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INDUSTRIAL WASTE WATER MANAGEMENT SYSTEM IN REAL TIME

Nowadays environmental protection is a very important problem. In the present study a procedure has been developed for the management of waste water in pharmaceutical industry. The parameters of waste water flowing into the sewerage system, are generally below the permitted threshold value, but sometimes above the limit. To improve this, an on-line measuring equipment set was applied, by which the chemical oxygen demand (later COD_{cr}) can be calculated on the basis of BRIX refractometric method. A mathematical model was developed for the estimation of the COD_{cr} value, its integral (in case of estimating the COD_{cr} value in the tanks) and the standard deviation. Furthermore, a real time control module was developed, which adjusts the parameters of the waste water to keep it every time under the limit. It works with three collecting tanks and controls the water flowing into them, then lets down the water into the drain, or suggests the transportation of the water for COD_{cr} removal. After a 45 day measuring period we used the collected data to simulate the model and as a result, COD_{cr} removal became less by 50%, while no water above the limit flowed into the sewerage system.

1. INTRODUCTION

Nowadays environmental protection is one of the most important problems of private individuals and industry. The management of waste water is a fundamental question in freshwater protection. A lot of studies deal with this topic [1, 2, 3, 4], and there are strict regulations that control the parameters of the waste water flowing into the drain. In Hungary the 2004 order of the Ministry of Environmental Protection deals with the parameters of the waste water, and ordains the limits of the pH, Chemical Oxygen Demand (later COD_{cr}), Biochemical Oxygen Demand, Total Nitrogen, Total Phosphorus, etc [5]

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which is allowed to let into the drain. In this study we discuss a control system of the waste water management for a Hungarian pharmaceutical factory.

This waste water is channelled into the public drain and its main parameters are COD_{cr}, conductivity and pH. The COD_{cr} limit depends on the drain type, but in this case it is 1 000 mg/L. If the COD_{cr} is above the limit cannot be flowed into the drain, it needs to be transported for further treatment and COD_{cr} removal.

Using the current technology, the waste water is collected into three tanks, each volume is 24 m^3. The first tank adjusts the pH of the water. The outflowing water fills the next two tanks alternately. These tanks are connected in parallel. When a tank becomes full, its water is pumped into the drain, meanwhile the coming water is collected into the other tank. This solution produces much water above the allowed COD_{cr} limit.

The difficulty of the improvement of this system is that the value of COD_{cr} cannot be measured on-line. The purchasable instruments are expensive, complicated and fragile apparatus with high working costs, but the largest problem with them is, that these analysers work on the basis of measurement of specific chemical reactions, and their working time is long, at least 6-10 minutes. It does not make real time control possible. The creation of a real time control system requires on-line measurement technics, which can measure a few parameters, and makes the estimation of COD_{cr} value possible with good precision (~100 mg/L) especially near the limit (1 000 mg/L COD_{cr}). The pH measurement and adjustment has already been solved.

The final purpose is a dynamic control and management system, which can calculate the current COD_{cr} value of the coming water, and makes decision of the selection of the tanks depending on the water level of the tanks and their current COD_{cr} value. The goal is to minimize the volume of the water, which is above the COD_{cr} limit, and to maximize the mean COD_{cr} value of this portion of water. The minimization of the volume is reasoned by the cost of transportation. The water which has COD_{cr} above 10 000 mg/L can be used for methane production.

2. MEASUREMENTS AND MODEL

The main part of the solved or solubilised compounds of the water comes from the washing of the pharmaceutical instruments of the factory when changing the manufactured medicine. It is a diluted covering solution for pills, and contains mainly sucrose, citric acid or its salts, tensids and talcum powder.

The base idea of our method is that the concentration of a sucrose solution can be measured by refractometrics, so we can expect a direct relation between BRIX and the COD_{cr} value [3, 4]. Since the refractometric measurement can be applied on-line, we expected that this measurement technic would be the basis of this control system.

The first step was to calculate the relation between the BRIX and COD_{cr} values at different sucrose solutions with precise laboratory measurements (R=0.9986).

After a lot of calculation, as a result I can say, that I have to expand the calculations with the conductivity, because of the composition of the waste water. I searched the maximum value of the correlation between measured COD_{cr} and $BRIX^*$ calculated by the first equation

$$\mathrm{BRIX^*} = \mathrm{BRIX} + \lambda \cdot \mathrm{C} \tag{1}$$

where $BRIX^*$ is the corrected value of the BRIX, BRIX is the measured value, C is the conductivity and λ is the questionable coefficient (R=0.7863 $\lambda = -0.1$).

As we can see on Fig. 1.A, we can use a logistic model.

The expected value of COD_{cr} (k) and standard deviation (σ) by this approximation, is a polynomial of degree n

$$\ln \frac{k}{k_\infty - k} = g_k(\mathrm{BRIX^*}) = \sum_{i=0}^{n} a_i (\mathrm{BRIX^*})^i \,, \tag{2}$$

$$\ln \frac{\sigma}{\sigma_\infty - \sigma} = g_\sigma(BRIX) = \sum_{i=0}^{n} b_i (BRIX^*) \,, \tag{3}$$

where a_i are the polynomial coefficients, k_∞ is the asymptote of k, the standard deviation (σ) of the COD_{cr} value is the difference of the squares of COD_{cr} measurement and the expected value of COD_{cr} (k), as a square function of the $BRIX^*$ and the fitted curve similar to Eqv. 2, where b_i are the polynomial coefficients, and similarly σ_∞ is the asymptote of σ.

The polynomial regression method was the parameter variation in a least square sense, and the model was best at n=2 (R=0.9737).

The resulted coefficient values at the estimation of the k and the standard deviation are (COD_{cr}) a_0=-6.05, a_1=1.09, a_2=0.2, and k_∞=72 000, (standard deviation) b_0=-4.42, b_1=1.38, b_2=0.16, and σ_∞=12 500.

The standard deviation values by the equation 3, evaluated at different $BRIX^*$ values may be quite large. These values are in the same order of magnitude with the expected value of COD_{cr}. Consequently, the temporary value of k is not suitable for the precise estimation of the temporary COD_{cr}. Fortunately, the waste water is collected into tank, and the integral value of the k may be more precise, because at calculation of standard deviation have to be summed the squares of these values by the rule of statistics. So the mean value of k is

$$\bar{k}_j = \frac{1}{j}\sum_{i=1}^{j} k_i \quad , \tag{4}$$

if we suppose that the sampling intervals were constant, the samples are independent from each other and the tank was empty at the beginning.

To achieve a 95% confidence interval, in the calculation of k^+, the k_j must increase with $1.64*\sigma_j$.

For the model check the mean CODs of the tank were calculated, namely the mean of the estimated CODs by BRIX*(k), and the mean of the measured CODs (X) and the 95% confidence intervals (k^+) of the mean COD. Each calculation was executed with 60 samples from the 45-day period measures. These samples were chosen either from the lower BRIX range (Fig. 1.B), or from the higher BRIX range and from the whole set randomly. In all cases the estimated values fitted to the measured values, and the mean of the standard deviation remains acceptable.

Consequently, the model is suitable for the estimation of the COD_{cr} of the waste water which is collected in the tank, and it may serve the basis of a decision, if the COD_{cr} of the water is below or above the limit. Thus a control system can be developed on the base of the measurement of BRIX*, and the estimation of the temporary and mean COD.

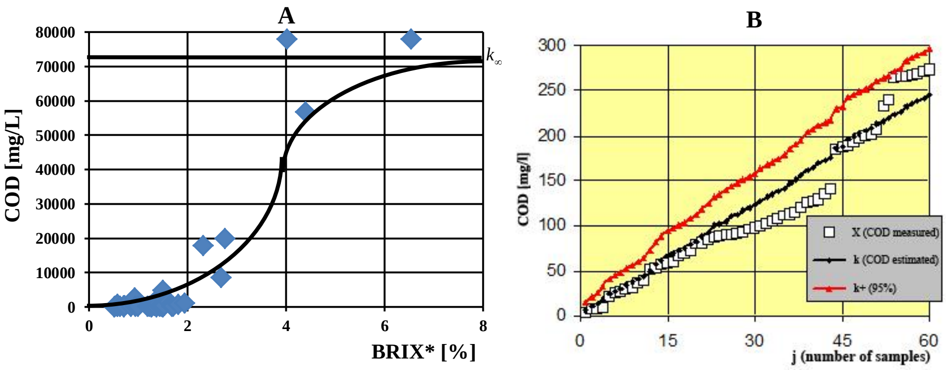

Fig. 1. The relation between the BRIX* and COD_{cr} is supposed to be logistic (A) and the calculation of the integral value of k (estimated COD), and k+, and the integral value of X (the measured COD) (B).

4. RESULTS

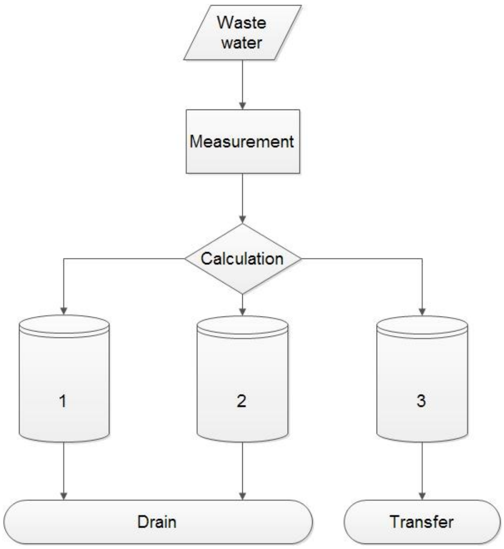

Fig. 2. The scheme of the control module.

A system plan was developed on the basis of the mathematical model (Fig. 2.). The system consists of three tanks, connecting pipes, pumps, the on-line measuring module and the control module. The direction of the waste water is controlled by a decision making module, which keeps the COD_{cr} of the first and second tanks below the limit, and collects the extremely high COD_{cr} into the third tank. The first and second tanks work alternately. The algorithm of the module is below.

The current COD_{cr} of the flowing waste water, and the mean COD_{cr} of each tank are estimated, and the further decision depends on these values.

If the temporary COD_{cr} is below 1 000 mg/L, then the system controls the water into that tank, which has lower mean COD_{cr} value actually. If the COD_{cr} is above the 1 000 mg/L limit, the system has to choose from three possibilities:

- if the mean COD_{cr} remains below the limit in each tanks, then the system chooses that tank whose mean COD_{cr} is lower;
- if each tank exceeds the limit with this portion of water, the control module directs it into the third tank, however it will dilute the water in it;
- if the COD_{cr} of the coming water is extremely high (>10 000 mg/L) the water is flowed into the third tank.

While a tank is filling up, the other tank may pump the waste water into the drain. To ensure the robustness of the system, the tanks are not filled up totally, only until 70%. If the level of the third tank exceeds a volume limit, the control module sends a warning message about the necessity of transportation of the waste water. The algorithm makes an effort to collect the water up to near the limit (70%), and pump out the water till the tank is empty.

The work of the control module was simulated with a dataset, which was collected during the 45 day test of the measuring module. The traditional method pumped 42 tanks (below limit) into the drain, and there was need to transport 24 tanks (above limit).

The developed control system pumped 54 tanks into the drain and there was need to transport 12 tanks. (Fig. 3.) Extreme COD_{cr} values did not occur during this period.

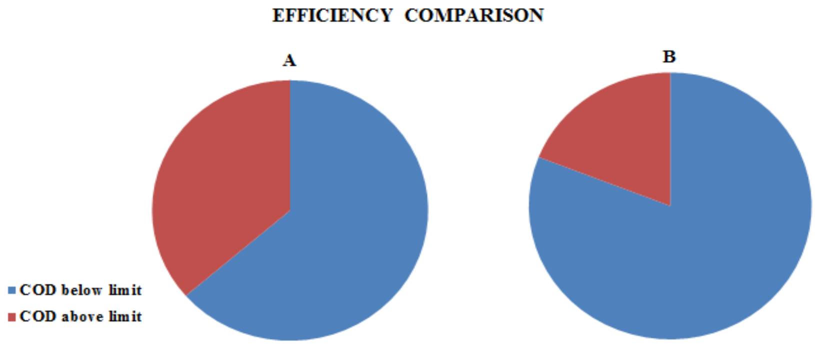

Fig. 3. The estimated performance of the traditional solution (A) compared to the new control module (B).

5. DISCUSSION

For the real time direction of a sucrose content waste water of a pharmaceutical factory, a complex system was planned. The system contains an on-line measuring module, which can measure mainly the BRIX and conductivity values of the water. A mathematical model was developed for data processing, and a control module was built for the decisions. The received data series by the measuring module was used for the testing and monitoring of the control module. The results show that the costly transportation and COD_{cr} removal decreased by 50%. However, the full validation of the control system requires yet the measurement of the mean COD_{cr} values of all tanks, and the comparison of them with the estimated mean COD_{cr} values. The algorithm of the control module may be improved further, for further reduction of the cost. In this area an artificial neural network may be effective.

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