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Technical and Economic Feasibility Study of Clarification and Ultrafiltration Methods Applied in Water Treatment Processes

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Abstract— **The aim of this study is to present a technical and economic feasibility analysis of clarification and ultrafiltration techniques applied to the water treatment process. Raw water samples were provided by EMBASA (Bahia Water and Sanitation Company). The samples underwent clarification and ultrafiltration methods, and the efficiency of solid removal was evaluated through parameters such as color, hardness, pH, and turbidity. Technical evaluation results indicate that both methods are technically viable and produce treated water within the desired legal specifications. Subsequently, the following economic engineering techniques were applied: Net Present Value (NPV) and Internal Rate of Return (IRR). They were instrumental in obtaining indicators that will support decision-making regarding the most economically attractive method. Through economic evaluation, it was found that the water treatment process by clarification is economically more viable than the ultrafiltration process. Therefore, this work encourages future studies, especially concerning the economic evaluation of the implementation of these techniques as well as energy consumption.**

Keywords:* *Water treatment; Ultrafiltration; Clarification; Technical and economic feasibility.

I. INTRODUCTION

The Water Treatment Plants (WTPs) aim to convert raw water (untreated water unsuitable for human and/or industrial consumption) into potable water (treated water suitable for human and/or industrial use). According to Mustafa (1998), water is directly sourced from nature through pumping stations in rivers, dams, lakes, underground aquifers, or oceans, typically containing impurities that hinder its direct use in industrial processes and human consumption. Therefore, it is necessary to treat it appropriately to meet the specifications required by these processes. The type of treatment needed for water purification is determined by its final use and, consequently, the specified quality for these applications.

Water treatment processes consist of a set of unit operations (physical and chemical) applied to achieve suitable conditions for a specific purpose. The main pollutants found in water can be classified as dissolved solids (DS), suspended solids (SS), organic compounds (OC), and microorganisms. Consequently, in the treatment of suspended solids to generate potable water (for supply), various unit processes must be employed to condition water according to the parameters established by the Ministry of Health/Office of the Minister (GM/MS) Ordinance No. 888 of 2021 in Brazil, for water to be considered suitable for human consumption. Well-known and widely used processes such as coagulation, flocculation, sedimentation, filtration, and disinfection constitute the conventional water treatment for supply. However, as noted by Oladoja (2015), new technologies are constantly being implemented and disseminated across all sectors. A promising example of these new processes involves the use of membranes through ultrafiltration.`

Clarification aims to remove particles that cause color and turbidity in water. It consists of a set of unit operations: oxidation, coagulation, flocculation, and settling, designed for solid removal (Figure 1). According to dos Reis (2010), clarification holds significant importance in the treatment of water for supply, directly related to the significance of the turbidity parameter in water potability.

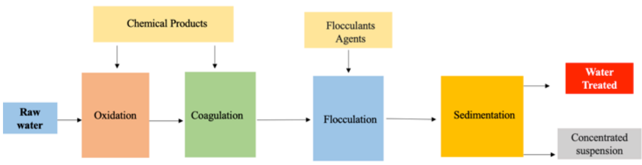

Figure 1: Raw water treatment stages

In the oxidation stage, control of odor and disinfection is achieved. The removal of these compounds is typically carried out through oxidation reactions with chlorine or ozone. Filho and Rita (2002) assert that oxidation through breakpoint chlorination is the most common technique for odor destruction and disinfection. Subsequently, there is coagulation, whose objective, according to Pavanelli (2001), is to destabilize suspended contaminants, causing particles to come into contact and agglomerate, forming floccules that settle. Next is flocculation, which is the stage of growth for the coagulated particles. During flocculation, slow agitation, achieved through mechanical or hydraulic means, is necessary to facilitate collision between destabilized particles from the coagulation process. The mixing should promote the growth of these particles without causing breakage until they reach a size sufficient for settling (Mustafa, 1998).

Finally, there is settling, where the particles are removed

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from suspension by the force of gravity. In this process, the residence time must be sufficient for the particles produced during flocculation to settle, ensuring that the clarified water meets specified color and turbidity requirements. At this stage, all sludge generated in the clarification process is removed, consisting of suspended solids extracted from the water and a portion of the chemicals added to the system.

On the other hand, in Ultrafiltration, particles are removed through a membrane separation system, where the feed is pressurized, generating two outlet streams: concentrate (rejected particles) and permeate, the desired product (Mustafa, 1998). The membrane separation process, especially ultrafiltration, is an emerging technology for water treatment due to the possibility of obtaining higher-quality water in more compact treatment plants, easy automation, reduced sludge generation, and competitive cost compared to the conventional treatment system (De Oliveira, 2010). The particles and solutes retained on the membrane surface are continuously removed in the concentrate flowing tangentially along the membrane surface. The clarified solution flows through the membrane as permeate (Figure 2) (Teixeira, 2001).

According to Schneider and Tsutiya (2001) and Blumenroth and Schneider (2001), in the production of potable water, ultrafiltration systems are employed for the separation of particulate, colloidal, and microbial material from raw water, offering the following advantages over conventional treatment systems: a) There is no need for the application of chemicals in good-quality raw water (except for chemicals used in the chemical cleaning of membranes, which are consumed in very small quantities compared to conventional treatment systems); and b) The separation mechanism is through the physical exclusion of particles larger than the membrane porosity, preventing the passage of particles larger than the pores.

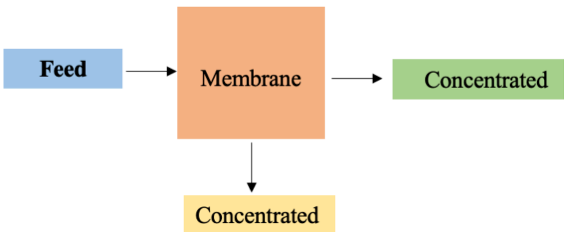

Figure 2. Streams in the membrane separation process.

In this context, this article aims to conduct a study of the technical and economic feasibility of clarification and ultrafiltration techniques applied to the water treatment process. Ultrafiltration and clarification are competing technologies, as they are capable of removing suspended solids in the same size range. Therefore, studies that combine technical assessments with economic evaluations of projects can contribute more comprehensively and guide decisions related to investments. Initially, aspects related to the methodology and parameters to be evaluated are explained. Subsequently, the results of technical and economic evaluations are presented and discussed. Finally, the conclusion of this work is drawn.

II. METODOLOGY

In order to analyze the technical and economic feasibility of water treatment processes, the research underwent the following stages: collection of the raw water sample, treatment of this sample using the methods of clarification and ultrafiltration, comparative analysis between the two techniques, and a preliminary study of economic feasibility. The raw water sample was provided by EMBASA, and the experiments were carried out at the Viera de Melo Water Treatment Plant and the Unit Operations Laboratory at Jorge Amado University Center.

2.1 Technical feasibility

The specification of potable water intended for human consumption is highly stringent. In Brazil, these parameters are regulated by the Ordinance of the Ministry of Health/Minister's Office (GM/MS) No. 888 of 2021. It establishes the procedures and responsibilities related to the control and surveillance of water quality for human consumption and its potability standard. The water quality parameters evaluated in the technical analysis of this study were:

a. **Turbidity:** It is an expression of the optical property of light passing through the sample, being scattered or absorbed instead of following a straight line (Clesceri et al., 1998). The values are expressed in nephelometric turbidity units (NTU). The analysis of this parameter was performed using the Turbidimeter equipment, Policontrol OPW2000 brand, where two water samples were used: raw water and treated water, thus obtaining different results for comparison.
b. **Color:** Results from the presence, in water, of substances in solution; it can be caused by iron or manganese, the decomposition of organic matter in water (mainly plants), algae, or the introduction of industrial and domestic sewage.
c. **pH (hydrogen ion potential):** Represents the balance between H+ ions and OH ions; ranges from 7 to 14; indicates whether water is acidic (pH below 7), neutral (pH equal to 7), or alkaline (pH greater than 7); the pH of water depends on its origin and natural characteristics but can be altered by the introduction of waste; low pH makes water corrosive; waters with high pH tend to form deposits in pipes; aquatic life depends on pH, with a recommended range of 6 to 9.
d. **Hardness:** Results mainly from the presence of alkaline earth salts (calcium and magnesium), or other divalent metals, in lower intensity, in elevated concentrations; causes unpleasant taste and laxative effects. Classification of water hardness (in CaCO3): Less than 50 mg/l CaCO3 - soft water, Between 50 and 150 mg/l CaCO3 - moderately hard water, Between 150 and 300 mg/l CaCO3 - hard water and Greater than 300 mg/l CaCO3 - very hard water.

Samples for the characterization of raw water, the subject of this study, were collected at the Viera de Melo Water Treatment Plant. The raw water has an average composition from 30 samples.

2.2. Economic viability

For the completion of this work, the following parameters were evaluated for the characterization of raw water: color, turbidity, total solids, and total hardness. Table 1 presents the results of the characterization of the raw water collected over the 60 days of sampling, totaling 30 samples.

Table 1 – Characterization of raw water

Parameter	Average value for 30 samples	Deviation
Color	40,5 Hazem	8,9%
Turbidity	7,11 NTU	9,3%
Total Hardness	25 mg/L CaCO3	8,2%
pH	7,03	1,1%

Analyzing Table 1, a considerable standard deviation is observed in the analysis of parameters. This is likely due to the fact that the samples were collected during a period of both drought and rainfall, which characterizes a significant variation in the quality of raw water. During rainfall, there is surface runoff of both pollutants and water itself, increasing the influx of sediments, thereby altering the parameters shown in Table 1.

3.2. Technical Analysis: Evaluation of the Contaminant Removal Performance between Treatment Technologies

After the collection and characterization of raw water, the performances of water treatment plants using clarification (conventional) and ultrafiltration (membranes) technologies were evaluated. The assessment was conducted on the following parameters: turbidity, total solids, pH, color, and hardness. These are typically the control parameters for evaluating the performance of Water Treatment Plants (WTPs). The removal efficiencies for each process are presented in Table 1, along with the parameters required by the Brazilian legislation, Portaria M.S: Ministry of Health Ordinance No. 518.

Table 2 – Characterization of water after clarification and ultrafiltration treatment techniques

Parameter	Clarification technique (conventional)	Ultrafiltration technique (membranes)	Ordinance M.S 888
Cor (Hazem)	14,18	4,05	< 15
Turbidez (NTU)	1,42	0,142	< 5
pH	6,92	7,03	< 5
Dureza total (mg/L)	94	95	< 300

* Ordinance GM/MS Nº 888, DE 4 DE MAIO DE 2021

According to Piveli and Kato (2006), apparent color is generally an indicator of the presence of metals (Fe, Mn), humus (organic matter resulting from the degradation of plant-derived material), plankton (a collection of microscopic plants and animals in suspension in water), and various substances dissolved in water. The data presented in Table 2 for the treated water demonstrate that both the conventional station and the ultrafiltration system have achieved water quality within the parameters required by the current ordinance, which is 15 Hazen. For the ultrafiltration system, lower values are obtained. These results are in agreement with those presented in Rosa (2021).

The results presented in Table 2 for turbidity indicate that, with the clarification (conventional) method, the average value obtained was 1.42 NTU, and for the ultrafiltration system, it was 0.14 NTU. Although the turbidity by the conventional system is higher, it did not exceed the maximum limit established for treated water according to the GM/MS Ordinance 888 of 2021, which is 5 NTU. Therefore, both techniques proved to be effective in reducing the turbidity of raw water, which was 7.11 NTU.

The results from Table 2 indicate that the average pH value for water treated by the clarification technique is 6.92. This value is lower than that of the raw water and the water obtained by the ultrafiltration system, which is 7.03. For the clarification (conventional) system, this difference is associated with the nature of the coagulation and flocculation treatment, which consumes the alkalinity of the medium and consequently decreases the pH. In the ultrafiltration process, contaminant removal is achieved physically. Therefore, the pH did not show a significantly different average value compared to the observed average for raw water. According to Libânio (2010), coagulation and flocculation depend on an optimum pH to be effective, and this optimum pH is the situation where colloidal particles have a lower surface electrostatic charge. On the other hand, Rosa (2021) states that for membrane treatment, pH is not a predominant factor in obtaining high-quality water.

Regarding hardness, the raw water is classified as "soft water" since its value is less than 50 mg/L CaCO3. It is noteworthy that ultrafiltration did not remove hardness because the rejection range of the ultrafiltration membrane does not encompass divalent ions such as Ca and Mg. These results align with those presented by Silva (2008). The clarification method (conventional) also does not impact the hardness of the treated water.

3.3. Economic evaluation of water treatment processes

For the economic evaluation of the two water treatment techniques, a project depreciation period of 10 years was stipulated, considering the minimum attractive rate (TMA) as 15% per year. Additionally, the flow rate of the raw water intake station is 2.1 m^3/s. According to the proposed methodology, the internal rate of return (IRR) should be compared with the TMA. For a profitable project, the IRR must be higher than the TMA. The IRR represents the profitability of the business/enterprise being studied. Furthermore, for the project to be viable, the net present value (NPV) must be greater than zero, and the NPV/Investment ratio must be greater than 2.5. Therefore, with data provided by EMBASA, Tables 3 and 4 present the cash flows related to the clarification and ultrafiltration processes.

Table 3. Cash flow from the clarification process (2,1m³/s) – MM US$

ITENS	ANOS									
	0	1	2	3	4	5	6	7	8	9
Net revenue	0	281	281	281	281	281	281	281	281	281
Variable Costs	0	10	10	10	10	10	10	10	10	10
Fixed costs	0	51	51	51	51	51	51	51	51	51
Gross Profit	0	220	220	220	220	220	220	220	220	220
Taxes	0	112	112	112	112	112	112	112	112	112
Net Profit	0	108	108	108	108	108	108	108	108	108
Depreciation	0	9	9	9	9	9	9	9	9	9
Cash Generation	0	117	117	117	117	117	117	117	117	117
Residual Value	0	0	0	0	0	0	0	0	0	10
Investment	237	0	0	0	0	0	0	0	0	0
Cash Flow	**-237**	117	117	117	117	117	117	117	117	127

Table 4. Cash flow from the ultrafiltration process (2,1m³/s) – MM US$

ITENS	ANOS									
	0	1	2	3	4	5	6	7	8	9
Net revenue	0	281	281	281	281	281	281	281	281	281
Variable Costs	0	5	5	5	5	5	5	5	5	5
Fixed costs	0	65	65	65	65	65	65	65	65	65
Gross Profit	0	210	210	210	210	210	210	210	210	210
Taxes	0	107	107	107	107	107	107	107	107	107
Net Profit	0	103	103	103	103	103	103	103	103	103
Depreciation	0	12	12	12	12	12	12	12	12	12
Cash Generation	0	115	115	115	115	115	115	115	115	115
Residual Value	0	0	0	0	0	0	0	0	0	12
Investment	313	0	0	0	0	0	0	0	0	0
Cash Flow	**-313**	115	115	115	115	115	115	115	115	127

With the cash flow data in hand, the Net Present Value (NPV), Internal Rate of Return (IRR), and NPV/Investment ratio were estimated for the clarification and ultrafiltration processes, as presented in the Table 5.

Table 5. VPL, TIR e VPL/ investment in clarification and ultrafiltration processes

Process	VPL MM US$	TIR %a.a.	VPL/Inv. Total
Clarification	811	48	3,4
Ultrafiltration	690	34	2,1

According to Table 5, for a specific flow rate of 2.1 m³/s, the clarification process is more economically viable than the ultrafiltration process, as it shows a higher Net Present Value (NPV), Internal Rate of Return (IRR), and NPV/Investment ratio than Ultrafiltration. According to Rosa (2021), the ultrafiltration station (membrane-based) has a high cost compared to the clarification station (conventional) due to its equipment and materials, especially the membranes that are made of specific and complex materials, as well as high-pressure pumps and pressure vessels, which increase the installation costs of this equipment.

III. Conclusion

Clarification, as a conventional water treatment, is a competing process to ultrafiltration. This research aims to provide an examination of the technical and financial viability of using ultrafiltration and clarifying techniques in the water treatment process. The choice of which process to use in water treatment will depend on the desired water quality as the final product, as well as the investment, operational, and maintenance costs. Through this study, it was possible to verify that both processes are technically feasible, meeting the desired specifications. Considering these criteria, the membrane station showed better efficiency due to its ability to maintain its characteristics despite fluctuations in raw water. On the other hand, dosages in the conventional station depend on changes in raw water quality, which often leads to adverse conditions in treated water quality. However, the economic evaluation showed that the water treatment process by clarification is less costly than the ultrafiltration process. Although the membrane station has a higher cost than the conventional one, other benefits are reported and related to the better quality of treated water, such as the removal of pesticides, which are not captured by the traditional cost calculation system. Therefore, this work motivates future studies, especially regarding the valuation of the benefits of this treatment system to contribute to a more in-depth cost/benefit a analysis and better support the decision-making process.

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