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DEVELOPMENT OF AN AUTOMATED PROTOTYPE FOR MONITORING OF MICROALGAE CULTIVATION IN PHOTOBIOREACTOR

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Abstract. *The burning of natural gas and coal for electricity and heat is a great source of greenhouse gas emissions (GHG). If we do not take action now, climate change will have severe and irreversible impacts across the world. Among all of the technologies currently employed to reduce this impact, biological methods are get attention of several researchers. One of these methods is the mitigation of emissions such as CO_2 and NOx using microalgae. Flue-gas emissions from fossil-fuel combustion in Power Plants can be used for microalgae cultivation, which produces a biomass with high added value and a source of animal feed, pigments, antioxidants and biofuels. However, there are many challenges to make the process feasible, e.g., development microalgae production systems and control of conditions for growth of algae. Considering the technical and financial difficulties to obtain accurate information about of microalgal growth during large-scale treatment, this research proposed an automatic monitoring process in real time, providing a more efficient process control. A prototype system is actually in developing stage for follow up the growth of microalgae in photobioreactors based on quantitative data analysis, considering planning issues and good laboratory practices. In this way, this research presents the way to embed the experience of the laboratory procedure of the monitoring of microalgae to an automated prototype applied in the field, with contributions focused on the gain of knowledge and intelligence to the process.*

Keywords: *microalgae, photobioreactors, automation, CO_2, NO_x*

1. INTRODUCTION

Climate change and the sustainable management of the planet's natural resources are major issues in society. Biological methods of environmental treatment have attracted the attention of several researchers and have the use of microalgae as one of the most studied items. Microalgae are a promising source of biofuels and bioproducts as they consume CO_2 to grow, multiply rapidly and can be grown in wastewater and marginal lands (Dogaris et al., 2015). Among the biological methods, the remediation of the emission of greenhouse gases by biological fixation stands out, since in addition to the environmental benefits in relation to the reduction of the emission of gases through photosynthesis, it generates the production of biomass (Kondili and Kaldellis, 2007). Recently, a Spanish application, developed by a consortium of companies, such as AlgaEnergy and Iberdrola, aimed at bio-fueling CO_2 from industrial combustion gases and transforming them into commercial bioproducts. This process involved the construction and operation of microalgae cultivation plant located next to Spain's second largest combined cycle power plant (Witt and Segura, 2016). According to Corrêa (2015), the reflection of the increasing attention directed to microalgae is the emergence of a new technological niche that has, as one of the greatest potentialities to be explored, the possibility of integration between culture systems for biomass production and the treatment of emissions.

Microalgae can be grown in different systems, such as open tanks and closed photobioreactors (*PBRs*). One of the main problems of open systems is the high occurrence of contamination. In this context, *PBRs* offer a relatively axenic

culture environment where conditions are more controlled, guaranteeing the predominance of the desired species and the exploitation of the maximum potential of microalgae as source of different compounds of high aggregated value (Brennan and Owende, 2010).

The monitoring of the growth of this microorganism in *PBRs* is necessary for the control of process parameters (e.g. biomass production, efficiency of gases mitigation, temperature and pH) in favor of maintain the quality of culture systems, usually realized through daily collections from laboratory analyzes. To measure the microalgae's growth, it is important to development a planning with the following questions: circulation's flow, stability of the measurement, production process, sampling technique, conservation and transport of samples from fieldwork to the laboratory. In other words, good laboratory practice refers to the organization and conditions which laboratory and fieldwork are planned, performed, monitored, recorded and reported. However, it's important to emphasize that methodology do not guarantee the elimination of human faults and deficiencies and that the microalgae's growth is directly influenced by several factors such as the presence of contaminants and effects caused by luminosity, temperature, *pH* and nutrient availability.

Considering the technical and financial challenges to obtaining reliable information regarding the monitoring of algal growth, the aim of this work is to develop an automated Photobioreactor monitoring process, to reduce the problems with conservation and transport of the sample to the laboratory, besides avoiding failures and incorrect values in laboratory procedures. The automation of the process aims to develop a prototype to remotely monitoring the growth of microalgae in photobioreactors in real time based on analysis of quantitative data, planning questions and good laboratory practices.

2. PROPOSED METHOD

This work proposes a method to transform the laboratory procedure to monitoring the growth of microalgae in a photobioreactor in an automated prototype applied to the field. In order to support the execution of the method, it is intended to follow the concepts and stages of development disseminated in Product Engineering. According to Back et al. (2008), the product development process (*PDP*) consists of the application of the principles, knowledge, processes, methods and tools, to develop actions to achieve product success and its development, from planning to validation. The research methodology is divided into three parts: 1) Microalgae laboratory culture unit, 2) Definition of the conceptual model and construction of the control and monitoring prototype, 3) Industrial microalgae culture unit for CO_2 mitigation in power plants. Figure 1 illustrates the parts of the research development.

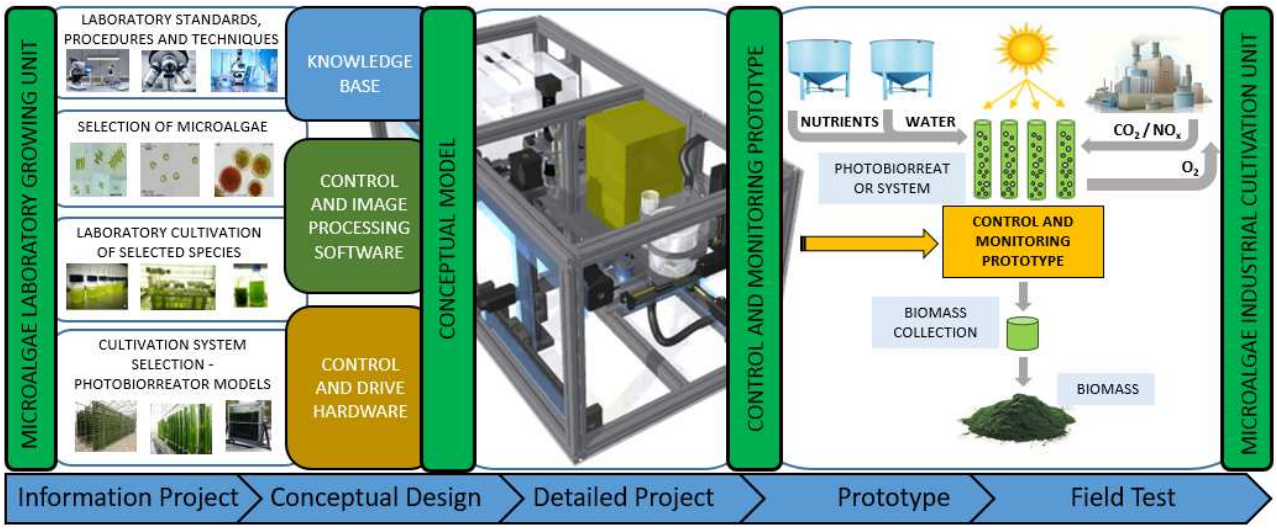

Figure 1. Macro flowchart of the research phases

In the laboratory cultivation unit, the steps that allowed the construction of the informational structure necessary for the development of the knowledge base, software of the monitoring and control system and the hardware of the project are concentrated (Information Project). The information obtained in the informational phase served as support for the creation of the conceptual model of the control and monitoring prototype of microalgae (Conceptual Design). With the project information defined, the concepts detail phase was started, when the engineering elements and the technical specifications are defined and executed and, with the results of this phase, a prototype for tests is obtained (Detailed Project). In the industrial culture unit, the prototype can be tested, adjusted and validated (Field Test).

2.1 Conventional microalgae monitoring and future proposal

This proposal can bring significant financial contributions, as well as providing information in real time, that allow to influence the decision making in the control of the cultivation variables. The conventional method of monitoring the growth of microalgae grown in *PBRs* is strictly laboratory. Figure 2 below, illustrates the steps of this method considering an application directed to remediation of the emission of gases generated by a thermoelectric plant.

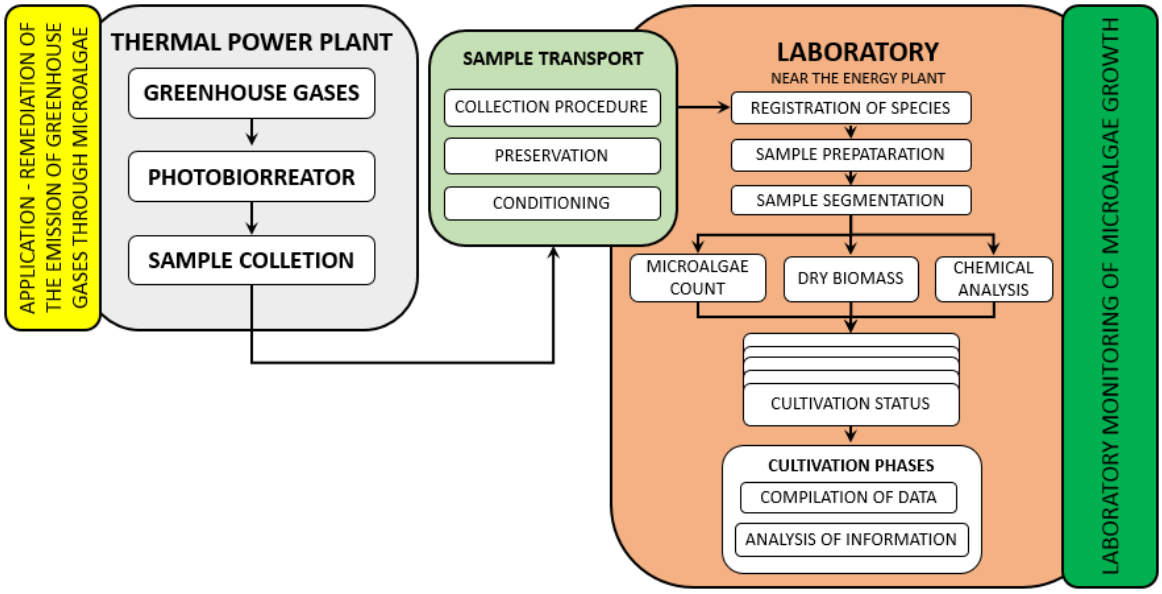

Figure 2. Conventional method of monitoring microalgae growth

In the proposed application, the photobioreactor must be installed near to flue gas stack to have access to the gases. In this way, it is advisable that the monitoring and cultivation laboratory is also close to the unit. Considering that the monitoring process is daily, the collection stage passes through the sample transport, where care such as the collection procedure, preservation and conditioning are important to maintain the reliability of the results, as it keeps the sample away from contaminants and live for the analyzes. In the laboratory, monitoring procedures are manual and require significant time consumption. Samples are listed by species, prepared and segmented for the various assays.

The laboratory tests are carried out on three forms: microalgae cell count, dry biomass weight and physical-chemical analyses, such as pH, dissolved oxygen and conductivity. By monitoring the information obtained in the tests, one can compile the results and analyze the position of the growth of the culture in relation to its phases. The delineation of the phases mapped during the study of the laboratory method, described in the item above, allowed the idealization of the new proposed method. Figure 3 presents the proposed method for monitoring.

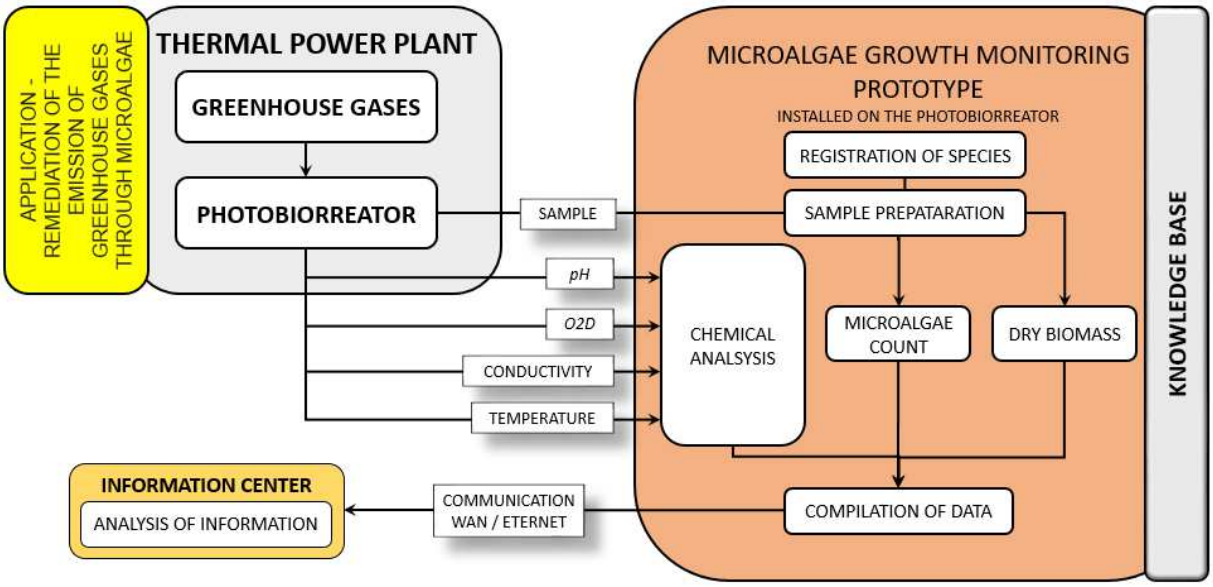

Figure 3. Representation of the proposed method

In this method, the developed prototype must be installed closed to photobioreactor, replacing the analysis performed in the laboratory. Due to the easy access to the sample, its transport will no longer be necessary, thus discarding the concerns related to the preservation and conditioning of the sample. The information for chemical analysis will be obtained from sensors installed in the photobioreactor; the variables for analysis are pH, dissolved oxygen, conductivity and temperature. The prototype will collect daily samples to quantify the microalgae growth and dry biomass. In this context, process automation and remote monitoring contribute to avoiding modifications of the collection data and accelerating the process to obtained results by compiling the information. From the communication network, the monitoring information can be transferred to a central to be analyzed. It is important to note that the application of the prototype is limited to monitoring only, so the equipment does not perform any control actions to influence the system.

3. RESULTS

The conceptual model of the monitoring prototype is shown in Figure 4. In the illustration, region "A" refers to the area destined to the control and communication system of the prototype, responsible for the process management and sensors for the acquisition of analysis information of chemical properties.

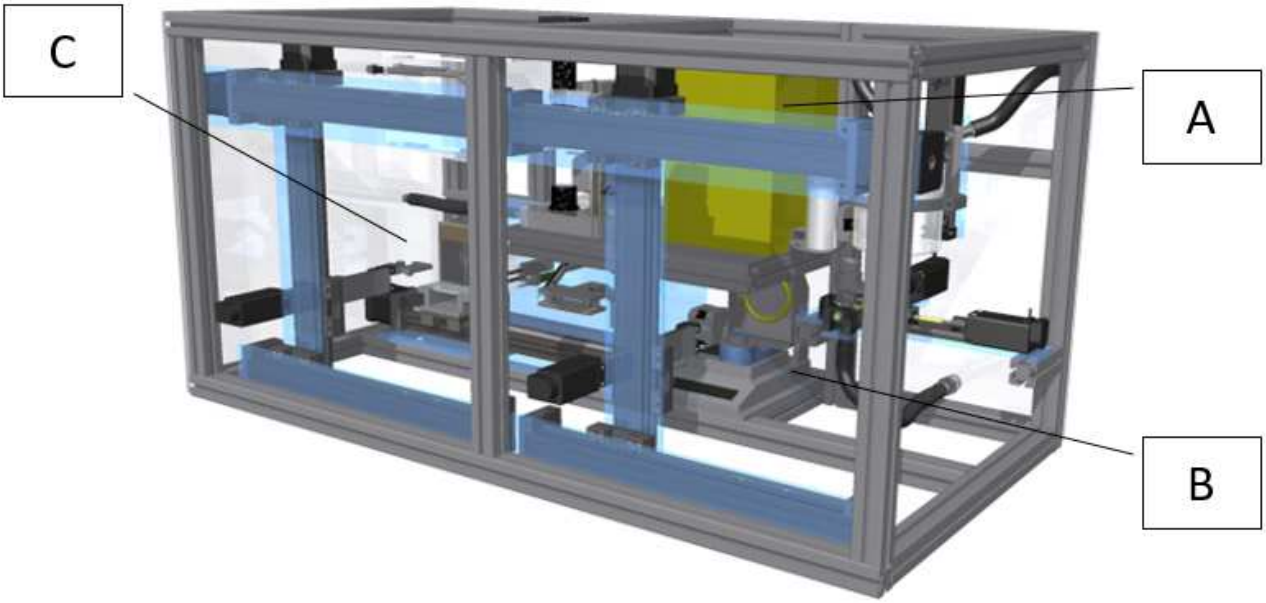

Figure 4**.** Concept of the prototype for the growth of microalgae

3.1 Automation of the microalgae counting procedure

The microalgae count aims to identify the growth of microalgae in relation to cell division and the integrity of the sample. The automation of this procedure allows the laboratory steps for sample integrity to be performed, however the intelligence the counting process will follow a methodology aided by digital image processing. In preliminary microalgae tests this methodology presented a small total error (approximately 5%) when compared to the result of manual counting (Francesconi et al., 2016).

The automation of this procedure results in two effects: 1) Creation of a video of the counting operation; 2) Definition of the mean number of cells obtained in the sample by counting in the Neubauer chamber. The first result will allow a qualitative monitoring of culture media aiming at the mapping of contaminations in the sample. The second result should aid the automation procedure to acquire the weight of dry biomass in relation to the volumetric quantity for biomass production. Figure 5 below, illustrates the main components of this step.

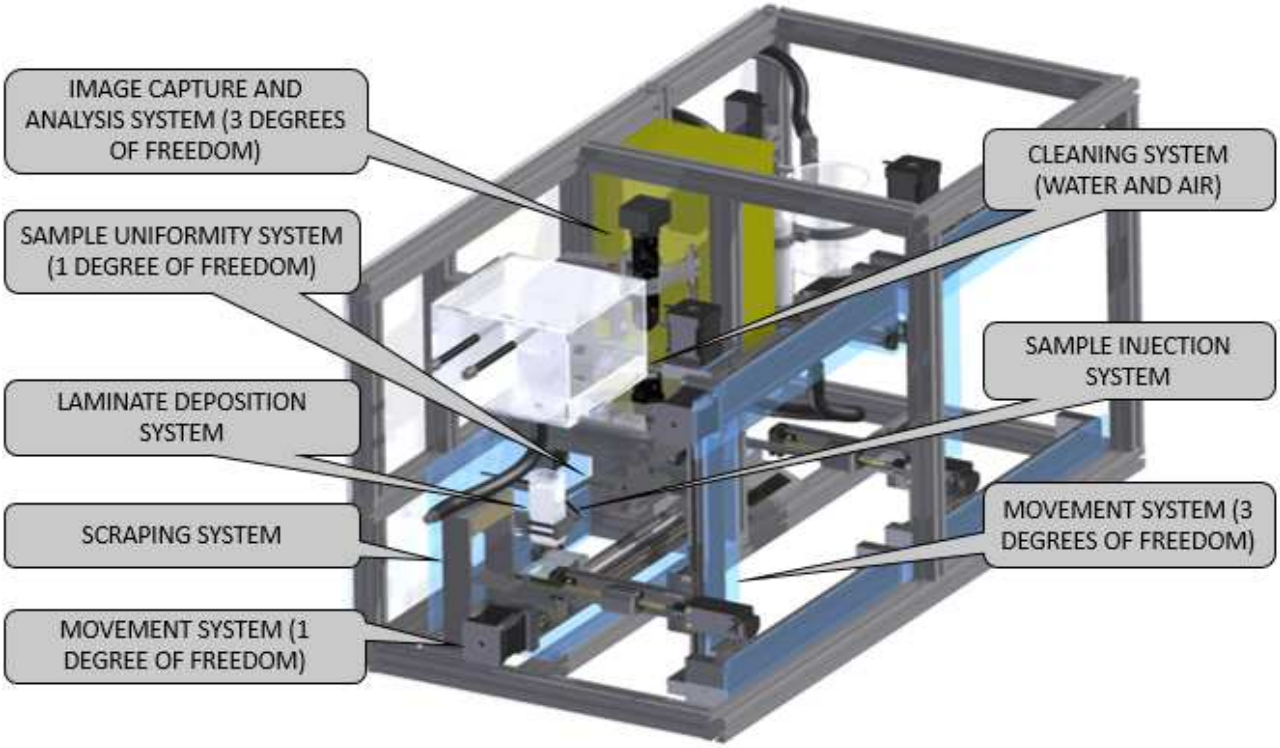

Figure 5**.** Proposed components for microalgae counting automation

The steps performed by the counting mechanism are illustrated in Figure 6.

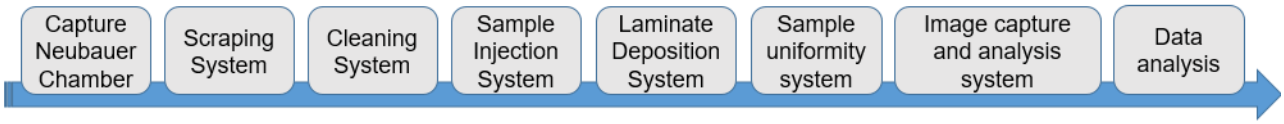

Figure 6**.** Steps implemented by the prototype for microalgae counting

3.2 Automation of the dry biomass weight acquisition procedure

The dry biomass is a physical analysis to identify the microalgae growth in a culture media. Thus, rapid and reliable methods to determine biomass concentration are required to facilitate the large-scale production of microalgae (Expósito et al., 2016). This operation results in the amount of mass (weight) obtained in a controlled volume. The definition of the volume to be used to obtain dry biomass is related to the result of microalgae count, for example, in a simplified way, if the result found in the count is "high", a low volume will already have mass representativeness. On the other hand, if the count is "low", higher volume will be required to represent mass change. Figure 7, illustrates the main components of this process in the prototype.

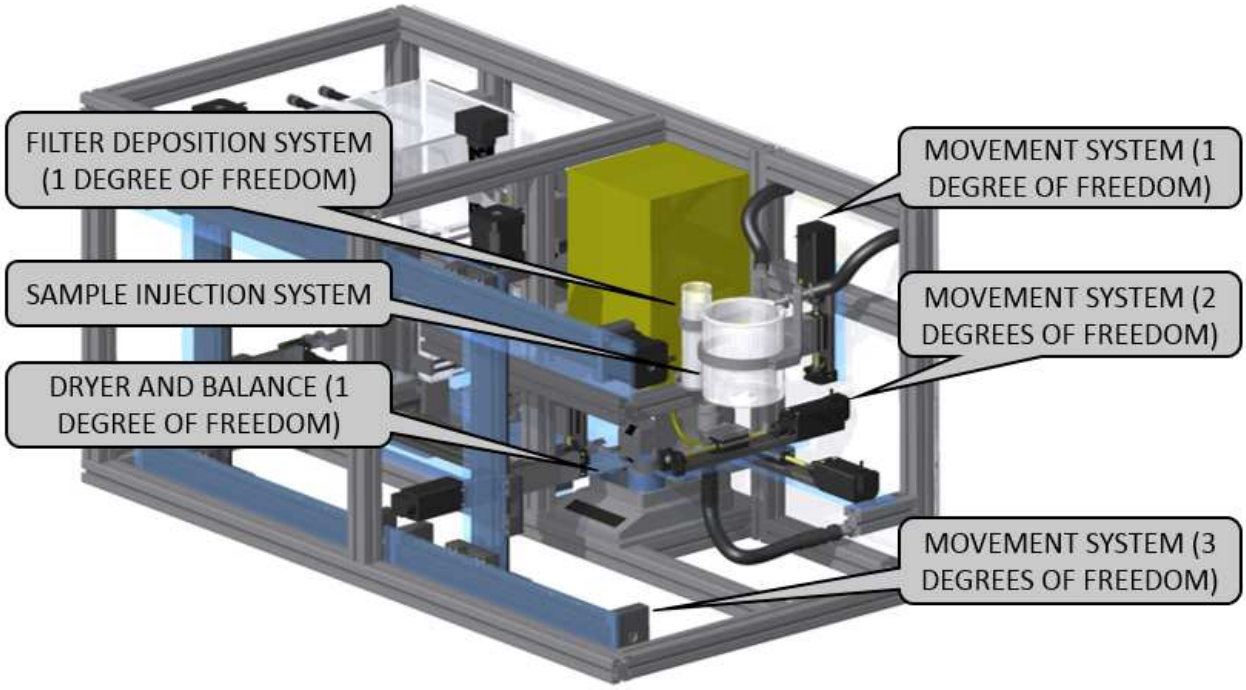

Figure 7**.** Proposed components for automation of dry biomass weight acquisition

The steps to be implemented by the dry biomass mechanism are observed in Figure 8.

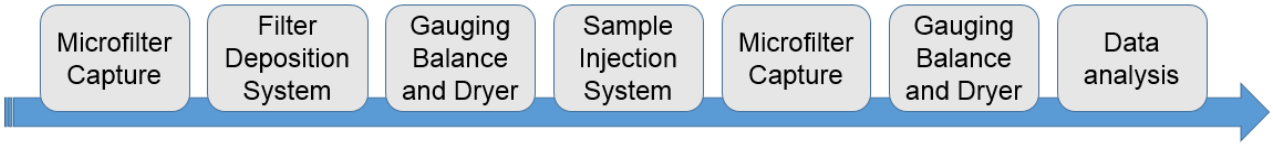

Figure 8**.** Steps implemented by the prototype to obtain dry biomass

4. CONCLUSIONS

The proposed conversion of the experience, technique and laboratory procedure for the monitoring microalgae grown in photobioreactors for an automated prototype applied to the field implies in knowledge and process intelligence. The first contribution is the elimination of preservation and transport of samples for laboratory analysis. The removal of this step from the analysis process eliminates some recommendations for preservation and storage of the sample. The second contribution is related to laboratory problems related to structure, which can compromise the reliability of information, influence results and, consequently, decision making. According to Knie et al. (2004), in the field of laboratory work, good practices recommend observing some basic requirements that essentially contribute to obtaining reliable results. The authors emphasize that potential contamination of the environment or the chemical testing system, even at very low concentrations, may have effects that cannot be explained at first sight. Finally, the third contribution is financial, since normally the monitoring of the cultivation media is done through manual and "offline" analysis, the proposed system can avoid that the sample needs to be collected and analyzed later, since that, this factor requires the cost of the daily movement of a professional team to collect and analyze the sample. Another hypothesis is the financial and structural in order to eliminate the need to build a new laboratory near the construction for each gas emitting plants.

5. ACKNOWLEDGMENTS

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7. RESPONSIBILITY NOTICE

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