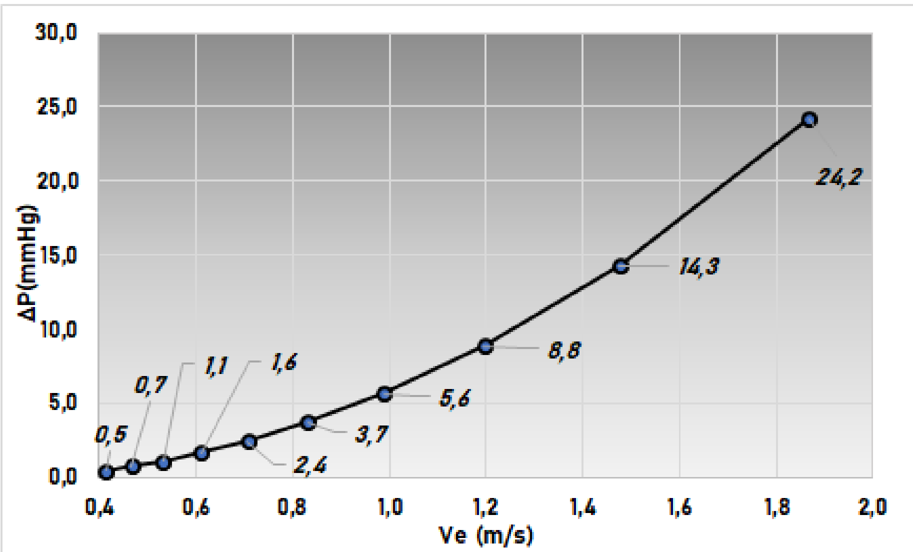

Figure 3. Relationship between pressure gradient and velocity in the stenosis zone. Source: Authors.

It is possible to observe a considerable increase in the pressure gradient and in the flow velocity at the narrowing point, as the area of the blood passage section is reduced. The greater the percentage of reduction in area, or severity of the stenosis, the greater tends to be the speed in the region subject to this pathology. As the blood leaves this area, there is an abrupt reduction in the flow velocity, due to the increase in the diameter of the section and thus, consequently, increasing the pressure inside the artery. This immediate addition causes an increase in surface tension, causing the vessel to dilate. Oliveira *et al.* (2010)

3.2 Energy expenditure

For this study, a random sample of ten male individuals of the same age, but of different height and weight, was examined. Based on the equation of energy expenditure at rest for an injury factor FI , so that SarS-CoV2 causes in 20 to 30% of patients' serious cardiovascular complications, such as myocardial ischemia, acute coronary syndrome, heart failure and shock. In situations of aggravation of the disease, the human body has an intense immune inflammatory response, which can lead to thrombosis and damage to extrapulmonary organs. Nascimento *et al.* (2020)
Therefore, the injury factor FI for situations in which the human body is subjected to severe sepsis is 1.6 . Then the energy expenditure in W:

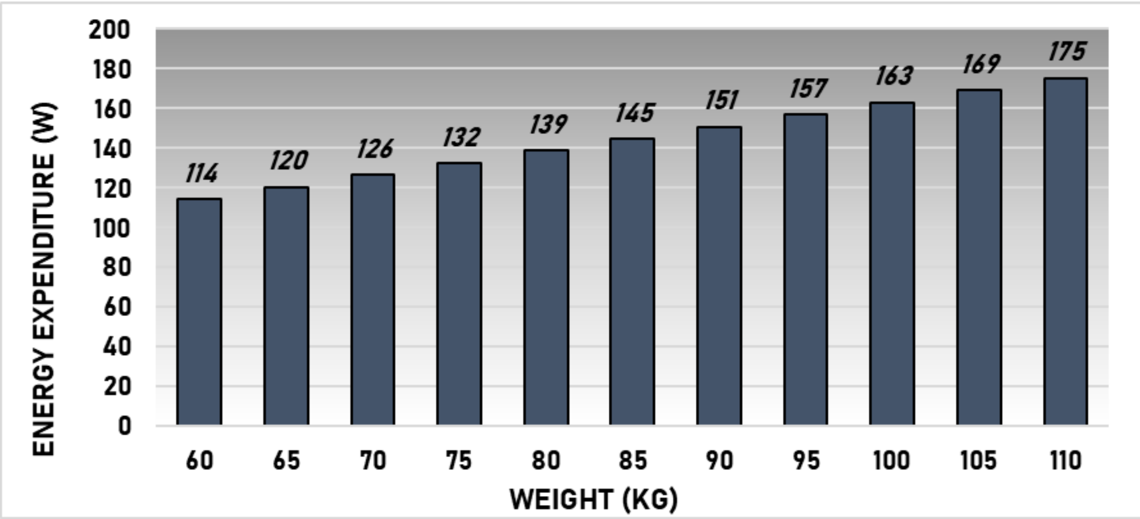

Figure 4. Energy expenditure. Source: Authors.

It is evident that the energy expenditure of the human body increases as the individual's weight is also increased, also justifying being one of the risk factors for complications in case of infection of the SarS-Cov2 virus, since the body demand for energy is much greater in patients that have greater weight.

4. CONCLUSION

Therefore, it was evident from the study that the energy expenditure in patients who are infected with the SarS-CoV2 virus is 60% higher than in uninfected patients. At the same time, the analysis confirmed that individuals who are heavier have energy expenditure 60% higher than in people with lower body weight, and in these cases the human body needs to spend more energy and consequently weaken. It is also clear that in cases of patients who have factors that can further aggravate the infection, such as stenosis, the increased pressure caused by this pathology becomes a considerable risk factor for the emergence of new complications resulting from the inflammatory process.

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