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Artificial neural networks in diagnostic system for purifying fumes installation

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The purpose of the paper is to present solution to design additional diagnostic system for, based on cutting-edge technology, purifying fumes installation. Neural networks, which determine the core of the system, were used as predictive models. Designed very efficient neural structures have served to build simulative diagnostic advisory system.

Keywords: artificial intelligence, neural networks, advisory systems, diagnostics

1. Introduction

In many scientific areas models of processes are exploited. One of the realms of science taking the advantage of models is diagnostics. Using models in diagnostic is widely presented for instance in [9] and [7]. It is well known that the most effective are analytical models. However, high precision of the model equations and accurate values of coefficients in those equations are highly demanded in case of obtaining effective model. Furthermore, there are many objects for which obtaining that kind of the model is extremely difficult. Very often problems are issued from lack of possibility in identifying the values of equations coefficients. In those situations applying artificial intelligence methods to obtain model of process seems to be one of the most efficacious solution. Especially in case of having practical experience, heuristic knowledge and archival values of demanded signals.

Problem with obtaining analytical models particularly appears in case of processes based on very new technologies. Lack of experience and knowledge about real course of process and all signals interactions leads to receive not accurate models and in consequence to not correctly working systems using them.

Purifying fumes installation based on electric beam technology is contained in the group of new techniques. Control and diagnostic system designed for that installation is mainly based on theoretical knowledge about course of chemical and physical process. What is more precise analytical equations describing all reactions phenomena and chemical ingredients interactions are not known. First work trials of the purifying fumes industrial process disclosed a possibility and necessity of designing supporting diagnostic system. Considering lack of analytical knowledge about process, it was decided that indispensable, from diagnostic point of view, models would be prepared basing on neural networks. Neural networks are generally described e.g. in [5] and [6], in case of diagnostic porpoise in [3] and [4].

As a one of the most universal type of neural network feed-forward were chosen to execute diagnostic system. The conventional back propagation algorithm was used in order to obtain efficiently working nets. Huge amount of design neural networks tasks and simulative comparisons were done, in order to emerge the most efficient neural structures. Finally those structures have served as a main component of foreseeing diagnostic system of most important process parameters.

At the very beginning of the paper diagnostic object and diagnostic problems are depicted. Following measured signals important from diagnostic point of view are enumerated. Then designing neural network issue is described. Parameters of neural networks structures are showed. Moreover comparison between real vales and the networks responds are showed. Final conclusions are mentioned at last.

2. Brief description of the diagnostic process

There are only a few installations using electric beam method for purifying fumes in the world. One of them which were designed as an industrial demonstration is situated in Szczecin [2]. Whole process assembles of four main sections. Artificial fertilizer is a by-product of purifying fumes installation.

Although the most important criterion of leading process is to obtain, as far as possible, clean fumes, not less important issue is to produce trade useful product. These both criteria are very often manually exclusive. The specific temperature and humidity of fumes, which allow compromising the opposing expectation and also content of ammonia, during main part of process, are ones of the most important fumes parameters. It is necessary to obey technological principles in order to compromise the opposing expectations. For that reason, firstly, fumes inserted into installation are tentatively prepared. In the first section the temperature and humidity of fumes are changing. Lower temperature is achieved by adding the water into the fumes. Steam is put into chimney gas to get higher humidity. Moreover, other ingredients are also added at this level. The first section is presented in Fig. 1.

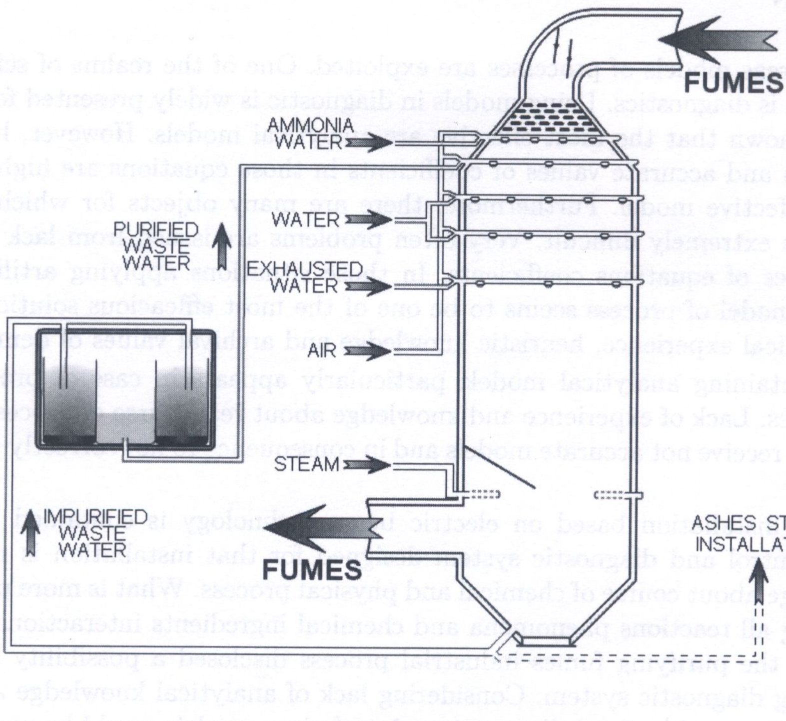

Fig. 1. Diagram of the first section

Next fumes are enriched by ammonia, which is shown in Fig. 2. Ammonia water is delivered in the wagon and then pumped into store tanks, afterwards is taken to the distillation system and also back to first section. The main part of this section presents a distillation appliance. Storing ammonia water, in two tanks system, apart from preparing ammonia from ammonia water and dosing ammonia is the activity of this section.

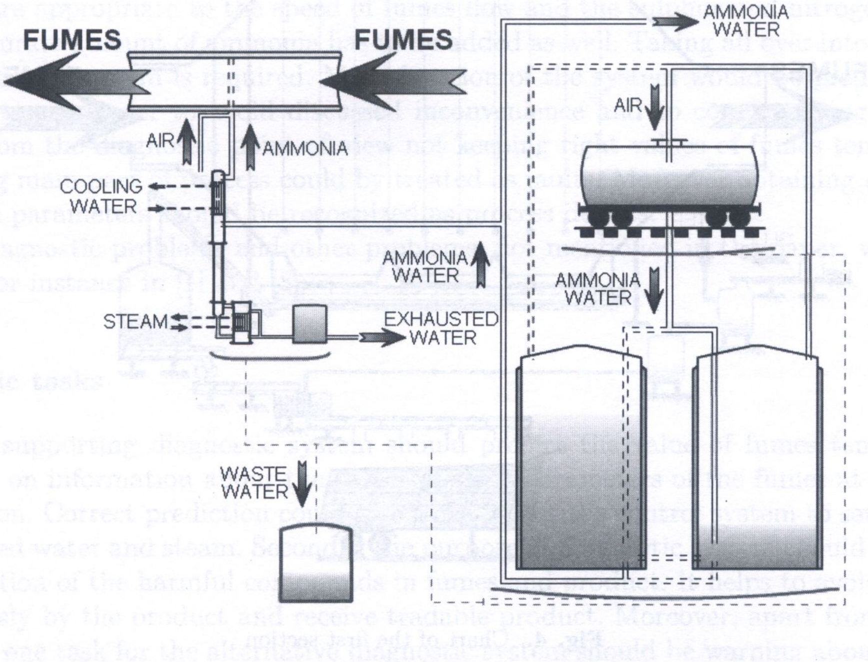

Fig. 2. The second section chart

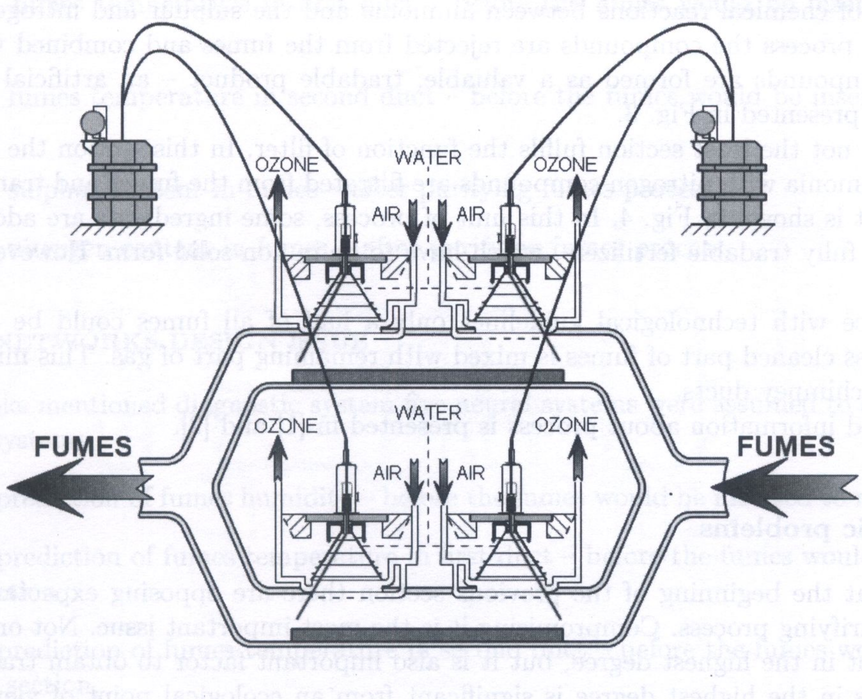

Fig. 3. The third section diagram

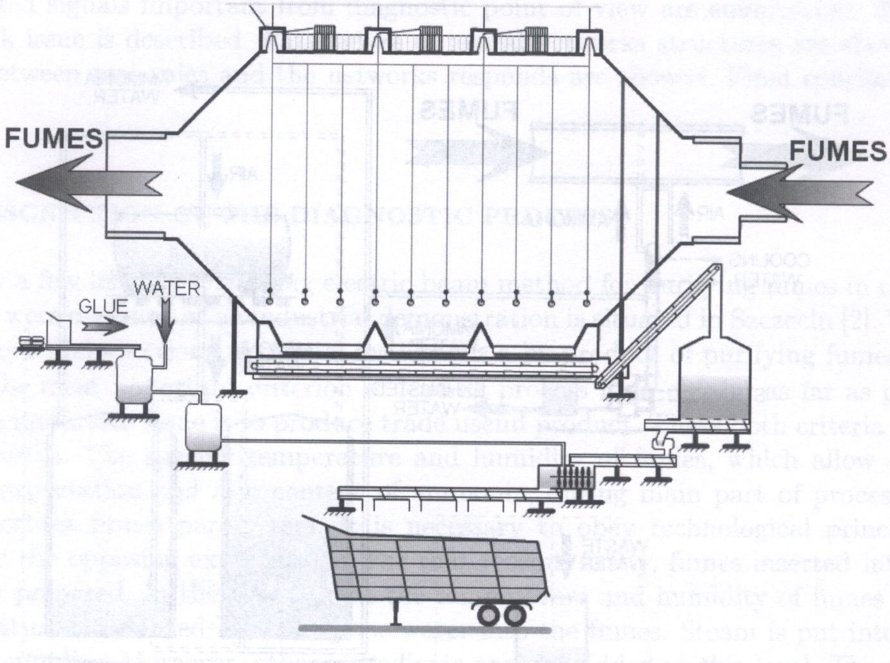

Fig. 4. Chart of the first section

The main section of the purifying process consists of two ducts with four accelerators, two accelerators located on each of two ducts. A high degree of vacuum is required inside the accelerators. From the accelerator, the electric beam goes into the pipes in which fumes flow. Two quite tight titan foils constitute the boundary zones between accelerator and pipe. Prepared in advance fumes are directed to this section, where an influence on the compounds is exerted by electric beams. This allows starting of chemical reactions between ammonia and the sulphur and nitrogen compounds. In effect of this process the compounds are rejected from the fumes and combined with ammonia. Newly arise compounds are formed as a valuable, tradable product – an artificial fertilizer. The third section is presented in Fig. 3.

The last but not the least section fulfils the function of filter. In this section the ammonia with sulphur and ammonia with nitrogen compounds are filtrated from the fumes and transported to the stockroom, as it is shown in Fig. 4. In this unit of process, some ingredients are added, as well, in order to obtain fully tradable fertilizers, which have to be in non-solid form. However, it also must not be powder.

In accordance with technological guidelines only a half of all fumes could be purified. After purifying process cleaned part of fumes is mixed with remaining part of gas. This mixture is pulled into one of the chimney ducts.

More detailed information about process is presented in [1] and [2].

2.1. Diagnostic problems

As mentioned at the beginning of the previous section there are opposing expectation connected with leading purifying process. Compromising it is the most important issue. Not only is purifying fumes significant in the highest degree, but it is also important factor to obtain tradable product. Purifying fumes in the highest degree is significant from an ecological point of view. Opposed to this is often the economic attitude. According to this point of view, the most important factor is to obtain tradable products. This means that the ratio of sulphur and nitrogen content has to be constant in appointed limits. The limits are even more important from a safety point of view. In the event of not respecting this rule the product may catch fire spontaneously. All requirements with regards to the product composition and quality of purifying fumes have to be reconciled. Compromise may be achieved only when the temperature and humidity of fumes in the main part of the process are appropriate to the speed of fumes flow and the sulphur and nitrogen compounds content. An accurate amount of ammonia has to be added as well. Taking all over into consideration additional diagnostic system is required. Main function of the system would be predicting pointed process parameters in order to avoid discussed inconvenience and to compromising the opposing expectation. From the diagnostic point of view not keeping right values of fumes temperature and humidity during main part of process could by treated as faults. Moreover obtaining different, from assumed, fumes parameters should be recognized as process defects.

Described diagnostic problems and other problems, not mentioned in the paper, were presented more detailed for instance in [1] and [8].

2.2. Diagnostic tasks

An alternative supporting diagnostic system should predict the value of fumes temperature and humidity based on information about the values of some parameters of the fumes at the beginning of the installation. Correct prediction could give a chance for the control system to set the adequate quantity of added water and steam. Secondly, the purpose of diagnostic system should be the prediction of composition of the harmful compounds in fumes and product. It helps to avoid catching the fire spontaneously by the product and receive tradable product. Moreover, apart from the parameters prediction, one task for the alternative diagnostic system should be warning about forthcoming malfunction in the accelerators systems and cooperation with the control system to avoid it.

Tasks for the diagnostic system are alarming operators about enumerated forthcoming faults of process parameters:

- not correct fumes humidity – before the fumes would be inserted to reaction section,
- not correct fumes temperature in first duct – before the fumes would be inserted to reaction section,
- not correct fumes temperature in second duct – before the fumes would be inserted to reaction section,
- not correct sulphur content in fumes – after purifying fumes process,
- not correct nitrogen content in fumes – after purifying fumes process.

3. Neural networks design issue

In order to make mentioned diagnostic system five neural systems were assumed to design. Purpose of the neural systems:

- diagnostic prediction of fumes humidity – before the fumes would be inserted to reaction section,
- diagnostic prediction of fumes temperature in first duct – before the fumes would be inserted to reaction section,
- diagnostic prediction of fumes temperature in second duct – before the fumes would be inserted to reaction section,
- diagnostic prediction of sulphur content in fumes – after purifying fumes process,
- diagnostic prediction of nitrogen content in fumes – after purifying fumes process.

Table 1. Breakdown of the signals used do design neural networks systems

Input signals	Porpoise of network – realization of task number: humidity	1st duct temperature	2nd duct temperature	sulphur content	nitrogen content
fumes flow intensity	YES				
humidity of input fumes	YES	YES	YES		
temperature of input fumes	YES	YES	YES		
temperature of water	YES	YES	YES		
intensity of water flow	YES	YES	YES		
temperature of ammonia water	YES	YES	YES		
flow intensity of ammonia water	YES	YES	YES	YES	YES
temperature of added ammonia		YES	YES		
flow intensity of ammonia		YES	YES		
fumes flow intensity in 1st duct		YES		YES	YES
fumes flow intensity in 2nd duct			YES	YES	YES
fumes temperature in 1st duct				YES	YES
fumes temperature in 2nd duct				YES	YES
output fumes humidity				YES	YES
quantity of added ammonia				YES	YES
accelerator A voltage				YES	YES
currents beam – head A1				YES	YES
currents beam – head A2				YES	YES
accelerator B voltage				YES	YES
currents beam – head B1				YES	YES
currents beam – head B2				YES	YES
output sulphur content				YES	YES
output nitrogen content				YES	YES

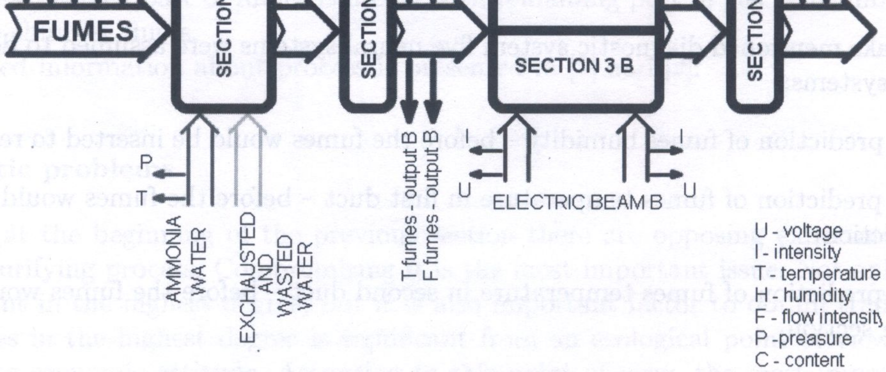

Fig. 5. Signals chart

The first designing problem was to choose all important parameters which have influence on the processes. Breakdown of the most important signals were done basis of operators of process. Table 1 presents breakdown of the signals used do design neural networks systems. Figure 5 shows location of the signals.

After calculating the signals main problems focus on finding parameters of used artificial neural networks which allow obtaining structures working with the best efficiency. Enumerated parameters were taking into consideration in order to determine the structures:

- form of input and output dates,
- type of transfer function in each layer,
- number of layers and neurons in each of layers,
- length of learning process,
- form of learning algorithm,
- form of training function,
- form of initializing function,
- type of neural network.

Table 2. Topology properties and parameters of designed neural networks

properties	Diagnostic prediction of				
	humidity	1st duct temperature	2nd duct temperature	sulphur content	nitrogen content
training / adaptation	training	training	training	training	training
scaling	yes	yes	yes	yes	yes
number of hidden layers	2	2	2	2	2
number of input neurons	7	9	9	15	15
number of neurons in 1st hidden layer	9	8	7	10	10
number of neurons in 2nd hidden layer	8	3	6	4	4
number of input neurons	1	1	1	1	1
transfer function in 1st hidden layer	*tansig*	*tansig*	*logsig*	*purelin*	*tansig*
transfer function in 2nd hidden layer	*tansig*	*tansig*	*tansig*	*purelin*	*purelin*
transfer function in output layer	*purelin*	*tansig*	*purelin*	*purelin*	*tansig*
quantity of epochs	150	150	350	150	200
learning function	*learnk*	*learnos*	*learnh*	*learnpn*	*learngdm*
training function	*trainlm*	*trainbr*	*trainbr*	*trainlm*	*trainlm*
initiating function	*initnw*	*initwb*	*initnw*	*initnw*	*initwb*
type of network	cascade-forward	feed-forward	cascade-forward	feed-forward	cascade-forward
value of correlation coefficient	0.97	0.91	0.95	0.92	0.92

Many simulations were done in order to calculate the parameters of neural systems. All simulations were done using the Neural Network Toolbox in Matlab® environment. Archival data was used in the training and validation process. The data used in the training process was different from that used in the validation process. Dates covered 14 days. Sample time was equal 10 seconds. Summing up, for each of used signals, almost 121 thousands of samples were taken into account. Length of learning between 100 and 400 epochs were checked. All form of learning algorithms, training functions, and initializing functions accessible in Matlab were taken under consideration. Finally type of neural networks was appointed. Feed-forward back propagation, cascade-forward back propagation, feed-forward back propagation with time delay and Elman type neural networks were taken into account. Topology properties and parameters of designed neural networks were presented in Table 2. Moreover values of correlation coefficients, ratio of system quality, are presented in the table. The values of correlation coefficient determined measure of networks efficiency.

In Figs. 6 to 10 responds of described neural systems are drown. Responds of real objects are showed at the graph as well. Presented graphs proof quite high degree of fitting network respond and real value recorded on the process. All networks give respond correctly following relatively significant fluctuation. For all networks respond some irregularities are observed.

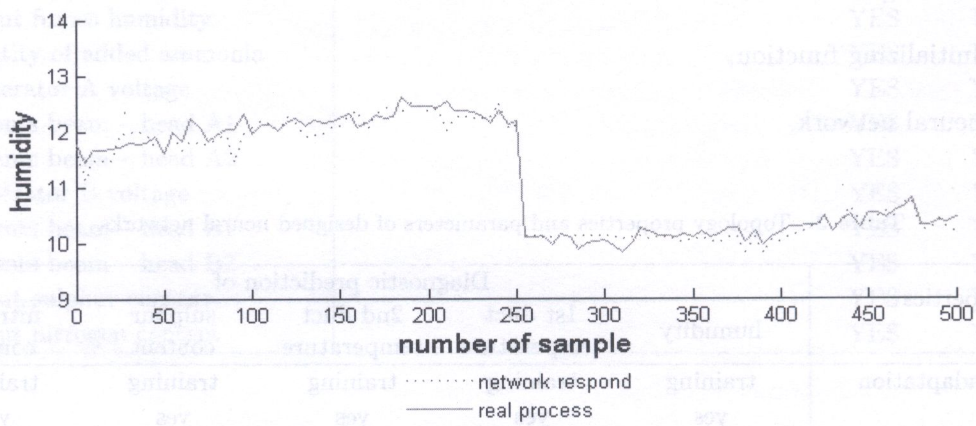

Fig. 6. Network and real process respond – humidity prediction; back propagation tuning

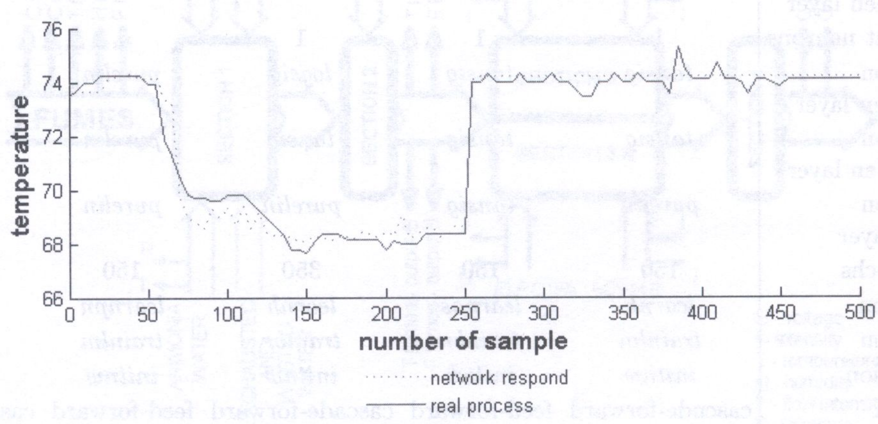

Fig. 7. Network and real process respond – temperature in the 1st duct prediction; back propagation tuning

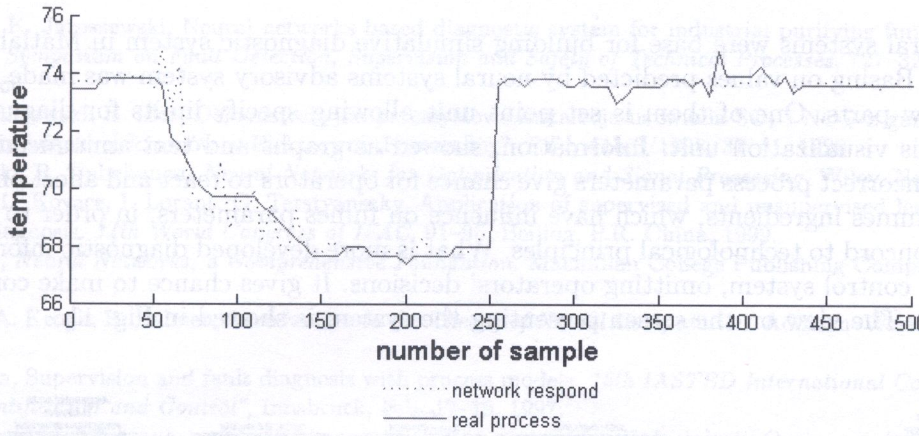

Fig. 8. Network and real process respond – temperature in the 2nd duct prediction; back propagation tuning

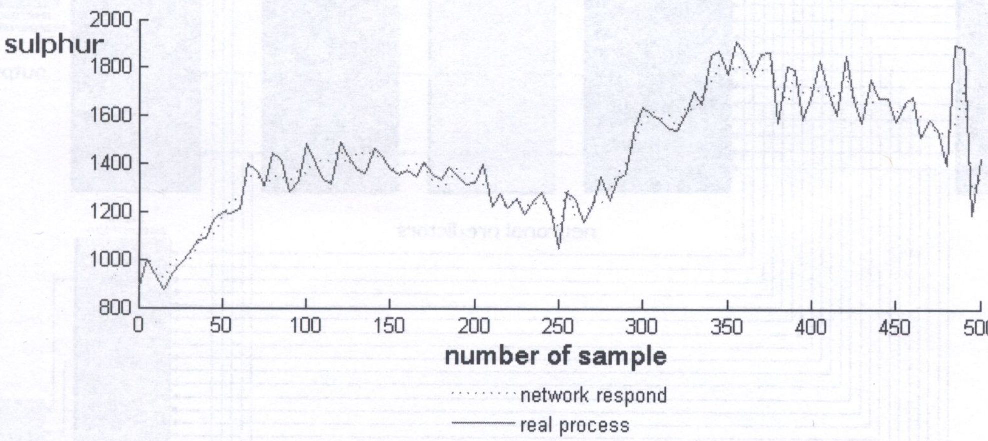

Fig. 9. Network and real process respond – sulphur prediction; back propagation tuning

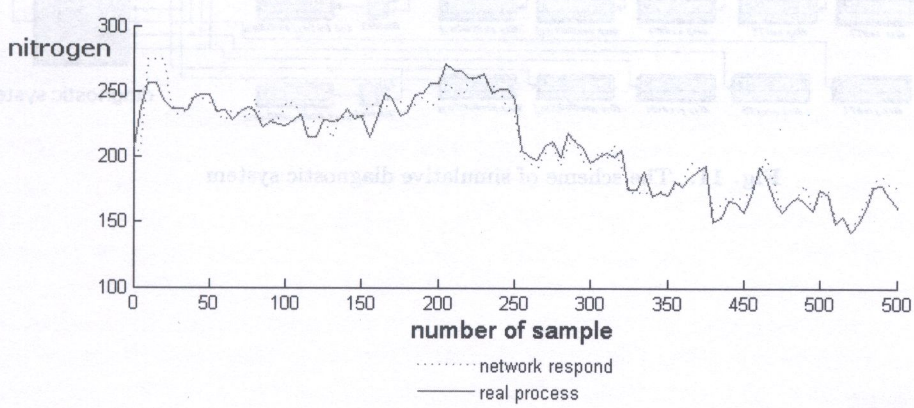

Fig. 10. Network and real process respond – nitrogen prediction; back propagation tuning

4. Realization of diagnostics system

Designed neural systems were base for building simulative diagnostic system in Matlab / Simulink environment. Basing on values predicted by neural systems advisory system was made. The system consists of few parts. One of them is set point unit allowing specify limits for diagnosed signals. Another one is visualization unit. Information, showed as graphs and text announcements, about forthcoming incorrect process parameters give chance for operators to react and affect on parameters of adding to fumes ingredients, which have influence on fumes parameters, in order to make fumes parameters concord to technological principles. What is more developed diagnostic information may by pass on to control system, omitting operators' decisions. It gives chance to make control system more efficient. The view on the screen presenting the system is showed in Fig. 11.

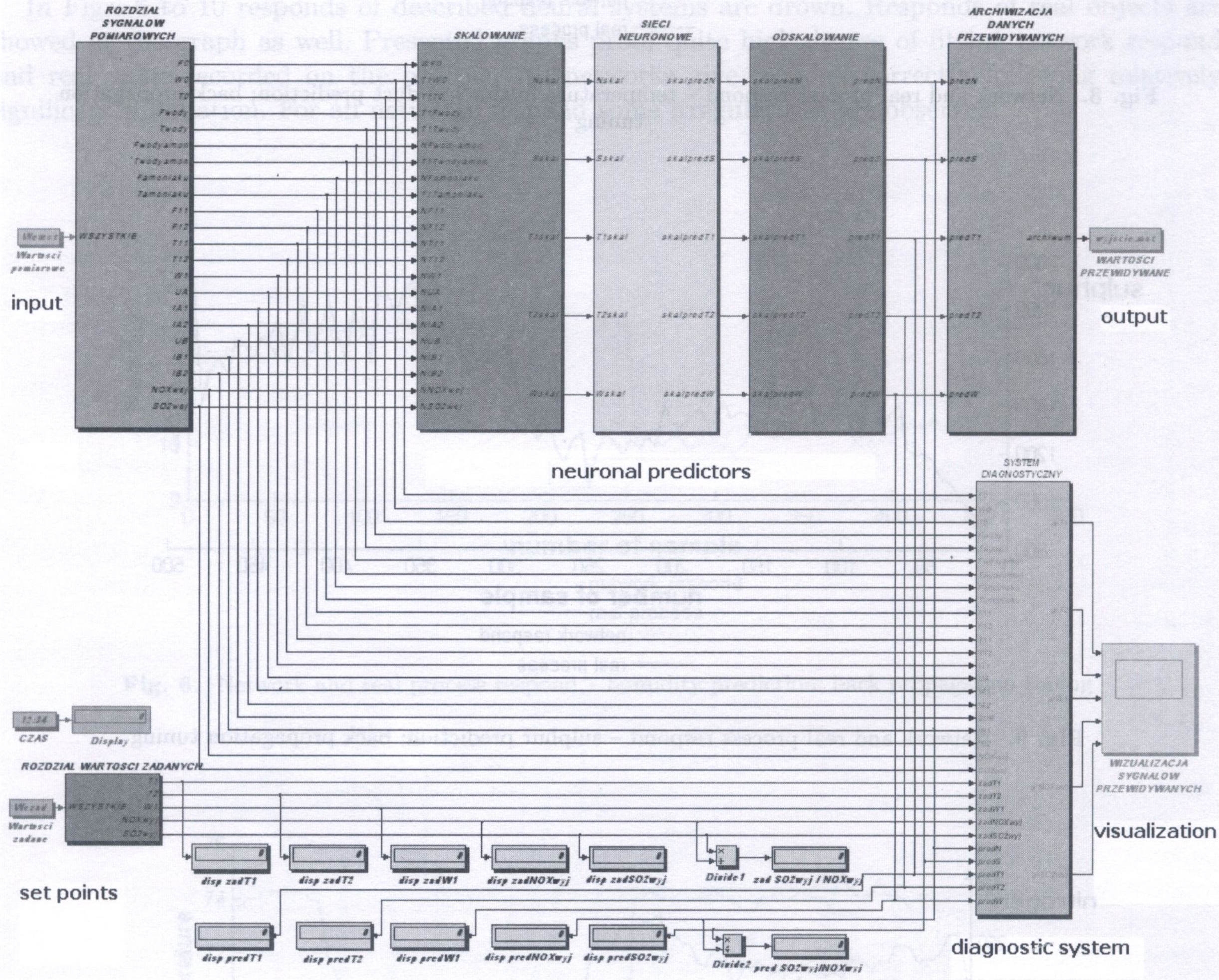

Fig. 11. The scheme of simulative diagnostic system

5. Summary

In case of designing diagnostic system for purifying fumes installation using electric beam tuned out that neural networks are reasonable solution. What is more, it seems to be the only one possibility. Method based on analytic model is unreliable.

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