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Mixing of high-capacity tanks for biofuel production

Introduction

There are many possibilities how to mix a batch in an anaerobic reactor. From the energetic viewpoint, there is mostly used mixing by mechanical impellers in stations for biofuel preparation. Impellers use to be mostly placed centrally on a shaft or they are built in sidewalls of a tank according to a tank capacity or more likely according to their arrangement (especially ratio of liquid level and tank diameter). Type of impellers, their adjustment, and relative size have to be chosen properly and also impeller speed and power consumption have to be determined correctly during fermenter design.

Impellers must fulfill many tasks in a reactor – they must ensure homogenization of a batch and especially they must prevent heavier particles from settling down to a vessel bottom resp. lighter particles from drifting up to a liquid level. At fermentation, it is sufficient when impellers work only for short time periods, because for the process requirements it is necessary to provide casual re-arrangement of substrate in whole reactor so the fermentation process takes place in the whole batch preferably uniformly.

In recent years many new stations for biofuel preparation are built in the Czech Republic. In the fermentation process technology fermenters of high-capacity are used. These large tanks have to be mixed and due to their size, side impellers are used for this purpose. A fermenter is generally constructed as a cylindrical vessel with flat (at large scales) or conic (at low scales) bottom. Mixing in large tanks is not simple especially when both solids heavier and lighter then liquid have to be mixed so they don't settle on a vessel bottom resp. at a liquid level.

In a literature, data about mixing of a batch in large tanks using side impellers can be found particularly in terms of the crude oil storage tank homogenization. For example, *Rushton* [1] and *Oldshue* et al [2] dealt with determination of optimal positioning of an impeller. However in addition to the homogenization, in case of anaerobic fermenters for biofuel generation it is also important to take in mind the above mentioned prevention of solids settling and drifting up or even assurance of wetting of light solid phase at a liquid level and its sinking under the level. There isn't enough information about this complex process of mixing using side impellers in a literature. Therefore some experimental were done in this work to supply new pieces of knowledge about this problem.

Experimental

The experiments were carried out in flat-bottomed transparent cylindrical vessel of inside diameter T = 600 mm. The vessel was geometrically similar to a real fermentation tank. Side impellers (corresponding to the real state) were supplied in correspondence with measurements of *Fox* and *Gex* [3] by jets, because the size of the impellers was too small due to the used scale of the experiment. The whole experimental layout is shown in Fig. 1.

The equipment enabled changing of all of the geometrical positioning parameters of jets (impellers), i.e. their height under a liquid level or above the vessel bottom h_i, horizontal positioning γ_i and also the horizontal (β_i) and vertical (α_i) inclination (see Fig. 2). The concrete values of all of the parameters at all of the tested configurations are listed in Table 1.

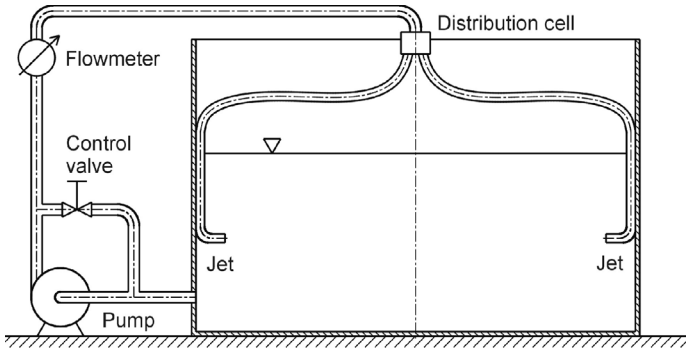

Fig. 1. Experimental layout of the laboratory scaled equipment

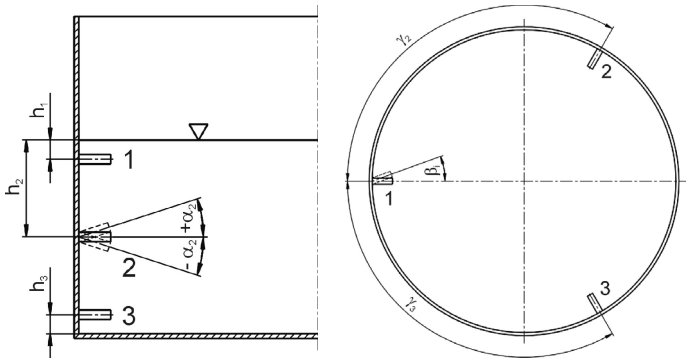

Fig. 2. Layout of jets (impellers) and variability of their positions in the vessel

All the configurations have one common characteristics. The horizontal inclination of all jets is set to 10° at them (except of variant A). This angle was obtained from the literature background research. From work [1] it follows that if it is necessary to reach a circulation of a suspension in a batch mixed by a side impeller rotating in clockwise direction, optimal horizontal inclination should be chosen in range 7°–12° in a direction so that the induced flow caused by the impeller had also clockwise direction from the top view on the vessel.

In a real fermenter, piggish slurry was mixed with corn silage and straw. In the experiments the piggish slurry was replaced with pure water, because the physical properties were

Table 1

Geometrical parameters of different tested configurations of jets positioning

Impeller	1				2				3			
Config.	*h* [mm]	*a*	*b*	*g*	*h* [mm]	*a*	*b*	*g*	*h* [mm]	a	b	g
A	24	0	70	0	122	0	70	120	24	0	70	120
B	24	-18	10	0	24	-18	10	120	122	-18	10	120
C	24	-18	10	0	122	-18	10	120	24	0	10	120
D	24	-18	10	0	122	-18	10	120	24	+18	10	120
E	24	-18	10	0	122	-18	10	15	24	+18	10	120
F	24	-18	10	0	24	-18	10	15	24	+18	10	120
G	24	-18	10	0	24	-18	10	15	220	-18	10	15
H	the same as D (doubled)				the same as D				the same as D			

very similar. The liquid level height was H = 244 mm. The same solid phase as in the real fermenter was used in experiments. The sucking of light solid phase from the liquid level in the batch and its consequential homogenization was observed visually during the experiments.

Due to the fact, that the primary aim of the experimental work was to optimize mixing in high-capacity fermenters, three impellers (jets) were placed along the vessel diameter in pitch 120° to reach sufficient power consumption during mixing (configurations A-D). However, during experiments some other positions of impellers were tested (configurations E-G) with the aim to optimize the positioning of impellers in newly designed fermenters.

Results

From the experimental results, it emerged that the localization of the whole power consumption in one place under the liquid level is the most advantageous variant for mixing process in fermenters (configuration G in Table 1). Light solid phase floating on the liquid level is highly sucked into the liquid by eddies, which are generated near the liquid level and subsequently the solids are sufficiently homogenized in the whole bulk of the batch. However, there exists also a danger in this configuration. Intensity of mixing in far distances from such localized impeller can decrease rapidly, which can lead for example to settling of particles at the bottom. It can occur especially in large tanks. This configuration is thus applicable mainly in low-capacity equipment. Moreover in high-capacity fermenters the power consumption produced by one impeller in such configuration would have to be very high.

In these cases (fermenters with volume above 1000 m^3) it is more suitable to place more side impellers in the vessel symmetrically. From the visual observation during experiments, configuration D was found out as the best one for good circulation of large volumes. The optimal localization and inclination of impellers rotating in clockwise direction can be clearly seen in Figure 3 (without impeller number 4 – see in text below). This configuration indeed ensures the best circulation of the mixed batch but it is necessary that the upper impeller provides also sufficient power consumption locally at the liquid level, which is necessary for wetting and sucking of particles under the liquid level.

In the previous work it was determined that the sufficient local power consumption, necessary for sucking of used silage particles under the liquid level using side impeller is 40 W/m^3. This value was similar to numbers published e.g. in [4]. Lower power consumption is satisfactory for the self batch circulation and for prevention of solids from settling. The increase of power consumption at the liquid level can be done by installation of impeller, which would have had higher power consumption then the other circulation impellers, or eventually by increasing of number of impellers installed in the same way of inclination at the same place just above each other as it is shown in Fig. 3. This layout then allows us to use the same type of side impellers in the whole tank.

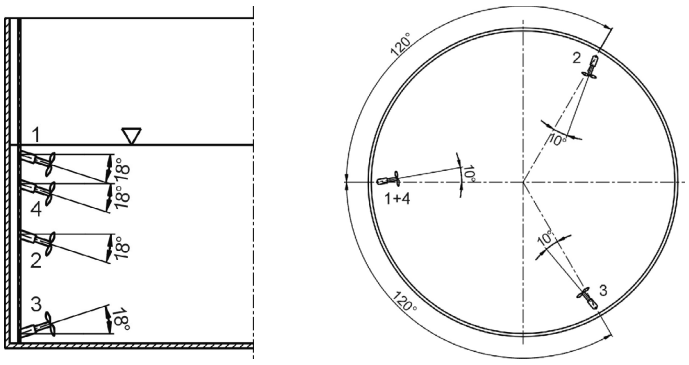

Fig. 3. Recommended layout of impellers in high-capacity fermenters

Conclusions

On the basis of experimental results, three impellers positioned symmetrically along the vessel diameter and along the liquid level height were found out as the optimal configuration for good circulation of batch in high-capacity tanks. Their height positioning and vertical and horizontal inclination was determined (Table 1 – configuration D). In case of light solid phase floating on a liquid level, local power consumption at the level must be increased by usage of higher-performance impeller or by increasing of number of impellers (Fig. 3).

In smaller tanks, just one impeller with sufficient power consumption and placed under the liquid level can be used for mixing in fermenters. The determined angles of inclinations and positioning of the impeller is listed in Table 1 (configuration G).

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