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MATHEMATICAL MODEL OF ENERGY INTEGRATION OF THE PROCESSES IN ATAD SYSTEM OPERATING UNDER UNCERTAINTIES

Prof. Natasha Grigorova Vaklieva-Bancheva, PhD
Institute of Chemical Engineering at Bulgarian Academy of Sciences,
Acad. G. Bontchev Street, Bl.103, 1113 Sofia, Bulgaria
Tel.: (+359 2) 979 34 81
E-mail: vaklieva@bas.bg

Assist. Prof. Rayka Kirilova Vladova, PhD
Institute of Chemical Engineering at Bulgarian Academy of Sciences,
Acad. G. Bontchev Street, Bl.103, 1113 Sofia, Bulgaria
Tel.: (+359 2) 979 34 81
E-mail: raika_vladova@abv.bg

Assist. Prof. Elisaveta Georgieva Kirilova, PhD
Institute of Chemical Engineering at Bulgarian Academy of Sciences,
Acad. G. Bontchev Street, Bl.103, 1113 Sofia, Bulgaria
Tel.: (+359 2) 979 34 81
E-mail: eshopova@gmail.com

Abstract: *This study proposes an approach for energy integration of processes in Autothermal Thermophilic Aerobic Digestion (ATAD) system for wastewater treatment for the purpose of their energy efficiency and sustainability improvement.*

The idea for that came from the fact that the ATAD systems have a sufficient energy potential which can be used for reducing the depth of the thermal shock that occurs in first bioreactors stages due to uncertainties regarding to the quantities, composition and temperatures of the incoming into the system raw sludge.

To reduce the impact of the stochastic parameters and to ensure efficient using of the waste heat for the sustainable operation of the ATAD system, a mathematical model of energy integration scheme with two heat storage tanks is proposed which will be suitable to be involved in a stochastic optimization framework.

Key words: *modeling, energy integration, two heat storage tanks, ATAD WWTP, uncertainties.*

INTRODUCTION

Autothermal Thermophilic Aerobic Digestion (ATAD) is process for urban and industrial wastewater treatment as a final product a soil fertilizer (class A Biosolids) is produced (Metcaf & Eddy Inc., et al., (2003).

The ATAD process is conducted by the help of non-pathogenic aerobic thermophilic microorganisms having exothermic metabolism. This metabolic activity generates heat and elevates the temperature of the sludge. The heat retention in the system leads to high level of pathogen reduction. Other ATAD advantages are its simplicity, high reaction rate and hence smaller sizes of bioreactors. ATAD process carries out in batch mode in parallel series of two or more consecutively connected bioreactors.

Systematic observations of conventional ATAD systems have found that incoming of each new portion of fresh sludge leads to decreasing the temperatures in the first bioreactors stages and hence fluctuations in the temperatures in the entire system (Layden, N.M., 2007). Having in mind that thermophilic microorganisms are sensible in respect of the temperature fluctuations, lower temperatures drastically slow down their growth and provoke thermal shock (TSk). The depth of thermal shock depends on the ambient temperature and the quantities and composition of incoming wastewater that vary during different seasons and days. Restoration of the normal operating conditions entails prolongation of stabilization and pasteurization processes and increasing the energy consumption for mixing and aeration.

Taking into account that heat production and retention is a basic for the ATAD system, many researchers have analyzed the opportunities to improve its energy efficiency by development either of mathematical models of the heat exchange (Liu, S. et al., 2012; Rojas-Hernandes, J. et al., 2012; Rojas-Hernandes J. et al., 2010) or with a connection of the process of biodegradation and physicochemical reactions (Gomez, J. et al., 2007).

On the other hand, Zhelev and co-authors (Zhelev, T. et al., 2008; Zhelev, T. et al., 2009). have proposed re-using the discharged heat from the second bioreactor stage for pre-heating the incoming fresh sludge based on the hypothesis that ATAD system has substantial energy potential which can be recuperated for the thermal shock reduction (Layden, N.M. et al., 2007).

The aim of this study is to propose a mathematical modeling approach for heat integration of the ATAD processes with one intermediate fluid and two heat storage tanks which can be included in a stochastic optimization problem so that a reduction of the impact of the uncertainties in the inflow parameters and more sustainable operating temperatures in the ATAD facilities to be achieved.

EXPOSITION

Description of conventional atad system

The object of study is industrial conventional ATAD system for municipal wastewater treatment. The system consists of 4 identical bioreactors organized in two independent series of two bioreactors (Fig. 1). The bioreactors from the first stage of each series 1A (1B) are designed for sludge stabilization and the bioreactors from the second stage 2A (2B) are used for sludge pasteurization.

The system operates in batch mode for 22-23 hours in continuous flow aeration and constant flow rate. Hydraulic time for sludge retention depends on the volume of daily loaded fresh sludge and it is about 6-8 days.

Once per day part of the treated sludge from the last bioreactors is discharged to "a product" storage. Then partially treated wastewater from the previous stage is displaced to the next one and the system is fed with the fresh sludge from the feed tank. It causes a TSk on the thermophilic microorganisms.

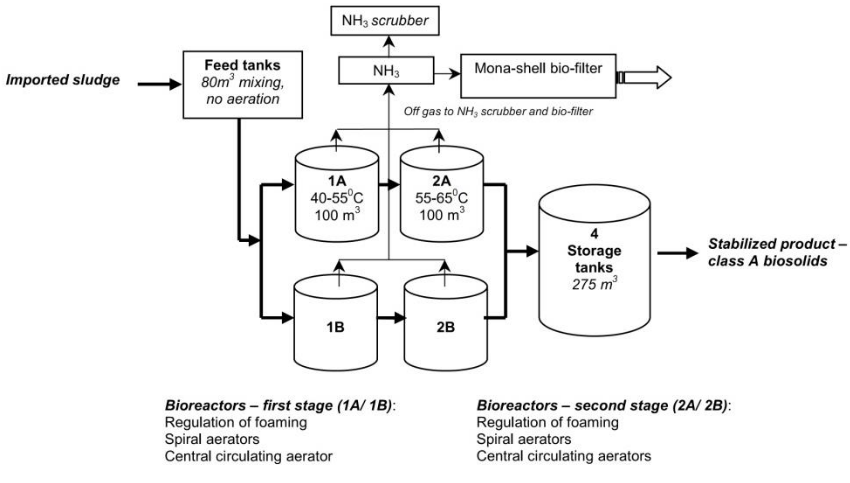

Fig. 1. Two-stage conventional ATAD system

As mentioned in the introduction, bacterial growth of microorganisms slows down as a result of TSk. It influences unfavorable on the biodegradation process, prolonging the process of restoration of normal operating conditions, the hydraulic time for retention and reducing energy efficiency of the process. The temperature drop in bioreactors depends on many factors as temperature, composition and quantity of incoming fresh sludge, temperature of partially treated sludge, ambient temperature which vary at different seasons and days. A great part of these parameters are stochastic, subjected of daily uncertainties and they have a significant impact on sustainable operation of the entire system.

On Fig. 2 are represented the results from real measurements for the depth of the TSk (Fig. 2a) and maximal temperatures measured at the end of the ATAD process (Fig. 2b) in bioreactors from first stage depending on the values of the temperatures and quantities of loading raw sludge.

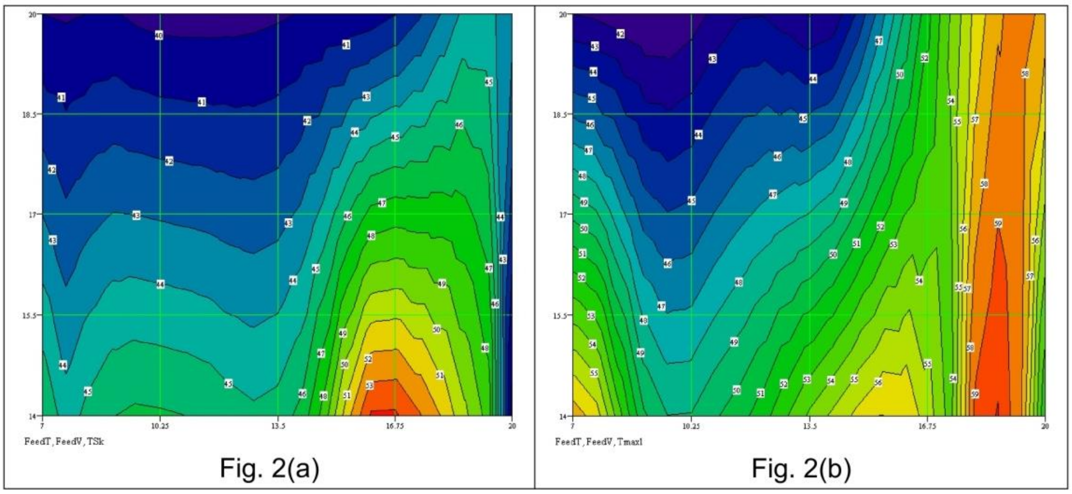

Fig. 2. Depth of the TSk (2a) and maximal temperatures achieved at the end of the process (2b) in bioreactors from the first stage depending on the temperature and quantity of loaded fresh sludge.

Taking into account the problem with stochastic (uncertain) input parameters and the fact that the streams belong to different batches, we purpose a mathematical model for re-design of ATAD for the purpose of energy integration of the processes with two heat storage tanks which will be suitable to be included in stochastic optimization problem.

Mathematical modeling of heat integrated atad system with one intermediate heating/cooling fluid and two heat storage tanks.

The proposed model of heat integrated ATAD system consists of a common intermediate heating/cooling fluid and two heat storage tanks, called *"H-Storage"* for heat and *"C-Storage"* for cold and two heat exchangers *HE-c* to heat cold fluid and *HE-h* to cool hot one, Fig. 3, (Gomez, J. et al., 2007).

At the beginning of the integration process, before loading the bioreactor 1-A(B), the cold sludge income into the heat exchanger *HE-c* with initial temperature T^{c0} [^{0}C]. It is heated counter-currently by the intermediate fluid coming from *"H-Storage"* tank, with an initial temperature T_m^{h0} [^{0}C] and leaves the heat exchanger with temperature T^{c1} [^{0}C]. After heat exchange the cooled intermediate fluid goes in the *"C-Storage"*. At the end of the integration process τ_c [h] the temperature in the cold storage tank becomes T_m^{c0} [^{0}C]. Likewise, the hot "product" with an initial temperature T^{h1} [^{0}C] passes through the heat exchanger *HE-h* and it is cooled by the intermediate fluid coming from the *"C-Storage",* with an initial temperature T_m^{c0} [^{0}C]. Then the cooled "end product" leaves *HE-h* with final temperature T^{h1} [^{0}C].The intermediate fluid is stored in *"H-Storage"* and at the end of the integration process τ_h [h] the temperature in the hot storage is T_m^{h0} [^{0}C].

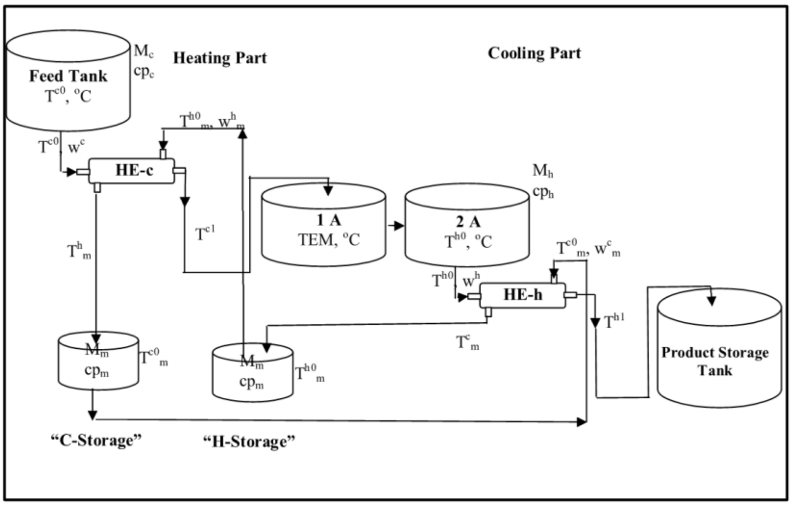

Fig 3. Heat integration scheme using two heat storage tanks

The equations for determination of the temperatures at inputs and outputs of both heat exchangers at the end on the integration process τ_c and τ_h are following:

$$T^{c1} = T^{c0} + (T_m^{h0} - T^{c0})R^c\Phi e^c \quad (1)$$

$$T_m^h = T_m^{h0} - (T^{h0} - T_m^{c0})\Phi e^c \quad (2)$$

$$T^{h1} = T^{h0} - (T^{h0} - T_m^{c0})\Phi e^h \quad (3)$$

$$T_m^c = T_m^{c0} + (T^{h0} - T_m^{c0})R^h\Phi e^h \quad (4)$$

where

T_m^h [^{0}C] is the final temperature of cooled hot intermediate fluid in *HE-c;*

T^{h1} [^{0}C] and T_m^c [^{0}C] are the final temperatures of cooled "end" product and heated intermediate fluid in *HE-h*

The terms used in equations (1) and (2) are following:

$$R^c = \frac{w_m^h cp_m}{w_c cp_c};\ w_c = \frac{M_c}{\tau_c}\ \text{[kg/s]};\ w_m^h = \frac{M_m}{\tau_c}\ \text{[kg/s]};$$

$$\Phi e^c = \frac{1 - exp(-y_c U_c A_c)}{1 - R^c\, exp(-y_c U_c A_c)};\ y_c = \frac{1}{w_m^h cp_m} - \frac{1}{w_c cp_c}$$

M_c and M_h are the masses of the cold sludge and hot "end product", M_m is the mass of the intermediate fluid in [kg] and A_c and A_h are the heat exchanger areas of *HE-c* and *HE-h* in [m^2]. The initial temperatures T_m^{h0} [^{0}C] and T_m^{c0} [^{0}C] in the "hot" and "cold" heat storage tanks calculate as follows:

$$R_m^{h0} = \frac{\Phi e^c(R^h\Phi e^h - 1)T^{c0} - R^h\Phi e^h T^{h0}}{(R^h\Phi e^h - 1)(\Phi e^c - 1) - 1} \quad (5)$$

$$T_m^{c0} = \frac{(\Phi e^c - 1)R^h\Phi e^h T^{h0} - \Phi e^c T^{c0}}{(R^h\Phi e^h - 1)(\Phi e^c - 1) - 1} \quad (6)$$

Thus, at given integration times τ_c and τ_h [h] initial temperatures T_m^{h0} and T_m^{c0} [^{0}C] and the values of $A_c, M_c,\ A_h,\ M_m$, the temperatures at the inputs and outputs of both heat exchangers can be exactly calculated using the model (1)-(6).

CONCLUSIONS

The study deals with the problems of energy efficiency improvement of ATAD system for municipal wastewater treatment. A description of real ATAD system is represented. The results obtained from real measurements conducted have shown the influence of stochastic (uncertain) input parameters of the system on the depth of the thermal shock. For reduction of that influence a scheme for energy integration of the processes in batch ATAD system with one intermediate heating/cooling fluid and two heat storage tanks is proposed. The mathematical model of the heat integration scheme is given. It will be suitable to be involved in stochastic optimization framework.

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