Analysis report on the project of Westcome Heat Exchanger A/S in Finland

This analysis report is prepared on the request of Preben Jensen, Westcome Heat Exchanger A/S. Information on the project in Finland used in this report is based on extensive communications with Preben Jensen in the recent three months. Analysis is based on our previous scientific research in anaerobic digestion of organic wastes for biogas production, on our experience on operation of biogas plants in both Denmark and China, and on the published scientific studies.

1. Calculation of retention time

In biogas plants, the anaerobic digestion tank is a continuously stirred tank reactor, the retention time (RT) of which is defined as the average residence time of the incoming biomass in the tank. RT is calculated by the following equation:

$$RT = \frac{V}{Q} .....(1)$$

Where V is the effective volume of the digestion tank, Q is the flow rate of the incoming flow, which is the same as the outgoing flow for a continuously stirred tank reactor.

For the project in Finland, the total volume of the two digestion tanks is 3800x2 m^3, and the incoming flow rate is 668m^3/d. So the RT should be

$$RT = \frac{3800 \times 2m^3}{668m^3 / d} = 11.4d .....(2)$$

It was mentioned that the RT was calculated individually for the food waste, which accounts for 20% of the total incoming flow, as the following:

$$RT = \frac{3800 \times 2m^3}{(668 \times 20\%)m^3 / d} = 56.9d .....(3)$$

The calculation by equitation (3) is incorrect. This is because the food waste fraction, which accounts for 20% of the incoming flow, is fully mixed with the already digested sludge. This fraction is not separately retained in the digestion tank, but pumped out of the digestion tank together with the outgoing flow, which is at a flow rate of 668 m^3/d. Say this in another way, the pump can not identify and separate this fraction, and have this fraction staying longer time than the rest fraction in the digestion tank. So, the RT of the food waste is 11.4 days, not 56.9 days.

2. Problems caused by the shortened RT

Normally, we classify organic waste into three categories, i.e., carbohydrates, proteins and lipids. Theoretically, these organic material can be completely degraded into simple molecules, such as CH_4, CO_2, H_2O, NH_3, and etc., but it takes too long time. So, in practice, when anaerobic digestion of organic waste is conducted at mesophilic temperature, RT is normally set at around 30 days to pursue a degradation of 60-80% of the organic material.

A specific laboratory study[1] has show how long the RT should be in order to have an 80% degradation of the lipid fraction. In the laboratory experiment, potato and vegetable are used to represent carbohydrates, lean meat is used to represent proteins, and plant oil is used to present lipids. Figure 1 shows the experiment results, from which we can see that it takes carbohydrates (her potato and vegetable) and proteins (her lean meet) about 10 days to have an 80% degradation, while lipids (her plant oil) about 55 days. Organic waste is normally in the form of particles, which has limited surface for the hydrolysis bacteria to attach, so longer RT is necessary to extend to compromise the degradation rates of different compounds and the biogas plant economy. This is why the RT for mesophilic anaerobic digestion is normally set at about 30 days in practice.

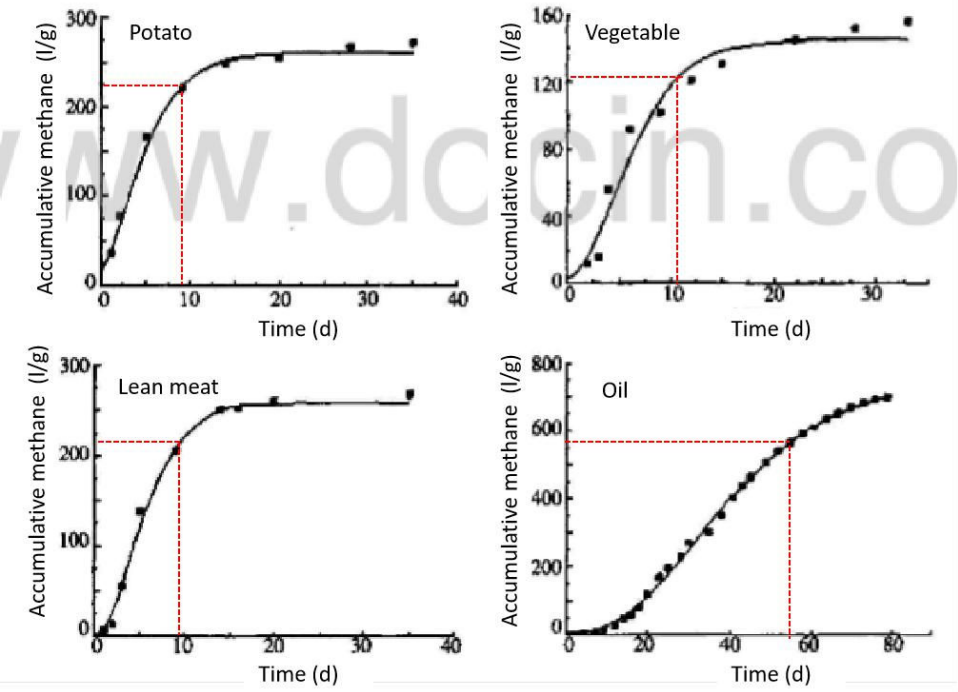

Figure 1. Cumulative methane production of anaerobic digestion of different organic material.

(The figure is adopted from a scientific research published at (https://www.docin.com/p-1311095894.html)

3. Speculations on factors reducing heat transmission in the heat exchanger

In the project in Finland, the shortened RT can give problems. First of all, the lipid fraction in the organic can not be degraded sufficiently. From Figure 1 we can see that the methane potential of oil is about 2-3 times higher than lean meat, potato and vegetable. It is mentioned that the food wastes are from restaurant such as McDonald's. Such waste contains high amount of oil and fat. Under a shortened RT

of 11.4 days, the oil and fat can not be sufficiently utilized for biogas production, and this is negative for the economy of the biogas plant and for treatment of the oil and fat fraction in the waste. Secondly, in such a short RT, the organic particles in the waste can not get enough breaking effect from agitation. This also means low degradation rates of carbohydrates and proteins, besides lipids. Thirdly, the lowered agitation effect due to shortened RT is a disadvantage for the produced biogas to release from the liquid phase to the gas phase in the digestion tank.

We understand that the design of the heat exchanger is based on the normal operation of the biogas plant. Transmission of heat from the hot channels to the cold channels is totally a physical process, following the principles of thermodynamics. Whenever there is contact surface and temperature difference, the heat will be transmitted. It is said that the transmission coefficient is only 0.1 instead of 0.54, as the designed parameter. We speculate that there might be two factors that have reduced transmission of heat. Our first speculation is that the oil and fat in food waste are not sufficiently degraded. These sticky compounds are accumulated and adhere to the surface of the wall of the hot channels of the heat exchanger, and thus prevent a sufficient heat transmission. Our second speculation is that the biogas retained in the liquid phase in the digestion tank may be pumped out together with effluent in the form of gas bubbles. Such bubbles reduce the contacting surface between the hot biomass and wall of the heat exchanger channels, and thus leading to a insufficient heat transmission.

4. Suggestion on how to tackle the problem

Our suggestion to tackle the problem in the project is to use only one of the existing two digestion tanks for digesting the food waste only. In this way, the retention time will be

$$RT = \frac{3800}{668 \times 20\%} = 28d\ .$$

And at the same time, increase the temperature of the digestion tank from 37^oC to 42^oC or higher. A higher temperature can to a great extent increase the biological reaction rate for hydrolyzing the particles of the lipid fraction into molecules for further degradation. In Denmark, many of the biogas plants treating food waste with high content of lipids are running at higher temperature in order to have a more complete digestion of the lipid fraction. If the organic waste fractions especially the lipid fraction are efficiently digested, there will be no accumulation and adherence of undigested lipids to the wall of the exchanger channels, and no gas bubbles in the effluent reducing the surface for heat transmission. Then the heat exchanger will comeback to its design efficiency for the project.

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