TEMPERATURE AND MIXING SIMULATIONS IN AN ANAEROBIC DIGESTER

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Abstract

Domestic wastewater treatment plants have high energy loads for a good development of treatment processes. The organic load of sludge resulting from wastewater treatment is an inexhaustible source of potential energy to the treatment plant, if used in an efficient process of anaerobic digestion (AD). Since AD is also a major consumer of energy, then to get a larger amount of energy than necessary for the process, it is necessary to optimize the anaerobic digester, both in terms of hydraulic and in terms of heat, so that the heat loss is minimal and the temperature distribution to be uniform.

Introduction

Municipal wastewater treatment plants (WWTP) are major energy consumers of the national power system and the cost of energy is an important part of the WWTP's operating cost.[1] Reducing energy consumption in WWTPs is difficult because the process is continuous and treatment technology is based on unitary processes (physical, chemical, and especially biological) that cannot be turned off to lower the power consumption. Treatment of wastewater in order to discharge the water at parameters required by regulations, leads to retention and formation of large quantities of sludge that includes both impurities contained in sewage waters and those formed in the processes of treatment.[2] In order to further processing the sludge or storing it, the sludge digestion is carried out through anaerobic or aerobic processes. In general anaerobic process is used, as it is done with lower energy consumption. Following the anaerobic degradation of the sludge most of the organic matter is converted to methane, carbon dioxide, water and hydrogen sulphide.[3] Efficiency of the high

rate anaerobic stabilization can be increased if one takes into account that the feed flow variations should be minimal, the temperature must be kept constant and the mixing system to be effective, so that colonies of bacteria to be put in permanent contact with influent biodegradable solid matter and the temperature inside the methane tank is uniformly distributed.[4, 5]
The most common system used for mixing the high rate methane tanks from the WWTPs is made of mechanical mixers, which generally works inside of a vertical tube. But mixing efficiency of this system is very much influenced by the sludge inflows and outflows of methane tank, and this is what this article aims to prove.

Methods

In this article were studied cylindro-conical methane tanks existent in a wastewater treatment plant from Romania. In this methane tank there is a mesophilic type anaerobic digestion. The biogas production through anaerobic mesophilic fermentation is energy intensive, both because the process required temperature is around 36-37°C throughout the year, but especially because mesophilic methanogenic microorganisms are not resistant to daily temperature variations higher than ±1°C.[6] This last point leads to a high degree of difficulty in regulating temperature so fine into large volume of sludge, such as methane-tanks.
In order to determine the thermal energy demand for heating and the sludge from methane tank at an optimal temperature for performing the process of anaerobic stabilization, it was necessary to determine the flow of influent sludge in the anaerobic reactor.
Necessary data has been collected, regarding climatic conditions of the area where the studied methane tanks are. Also, data were gathered regarding the geometry and the materials methane tanks are made of. By using these data sets, has been calculated the specific thermal resistance and the thermal energy demand to cover losses through the walls, dome and bottom of methane tank. Also, has been calculated heat flow through walls, dome and bottom of methane tank, in two different situations, considering the average air and soil temperature during the cold season and the warm season. Cold season has been considered from November to April, and warm season has been considered from May to October. The average temperature of the air (see Table 1)was considered as an average of multiannual averages of each month. Sludge flows considered are the multiannual monthly averages, data being collected from the WWTP (see Table 2).

Table 1 - Multiannual monthly average temperatures of air considered in calculation [The National Meteorological Administration of Romania]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{air} [°C]	0,84	1,64	5,5	10,4	15,8	20,2	22,2	22,6	18,1	13,1	7,3	2,97

Table 2 - Thickened sludge influent in the anaerobic stabilization process - Multiannual averages of the flow rates

Month	Jan	Feb	Mar	Apr	May	Jun
Monthly multiannual average per hour [l/s]	4,17	3,55	4,20	4,08	3,51	3,62
Month	Jul	Aug	Sep	Oct	Nov	Dec
Monthly multiannual average per hour [l/s]	4,18	4,59	4,12	3,90	3,87	3,72

As the solids content from influent sludge is less than 6%, and the composition (in terms of chemical compounds) varies greatly, for this calculation it is considered a sludge constant-pressure specific heat of 4180 J/(kg*K), the same that applies to water. The fresh sludge temperature, before being heated to enter into methane tank, was considered as follows: 15°C during the warm season and 9°C during the cold season. The optimum temperature for the mesophilic anaerobic stabilization of sludge was considered in calculation with the value of 37°C.

Using ANSYS DesignModeler and ANSYS Fluent CFD has been developed a model, based on the geometry of the cylindro-conical methane tanks existent in the studied wastewater treatment plant.

Have been considered the following assumptions:

- The central tube of the internal recirculation was excluded from the sludge volume of the methane tank, but its influence was considered by imposing an average speed to the sludge exiting and entering the methane tank thru the outlet and inlet of that pipe. The flow rate imposed through the central tube is 1 m /s, corresponding to 8.6 recirculations per day of the whole volume of sludge in the methane tank. This value was obtained for a speed of the mixing system between 400 and 500 revolutions / minute.
- influent sludge flow was considered with yearly averages recorded in the studied WWTP of 0.00396 m^3/s.
- influent sludge temperature was considered at 40°C.
- recirculated influent sludge temperature was considered at 40 ° C.
- for modeling and simulation of anaerobic digestion process, was considered a constant heat flux of 40.38 W/m^2 through walls, dome and foundation of the methane tank, from the inside out. This value is calculated monthly average heat flow based on the monthly average annual air temperatures in the area of the WWTP, considering a temperature of 37 ° C for the entire volume of sludge in the methane tank. In calculating the average annual heat flow through the walls of methane tank were considered medium heat flows through each of the three constructive elements of the methane tank (foundation, cylindrical dome and vertical wall), considering the thickness and properties of each

material, and the area of each element of construction. There have also been taken into account climatic characteristics of the area in which the studied WWTP is located.[7]

- for sludge volume meshing, tetrahedral meshes were used.[8]
- For the mass transfer borders of the considered domain, were used velocity-inlet and pressure-outlet conditions type.
- all pipes (fresh sludge inlet, fermented sludge outlet, outer flow and return of the exterior circulated and heated sludge) were considered with a diameter of 0.2 m.

Purpose was to study and optimize the heating process of the sludge from methane tank so that thermal energy consumption to be reduced and spatial distribution of temperature inside methane tank to be more uniform at the optimal operation value for the mesophilic anaerobic digestion process (37 °C).
The methods considered for achieving the goal was changing the value of heated and recirculated sludge flow.

Results and discussion

The volume of the sludge in the methane tank is is 3,400 m^3, the resulted mesh for sludge inside the methane tank has 424,403 nodes and 2,445,613 tetrahedral volume elements, and it was used in all four simulations. Four numerical simulations were carried out and in each case the recirculated and heated sludge flow rate was varied, in order to determine the optimal solution.

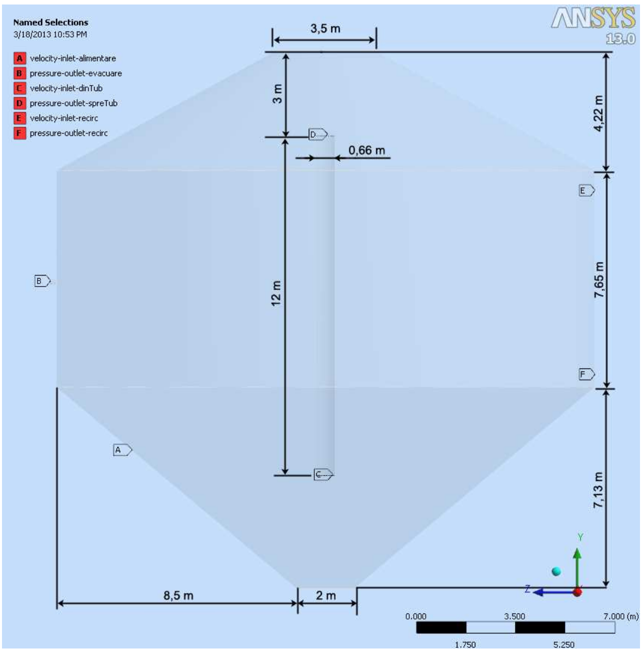

Fig. 1 - The geometry of the methane tank interior

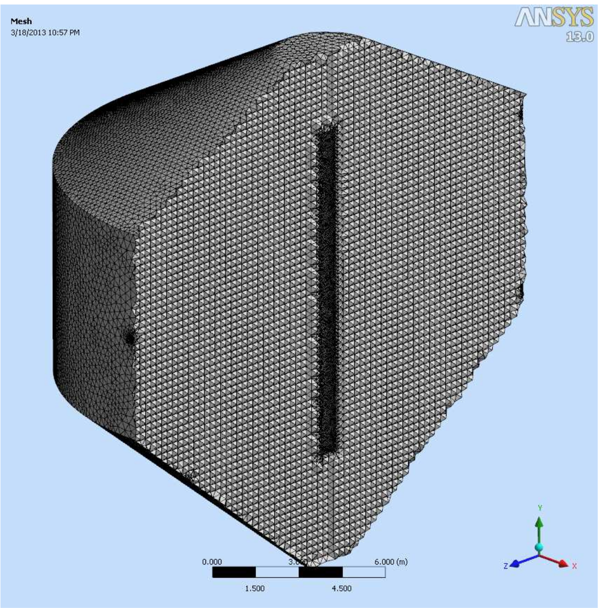

Fig. 2 - The tetrahedral mesh of the sludge inside the methane tank

In case No. 1 it was considered for external recirculation and heating at 40°C a flow with the value of 850 m3/day, equivalent to a quarter of the volume of methane tank recirculated within 24 hours. The following graphical representations are part of the simulation results of case no.1, representative of the intended purpose of the simulation.

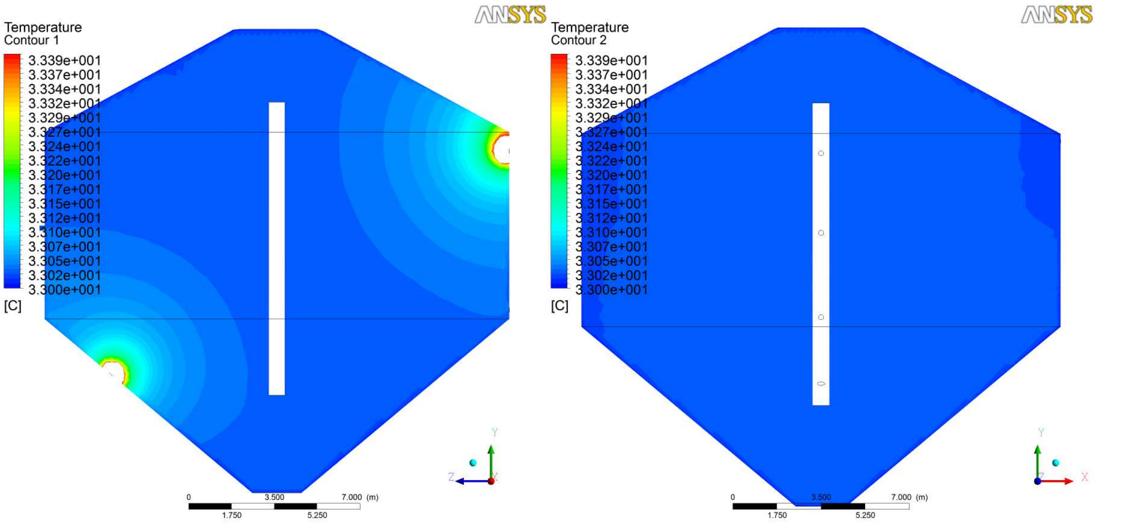

Fig. 3 - Case 1. Contours of equal temperature in vertical cross sections: a) through the yOz plane of the inflows and outflows of the methane tank (left); b)through the xOy plane, which is perpendicular to the inflows and outflows plane of methane tank (right).

In case No.2 it was considered for external recirculation and heating at 40°C a flow with the value of 1700 m3/day, equivalent to half of the volume of methane tank recirculated within 24 hours.

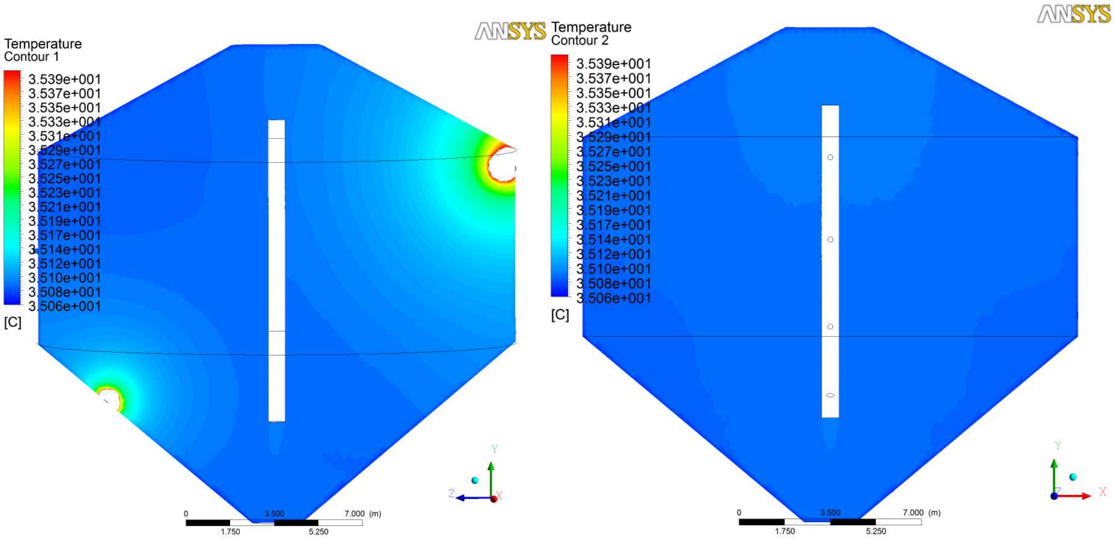

Fig. 4 - Case 2. Contours of equal temperature in vertical cross sections: a) through the yOz plane of the inflows and outflows of the methane tank (left); b)through the xOy plane, which is perpendicular to the inflows and outflows plane of methane tank (right).

In case No.3 it was considered for external recirculation and heating at 40°C a flow with the value of 2550 m3/day, equivalent to three quarters of the volume of methane tank recirculated within 24 hours.

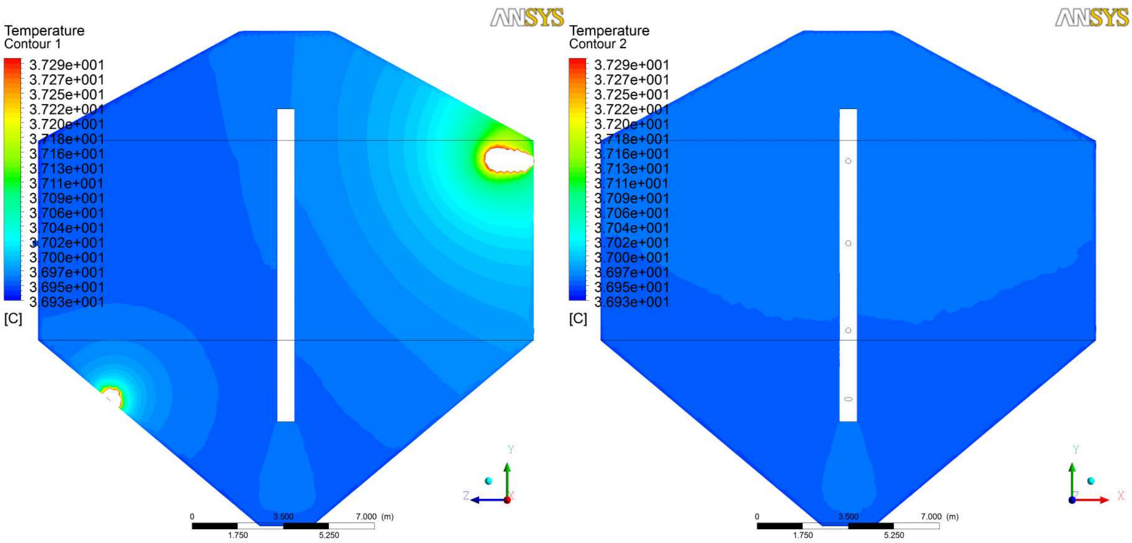

Fig. 5 - Case 3. Contours of equal temperature in vertical cross sections: a) through the yOz plane of the inflows and outflows of the methane tank (left); b)through the xOy plane, which is perpendicular to the inflows and outflows plane of methane tank (right).

In case No.4 it was considered for external recirculation and heating at 40°C a flow with the value of 3400 m3/day, equivalent to the whole volume of methane tank recirculated within 24 hours.

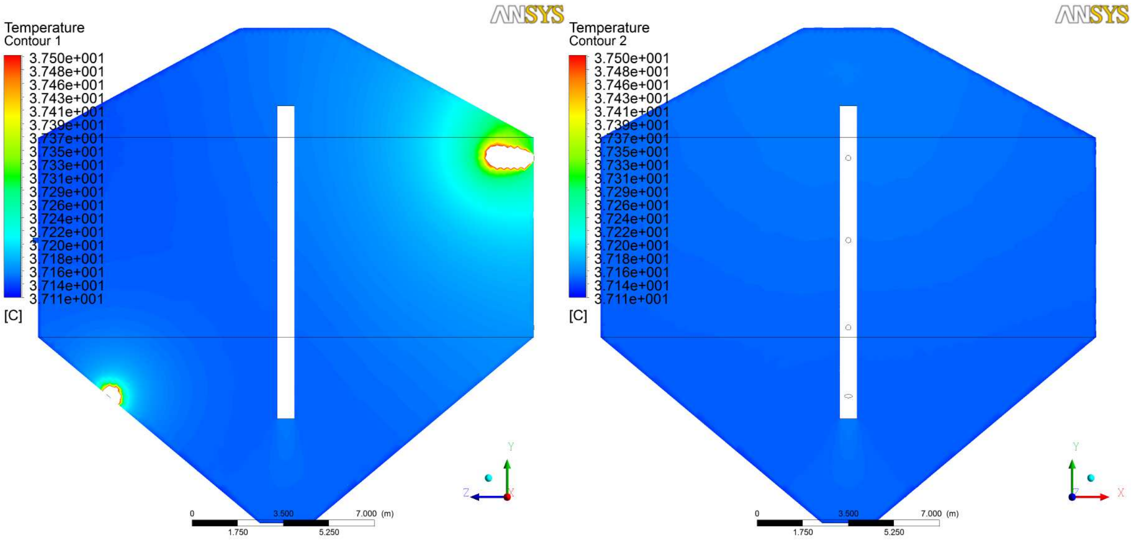

Fig. 6 - Case 4. Contours of equal temperature in vertical cross sections: a) through the yOz plane of the inflows and outflows of the methane tank (left); b)through the xOy plane, which is perpendicular to the inflows and outflows plane of methane tank (right).

The average values of temperature for each of the four cases of numerical simulation are shown in the comparative figure below.

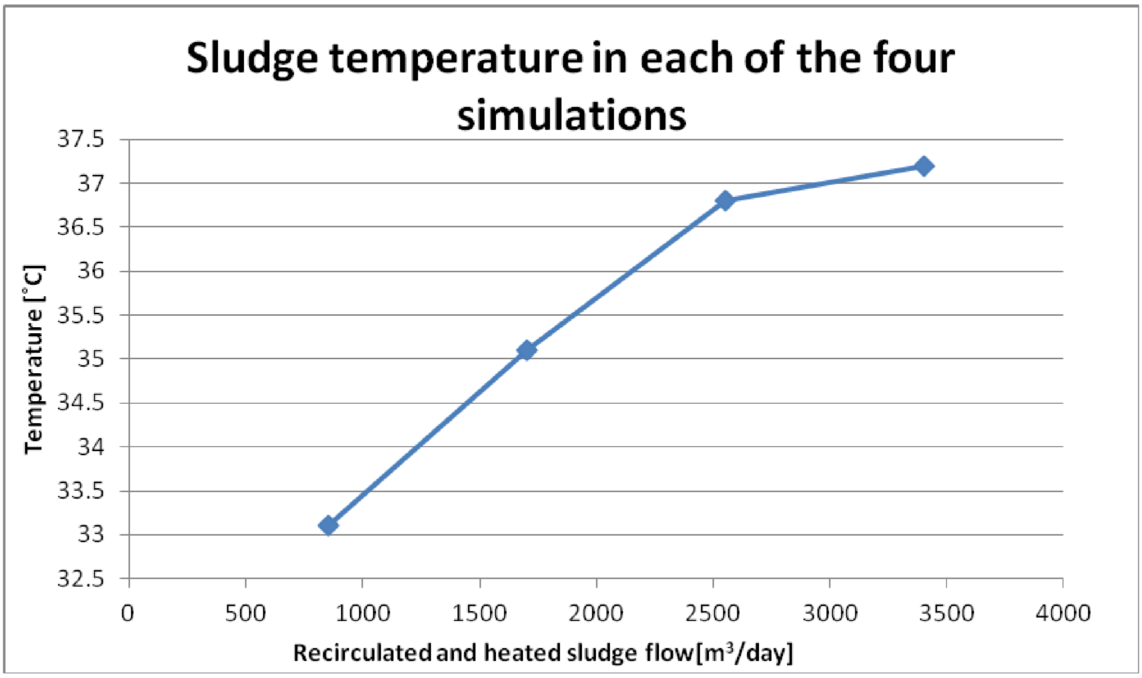

Fig 7 - Variation of temperature in the anaerobic reactor according to the flow rate of externally recirculated and heated sludge

Was taken into account the increased entry speed value of the recirculated sludge within permissiveness. Pipes which carries the sludge may not have a very small section as sludge generated from wastewater treatment can create sticky deposits inside pipes and methane tank components maintenance is performed under very difficult conditions. These conditions involve emptying and venting the methane tank to prevent the risk of explosion and poisoning with hydrogen sulphide and carbon oxides, gases that can enter into the composition of the biogas produced in the methane tank. Also, at relatively large sections of pipe, increasing flow is not an effective solution because it represents an additional intake of energy, both thermal energy for heating and electricity for pumping the sludge through heat exchangers and reintroducing it into methane tank.

Conclusions

The recirculation and heated sludge flow was varied from a quarter of the reactor volume per day, to half, then to three quarters, and finally recirculation of the whole volume of the anaerobic reactor a day. Although the optimum temperature under mesophilic anaerobic process development was achieved by daily recirculation of three-quarters of the volume of methane tank, there was also performed the fourth case, in order to determine the increase variation of the temperature.
Must be noted that, although in any two consecutive cases the recirculation heated flow increase is constant (850 m3/day), the temperature increase is not constant.
Thus, when increasing daily recirculation flow from a quarter to half of the volume of the reactor, the temperature increase was 2°C, while increasing daily recirculation flow up to half of the volume of methane tank, the temperature increase was less. The small increase in temperature occurs between the last two cases, with less than 1°C.
Based on simulations results it can be concluded that the optimum operating regime is when daily external recirculated and heated sludge flow is around the value of three quarters of the interior volume of the methane tank (case no.3).

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