Automation of oxygenation process in biological treatment plants

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ABSTRACT: Basic applications of programmable controllers in the sewage aeration control systems are considered. Configurations of binary control systems with one- and two-speed blowers as well as systems with PID programmable regulators are presented. Advantages and disadvantages of these solutions and experiences collected during utilization of implemented projects are discussed.

1 INTRODUCTION

Modernized or newly built sewage treatment plants provide not only mechanical cleaning but also a second stage of purifying — biofiltration. Sewage biofiltration consists on biochemical decomposition of organic pollutants by specific microorganisms that form so called *activated sludge*. These microorganisms grow in the aerated *activated sludge chambers*. Oxygenation that takes place in these chambers is one of the basic and most energy-consuming technological processes performed in sewage treatment plants. Its cost can run up to 70% of total treatment plant operating expenses.

Providing an effective control of the oxygenation system is thus one of the main tasks of the plant automation designer. The general concept of aeration control system should be already taken into account at the technological investment stage. This is so because the type of blowers purchased (with one- or two-speed rotary pistons, designed for continuous running or intermittent running, able or not to cooperate with a frequency converter), as well as their number and capacity affect decisively the possible performance of the aeration control system.

Maintenance of the appropriate level of oxygen dissolved in sewage is a crucial factor influencing effectiveness of purification. Oxygen shortage in activated sludge chambers results in the sludge atrophy while oxygen surplus is correlated with significant cost of useless aeration. The manual control of blowers or cyclical switching blowers on and off for some set periods of time are ineffective — because the sewage load and the resulting demand for oxygen significantly vary in time. Such fluctuations result from the mode of industrial plants operation (daily, weekly and seasonal differences); domestic sewage output (variations of daily routines) and weather conditions (rainfall and temperature). Consequently, measurement and regulation of sewage oxygenation are required, in order to keep it at the technologically appropriate level, irrespectively to the sewage load.

2 AERATION CONTROL SYSTEM

Depending on the means provided for automation by the investor, the aeration control might be the sole automatic system in a sewage treatment plant or can be only a part of a complex plant control system. In the later case, one of the programmable logic controllers (PLC) is usually applied.

Most frequently used aeration PLC control systems are:

- binary control systems with one- and two-speed blowers,
- systems with PID programmable regulators and frequency converters.

Since each solution has its own advantages and disadvantages, selection of the appropriate one depends on technical and economical aspects. Therefore, the final decision should be made not only by the control engineer but also by the investor and technologist.

2.1 *Binary control systems*

The simplest and cheapest option allowing for the regulation of aeration is binary control of several one-speed blowers (Fig. 1). All blowers operating in parallel fulfill the maximal air demand (as estimated by technologist). Turning blowers on and off (gradual adjustment) provides for a variable air demand. The number of operating blowers (switched on) depends on the measurement of the current level of oxygen dissolved in a spot, which was chosen by the technologist as the representative point of the chamber.

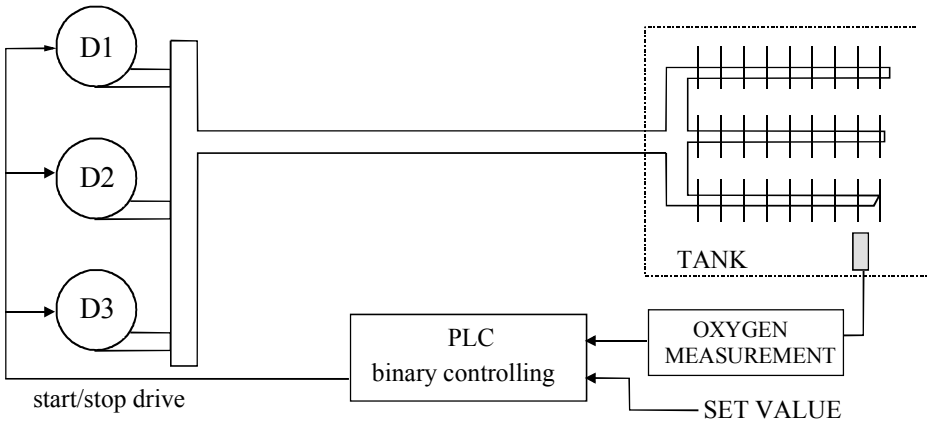


Figure 1. Binary aeration control system

The accuracy of regulation depends on the number of blowers operating at the maximum demand, established zone of hysteresis, and dynamic properties of controlled processes. The important limitation is set by the maximal permitted number of times the blower can be switched during one hour (this value is given by the producer among the other technical data). Exceeding this limit might result in overheating of blower's drive. Each instance of switching the blower on produces disturbances in the power network. These disturbances should be limited by starting drives in the *star-delta* connection or by applying some soft start/stop electronic system. From the perspective of control engineering, the accuracy of control thus obtained is far from perfect, yet it is sufficient to vary the aeration level within the limits established by an expert technologist.

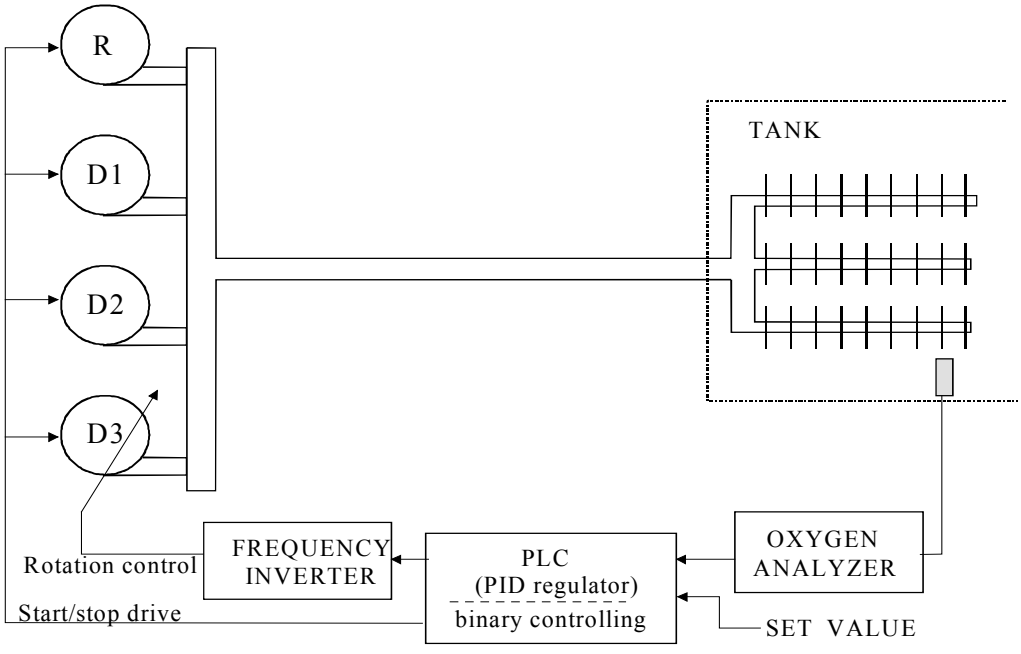


Figure 2. Single chamber aeration control system with PID regulator

The binary control systems might do also with the two-speed blowers. The control system regards such blower as two separate blowers with different capacities. In such cases, changes in aeration output might be executed not only by switching blowers on and off, but also by selecting one of the two rotational speeds of the blower. Possibility to change the blower output by switching between its two gears results in the increase of the available number of aeration system output levels.

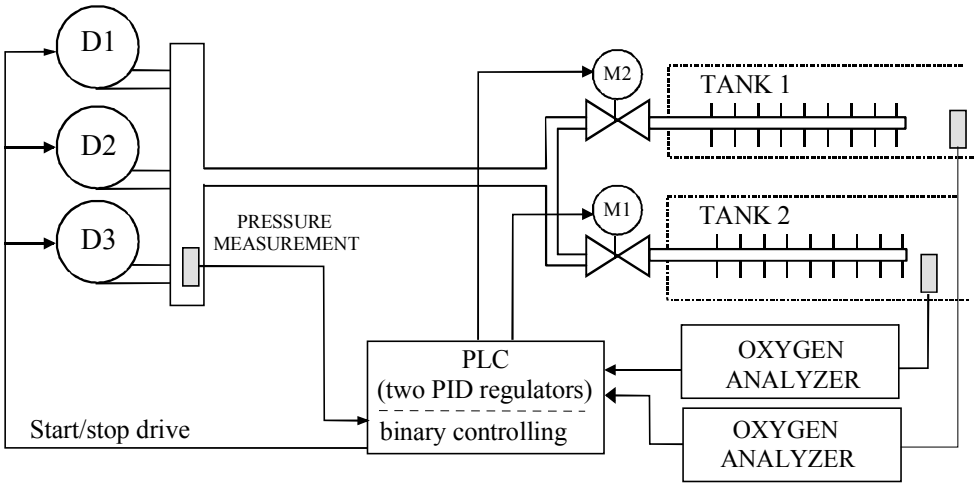
The sequence in which blowers are switched on should be changed automatically from time to time, in order to provide for the equal wearing of devices.

The main disadvantage of the binary control system when compared to the systems described next, is the excessive energy consumption.

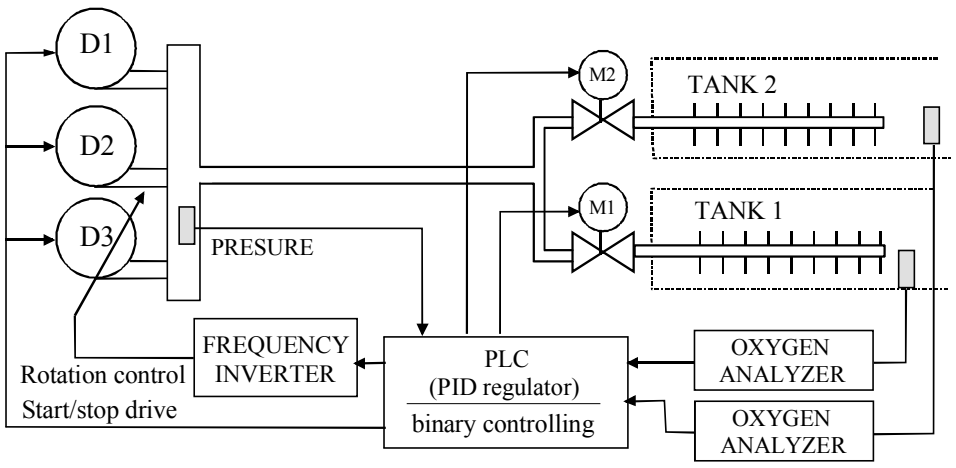
2.2 *Control systems with the PID regulators*

Successive variants of control system considered deal with continuos regulation of blower drive rotation speed by means of frequency converter which allows for precise adjustment of blower output to the process demand (Shinskey 1998).

The simplest aeration system with step-less regulation for one chamber of activated sludge is illustrated in Figure 2. It consists of grate system, one blower fitted for co-operation with inverter and several one- or two-speed blowers. The blower unit output is controlled on the base of measurements of sewage oxygen content. The blower which output is continuously controlled operates all time. The other blowers are automatically switched on and off by a binary control system, depending on the current oxygen demand. In other words, the total output is roughly met by running an appropriate number of on/off blowers and the fine-tuning is done using the proportionally controlled blower.



a)



b)

Figure 3. Two-chamber aeration control system: a) binary blowers' control, b) continuous blowers' control

An additional, reserve blower is often included in this kind of systems. It is another blower provided with drive fitted for co-operation with a frequency converter. Such arrangement significantly adds to system reliability, as the breakdown of any blower does not cause longer interruption in system's operation. Under normal conditions these blowers periodically replace each other at work, what provides for uniform wearing.

In a freely programmable controller the PID regulator can be implemented in a hardware or software form. Also the device regulator or even the regulator integrated with frequency converter might be used.

If the plant exploits more than one chamber of activated sludge, the described aeration system might be either replicated for each chamber separately or a consolidated system might be used, as presented in Figure 3. In the later case, the blowers operate on a common collector in which the control system stabilises pressure on the pre-set level. The measurements of oxygen dissolved in each chamber are fed to the control systems, which uses electric airflow choke valves as executive elements.

It is important to remember that functional range of blowers' rotations varies from 30 to 120% of nominal values. Quality of pressure stabilization depends mostly on the capacity of air tank and pipelines. The larger this capacity, the easier becomes pressure stabilization. Air pressure stabilization system might use both modes of blowers' control: binary (Fig. 3a) or by PID regulator (Fig. 3b). Execution of binary control might be difficult if capacity of collector and pipelines' is not large enough.

2.3 *Cascade system*

Cascade system (Fig. 4) allows adjusting the set level of oxygenation to the current sewage contamination load. Such system can dispense with the pre-set technologically secure oxygenation level by adjusting it to the treatment plant's working conditions. It results in improving working conditions of sewage purification. The set value of oxygenation level is determined on the basis of constant measurement of ammonia concentration in the activated sludge chamber (Szetele 1998). Although chemical constitution analyzers are rather expensive, big treatment plants are already being equipped with them, as it allows for higher standards of sewage purification. If such analysers are installed, their measurement signals can be used for implementation of the cascade system described.

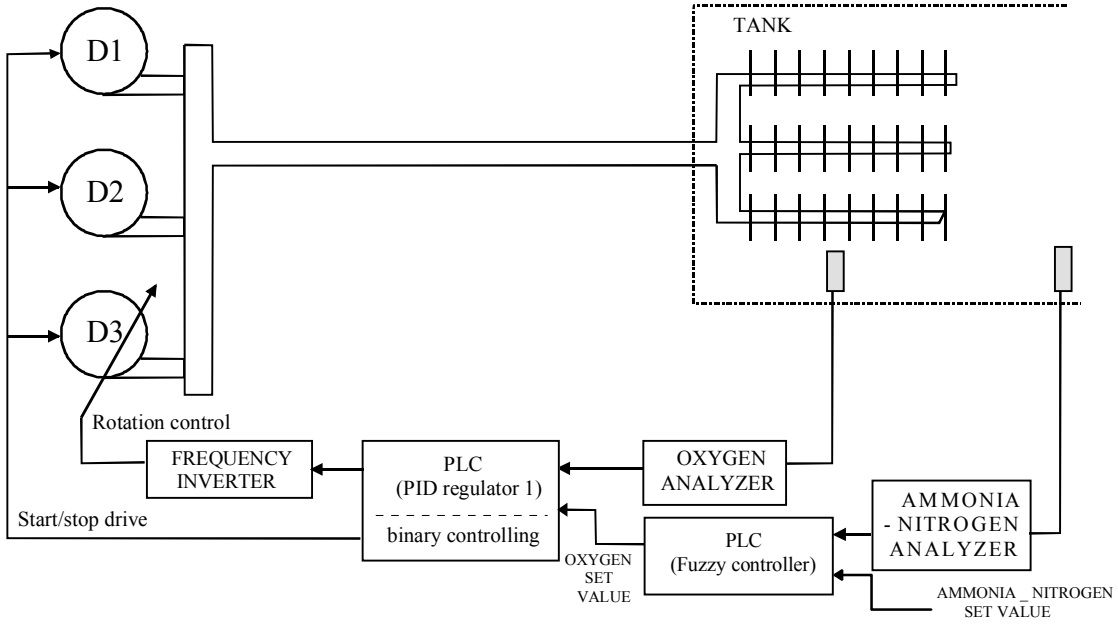


Figure 4. Cascade system of controlling aeration system

2.4 *Adjustment of regulators' settings*

In order to identify dynamic properties of sewage treatment plants active experiments might be used. The knowledge of these properties might help to elaborate appropriate regulator's settings. An abrupt change of blower's output performed in close proximity to working point might be used as the identifying signal. Settings determined by the classical methods provide only a good starting point for the search of proper settings. There are several reasons for such situation. First, the object is not stationary and the oxygen demand changes significantly during the daily cycle. Second, there are many technological and exploitation limitations (e.g. restriction of noise emitted by operating blowers by limiting the rate of change of blowers' rotational speed). Usually, when bringing a plant into operational mode, a lot of time is taken by efforts to improve the control settings by trial and error. Difficulties increase in case of interaction among control systems. Simulation methods can be useful in such circumstances.

3 SUMMARY

Comparison of experiences from exploitation of the described variants of aeration control methods points on the system with PID regulator as a technically better solution. Such system assures better quality of regulation, causes less disturbance in the power supply network and provides more favourable operation conditions of drivers. Yet, all systems described allow for proper execution of sewage purification, as the precise maintenance of sewage oxygenation level is not of critical importance.

Practically speaking, the choice of a suitable variant of aeration control system is dictated by the economical reasons. The binary control system is obviously the cheapest in investment but most expensive in exploitation. Investors are not unanimous in the matter of applying stepless oxygen regulation with frequency converters because such solutions are relatively costly. When the sewage load varies only slightly and the capacity of blowers is well matched, the savings coming from the use of frequency converter might be insignificant. Also, once the sewage treatment plant is build, environmental investors are rarely involved in its operation and thus not directly interested in operation costs — this further emphasise the preference for the cheapest solutions.

Generally, the sludge aeration process is non-stationary as well as not non-linear. Therefore it might be expected that application of fuzzy logic to identify the proper level of oxygen in sludge and to adjust the PID parameters should bring good results(Cox 1999). A cascade regulator presented in Figure 4, which uses fuzzy logic to set the level of oxygenation, might serve as an example in this respect.

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Solnik W., Zajda Z. Aerācijas procesa automatizācija bioloģiskās attīrīšanas stacijās.
Rakstā apskatītas notekūdeņos izšķīdušā skābekļa daudzuma regulēšanas sistēmu pamatrealizācijas, izmantojot loģiskos mikrokontrolierus.Piedāvātas bināri regulējamas gaisa pūtēju sistēmas ar vienas un divu pakāpju konfigurāciju kā arī sistēmas ar programmējamiem PID regulatoriem. Aprakstīti šo risinājumu trūkumi un priekšrocības, kā arī realizēto projektu ekspluatācijas laikā iegūtā pieredze.

Сольник В., Зайда З. Автоматизация процесса аэрации на биологических очистительных станциях.
В статье рассмотрены основные реализации систем регулирования количества растворимого кислорода в сточных водах с использованием логических микроконтролеров. Представлены конфигурации систем бинарного регулирования с одно- и двухстепенчатыми воздуходувками как и системы с программными регуляторами PID. Обсуждены недостатки и достоинства этих решений, а также опыт собранных во время эксплуатации внедренных проектов.