# Automatic Dissolved Oxygen Control to Oreochromis Fish's Crop in Geomembrane Tank

## Control automático de oxígeno disuelto en un cultivo de tilapia en tanque de geomembrana

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***Abstract*—Huila is a Colombian state with a high production of Oreochromis fish, its contribution to national production is of 53%, that is distributed in 338 hectares of ponds on land and floating cages. The environmental and climatic characteristics of the region allow having dissolved oxygen production in the ponds between 4ppm and 12ppm during the day, but at night the situation is unfavorable, since the amount of dissolved oxygen can decrease up to 1ppm while carbon dioxide increases. Therefore, it is necessary to have adequate oxygenation equipment and systems to prevent delayed in fish growth and to decrease death rates. This article presents the design and implementation of an automatic dissolved oxygen control system by manipulation of a water recirculation flow that operates in parallel with an industrial oxygen generator. The implemented system tracks and records the temperature and oxygen variables present in the geomembrane tank to evaluate the process evolution for different periods of the fish development cycle. The data was acquired using an Atlas Scientific dissolved oxygen sensor kit and a DS18B20 temperature probe they send the data directly to a Raspberry Pi that transmits by wireless the information collected from the process to the SISCEFA web server and a mobile application through which users can observe the data traceability. The dissolved oxygen concentration was maintained within the threshold established and the fish rate death decrease.**

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***Index Terms*— Automatic, Control, Dissolved Oxygen, Oreochromis fish.**

***Resumen*— Huila es catalogado como uno de los departamentos con mayor producción de tilapia en Colombia, aporta el 53% de la producción total del país con 338 hectáreas de estanques en tierra y jaulas flotantes. Las características ambientales y climatológicas de la región permiten alcanzar una producción de oxígeno que oscila entre 4ppm y 12ppm durante el día, sin embargo, en las noches la situación no es tan favorable, pues la cantidad de oxígeno disuelto puede disminuir hasta 1ppm mientras la de dióxido de carbono aumenta. Por tanto, se requieren equipos y sistemas de oxigenación para evitar retrasos en el crecimiento de los peces y disminuir las tasas de mortalidad. En este artículo se presenta un sistema automático que controla la concentración de oxígeno disuelto manipulando un caudal de recirculación de agua que opera en paralelo con un generador de oxígeno industrial. El sistema monitorea y registra las variables de temperatura y oxígeno presentes en una geomenbrana para generar históricos que permitan evaluar el proceso. La adquisición de los datos se realizó por medio de un sensor de oxígeno de la empresa *Atlas Scientific* y una sonda de temperatura DS18B20, los cuales envían los datos directamente a una *Raspberry Pi* que transmite de forma inalámbrica la información recolectada del proceso a un servidor web SISCEFA y a una aplicación móvil a través de las cuales los usuarios pueden observar la trazabilidad de los datos. El sistema mantuvo el oxígeno disuelto dentro de los límites establecidos y la mortalidad de peces disminuyó.**

***Palabras claves*— Automatización, Control, Oxígeno Disuelto, Pez Oreochromis.**

***Resumo*— Huila é um dos estados com maior produção de tilápia na Colômbia, contribui com o 53% da produção total do país, com 338 hectares de lagoas em terra e gaiolas flutuantes. As características ambientais e climatológicas da região permitem obter uma produção de oxigênio entre 4ppm e 12ppm durante o dia; no entanto, à noite a situação não é tão favorável, pois a quantidade de oxigênio dissolvido pode diminuir para 1ppm enquanto a de o dióxido de carbono aumenta. Portanto, são necessários equipamentos e sistemas de oxigenação para evitar atrasos no crescimento dos peixes e mitigar as taxas de mortalidade. Este artigo apresenta um sistema automático com controle da concentração de oxigênio dissolvido, mudando o fluxo de água recirculante que opera em paralelo com um gerador industrial de oxigênio. O sistema supervisa e registra as variáveis**

**de temperatura e oxigênio em uma geomembrana para gerar dados de históricos que permitem avaliar o processo. A aquisição dos dados foi realizada usando um sensor de oxigênio da empresa *Atlas Scientific* e uma sonda de temperatura DS18B20 que envia os dados diretamente para uma *Raspberry Pi* que transmite sem fio as informações coletadas do processo para um servidor da web chamado SISCEFA, além disso, foi desenvolvido um aplicativo móvel para os usuários possam observar os dados no tempo real. O sistema manteve o oxigênio dissolvido dentro dos limites estabelecidos e a mortalidade dos peixes diminuiu.**

***Palavras chaves*— Automação, Controle, Oxigênio Dissolvido, Peixe Oreochromis**

## I. INTRODUCTION

Fish production is an industry that promotes the breeding of various species of fish, among them highlight the Oreochromis, also known as Tilapia at the region. The production cycles of this variety are short because its growth is accelerated, such a characteristic has contributed to increases the production of this species in Huila state, where fish farmers own and maintain large ponds of different types to raise and reproduce Oreochromis fish.

A The geomembranes are a common pond type they are a circular or square tank with a maximum depth of 2 m, dimensions of width and length varying according to production [1] [2], and a drain to nearby land, river or lake. For safety, they are located in places without strong water currents to guarantee that surface and depth are not agitated or affected [3], besides they must be supported by some metallic structure.

Throughout the day, region environmental characteristics are appropriated helping to maintain the concentration of dissolved oxygen in the water within the range required for the production of Oreochromis in geomembranes (4ppm to 5ppm) [4], however, for nighttime periods the dissolved oxygen concentration decreases because of the absence of sunlight and plankton photosynthesis process, moreover, at night the plankton also consumes oxygen [5], Typically, dissolved oxygen in a productive oreochromis crop is close to 5ppm for daytime, and it may drop to 1 ppm for the night.

Nevertheless, the oxygen concentration low values are not the only problem, when the water pond is dirty, concentration values overpassing maximum recommended values can be also because the sediments combined with oxygen can become ammonium, a toxic substance to the fish [6]. Hence, both scenarios are not desirables because of delaying the development and increasing the death rate of the Oreochromis fish [5] [7]. So, dissolved oxygen concentration variations depend on quality water, specifically of its temperature, pH and turbidity, these variables and solar irradiance have the greatest impact on fish development.

An oxygen dissolved record it is represented in Fig. 1, the values were collected tracking a geomembrane tank for three days, when still there is no automatic control strategy implemented. The graph shows dissolved oxygen concentration values lows for both day and night, which oscillate between a minimum value of 1.6ppm and maximum of 2.3ppm, these values create unsuitable conditions for the development of the species, causing stress and high levels of the death rate.

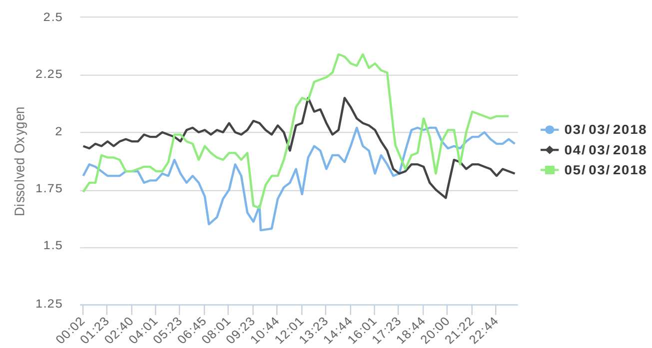

Fig. 1. Dissolved oxygen record in a geomembrane tank without control for 3 days.

To reduce the death rate and increase fish production, the fish farmer does manual oxygen measurements at least three times throughout the day and also uses one electromechanical oxygenation systems which turning on and off manually a pump to generate oxygen by recirculation and fall of water in the pond [8], most of these systems are turned on according to the experience of the fish farmer, hence it is common that system operates some time intervals for the day and uninterruptedly during the night, this is a preventive strategy, Therefore the producers incur high production costs derived from the energy consumption of the oxygenation system, which can operate for at least 12 continuous hours. Hence, although the dissolved oxygen in water is an Oreochromis fishes productive process critical variable, its control is not always the right one [9].

Another variable that strongly influences Oreochromis fish production is the solar irradiance which depends on sunlight as well, its relevance is directly associated to the oxygen consumption of the fish and indirectly to the oxygen generation because the radiation from sunlight increases the water's temperature contributing to accelerating the photosynthesis chemical reactions.

In this context, we developed an automatic control system to guarantee dissolved oxygen concentration values within the recommended range for all-day by manipulation of a water recirculation flow. The system installed works in parallel with an industrial oxygen generator. Moreover, we implemented a website and mobile application to record the dissolved oxygen concentration and temperature on an ongoing basis.

The next document sections are organized as follows: In section II, the main methods of our approach are explained. Section III describes the experimental set-up. The results are shown and discussed in section IV. Finally, in section V we conclude about the tests performed.

## II. METHODS

This section presents the methodological proposal used. We implemented an automatic solution based on recirculation system in aquaculture (RAS) [10] and a relay control method to regulate oxygen concentration values. Dissolved oxygen control system architecture is illustrated in Fig. 2. So, hardware and software interact to activate oxygenation system when oxygen concentrations lows or outside recommended values.

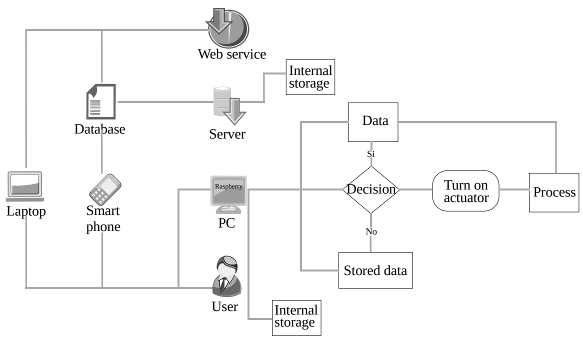


Fig. 2. Dissolved oxygen control hardware and software architecture.

The proposed architecture was based in [11], it allows supervision and measurement of physical-chemical water parameters: dissolved oxygen concentration and temperature. The control module receives variables values through installed sensors in the geomembranes, then it sends by internet to a web server to display them through a web page developed in PHP with the scheme Model Vista Controller (MVC) and a mobile application. Web services and database implemented in MySQL ensure remote and direct access to any user.

Control implementation is done with a Raspberry PI 3, that works at 5 volts DC and has GPIO ports at 3.3 V. It receives dissolved oxygen and temperature measurements from sensors submerged in the geomembrane. From this information, relay control turns on or off the oxygen generator and the electric pump to enable the RAS scheme. Moreover, an algorithm developed in the Python version 3.6 language was used for data acquisition.

The temperature measurements in the geomembrane tank were done with DS18B20 sensor, which has an accuracy of ± 0.5 ° C and it is connected to the GPIO port. The dissolved oxygen measurement was done with Atlas Scientific sensor, it has an accuracy of +/– 0.05 mg/L and its data is sent through I2CM UART communication protocol. This oxygen sensor is a polarographic electrode that measures the concentration of dissolved oxygen in the water and aqueous solutions. The main oxygen sensor parts are illustrated in Fig. 3.

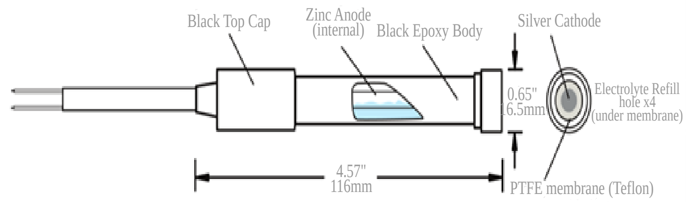


Fig. 3. Dissolved oxygen sensor Atlas Scientific [12].

Respect to the relay controller response we have that it goes through two states: "all" or "nothing" depending on the error signal magnitude. So, the action control is enabled for a negative error outside of the minimum threshold (ε2), it is disabled when positive error magnitude overpasses the maximum threshold (ε1) and it is unchanged to error values within the minimum and maximum errors thresholds because there are no intermediate states. Then, depending on the dissolved oxygen concentration in the geomembrane water the behavior of the relay control can be described according to Eq. (1).

(1)

Specifically, to the geomembrane oxygenation whether the dissolved oxygen value reaches and exceeds the reference value (Ref) the dissolved oxygen generator and the electric pump are energized to keep the RAS scheme application works. Then, once the dissolved oxygen reaches a maximum threshold (Ref + ε1) that allows to stabilize the water quality in the geomembrane, the relay turns off the dissolved oxygen generator and electric pump. After the maximum threshold is reached the dissolved oxygen variable decreases until crossing the reference value again, however, the actuators are not turned on, that only happens at the time instant (t2) when the level reaches a value (Ref - ε2).

So, the RAS scheme starts turned on the electric pump and dissolved oxygen generator, therefore, the controlled variable oscillates around the reference value. The output oscillation between two limits is a common characteristic response of a process under two-position control.

Highlight that values range from minimum to maximum threshold of dissolved oxygen is defined as tolerance zone or differential zone. Also, for the controller can represent the hysteresis (ε2 + ε1) which must be adjusted to avoid a high operating frequency (oscillation) in the actuators. So, the hysteresis represented in Fig. 4 can be defined such as the difference between the switching off and on times of the controller or the actuators closing and opening times, which allows calculating operating frequency and duty cycle.

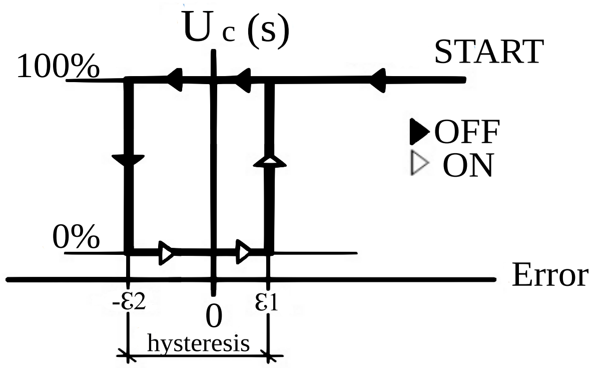

Fig. 4. Representation of hysteresis or differential band [13]

In the previous design there is a compromise between the adjustment of the regulation of dissolved oxygen and the price that has to be paid in terms of the rate of change of the input. These types of commitments are those that appear in all control designs.

## III. Experimental

With system implemented and sensors installed in the geomembrane, we established the hysteresis value of 0.2 ppm, which corresponds to the range around the setpoint wherein the control system will be operating. The setpoints values were varied from 2ppm to 4.4ppm.

The dissolved oxygen sensor correct work was verified by a comparison between values registered in SISCEFA and measurements obtained manually with Hanna Instruments dissolved oxygen sensor HI 98193.

Tracking and control were carried out from April to June 2018, data are acquired every 5 minutes. After setpoint is fixed a relay control is connected for turning on dissolved oxygen plant and electric pump to activate the RAS scheme, which compares the current value with the defined value and execute the required corrections to maintain dissolved oxygen concentration above the reference. To evaluate the behavior of the dissolved oxygen in geomembrane, the variables tracking Control algorithm was designed to work only at night period.

## IV. Result

Throughout the project, we confirm the relationship between solar irradiance and dissolved oxygen concentration. The behavior of both variables during a day is illustrated in Fig. 5, where the graph shows that solar irradiance and oxygen vary the directly proportionally way. Without control both variables increase progressively from early morning until achieving the maximum value nearly the mid-afternoon and decreasing when the sunlight is little or null.

To evaluate the relay control effect were chosen nine dates to present results related to dissolved oxygen concentration, that are directly influenced by solar irradiance, in fact, for each date selected Fig. 6 presents solar irradiance values registered from a meteorological station installed in TecnoParque La Angostura, likewise, Table 1 highlight the most representative values registered. We observed that when the irradiance is high dissolved oxygen concentration increases and vice-versa [14].

TABLE I
Solar Radiation record from meteorological station of TecnoParque La Angostura.

| | Solar Radiation (watt/m$^2$) | | | | |
|---|---|---|---|---|---|
| Date | 8:00 am. | 11:00 am. | 1:00 pm. | 3:00 pm. | 6:00 pm. |
| 20/04/2018 | 152 | 608 | 565 | 387 | 12 |
| 21/04/2018 | 412 | 398 | 640 | 374 | 8 |
| 22/04/2018 | 236 | 615 | 226 | 249 | 10 |
| 23/04/2018 | 215 | 707 | 1068 | 203 | 11 |
| 23/05/2018 | 98 | 425 | 223 | 217 | 2 |
| 26/05/2018 | 373 | 547 | 727 | 724 | 4 |
| 31/05/2018 | 215 | 521 | 953 | 784 | 7 |
| 1/06/2018 | 47 | 221 | 1019 | 598 | 3 |
| 3/06/2018 | 227 | 1061 | 363 | 804 | 8 |

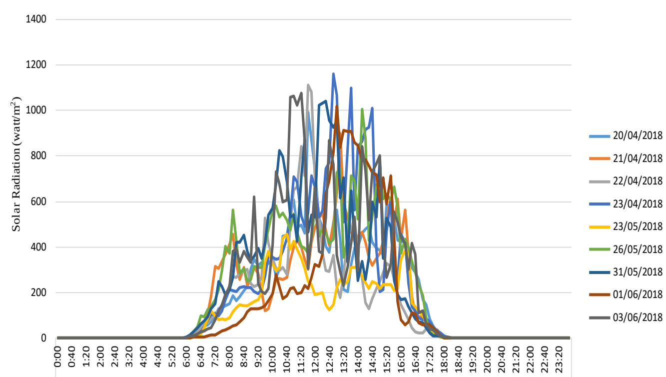

Fig. 5. Solar Radiation (watt/m$^2$)

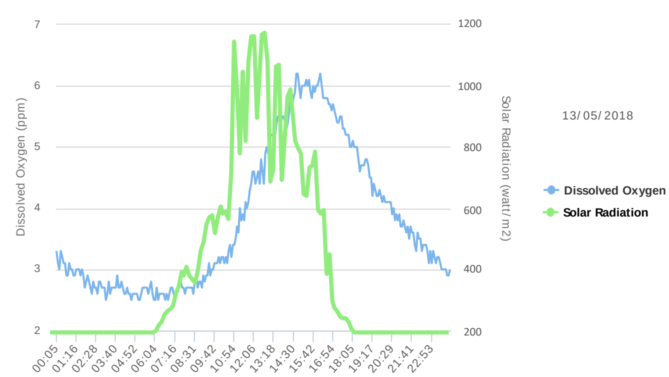

Fig. 6. Dissolved oxygen vs Solar Irradiance.

Then the dissolved oxygen concentration is evaluated to four set-points: 2.1ppm, 2.5ppm, 2.8ppm, 3.5ppm, 4,4ppm, the results obtained are presented in Fig. 7, Fig. 8, Fig. 9, Fig. 10 and Fig. 11, respectively.

The graphs show the control system effect because for all the set-points dissolved oxygen concentration maintains around the reference established during the all-night period. By contrast, during the day dissolved oxygen concentration varies depending on the solar irradiance values, this can be verified by comparison of each graph and the values registered in Table 1 and depicted in Fig. 5. So, the highest values of dissolved oxygen concentration match to the days with solar irradiance elevated and vice-versa.

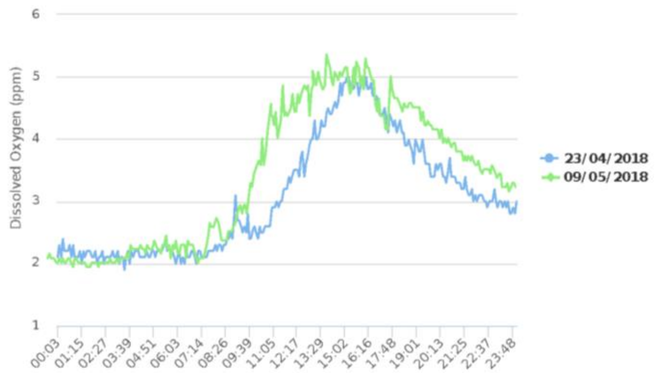


Fig. 7. Dissolved oxygen control with 2.1ppm set point

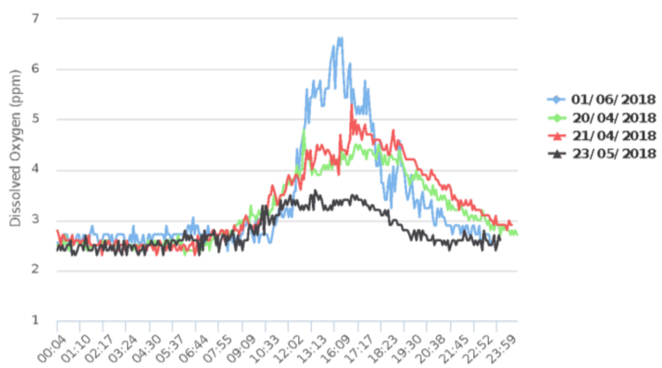


Fig. 8. Dissolved oxygen control with 2.5ppm set point

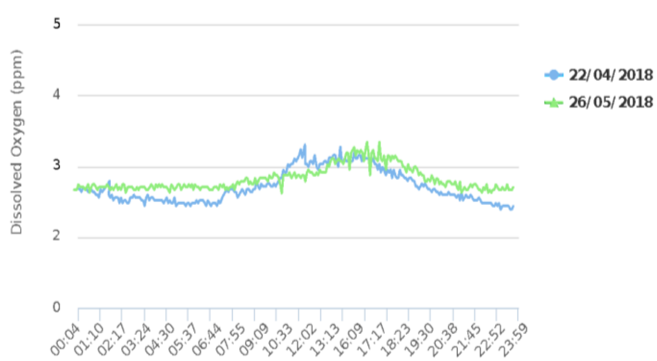


Fig. 9. Dissolved oxygen control with 2.8ppm set point

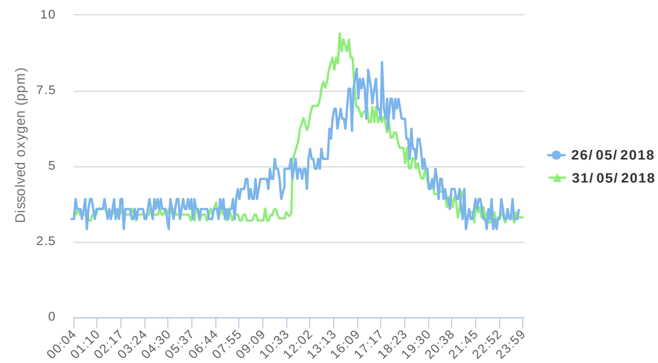


Fig. 10. Dissolved oxygen control with 3.5ppm set point

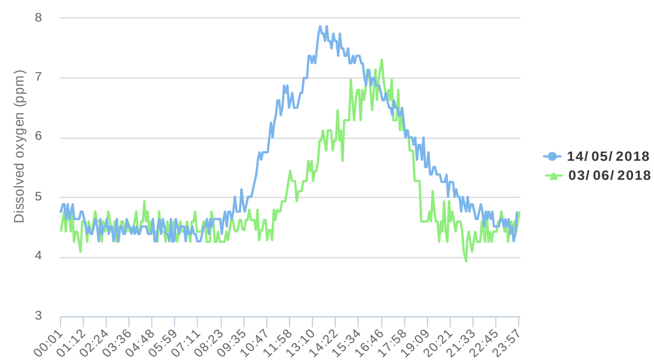


Fig.11. Dissolved oxygen control with 4.4ppm set point

Results obtained from control strategy implemented are good for all values of setpoint within dissolved oxygen range worked (2.1 ppm to 4.4ppm), because control system guarantees the oxygenation levels steadies in geomembrane tank for all cases. Based on recommendations of professionals specialized in fish breed, value of 4.4 ppm was adopted as setpoint operation, in this case the amount of dissolved oxygen in daytime reaches values up to 7,9 ppm and remaining stable during night period guaranteeing adequate dissolved oxygen levels for all-day, this creates a safe environment to fish growth and development. We emphasize that by ensuring required oxygen levels the mortality was reduced, particularly in the geomembrane evaluated the number of dead fish was reduced from 5 daily to 0.

Another result to highlight is associated to water temperature in geomembrane, which is maintained constant despite of solar irradiance variations, this is depicted in Fig. 6.

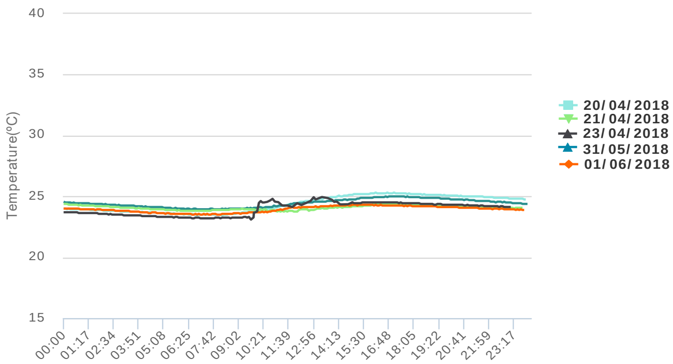

Fig. 12 temperature in geomembrane.

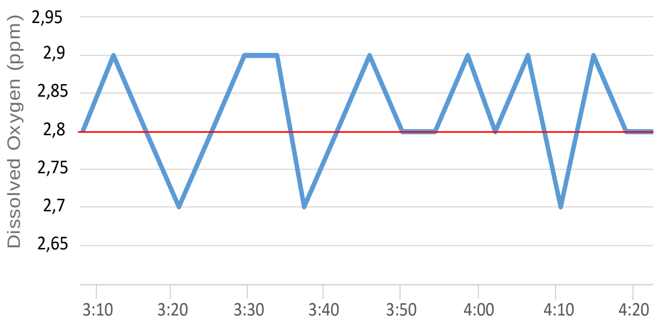

Fig.13. Controlled variable behavior.

In Fig. 13 controlled variable behavior is presented, graph shows dissolved oxygen concentration changes for approximately one hour, from it, we can state the maximum control duty cycle in 8 minutes, i.e., control strategy frequency is 2,1mHz, but these values are not constants. However, although relay control is sensitive to controlled variable disturbances, it can be acceptable, because it guarantees dissolved oxygen concentration values within established operation range, besides it has conservative duty cycles, which allow to the actuators not be activated constantly.

## V. Conclusion

Relay control duty cycle is not constant, it means that actuators can be turned on for lengthy periods in the nighttime, that can generate considerable energy consumption and increasing actuators mechanical wear. Nonetheless, energy consumption will always be less because system automatic implemented guarantees actuators work only when dissolved oxygen concentration is low. Therefore, for daytime, the automatic control does not work because the dissolved oxygen tracking allows turn off relay control when the oxygen production is increasing owing to solar irradiance presence. So, there is an important contribution in energetic terms, process data traceability, and decreasing fish death rate, all this with an economic control strategy that requires shorts implementation times. However, we highlight that controlled variable irregular behavior suggests dissolved oxygen concentration variations are slow and highly not linear, then, a relay control strategy is not the better choice and the PID strategy should be considered.

On the other hand, from the fish rate death decrease we could establish that in a geomembrane tank with Oreochromis fish living in a maximum depth of 40 cm at the average climate like Huila, the right temperature must be around 20 to 30°C.

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