Turbidity control on dissolved air flotation process using fuzzy logic

Rodolpho Rodrigues Fonseca, Ivan Carlos Franco, José Pedro Thompson Jr and Flavio Vasconcelos da Silva

ABSTRACT

This study intends to explore fuzzy logic control on clean water turbidity process with dissolved air flotation (DAF). Three different strategies were tested to regulate clean water turbidity by manipulating the saturator vessel flow output aiming for low actuators control effort. Saturator pressure was the manipulated variable (MV) in the first control loop named SISO I. The second control loop, SISO II, used recycle stream valve opening as MV. The third control loop (MISO) was developed applying fuzzy logic instead PID control. Several performance criteria were used to analyze the process control performance such as integral absolute error (IAE), recycle stream valve and saturator vessel pressure regulating valve control efforts, ECV_{01} and ECV_{02} respectively. Results from SISO I and SISO II strategies showed that recycle stream is a better MV than saturator vessel pressure for clean water turbidity control in the DAF process. Only SISO II and MISO strategies proved to be capable of regulating the process variable. However, MISO control showed better performance based on IAE value against SISO II, with a reduction of 11.24% on its value, even the recycle stream valve control effort for MISO control being fairly higher than that for SISO II. Nevertheless, fuzzy logic control application gave rise to better turbidity control, and consequently prevented the excessive use of clean water in the recycling stream.

Key words | automation, dissolved air flotation, fuzzy

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INTRODUCTION

Several techniques have been used in both water treatment stations (WTS) and effluent treatment stations (ETS) to remove contaminants to acceptable levels for human consumption and nature. Biological treatment by activated slurry for degradation of biodegradable organic material, chemical treatment as advanced oxidation process (AOP) for the degradation of non-degradable organic material, and finally, physical processes such as filtration, decantation, and flotation for solid removal are the most common existing techniques (Tchobanoglous 1991).

Dissolved air flotation (DAF) is a typical process in the clarification step of water treatment. It involves the injection of air microbubbles in the effluent by promoting solid particle drag in suspension. These are less dense than water and tend to accumulate at the liquid surface, usually fine-grained solid particles. Generally, the process operates continuously and is subject to large variations in its conditions, like processing water temperature (Edzwald 2010).

Basically, the principle of flotation can be described by air microbubbles' adherence to solid particles suspended in liquid phase; thereby decreasing the microbubble-particle aggregates' apparent density. A large number of factors may influence the formation of such aggregates, such as particle net electrical charge, attraction and repulsion forces among particles, their sizes, concentration, and the diameter of microbubbles. Many mathematical models have been proposed to describe their formation, trajectory, and collision efficiency with suspended particles (Edzwald 1995; Leppinen 1999; Leppinen 2000; Han 2002; Haarhoff & Edzwald 2004; Edzwald 2010). The use of computational fluid dynamics (CFD) techniques has also been used to describe DAF behavior, in an attempt to better understand the separation process (Rodrigues & Béttega 2018).

Flotation process is usually preceded by a flocculation step, which agglomerates the suspended material into larger particles, and thereby makes the separation easier.

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Thus, the time required for flocculation in the flotation system is considerably less than that in the sedimentation process (Crossley & Valade 2006). Besides this reduction, the use of DAF reduces the facility area of a water treatment station, and increases the processed water flow rate; therefore, it reduces costs related to the water treatment (Haarhoff 2008).

For DAF process understanding, Bratby & Marais (1975) studied the dynamics of air saturation in water and they found that the air dissolution has low efficiency under low pressure and in saturators with dispersed air in water. Crittenden *et al.* (2012) showed that air dissolution in water is affected by both temperature and pressure used in saturator vessel dissolution. In another study, Dassey & Theegala (2012) concluded that the production of microbubbles is higher when the system temperature is lower, and it is linearly related to the hydraulic retention time of water in the saturator vessel. Meanwhile, Bahadori *et al.* (2013) proposed a mathematical model to predict the concentration of dissolved air in water depending on the temperature and pressure used in a non-packed saturator vessel.

Another important aspect regarding DAF is the flow dynamics of the present phases in the floating tank. As mentioned before, CFD techniques were used (Lakghomi *et al.* 2015; Chen *et al.* 2016; Rodrigues & Béttega 2018) to understand the flow pattern and the relationship between microbubbles and solid particles during the flotation process. As an example, Lakghomi *et al.* (2015) found that the average diameter of microbubbles and their density influence the type of flow, once a stratified flow inside the flotation tank improves the removal of particles. In another study, Chen *et al.* (2016) determined the relationship between the concentration of microbubbles in the float separation zone depending on its depth and the diameter of microbubbles using a three dimensional numerical technique. They found that the lesser the average diameter of microbubbles, the higher their concentration in the float; even in a flotation tank with shallow separation zone, which is favorable to solid particles removal in DAF.

The production of microbubbles is therefore essential to DAF process efficiency and there is a significant operational cost to produce them, related to the energy used in saturator vessel pressurization and also clean water recycle stream pumping (Edzwald 2010).

It is well known that every process standardization results in final product quality assurance, which also applies to the water treatment process, and automation is a good way to obtain product standardization with control systems that keep the desirable process variable constant; that is, independent from the imposed perturbations throughout the process. Even with DAF being a multivariable process, its automation is a viable option to increase DAF efficiency, not only through the possibility of reducing operational costs but also because the standardization of clean water turbidity once it is possible to regulate this process variable. With DAF process automation, it is possible to keep flotation output water parameters controlled, for example, pH and turbidity. Many papers have been published reporting flotation processes control (Carvalho *et al.* 1994; Vieira *et al.* 2005; Yinfei *et al.* 2011; Xiaoping & Aldrich 2013); however, they are restricted to flotation columns that is mainly found in mineral separation processes, but is not common in water treatment stations.

Shean & Cilliers (2011) made an extended review of new process control technologies in flotation columns. They noticed that although many papers have been published in this area, technological transfer to industrial applications has become a major challenge by reason of the complexity of flotation systems that have non-linear dynamics, challenging the process control design.

An interesting methodology for multivariable systems as DAF processes is the predictive control strategy (Skrjanc *et al.* 2004; Harnischmacher & Marquardt 2007). However, Shean & Cilliers (2011) pointed out that its application may only become more efficient when trustworthy and reliable dynamic models are available, better development of regulatory controls of primary variables is possible, and with new methods to determine control robustness.

The use of artificial intelligence in control systems of flotation columns has been proved to be a powerful tool to reach control objectives and is widely applied to flotation column plants (Carvalho & Durão 2002; Bergh & Yianatos 2003; Vieira *et al.* 2005; Yinfei *et al.* 2011). However, there is a lack of papers concerning control strategies to DAF for clean water production.

Thus, this work puts forward the development of a control system applied to DAF. The control strategies proposed in this paper were developed to maintain the predefined turbidity conditions for clean water, actuating on different final control elements, and employs artificial intelligence technique in the control loop. The first strategy, named SISO I, uses saturator pressure (P) as manipulated variable (MV) and PI control once it is related to the microbubbles production. The second strategy (SISO II) applies to recycle stream valve opening ($V01_{\%}$) as MV and also a PI control, once the third strategy (MISO) was developed using multiple input fuzzy logic control and $V01_{\%}$ as MV to control clean water turbidity.

MATERIALS AND METHODS

Dissolved air flotation pilot plant

In this work, an automated DAF pilot plant assembled in the Laboratory of Automation and Process Control (LCAP) located at University of Campinas – Brazil, was used to evaluate the proposed control strategies for output clean water turbidity regulation. Figure 1 shows the DAF pilot plant used in this work.

The effluent treated in the DAF pilot plant during the experiments was prepared with clay particles suspended at 40 nephelometric turbidity unit (NTU), in an attempt to simulate river effluent, which is usually treated to produce drinking water. The effluent treatment was operated continuously by first flocculating the suspended particles with the addition of sodium aluminate ($NaAlO_2$) solution at 1% v/v and tannin SG solution at 5%v/v, followed by floc separation by applying a DAF tank of 67 L volume. The DAF pilot plant flow diagram is depicted in Figure 2, and more details about the DAF pilot plant automation can be found elsewhere (Fonseca *et al.* 2017).

In this process, $NaAlO_2$ and tannin SG solutions were continuously pumped to the flocculation tank with proportional volumetric flow rates of 1:90.9 and 1:156.25 to the effluent flow rate, respectively. These volumetric flow rates values were established using the jar test method described by Tchobanoglous (1991). The effluent flow rate used during the experiments was kept constant and equal to 3 L/min. After flocculation, the effluent was sent to the flotation tank, where microbubbles were added, aiming at floc removal by a mechanism of collision and attachment, followed by microbubbles-particles formation and apparent density reduction as discussed before. Then, the treated water in the flotation tank was drained to a sand filter to remove the last remaining particles, producing clean water with low turbidity.

Microbubbles were produced in consequence of a great pressure drop in the needle valve (V01) located on the clean water recycle stream pipe that inputs to the flotation tank. In this paper, a micro-needle valve with C_v coefficient equal to 0.03 was utilized. It is possible to produce microbubbles because part of the stored clean water was pumped to an unpacked saturator vessel, which was pressurized with air. The pressure inside saturator vessel was regulated by a pressure regulating valve (V02).

To monitor and control the separation process, an online turbidimeter with a sample time of 1 second was installed to continuously measure treated water turbidity at the flotation tank output stream, as depicted in Figure 2.

All the experiments started from a steady state condition, which was achieved by filling the flocculator and flotation tank with clean water. The process control aim during the experiments was to maintain flotation stream output turbidity on a set point value equal to 4 NTU, which represents a reduction of 90% in effluent turbidity.

Turbidity control strategies

In this paper, three different strategies were tested in an attempt to control flotation output stream turbidity as

Figure 1 | DAF pilot plant.

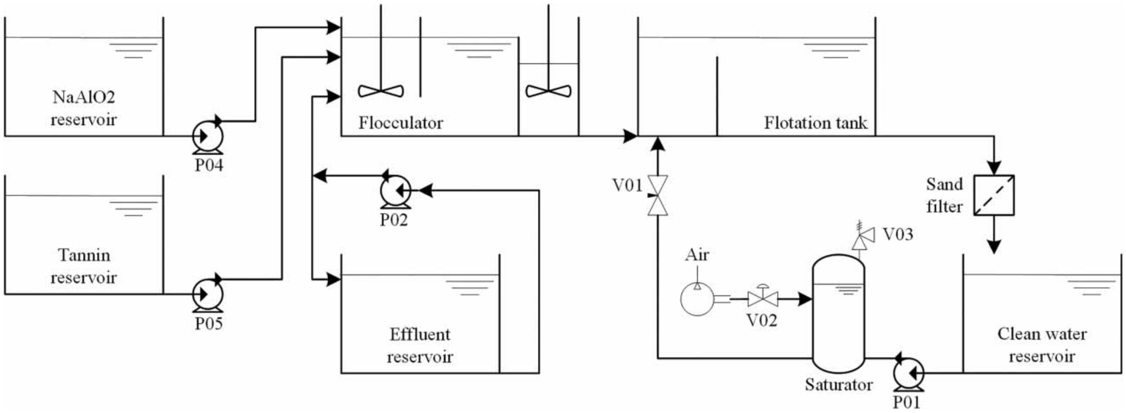

Figure 2 | Process flow diagram.

mentioned before. The first control loop, SISO I, was set using saturator vessel pressure (P) as MV, as this parameter affects the production of microbubbles in the flotation process, once air solution in water is highly affected by the pressure value at the saturator (Edzwald 2010). If pressure is low, the flotation process becomes unfeasible because microbubble production is decreased. For this reason, lower and upper limits for this MV were set at 4 and 7 bar. The upper limit was set because, above 7 bar, pressure could damage some instruments on the flotation pilot plant. The SISO I control loop was implemented using a proportional-integral (PI) controller with anti-reset windup, tuned utilizing a First Order Plus Dead Time (FOPDT) model identified from plant using the response curve method. The method to tune the PI control was based on error minimization, aiming at a process response time lower than 1,500 s in a simulation using the identified FOPDT model on Simulink/MATLAB software with Signal Constraint toolbox. For SISO I, the clean water recycle flow rate (F) was kept constant using feedback control, which is not discussed in this paper for brevity but can be found elsewhere (Fonseca *et al.* 2017).

On the other hand, the SISO II control strategy was designed to use needle valve opening ($V01_{\%}$) as MV to regulate flotation output stream turbidity. It was chosen because by manipulating $V01_{\%}$, it was possible to change the recycle stream flow rate, which is related to the amount of microbubbles in the contact zone of the flotation tank. As the recycle flow increases, the amount of microbubbles delivered to the flotation process increases as well, improving the floc removal efficiency and, consequently, allowing turbidity control. For this control strategy, the saturator vessel pressure (P) should be constant and therefore a feedback control, not discussed in this paper for brevity, was implemented to keep inside pressure at 6 bar. With saturator pressure equal to 6 bar and $V01_{\%}$ less than 25%, not enough microbubbles were produced and no flotation could be observed. Also with P equal to 6 bar but with $V01_{\%}$ above 38%, the recycle fraction was too high, reducing clean water productivity and even excessively diluting the effluent inside the flotation tank, affecting the turbidity measurement. Therefore, both lower and upper limits were established for valve opening at 25% and 38%, respectively. On SISO II, a PI control with anti-reset windup was also used and tuned with the same method mentioned for SISO I.

Meanwhile, the third control loop (MISO) was developed applying fuzzy logic on the process control. Flotation systems are typical nonlinear processes and it is well known that the design of linear control algorithms as PID is challenging for these type of processes (Shean & Cilliers 2011). For this reason, a fuzzy logic controller was applied as it has non-linear characteristics that justifies its usage in non-linear process controls, such as flotation systems (Carvalho & Durão 2002).

To analyze process control, some performance criteria were used, such as Integral of Absolute Error (IAE) and Control Efforts for the needle valve (EC_{V01}) and pressure regulating valve (EC_{V02}), which are represented in Equations (1) to (3), in which $e_{tu}(k)$ is the flotation output stream turbidity error at instant k and Δu the difference between two consecutive values of control action (u(k)) required on each actuator.

$$\mathrm{IAE} = \sum_{k=0}^{i} e_{tu}(k) \tag{1}$$

$$\Delta u = u(k+1) - u(k) \tag{2}$$

$$\mathrm{EC} = \sum_{k=0}^{i} (\Delta u)^2 \tag{3}$$

Using both performance criteria, it was possible to verify whether the process variables were properly regulated by the IAE value, but also possible to determine the actuator effort required to achieve the process control by calculating EC criteria.

Fuzzy control design

A fuzzy Mamdani controller with centroid-of-area defuzification method was designed with two inputs, the instant error of flotation output stream turbidity ($e_{tu}(k)$) on instant *k* and its difference ($\Delta e_{tu}(k)$) between $e_{tu}(k)$ and the error registered 3 minutes before instant *k*, which means 180 samples before $e_{tu}(k)$, as demonstrated in Equation (4).

$$\Delta e_{tu}(k) = e_{tu}(k) - e_{tu}(k - 180) \tag{4}$$

The input $\Delta e_{tu}(k)$ was chosen to supply fuzzy control system with the process variable dynamics during process operation. Based on previous knowledge about the DAF pilot plant dynamics, output stream turbidity has a sluggish response for variations in process input variables like steps in the recycle stream flow rate. Thus, MISO was developed using a wide interval between error values for $\Delta e_{tu}(k)$ on fuzzy inputs to take account of these sluggish dynamics, which could provide an advantage against SISO I and SISO II, both strategies based only on instant error $e_{tu}(k)$.

The fuzzy output was defined as an increment in the control signal ($\Delta u(k)$), configuring a velocity control algorithm form. In terms of MV, it was decided to choose the variable that allowed the best turbidity control between the two strategies: SISO I and SISO II. By doing so, it could be possible to compare performances between the best linear control strategy and the non-linear fuzzy logic control.

The fuzzy base rule was designed in accordance with the specialist knowledge about the relationship between DAF pilot plant dynamics and the fuzzy inputs, as discussed before. Table 1 indicates the fuzzy base rule designed for MISO control.

The base rule indicated in Table 1 was designed to provide control action reduction when $e_{tu}(k)$ and the tendency of turbidity error observed by $\Delta e_{tu}(k)$ are both negative values, meaning that flotation output stream turbidity has a tendency to its set point value. Analogous for both $e_{tu}(k)$ and $\Delta e_{tu}(k)$ positive values, the control action was set to increase because flotation output stream turbidity shows high error and no tendency to the set point value. The non-linear dynamic of the DAF process was also considered in a fuzzy base rule design based on specialist knowledge.

Table 1 | Fuzzy base rule

$\Delta e_{tu}(k) \backslash e_{tu}(k)$	Very low	Low	Zero	High	Very high
Negative	A	A	B	D	D
Null	B	B	C	D	E
Positive	B	C	D	E	E

The input $e_{tu}(k)$ was set with five transfer functions (MFs) from Very Low to Very High and the input $\Delta e_{tu}(k)$ with only three MFs (Negative, Null, Positive), reducing the base rule design effort due to the small number or rules. Based on specialist knowledge about the DAF pilot plant operation, the discourse universe for $e_{tu}(k)$ and $\Delta e_{tu}(k)$ were set to $[-2,2]$ and $[-0.4,0.4]$, respectively.

According to Table 1, the output was established with five MFs, named alphabetically from A to E, in crescent order of control output Δu value. The output discourse universe was set to $[-0.045,0.045]$ also accordingly to specialist knowledge about DAF pilot plant operation conditions. Figure 3(a) indicates the MFs of inputs and output of fuzzy controller and Figure 3(b) represents its surface response for MISO control.

RESULTS AND DISCUSSION

SISO I and SISO II control tuning

The linear control strategies on SISO I and SISO II used PI controls that were tuned based on FOPDT models identified from the DAF pilot plant, as discussed before. The parameters of FOPDT models and controllers parameters are presented in Table 2. In both cases, preliminary tests were performed on DAF pilot plant using SISO I and SISO II control loops with PI tuning parameters presented in Table 2. Based on DAF pilot plant control performance, it was observed that it was necessary to retune the controllers' parameters to new values shown in Table 3, in order to improve the process response. The parameters retune was expected because FOPDT model dynamics are poorly representative for non-linear processes, such as DAF. However, this tune method is easy and less time consuming than other more advanced techniques, and for this reason, was used in this paper.

Turbidity control using SISO I and SISO II control strategies

Comparing the results for turbidity regulation on the DAF pilot plant obtained by applying SISO I and SISO II with

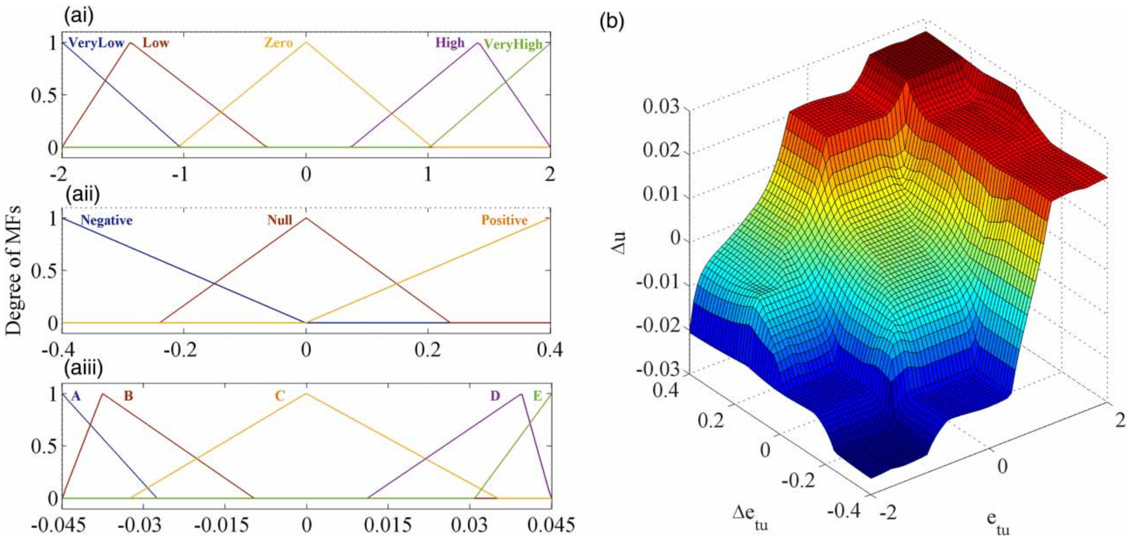

Figure 3 | (a) MFs of (i) input e_{tu}, (ii) input Δe_{tu} and (iii) output Δu; (b) fuzzy surface response.

Table 2 | FOPDT and PI parameters for SISO I and SISO II control loops

FOPDT	SISO I	SISO II
K_p	−2.9 (NTU/bar)	−0.81 (NTU/V01%)
τ_p	850 (s)	400 (s)
td	500 (s)	350 (s)
PI	**SISO I**	**SISO II**
K_c	0.26 (bar/NTU)	0.048 (V01%/NTU)
τ_I	185.7 (s)	19.2 (s)
τ_T	1.5 (s)	1.5 (s)

Table 3 | Retuned PI parameters for SISO I and SISO II control loops

PI	SISO I	SISO II
K_c	0.52 (bar/NTU)	0.015 (V01%/NTU)
τ_I	185.7 (s)	66.7 (s)
τ_T	1.5 (s)	1.5 (s)

retuned PI control, shown in Figures 4(i) and 5(i), respectively, the main difference observed was the presence of an offset in turbidity value under SISO I, indicating that pressure is not the best MV. Fonseca *et al.* (2017) observed similar process dynamics when using a different needle valve with higher C_v as actuator, and concluded that, under the experiment conditions, valve opening in the recycle stream is a better MV for turbidity control in DAF process than saturator vessel pressure.

Upon observing in Figure 4(ii) the MV for SISO I, it was found to be saturated on the lower limit (4 bar) at initial time. This pressure operating condition does not make flotation unfeasible, but produces fewer microbubbles than higher saturator pressures. This condition propitiated the contamination of the separation zone with non-floated flocs in the flotation tank, and these flocs were drained to an online turbidimeter. This resulted in many spikes in the turbidity signal, as can be seen in Figure 4(i), even using digital filters on signal acquisition. Thus, SISO I was defined as inefficient for turbidity control.

On the other hand, no separation zone contamination with flocs was observed when using SISO II control, which allowed an effective turbidity control, as shown in Figure 5(i). However, the MV became saturated on lower and upper limits during the experiment, as depicted in Figure 5(ii). The $V01_{\%}$ saturation on 38% after 3,600 s can be explained by the recycle stream temperature rise of almost 2 °C shown in Figure 6, which reduces air solubility in water, resulting in less microbubble production. This temperature increase can be explained by an effluent temperature rise in the DAF pilot plant, once the effluent treated during the experiments was kept inside tanks under weather conditions. Therefore, the recycle stream temperature is a natural disturbing variable on DAF process control because it affects turbidity control depending on weather conditions. Some authors have already reported that recycle stream flow may vary from region to region as the weather changes, to make DAF feasible (Crittenden *et al.* 2012).

After analyzing control effort on SISO I and II strategies with EC_{V01} and EC_{V02} values presented in Table 4, it is

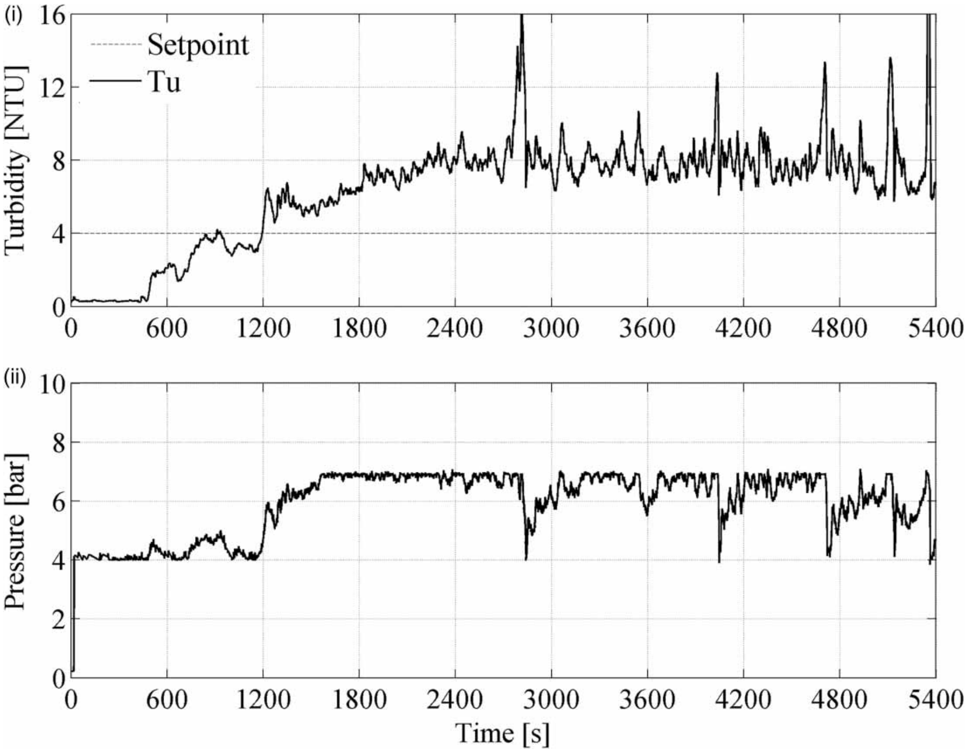

Figure 4 | Process (i) and manipulated (ii) variable dynamics under SISO I control.

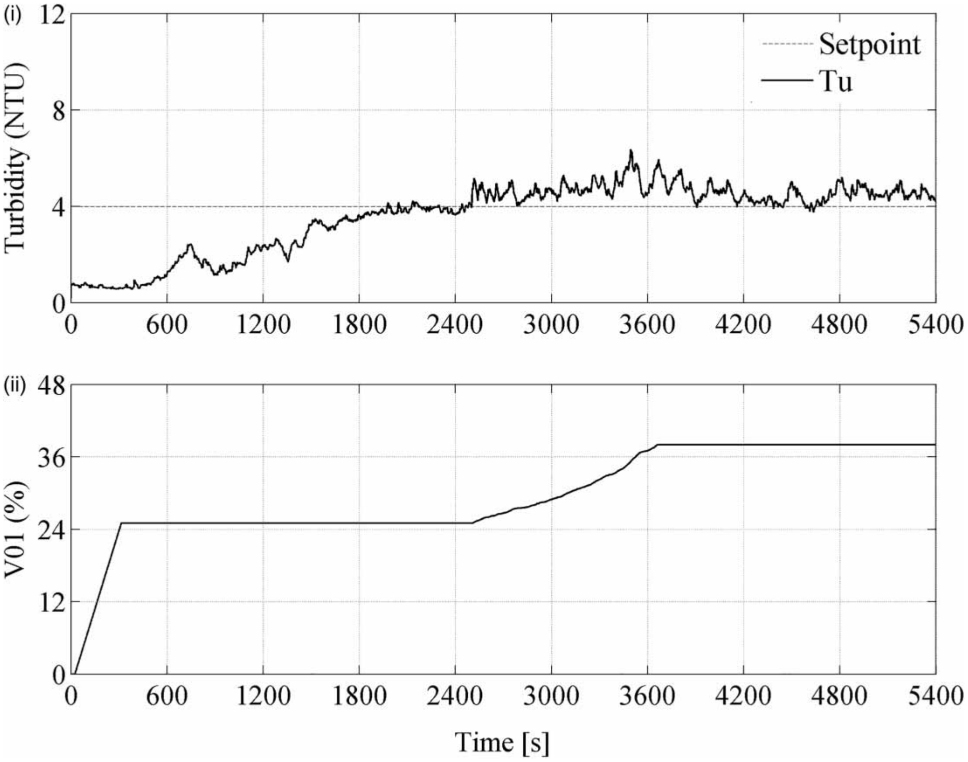

Figure 5 | Process (i) and manipulated (ii) variable dynamics under SISO II control.

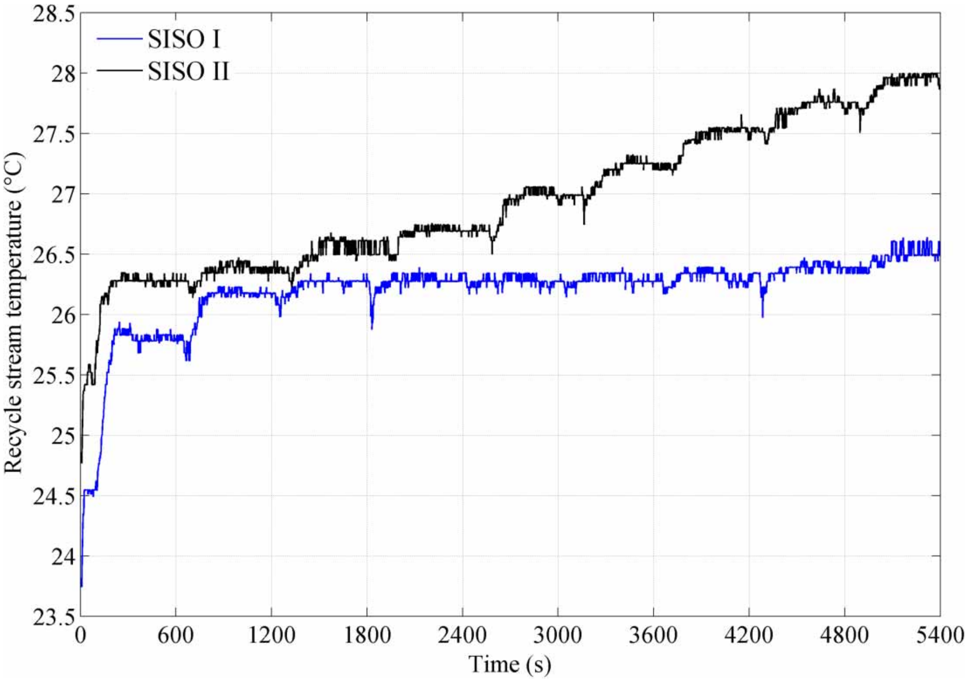

Figure 6 | Recycle stream temperature profiles under SISO I and II control strategies.

Table 4 | EC and IAE values for SISO I and II

Criteria	SISO I	SISO II
$EC_{V01}[(V01_{\%})^2\ s]$	1226,4	946,7
$EC_{V02}\ [bar^2\ s]$	140,8	36
IAE [NTU s]	17883,6	5920,4

evident that the actuators were much more required under SISO I and still did not allow process variable control as discussed before. EC_{V01} showed a high value for SISO I against SISO II because the saturator pressure manipulation forced the needle valve to be continuously actuated to keep the recycle flow constant. On the other hand, a low value of control effort (EC_{V02}) was observed for SISO II, because the saturator vessel pressure was not subjected to variations during the experiment as was observed in the case of SISO I control.

In terms of turbidity control performance, IAE criteria also corroborate to verify the poor performance of the SISO I control strategy, once its value was almost three times higher than IAE value for SISO II caused by the offset observed in the turbidity value in Figure 4(i). Therefore, based on the results observed for SISO II, valve opening $V01_{\%}$ was selected to be the MV on MISO control strategy.

Turbidity control using MISO control strategy

After analyzing the results for MISO control presented in Figure 7, it is observed that turbidity could be regulated at 4 NTU, and the control action was faster under the MISO strategy, with the needle valve being fully opened, approximately, at 1,600 s against 3,700 s of SISO II. This can be explained by the fuzzy control input $\Delta e_{tu}(k)$ that allowed an anticipated control action based on process variable error tendency as mentioned before. It could also be observed when the actuator moved away from the lower limit at 1,000 s, and the flotation output stream turbidity value was still lower than its set point at that moment. Using a liner control strategy like SISO I and SISO II, this control behaviour could only be observed after a change in $e_{tu}(k)$ error from a negative to a positive value (Seborg et al. 2004). It was also possible to verify that fuzzy control reduced needle valve opening (V01%) on the recycle stream after turbidity regulation, aiming to reduce clean water consumption but still maintaining flotation output stream turbidity under control. This behavior is beneficial in terms of environmental and process operation aspects because less clean water is needed in the recycle stream, meaning less energy is used in pumping clean water to the saturator vessel, which also eventually increases clean water process productivity.

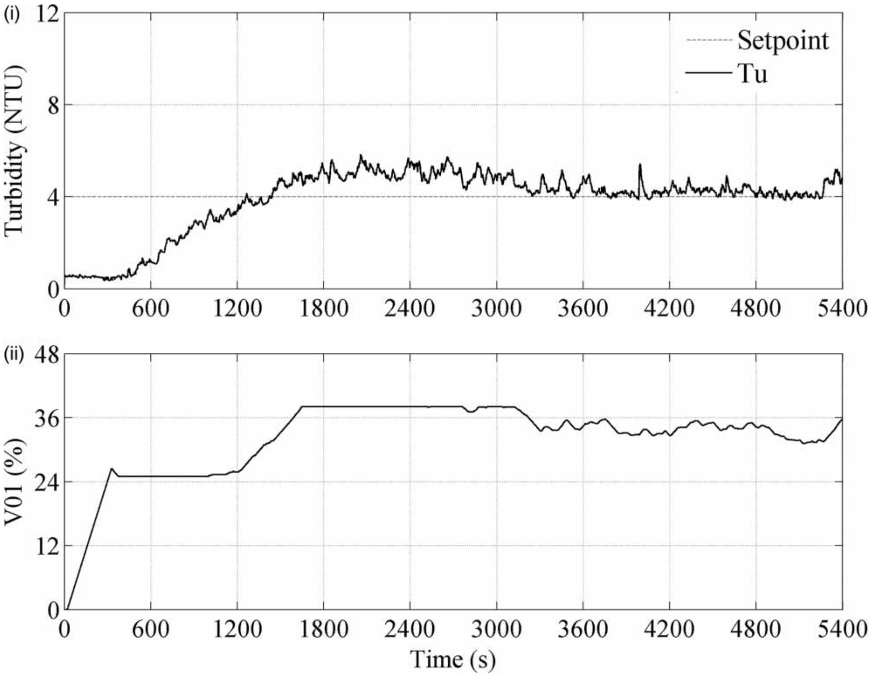

Figure 7 | Process (i) and manipulated (ii) variables dynamic under MISO control.

The recycle stream temperature profile shown in Figure 8 for MISO control indicates that air solubility was not affected at the same intensity as in the case of the SISO II control experiment because of the different weather conditions in effluent storage between the experiments, although the temperature has also increased during the assay, affecting microbubble production negatively. However, the temperature rise did not affected expressly the DAF process as in the case of SISO I as no contamination of the separation zone of the flotation tank with non-floated flocs was observed, meaning that the microbubbles produced were sufficient during the experiments. This is confirmed by the comparison of the turbidity signal between SISO I and MISO experiments; the absence of

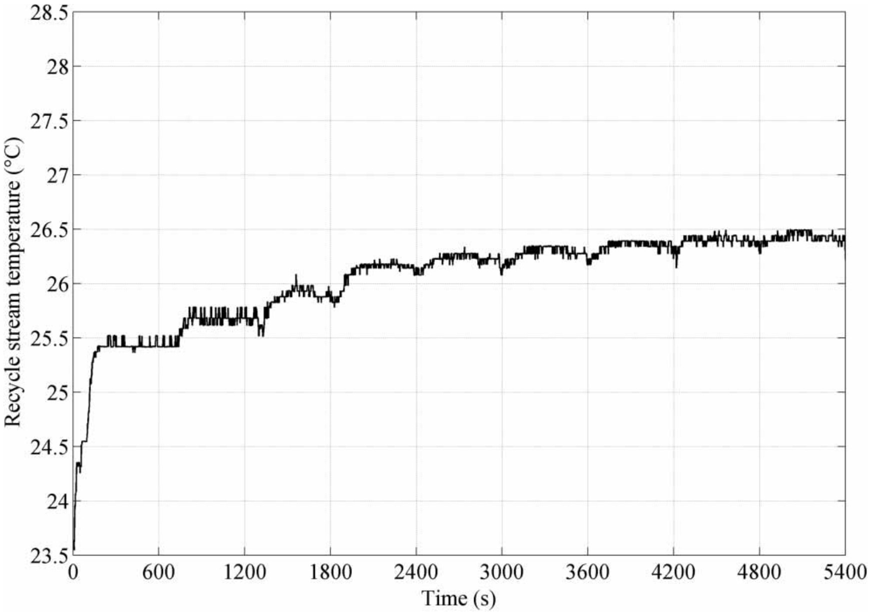

Figure 8 | Recycle stream temperature profile under MISO control.

spikes on the turbidity signal for MISO in Figure 7(i) demonstrates that the separation zone was not contaminated with non-floated flocs.

After analyzing control performance between SISO II and MISO strategies, it is clear that both control strategies were able to regulate flotation output stream turbidity, and the absence of offset in both cases demonstrates it. However, MISO control showed better performance based on IAE value presented in Table 5, indicating that the process variable was kept closer to setpoint using non-linear control strategy.

Besides this, pressure regulating valve control efforts (EC_{V02}) were similar among SISO II and MISO strategies, which was expected by reason of saturator vessel pressure maintenance at 6 bar during the experiments. However, the needle valve control effort value (EC_{V01}) was slightly higher for MISO, as indicated in Table 5, which can be explained by needle valve regulation after turbidity being stabilized at the set point value aiming at a decrease in clean water consumption. Thus, even at the cost of penalizing the actuator effort a bit more when applying non-linear control on MISO strategy, it propitiated a better flotation output stream turbidity control by avoiding excessive clean water utilization on the recycle stream. Another advantage obtained with the DAF pilot plant automation by regulating the flotation output stream turbidity is the reduction in frequency of the sand filter cleaning procedure because fewer non-floated flocs in the flotation tank are drained to the sand filter. Environmental and economic benefits can be highlighted because less water will be consumed on sand filter regeneration during DAF process maintenance, confirming that automatic control of flotation output stream turbidity is advantageous.

CONCLUSION

The present study has demonstrated that the saturator vessel pressure as an MV is not the best choice for DAF pilot plant turbidity control; needle valve opening on the recycle stream being the most adequate. It was observed by the best control performance obtained applying linear control strategies was the SISO II strategy, using the needle valve opening as MV. On the other hand, even the non-linear MISO control strategy requiring higher control effort by using fuzzy logic to improve control action, the flotation output stream turbidity control was improved, reducing recycle stream flow rate and sand filter contamination with non-floated flakes. Not only does the filtering system improve without penalizing the actuators with high control effort, but it also decreases additional consumption of clean water in sand filter regeneration.

Table 5 | EC and IAE values under MISO control

Criteria	MISO
EC_{V01} [$(V01_{\%})^2$.s]	952,2
EC_{V02} [bar^2.s]	36
IAE [NTU.s]	5255,2

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