

# The Development of a Neuro-Fuzzy Expert System for Wastewater Treatment Processes Monitoring

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*This paper presents the extension of the hardware-software experimental system SENFpHCTRL initially developed for wastewater pH control, for monitoring other parameters (total suspended solids, extractable, biochemical and chemical oxygen demand, phenols and chlorides) from other chemical processes of a treatment plant, such as: precipitation, coagulation and flocculation, oxidation and reduction (processes briefly presented at the beginning of the paper). The process of expanding the SENFpHCTRL system involved the adding to the initial expert system of a set of heuristic knowledge for other parameters and the development of the system graphical interface. It is also presented the adapted form of the system hardware component at PC and microcontroller level and the results of the simulations made with the extended system.*

*Keywords: wastewater, expert system, control, monitoring, extended system*

The main goal of the paper is that of presenting the extension of the hardware-software prototype system SENFpHCTRL initially designed for wastewater pH control ([1, 2, 12]) for monitoring a set of parameters (extractable, total suspended solids (TSS), biochemical (BOD) and chemical oxygen demand (COD), chlorides (Cl) and phenols ( $C_6H_5OH$ )) from other chemical processes, such as: precipitation, coagulation and flocculation, oxidation and reduction (processes described in [1-11]). The identification of other parameters from a plant chemical step (at the step input and output-the biological step input) was achieved applying principal components analysis (PCA [18, 19]) method on a large data base.

To expand the SENFpHCTRL prototype system developed in ([1, 2]), GNU C ([15]) 4.2.1 programming environment under UNIX OpenBSD 5.2 operating system was used. Initially, to the SENFpHCTRL initial expert system (ES) (knowledge base (KB) and inference engine (IE)) it was added a heuristic knowledge for the identified parameters. The system graphical interface was developed (in text mode) considering the portability on other microcontrollers, including the ones without hardware graphical capabilities. It is also presented the hardware component form of the extended SENFpHCTRL system adapted for other parameters at PC and microcontroller level and the results of the simulations.

The paper is organized as follows:

-A short description of other chemical processes (precipitation, coagulation and flocculation, oxidation and reduction) from a wastewater treatment plant (WWTP);

-The identification of the treatment process significant parameters using a factorial analysis method (the so called principal component analysis-PCA). In this sense, were used data from a studied industrial plant;

- Extension of the SENFpHCTRL expert system (ES) component (the KB and IE extension) with a set of heuristic knowledge for other parameters monitoring. While the initial SENFpHCTRL system achieves the automatic control of wastewater pH, the extended version achieves also the monitoring of a new set of parameters. It is presented the extended SENFpHCTRL system graphical interface under UNIX OpenBSD operating system and the system adapted

hardware component at the PC and microcontroller level. There are also presented some of the results of the simulations made with the extended system.

## Chemical Processes from a WWTP

According to [3], the chemical processes from a WWTP occur during wastewater chlorination and TSS coagulation. Related methods are based on the action of different chemical substances (reagents) on wastewater, with the goal of wastewater neutralization, precipitation, coagulation and flocculation, oxidation and reduction [4]. The wastewater pH neutralization process was studied in detail in papers [1, 2].

The precipitation process assumes the reagents dosage in order to remove the TSS and BOD through sedimentation and the phosphorous and heavy metals removal. The aluminum sulphate ( $Al_2(SO_4)_3$ ), aluminum chloride ( $AlCl_3$ ), calcium hydroxide ( $Ca(OH)_2$ ), ferric chloride ( $FeCl_3$ ) and ferric sulphate ( $Fe_2(SO_4)_3$ ) are used as reagents. According to [5] through precipitation, TSS can be removed in proportion of 80-90% and BOD up to 50-80%. The precipitation can be applied either directly to the source of the wastewater flow (for a more efficient removal of heavy metals), or for phosphates, sulfides and fluoride removal (as main treatment technique). For phosphorus removal through precipitation, salts of polyvalent metal ions as calcium (Ca) under hydrated lime ( $Ca(OH)_2$ ) form, aluminum (Al) or iron (Fe) are used. For heavy metals (arsenic, barium, cadmium, copper, mercury, nickel, selenium and zinc) and dissolved organic substances removal, reagents as hydroxide (OH) and sulfides ( $S^{2-}$ ) are used. An important aspect is that during the precipitation process the adjustment of pH and reagents dosage is necessary [6].

Through coagulation, the small particles composed from microbes, mud and other suspended materials from wastewater are removed, while flocculation involves the formation of links between particles through absorption of polymer molecules [7]. A number of chemicals, such as aluminum sulphate, are added into the treated water and rapidly mixed in large tanks. These reagents cause small particles to unite (to coagulate). These particle formations

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Chemical step input			Chemical step output		
Parameter	Weight	Accepted/ Not accepted (Y/N)	Parameter	Weight	Accepted/ Not accepted (Y/N)
pH	0.766	Y	pH_out	0.741	Y
TSS	0.870	Y	TSS_out	0.836	Y
Extr.	0.913	Y	Extr_out	0.906	Y
Phenols	0.738	Y	Phenols_out	0.817	Y
COD	0.671	Y	COD_out	0.679	Y
BOD	0.729	Y	BOD_out	0.787	Y
H <sub>2</sub> S	0.863	Y	H <sub>2</sub> S_out	0.538	N

**Table 1**  
THE SIGNIFICANT VARIABLES  
SELECTION

are grouping and are sinking to the bottom of the tank [8]. The coagulation and flocculation goal is to force the small pollutant particles to aggregate, to form sufficiently large agglomerations to be separated through sedimentation from wastewater. There are three main types of coagulants used in particles aggregation, namely: electrolytes, organic polymer and synthetic polyelectrolytes. These coagulants are added into the flocculation tanks to form the sediment (flocs) to be removed. Once the flocs are decanted, the water is prepared for the next stage of treatment.

Through oxidation and reduction, toxic organic compounds are converted in less harmful ones using various oxidants (chlorine, hydrogen peroxide) [7]. This procedure is applied to wastewater that contains pollutants that are difficult to remove or are very toxic, such as chromium, chlorine and hypochlorite, hydrogen peroxide and nitrite. The consumption of chemical reducing agent is directly proportional to the contaminant loading. An important aspect is checking the WWTP effluent to determine the excess of reducing agents, excess that also needs to be removed. According to [5], some of the most important applications of chemical reduction in wastewater treatment domain are: BOD and COD reduction, ammonia removal, non-biodegradable chemical oxidation of organic compounds, concentration of residual organic substances reduction, odors control in pumping stations and sewage networks, reduction in bacteria content of WWTP effluent, control of fungi and bacteria from sludge, corrosion control, fat removal and oxidation of iron sulphate. For the oxidation process, monitoring some parameters, such as the oxidation-redox potential, pH, ozone and oxygen concentration, the oxygen content and the halogenated organic compounds in the effluent, is absolutely necessary [6].

#### The identification of the treatment process significant parameters using a factorial analysis method

This section aim is to identify those parameters from a Romanian Refinery plant chemical and biological steps with the highest influence on the associated processes running. The initial SENFpHCTRL system developed in [1, 2] for wastewater pH control was extended for monitoring a set of other parameters. This means the extension of the SENFpHCTRL expert system (KB and IE) component with a set of heuristic knowledge for monitoring other parameters.

In order to determine this parameters, the PCA method was used, applied to the data from the analyzed plant chemical step input and output (the biological step input), using the IBM SPSS Statistics software. In this respect, a data base with two hundred eighty-eight records (industrial data from a Romanian Refinery plant) was built, in which the variables that were submitted to PCA analysis were:

- At the plant chemical step input: pH, sulphides and hydrogen sulphide (H<sub>2</sub>S), TSS, extractable (Extr.), phenols (C<sub>6</sub>H<sub>5</sub>OH), COD, BOD and Cl;

- At the plant chemical step output (biological step input): pH (pH\_out), H<sub>2</sub>S (H<sub>2</sub>S\_out), TSS (TSS\_out), extractable (Extr\_out), phenols (Phenols\_out), ammonia nitrogen (NH<sub>3</sub>), nitrates (NO<sub>3</sub><sup>-</sup>), nitrites (NO<sub>2</sub><sup>-</sup>), phosphates (Phosph.), COD (COD\_out), BOD (BOD\_out).

In table 1, it is presented the selection of the significant variables, using weight as selection criterion (weight >0.6).

Studying table 1, from all the parameters analyzed using PCA, the ones that will be used in developing the new rules which complements the initial expert system (KB, IE) associated to the extended SENFpHCTRL system, are: TSS, extractable, BOD, phenols, COD and chlorides. It must be mention, that pH parameter wasn't taken into consideration, due to the fact that for this parameter we have already build a set of rules in the system initial form.

In this section were identified those parameters (TSS, extractable, BOD, phenols, COD and chlorides) for which the initial ES will be extended with a new set of rules and for which the extended SENFpHCTRL system will supply the monitoring.

It must be also mentioned that the extended system will maintain the SENFpHCTRL name and that all the PCA results have been reported at the studied plant chemical and biological plant steps particularities.

#### The Neuro-Fuzzy Expert System Extension

The Neuro-Fuzzy Expert system (SENFpHCTRL) it is a hybride one, based on two artificial intelligence (AI) techniques, the so-called adaptive neuro-fuzzy inference systems combined with expert systems. In its initial form, the system achieves the automatic control of wastewater pH [1, 2].

#### The Expert System Extension

While the initial hardware-software prototype system SENFpHCTRL ensures the wastewater pH automatic control, the extended version of the system achieves also the monitoring of the determined parameters (TSS, extractable, BOD, phenols, COD and chlorides).

In figure 1, it is proposed the architecture of a neuro-fuzzy expert system for process monitoring and for signaling the critical states for each of the parameters presented in table 2.

The SENFpHCTRL system extension assumes the completion of initial ES [1, 2], respectively the knowledge base (KB) and inference engine (IE) completion with a set of heuristic knowledge (deductive rules and decisions) for other parameters monitoring. The heuristic knowledge was

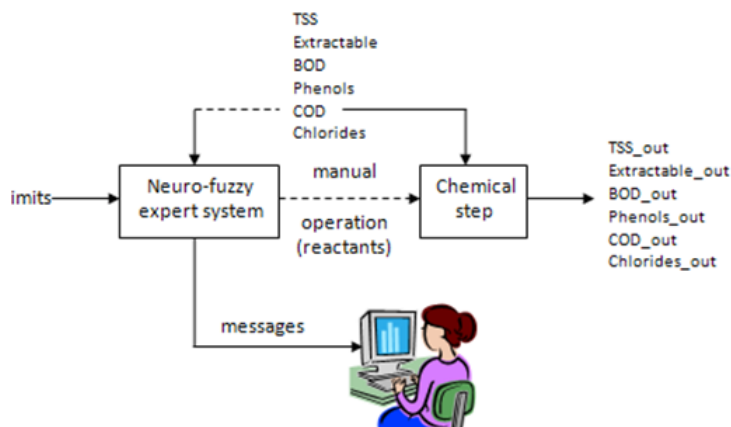


Fig.1. The proposed neuro-fuzzy expert system architecture

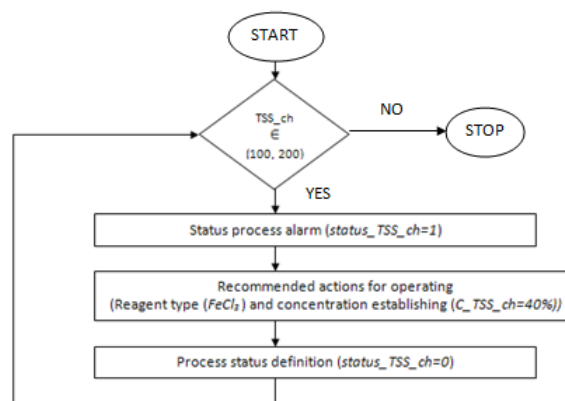


Fig 2. KB rules - selection

Parameter	Chemical step input Maximum limit [mg/liter]	Chemical step output (biological step input) Maximum limit [mg/liter]	Limits [mg/liter]	Alert [mg/ liter]
TSS	200	100	60	42
Extractable	200	35	20	14
BOD	1200	500	25	17.5
Phenols	50	50	0.2	0.14
COD	2000	800	125	87.5
Chlorides	500	500	500	350

**Table 2**  
PARAMETERS LIMITS USED IN  
THE ANALYZED PLANT [14]

deducted by the first author based on the researches made on the studied industrial plant and on the plant data base and imposed limits (table 2) [14].

The initial KB [1, 2] of the ES was completed with a set of deductive rules for other parameters, rules according to which:

1-The nature and the concentration of the chemical reagent that must be used for parameters monitoring (TSS, extractable, BOD, phenols, COD and chlorides) are established;

2-It is checked if the parameter has reached the imposed limits, in which case a warning is generated to turn off the chemical reactant dosage. Otherwise, the warning regarding the necessity of further reactant dosage is maintained;

3-Warnings are provided regarding the processes status from the plant chemical (*status\_ch*) and biological step (*status\_bio*) with the following meaning: 0 - process without problems (the imposed limits was reached)/chemical agent dosing process turn off, 1 - exceeding of the maximum allowable limits (alert) and -1 -emissary pollution warning.

As above mentioned, the initial KB [1, 2] of the ES was completed with a set of new rules (thirty-six rules for determined parameters) that establish the type and

concentration (C) of the chemical reagent (iron chloride- $\text{FeCl}_3$ , hydrated lime- $\text{Ca}(\text{OH})_2$ , ozone- $\text{O}_3$ , sodium phosphate- $\text{Na}_3\text{PO}_4$ ) that will be used in adjusting the parameters and the status of the processes from the chemical or biological step (0 - process without problems (was reached the imposed limits), 1- alert and -1 - emissary pollution warning).

A selection of the rules (forty-two rules developed for both plant steps- chemical and biological- for each of the determined parameters) added to the initial SENFpHCTRL expert system KB, is presented in figure 2 under logical scheme form (as for example for *TSS\_ch* parameter). In the same way, were developed the rules for the remaining parameters.

The ES initial IE [1, 2] was completed with rules for visual warning (on the screen), with the following meanings:

1. Green color - the parameter value is less than or equal to the imposed limits (monitoring process done);
2. Red color - equivalence point warning (the system is in the pH equivalence point domain), respectively the exceeding of the maximum allowable limits imposed for the determined parameters;
3. Yellow color - high values of the parameters (alert).

```

1.  if (status_ch == 0) then begin
    wattron (win_input_fc, COLOR_PAIR(2));
    mvwprintw(win_input_fc, 4, (col-strlen((char *) msg_alert_emisary_pollution))/3,
    "%s", (char *) msg_status_bar);
    wattroff(win_input_fc, COLOR_PAIR(2)); end
2.  if (status_bio == 1) then begin
    wattron(win_output_fc, COLOR_PAIR(7));
    mvwprintw(win_output_fc, 4, (col-strlen((char*) msg_alert_emisary_pollution))/3,
    "%s", (char *) msg_status_bar);
    wattroff(win_output_fc, COLOR_PAIR(7)); end
3.  if (TSS_ch_reagent!=0) then begin
    mvwprintw(win_input_fc, 8, col/50+strlen((char*)msg_tss)+18, "reagent:FeCl3
    c=40%%0");
    else mvwprintw (win_input_fc, 8, col/50+ strlen(( char*)msg_tss)+18, "\0); end
4.  if (COD_bio_reagent!=0) then begin
    mvwprintw(win_output_fc, 16, col/50+strlen(( char*)msg_cod)+18, "reagent:Ca(OH)2
    c=10%%0");
    else mvwprintw( win_output_fc, 8, col/50+strlen(( char*)msg_cod)+18, "\0); end

```

Fig. 3. IE rules - selection



A selection of the rules (eighteen rules used for generating visual warnings on the screen) that were added to the initial IE is presented in figure 3.

It must be mentioned that these rules for monitoring the parameters are not meant to be general rules, due to the fact that they were developed for the particular case of the analyzed industrial plant.

### The User Interface

The extended SENFpHCTRL neuro-fuzzy expert system was developed by the authors using the GNU C [15] programming environment, version 4.2.1, under UNIX OpenBSD version 5.2 operating system.

Although it benefits of the POSIX standard, the system program was developed in text mode considering the portability on other microcontrollers, including those without hardware graphic capabilities. The system can be remotely operated using low speed data connexions (serial lines and radio connexions).

The system text interface was developed using the *ncurses* ([16]) and *panel* libraries available in GCC. In Fig. 4 it is presented the extended SENFpHCTRL system user interface.

The graphical interface of the UNIX BSD operating system has more workspaces (in this case, were configured four workspaces). For instance, workspace 1 for SENFpHCTRL extended system was configured as follows:

1. Workspace 1 – contains the extended SENFpHCTRL system interface (fig. 4) composed of four windows: the monitoring of the numerical parameters from the wastewater pH neutralization process (window 1), the monitoring of the hardware system parameters (window

2), the monitoring of the determined parameters (TSS, extractable, BOD, phenols, COD and chlorides) at the chemical step input (windows 3) and the pH and the parameters monitoring at the chemical step output, respectively at the biological step input (window 4). The first window (fig. 4-window 1) provides information regarding:

- The pH value (*pH<sub>in</sub>*) read (measured) directly from the pH transducer using the monitoring interface;
- The mediated value of the pH (*pH<sub>med</sub>*) readings;
- The *error* value defined as the difference between the pH set point (SP) and the mediated pH value (*pH<sub>med</sub>*);
- The consumptions of F<sub>1</sub> (the acid stream flowrate) and F<sub>2</sub> (the alkaline stream flowrate) reagent estimated by the expert system;
- The estimated time until the pH value reaches its SP, according to the expert system rules;
- The state (on/off) of the acid or alkaline reagent dosage pumps, according to the expert system decision;
- The ANFIS ([1,2]) alkaline reagent (F<sub>2</sub>) flowrate command;
- The ES intervention on the ANFIS generated command, through the IE supplied command;
- The final command ([1,2]) applied on the F<sub>2</sub> dosage pump;
- The signaling of pH equivalence point proximity – *Status<sub>PE</sub>* (pH domain: 5...9 units): green color (outside the pH domain), red color (in the pH equivalence point domain);
- The process startup and current time, on which can be determined the process transient times (T<sub>p</sub>).

The interface presented in figure 4 Window 1 it is completed by the pH dynamics, presented in figure 5.

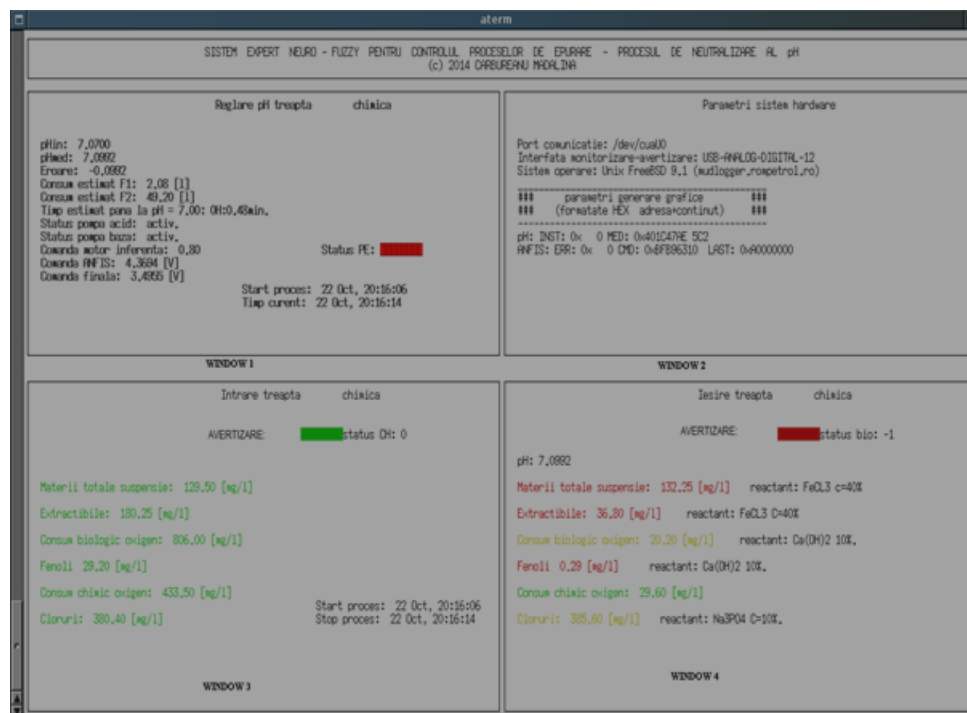


Fig. 4. The extended SENFpHCTRL system user interface

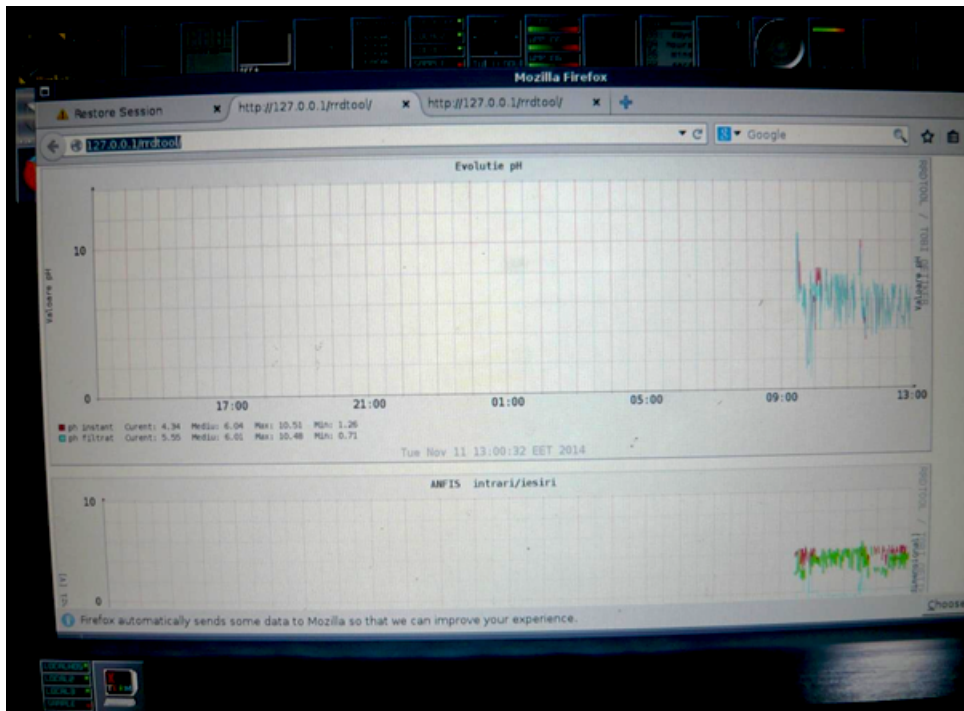


Fig. 5. pH dynamics

Window 2 (fig. 4-window 2) supplies information regarding:

- The serial communication port;
- The type of the monitoring-warning interface;
- The type of the operating system that is used;
- The parameters (in hexadecimal) that are used for generating the charts.

In window 3 (fig. 4-window 3) there are supplied the following information:

- In the case when any of the determined parameters is located within the limits (table 2) set by the ES, it is displayed in green color. If any of the parameters exceeds the imposed limits, that parameter will be displayed in red color, together with the adequate chemical reagent for its correction (according to the ES rules). The alert is activated (red color), when at least one of the monitored parameters do not fit into the limits presented in table 2;
- The process startup and stop time, used in the transient time calculation;
- The process state in chemical step (*status\_CH*): 0 (process without problems, the parameters have reached the imposed limits - green color), -1 (warning regarding the surpassing of the maximum alert limit-red color).

In windows 4 (fig. 4-window 4) there is supplied information regarding:

- The value of the controlled pH;
- In the case when any of the parameters is within the limits established by the ES, its display is done in green color. If any of the parameters exceeds the imposed limits and the alert limit, this parameter will be displayed in yellow color (alert), together with the adequate chemical reagent for its control (according to the ES). The pollution warning is activated (red color) when at least one of the monitored parameters exceeds the limits described in table 3;

- The process status at the chemical step output, respectively at the biological step input (*status\_bio*): 0 (process without problems, the parameters has reached the imposed limits - green color), 1 (alert - yellow color), -1 (pollution warning - red color).

The interfaces presented in figure 4 - Window 3 and Window 4, are completed by the TSS, extractable, BOD, phenols, COD and chlorides dynamics, presented in figure 6.

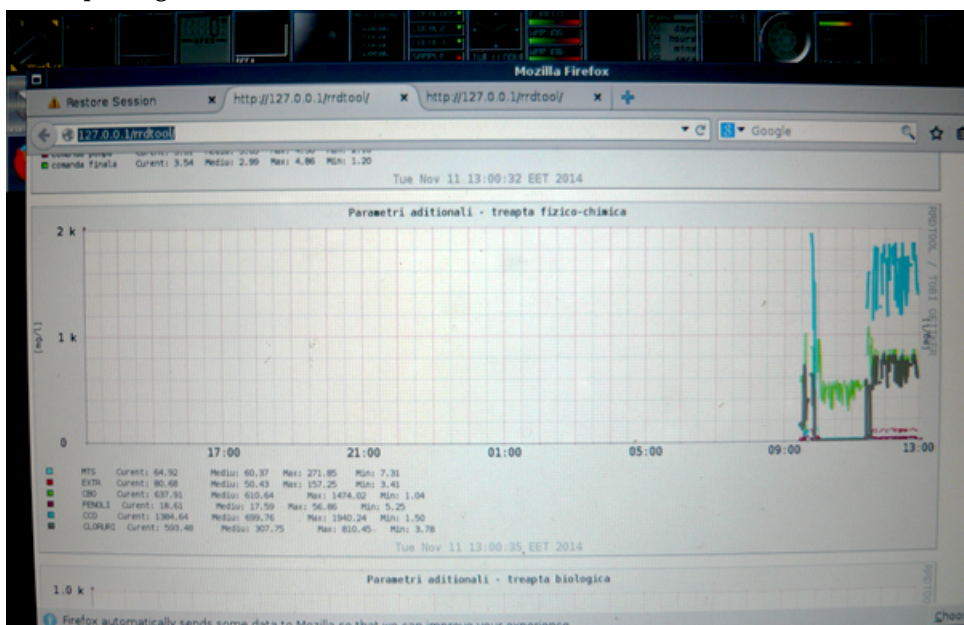


Fig. 6. TSS, extractable, BOD, phenols, COD and chlorides dynamics

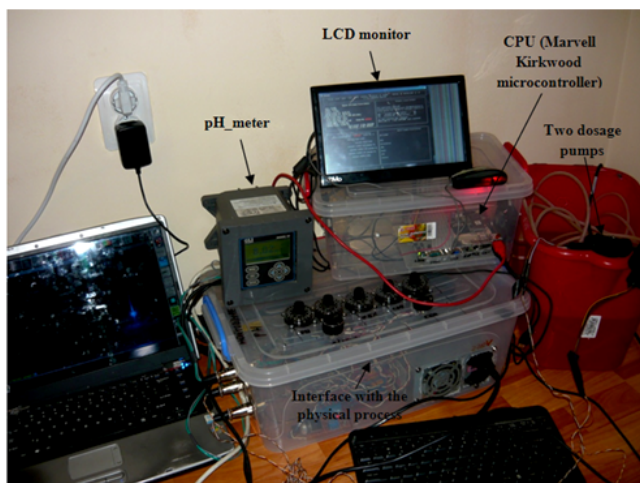


Fig.7. Extended SENFpHCTRL system - at microcontroller level

So, the extended SENFpHCTRL system allows two operating modes for wastewater pH control, respectively in automatic and in manual regime (at the experimental and simulation level), and also achieves the monitoring of the determined parameters. The extended system behaviour is as follows: when the process of wastewater pH automatic control has ended (adjusted pH,  $status_{PE}=0$ ) and the monitoring of the parameters at the chemical step input ( $status_{CH}=0$ ) was achieved, the system passes automatically to the chemical step output window (fig.4 - window 4). The system commands the end of the parameters monitoring process ( $status_{bio}=0$ ).

#### The Extended SENFpHCTRL System-Simulations

The results of the experiments made with the extended prototype system SENFpHCTRL implemented at microcontroller level (fig. 7) for acid and alkaline pH control, as recorded within the Mud Logging laboratory of a Romanian oil Drilling Company are presented in ([1, 2]).

For monitoring the determined parameters (TSS, extractable, BOD, COD, phenols and chlorides) with the extended system implemented at microcontroller level a set of simulations was achieved, a selection of which is presented in table 3.

Due to the lack of specialized transducers for each of the determined parameters, experimental results are not available, so that, for each of these parameters (from

physical-chemical step input and from physical-chemical step output-the biological step input) the extended SENFpHCTRL system through its extended expert system (KB and IE extension) achieves the following functions:

1-It verifies if any of the determined parameters from the physical-chemical step input and output is located (visual warning-green color) within the limits set by the developed ES;

2-It verifies if any of the parameters from physical-chemical step input (Phy-chem. I) exceeds the imposed limits (alert-red color) and if any of the parameters from physical-chemical step output (biological step input - Phy-chem. O) exceeds the imposed limits and the alert limit (alert-yellow color). It must be mentioned that in the case of the parameters from the biological step input, the red color is used to signal pollution warning;

3-It establishes the nature and the concentration of the chemical reagent that must be used for a parameter monitoring;

4- It verifies if, after the applied monitoring, the parameter has reached the imposed limits. If it was reached the imposed limits, the system warns that it is necessary to turn off the reagent dosage process, otherwise it maintains the warning regarding the need of reagent dosing;

5-It supplies warnings (including visual warning - on screen) regarding the state of the processes in the chemical step ( $status_{CH}$ ) and at the biological step input ( $status_{bio}$ ).

A selection of the simulations (for parameters monitoring) with the extended SENFpHCTRL system at microcontroller level, is presented in table 3 and table 4.

As it can be observed in table 3, the first case that was considered was when all the determined parameters values from physico-chemical step input are exceeding the imposed maximum limits (table 2). In this case, at this step the alert signal (-1) is activated, respectively the processes status from this step is set to  $status_{ch}=-1$  (alert). As a result, the extended system establishes for each of the parameters the chemical reagent that can be used and their concentration. After the dosage of the necessary chemical reagent with a certain concentration, each of the adjusted parameters are situated in the admissible limits (green color), therefore the reagent dosage process was turn off and the  $status_{ch}=0$ . At the

Physical-chemical step input								
Param.	State I				State II			
	Value	Optical warning	Reagent (Yes/No)	Status_ch	Value	Optical warning	Reagent (Yes/No)	Status_ch
TSS	311.50	red	Yes FeCl <sub>3</sub> .40%	-1	196	green	No	0
Extr.	376.25	red	Yes FeCl <sub>3</sub> .40%		199.25	green	No	
BOD	1814	red	Yes Ca(OH) <sub>2</sub> -10% IE (c)		1170	green	No	
C <sub>6</sub> H <sub>5</sub> OH	68.90	red	Yes Ca(OH) <sub>2</sub> -10%		46.70	green	No	
COD	2251.50	red	Yes Ca(OH) <sub>2</sub> -10% IE (c)		1729.50	green	No	
Cl	512.30	red	Yes Na <sub>3</sub> PO <sub>4</sub> -10%		380.40	green	No	

**Table 3**  
EXTENDED SENFpHCTRL SYSTEM AT MICROCONTROLLER LEVEL-SIMULATIONS RESULTS (SELECTION 1)



Physical-chemical step output								
Param.	State I				State II			
	Value	Optical warning	Reagent (Yes/No)	Status <sub>bio.</sub>	Value	Optical warning	Reagent (Yes/No)	Status <sub>bio.</sub>
TSS	40	green	No	0	197	red	Yes FeCl <sub>3</sub> -40%	-1
Extr.	13.65	green	No		41.10	red	Yes FeCl <sub>3</sub> -40%	
BOD	17.47	green	No		9.65	red	Yes Ca(OH) <sub>2</sub> -10%	
C <sub>6</sub> H <sub>5</sub> OH	0.11	green	No		0.48	red	Yes Ca(OH) <sub>2</sub> -10%	
COD	37.70	green	No		116	yellow	Yes Ca(OH) <sub>2</sub> -10%	
Cl	342.50	green	No		385.60	yellow	Yes Na <sub>3</sub> PO <sub>4</sub> -10%	

**Table 4**  
EXTENDED  
SENFpHCTRL  
SYSTEM AT  
MICROCONTROLLER  
LEVEL-  
SIMULATIONS  
RESULTS  
(SELECTION 2)

physical-chemical step output, respectively at the biological step input, all the parameters are in the ES established limits (green color), so the processes are smoothly operating (*status\_ch*=0). As it can be observed, the monitoring for BOD and COD parameters from physical-chemical step input was used the IE command (*c*) for pH control. Therefore, the IE command generated by the developed R-ANFIS.fis ([1]) must be adjusted, respectively increased.

The second case (presented in table 4) was considered when all the parameters from physical-chemical step input are between the imposed limits, respectively all the processes are working properly (*status\_bio*=0). Because of different disturbances (such as the chemical reagent changes in concentration and flowrate) and plant faults, the parameters values at the biological step input are not within imposed limits, therefore the alert signal (for COD and Cl) and the pollution warning for the rest of the parameters has been activated. The system establishes the processes status (*status\_bio*= -1), the type and the concentration of the chemical reagents necessary to adjust these parameters. After the reagents dosage the parameters reached the imposed limits (green color), therefore *status\_bio*=0.

The extended system has the following behavior: when the automated process for wastewater pH control [1, 2] was finished (*status\_PE*=0) and the monitoring of the parameters at the physical-chemical step input (*status\_CH*=0) was achieved, the system passes automatically in physical-chemical step output (biological step input) window (fig. 4 - window 4). The systems command the ending of the determined parameters monitoring process when *status\_bio*=0.

## Conclusions

The wastewater treatment processes (neutralization, precipitation, coagulation and flocculation, oxidation and reduction) are very complex due to their non-linearity (high non-linearity in the case of the wastewater pH neutralization process). The control of these processes can be made by means of conventional control or by using AI techniques [1, 2].

In this paper the author's main contributions are:

- the identification of the treatment process significant parameters using a factorial analysis method (the so called principal component analysis-PCA) applied on data from a studied industrial plant. For the determined parameters the

initial SENFpHCTRL system was extended to allow their monitoring;

- the initial system SENFpHCTRL developed by the first author only for wastewater pH control [1, 2] was completed with a set of subroutines (rules, functions, C language code) to work with other parameters (TSS, extractable, BOD, COD, phenols, chlorides) from the analyzed WWTP chemical processes (precipitation, coagulation, flocculation, oxidation and reduction);

- the initial expert system (the KB and IE) [1, 2] associated to SENFpHCTRL system, developed by the first author initially for wastewater pH control (in automatic and also in manual regime), was completed with a set of heuristics knowledge (deducted by studying the data from the analyzed WWTP chemical step input and output) for the determined parameters. Through these rules it is established if the determined parameters are within imposed limits or not, different visual warnings (green, yellow, read) are provided depending on the existing situation. The type and the concentration of the reagent required in monitoring a certain parameter is established and the status of the plant processes at the chemical step input and output (the biological step input) is also supplied;

- the initially developed SENFpHCTRL system was completed with a graphical interface specific to microcontrollers with text terminals;

- the hardware implementation of the extended SENFpHCTRL system was made at PC and also at microcontroller (Marvell 88F6281) level;

- the achievement of a set of simulations (a selection being presented in table 3 and table 4) with the extended system for other parameters monitoring.

In our future work, the extended SENFpHCTRL system will be adapted to operate with flowrates from other industrial WWTPs. The use of real transducers for the determined parameters, the implementation of the automated command for the corresponding chemical reagents and also the final system implementation into a compact physical device are required.

The extended SENFpHCTRL system (that uses a hybrid controller developed by the first author-adaptive neuro-fuzzy inference systems (ANFIS)+ES) at PC and microcontroller levels supported by the UNIX operating system, fits into the technology current trends, considering the control technique and the equipment miniaturization. It can be said that, in contrast to the systems that are using conventional control methods, the systems that are using

AI techniques (or combinations of them) are proved to be a more appropriate and effective approach in wastewater treatment processes control with essential nonlinearities.

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