OPTIMIZING THE OPERATION OF BIOGAS PLANTS

Gheorghe BĂRAN[1*], Corina Alice BĂBUȚANU[2], Florentina BUNEA[3], Gabriela OPRINA[4], Lucian MÂNDREA[5]

The flow sheet and the operation of biogas plants from animal farms must assure: best parameters of methane-genesis process, quantity and quality of feed stock, efficiency of anaerobic digester and minimum energy consumption. The energy balance includes energetic value of the digested sludge, which is a natural fertilizer.

Keywords: biogas, anaerobic digester, hydrodynamics

1. Introduction

The hydrodynamics of the liquid-solid-live substance (bacteria) mixture processes (agitation) with application to biologic systems with industrial importance is noted, at a qualitative level in the '70s [4]. The older treaties [10] or the more recent ones [5], [6], as well as the new ones [2], [3] are approaching the problem of liquid-solid phase mixture in the absence of live substance inside the reactor.

In the case of the biologic reactors, like the anaerobic digesters (AD), in biogas production appears the problem of selecting the mixture system/equipment which ensures the best conditions to the biologic process (in particular to the biogas production process), with a reasonable energy consumption.

2. State of the biogas area

In Romania the biogas production has developed between the years 1970-1990 in two directions, with Romanian equipments and technology:

1) inside the waste water treatment plants at Bacău, Iaşi, Oradea, Piteşti, Tg. Mureş, et al. – big cities, with food industry. The estimated biogas production in Romania was 30 mil. m^3/year. In the present are yet functioning the plants from Piteşti, Alexandria, Tg. Mureş, where an electric generator made in Holland is supplied by the biogas;

[1] Prof. PhD. Eng., INCDIE ICPE-CA Bucharest, e-mail: baran_gheorghe@yahoo.co.uk
[2] Eng., INCDIE ICPE-CA Bucharest
[3] PhD. Eng., INCDIE ICPE-CA Bucharest
[4] PhD. Student Eng., INCDIE ICPE-CA Bucharest
[5] Assistant prof., Power Engineering Department, University "Politehnica" of Bucharest, Romania

2) inside the animals (pigs) complexes/ farms with a capacity of over 30000 heads/year. The plants were having two ADs of 400 ÷ 750 m^3 and even 1500 m^3, working in parallel, with a production of 0.6 Nm^3/ m^3 reactor/day. For a farm with 30000 pigs, in the project, a biogas production of 700000m^3/year was predicted. We are mentioning that some authors of the paper have done the energetic balance at a farm from Roman and they have discover that, in a hard winter, the production do not cover entirely the annual energetic consumption of the biogas plant and there are no solutions for valuing the activated sludge – like a very good natural fertilizer (as in the case of Ireland).

Once with the reduction/disparity of the farms, the biogas plants have been abandoned after 1990, especially because of the promotion of the methane, bottled or not.

Small (5 ÷ 10 m^3) or medium (20 ÷ 50 m^3) capacity plants have been designed and realized for the food industry or individual farms; the projects were inspired by the Chinese model, with the observation that those plants are working in the south of the country. These plants have also been abandoned.

On international level, the biogas production has developed in steps. Thus, in the '80s, in England 6 ADs of 23 ÷ 400 m^3 were running; in 1990, in Germany were about 200 installations; nowadays, in Branderburg land, 22 ADs are working, with powers between 200 ÷ 1200 kW, at an average investment of 4000 Euro/kW. In Germany there are two periodic publications [8], [9] in which problems concerning the hydrodynamic of ADs, financial aspects, improvement of the conversion efficiency, plants security, new types of biogas installations, et al are presented.

After the year 2000, biogas production is developed also in Poland and, in 2003, 3 electric power plants using biogas like fuel were running, with a total power of 0.8 MW; theirs extension to 4 up to 5 MW is foreseen.

An interesting example, as technology and management, is that from Ireland. The plants have 2 serial reactors: the first of 150 m^3 at a working temperature of 55°C and the second of 450 m^3, at 37°C. The raw material is composed from semi-liquid dejections collected for free from the local farms (14 t/day) and food residue (6 ÷ 8 t/day). The liquid part evacuated from the AD is returned to the farmers like fertilizer, also for free; the solid part, dried and compacted, is commercialized.

Table 1

Running installations in USA

Animals	Number of animals	Number of farms
Milk cattle	110 ÷ 3750	15
Pigs	2800 ÷ 5000	3
Ducks	500000	1

In USA 19 installations are running (table 1), most of them in the mesofil range (27 ÷ 30°C).

The biogas production in the pigs farms at an AD charge of 82 ÷ 110 m^3/day is 850 ÷ 1150 m^3/day, higher than that realized in Romania. The investments needed were of 290000 ÷ 576000 USD. The technological solutions adopted are different from a farm to another; at the selection and design of the installations have cooperated Universities and private companies (for example the University of Iowa and Fox Engineering) or specialized companies (RCM Digesters); 50% of the funds were coming from departments of the Ministry of Agriculture of USA.

The diversity of the solutions adopted, as well as the hydrodynamics researches [7] outline the importance and actuality of this problem; particularly, in Romanian case, the demand of installations for farms or small treatment plants will become acute.

3. The hydrodynamics of anaerobic fermentation reactors

In order to obtain a constant concentration in all volume of AD and to ensure the best conditions for the biogas production process, for a known volume, the reactor form and the equipment for hydraulic mixture of the suspensions has to be chosen. Taking over the experience from the chemical, food and alumina preparation industries, most ADs are cylindrical and equipped with rotors.

Mostly, there are two types of reactors: some with $H > D$ (fig. 1.a) and others with $H \approx D$ (fig. 1.b), which are satisfying the condition of minimum material consumption; this happens because they have a form very close to a sphere.

In the case of anaerobic digesters with $H > D$ and incased rotor the laminar, permanent flow between two coaxial cylinders is considered. The Reynolds number of the flow is

$$\mathrm{Re} = \frac{D_e v}{\upsilon} = \frac{4Q}{\pi \nu \left(D + d\right)} < \mathrm{Re}_{cr}, \tag{1}$$

where D_e is the equivalent diameter (the flow section/ wetted perimeter) and Re_{cr} has to be determined in the laboratory. Integrating the Navier Stokes equations the velocity distribution is obtain, in the hypothesis of the permanent flow with axial symmetry

$$v_z = \frac{k}{4}\left(r^2 - \alpha \ln r + \beta\right) \tag{2}$$

with $\alpha = -\dfrac{\left(r_2^2 - r_1^2\right)}{\ln\dfrac{r_2}{r_1}}$ and $\beta = \dfrac{\left(r_2^2 \ln r_1 - r_1^2 \ln r_2\right)}{\ln r_2 - \ln r_1}$; k is a constant that depends of the specific weight of the hydro-mixture and of the pressure drop given by the viscous friction.

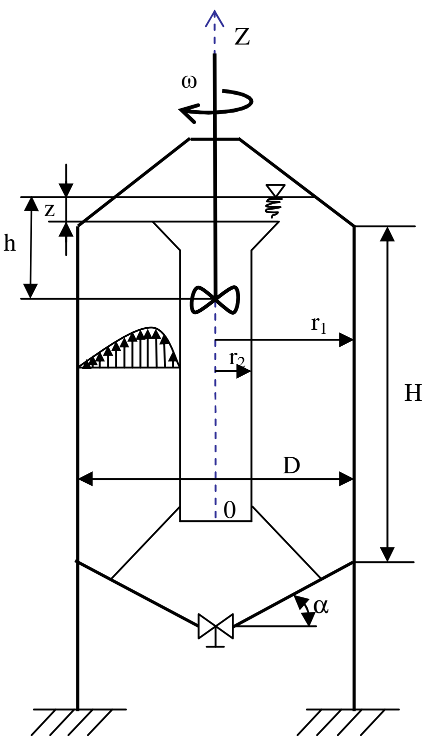

Fig. 1. a) Incased rotor reactor H > D

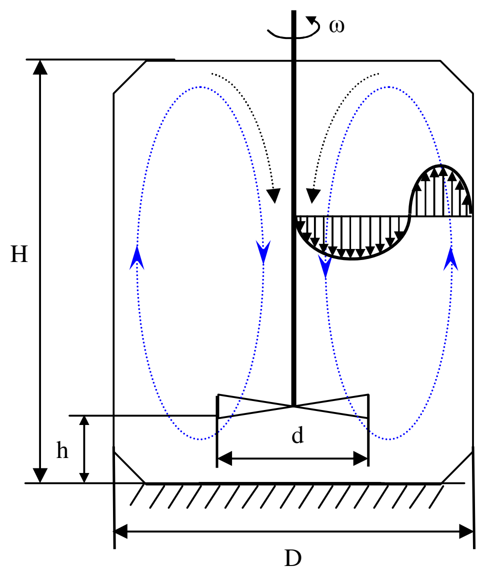

Fig. 1. b) Free rotor reactor H ≈ D

The velocity has a maximum situated at the distance r_m which depends exclusively of the reactor geometry.

$$v_{\max} = \frac{dv_z}{dr} = \frac{k}{4}\left(r_m - \frac{1}{r_m}\frac{r_2^2 - r_1^2}{\ln\dfrac{r_2}{r_1}}\right) = 0 \quad \Rightarrow r_m - \frac{1}{r_m}\frac{r_2^2 - r_1^2}{\ln\dfrac{r_2}{r_1}} = 0 \quad \Rightarrow r_m = \sqrt{\frac{r_2^2 - r_1^2}{\ln\dfrac{r_2}{r_1}}} \quad (3)$$

The unit viscous friction stresses have the expression

$$\tau = \eta \frac{dv_z}{dr} = \eta \frac{k}{4}\left(2r - \frac{\alpha}{r}\right) \tag{4}$$

and they become null at $r = r_m$ (fig. 2).

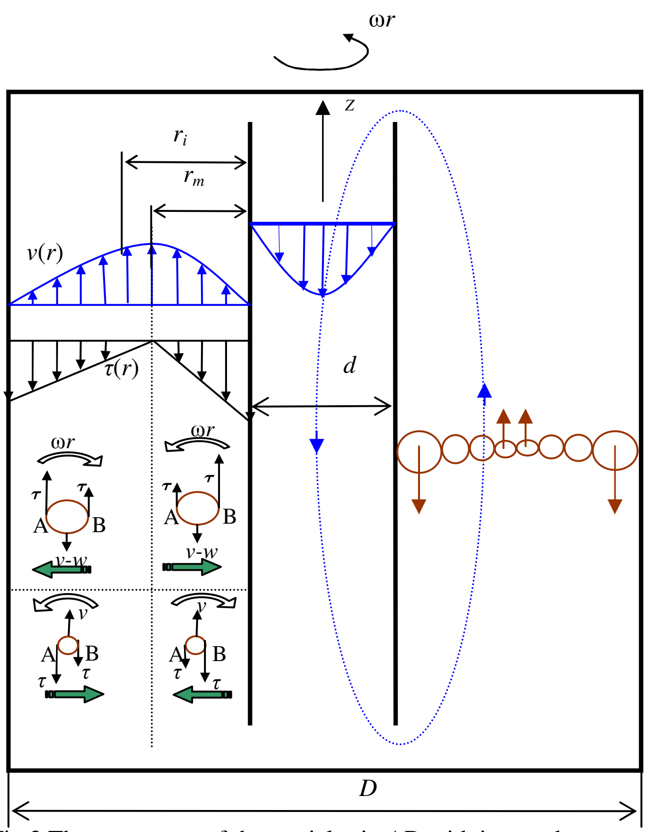

Fig.2 The movement of the particles in AD with in cased rotor

In [1] the suspensions dynamics in such a reactor was studied, considering the suspensions homogeneous.

We superpose over this flow solid particles, supposed spherical, isolated, respectively in small concentrations (having the hydraulic size w). In function of size and density, some of the particles are descending with a relative velocity w-v, others are taken by the current with the velocity v. Also, the different stresses τ on the ray, impart to the particles a rotational motion and through the Magnus effect they are moving on the ray, like in figure 2. It results that the bigger particles (or the heavy ones) will move to the wall and the small ones through the flow axis; the movement sense is different. The result is an “agitation” of the particles with radial components, ascendant or descendent, which may encourage the biogas production process. Theirs concentration varies both on the ray and on the vertical. The rotor flow rate, the central cylinder diameter, the distance to the bottom of the reactor as well as α angle have to ensure the washing of the suspensions deposited on the bottom of the reactor.

The specific of the flow in the $H \approx D$ type reactors and the dynamics of the particles are presented in figure 3 for two rotational directions of the rotor.

In this case exists a ray r_0 at which the velocity is becoming null and changes its direction; the value of this ray can be determined from the continuity equation

$$\int_0^{r_0} v_z(r) 2\pi r dr = \int_{r_0}^{D/2} v_z(r) 2\pi r dr .$$

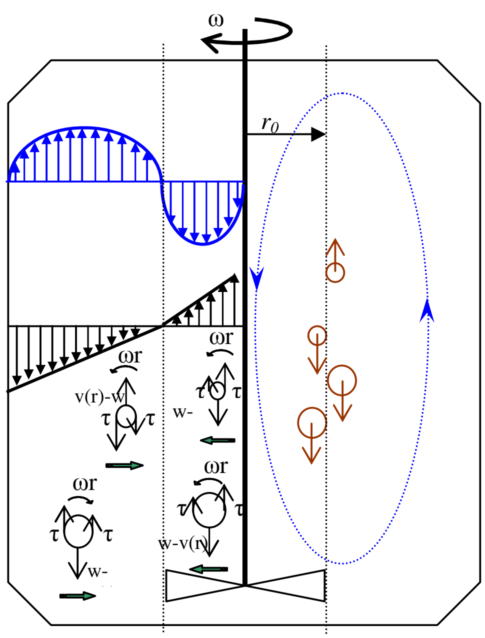

Fig.3 The movement of the particles in the AD with free rotor in a case

Indifferent of the rotational direction, respectively of the upset direction of the rotor, all the particles have the tendency to move to the zero velocity vertical, the ascending or descending direction of the movement being determined only by their size (weight). The numerical integration of the Navier-Stokes equations in the case of the flow in the type 1 reactors ($H > D$) outlines at small Reynolds numbers the existence of some vortexes [12] which can encourage or not the biogas production process.

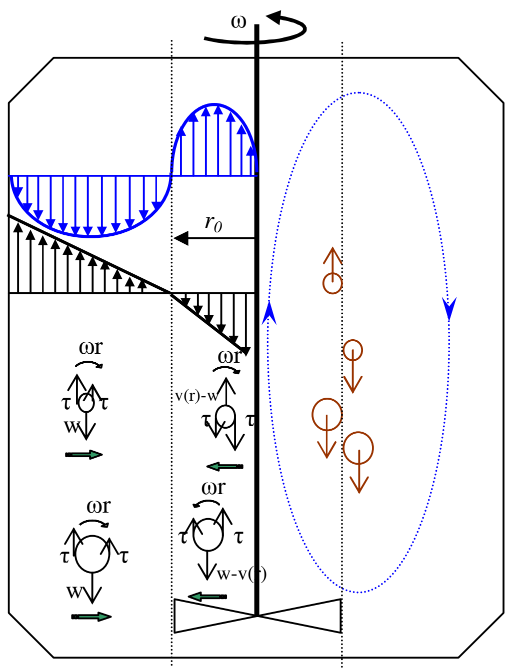

Fig.4 The movement of the particles in the AD with free rotor in other case

For hydro-mixtures with the density and viscosity close to those of the water, the experimental laboratory results can be used in industrial installations, using the Reynolds similitude criteria (if the flow is laminar and permanent).

4. Conclusions

The theoretical study of the laminar flow in two types of anaerobic digesters shows a different movement and distribution of the suspensions, meaning:

- inside the anaerobic digester with incased rotor, the heavy particles are moving to the walls and they have the tendency to descend (figure 2);
- inside the anaerobic digester with free rotor, indifferent of the liquid phase direction of flow, the particles are moving to the $r = r_0$ vertical (figure 3 and figure 4) and they have an ascending or a descending movement in function of their size (density).

The numerical solutions show the existence of some vortexes, even at small Reynolds numbers.

The dynamics of the particles inside the anaerobic digester represents the theoretical bases for the study of the biogas production processes.

REFERENCES

[1]. *Gh. Băran, N. Băran*, Studiu privind funcţionarea reactoarelor de amestecare cu elice întubată, Revista de Chimie, vol. 54, nr. 7, p. 639-641, Bucureşti, 2003.
[2]. *C. D. Tacă, M. Păunescu*, Particularităţile determinării puterii necesare amestecării în cazul realizării suspensiilor de particule solide Revista de Chimie, vol. 50, nr. 4, p. 200-205, Bucureşti, 1999.
[3]. *Gh. Băran, D. Beuran*, Hidrodinamica suspensiilor, Ed. Tehnică, Bucureşti, 2000, ISBN 973-31-1423-5.
[4]. *N. Blakebrough*, Efectele agitării în sistemele biologice, Revista de Chimie, vol. 23, nr. 8, tradus din The Chemical Engineer, nr. 258, p. 58-65, 1972.
[5]. *C.F. Pavlov, P.G. Pomancov, A. A. Moscov*, Procese şi aparate în ingineria chimică. Exerciţii şi probleme, Ed. Tehnică, Bucureşti, 1981.
[6]. *V. Jinescu*, Utilaj tehnologic pentru industrii de proces, Ed. Tehnică, Bucureşti, 1989.
[7]. *M. Cazacu*, Gh. Băran, Hydrodynamic aspects of the biogas digester, Proc. World Renewable Energy Congress, Field 5 Biomass, Reading, United Kindom, vol. IV, p.134-138, 1996.
[8]. *** Biogas Journal 10 Jahrgang, nr. 1/2007 ZKZ
[9]. S. Prechtl, Optimierungspatenzial von biogasanlangen, Forum New Power, nr. 2, p. 6-9, 2007.
[10]. E. Bratu, Operaţii şi utilaje în industria chimică, Ed. Tehnică, Bucureşti, 1969.
[11]. Băran Gh., Mândrea L, Influenţa geometriei reactoarelor de omogenizare asupra curgerii, Revista Hidrotehnica nr. 8, p. 147 – 149, 1998.
[12]. Băran Gh., Mândrea L, Studiul curgerii în reactoarele de omogenizare. Revista Hidrotehnica nr. 2, p. 39-44, 1998.