MATHEMATICAL MODEL OF THE PROCESSES OF STEP-BY-STEP PROCESSING OF ORGANIC WASTE

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Abstract— **It is stated in the paper that the key products obtained in a biogas digester from anaerobic processing of agricultural organic waste is biogas, high-quality organic fertilizers and B_{12} vitamins. A program was compiled and solution was found for the method of menatogenesis mixing in a biogas digester and the operation mechanism of this digester. In addition, information is provided that experiments were conducted with the program in production on biogas devices.**

Keywords—mixing, biogas, biomass, anaerobic, process, methanogenesis, bioreactor, hydraulics, bubbling, foam, winged mixers, biomass friction coefficient, bioreactor fill factor, organic waste, centrifugal force, friction force, inertia force, diameter, volume, mixer blade.

I. INTRODUCTION

In world practice, it is believed that the main product obtained in a biogas digester under anaerobic processing of agricultural organic waste is biogas, high-quality organic fertilizers and B_{12} vitamins. The highest quantity and quality of the product obtained with these digesters is expressed in the degree of necessity of the performed technological processes. [1,2,3,4]. One of the requirements for the implementation of anaerobic processes is the mixing of biomass in the bioreactor so that this process does not negatively affect the ongoing methanogenesis inside it [5,6,7,8]. In long-term experiments, the bioreactors were compared with hydraulic, bubbling and generalized mixing digesters [9, 10, 11, 12].

II. STATEMENT OF THE PROBLEM

The most common type of a bioreactor is a bioreactor with winged mixers. In bioreactor with winged mixers, the speed of rotation of the mixer should be in a certain interval. In many cases, to ensure complete mixing, the mixer speed is increased. As a result, foam appears in the digester. In experiments, the analysis was made to changes the mixer speed along the diameters of the bioreactor. For this purpose, the velocity of biomass mixing in bioreactors with diameters of 3 metr, 4 metr and 5 metr was determined (bioreactors with such dimensions are the most common [2,3,4,5]). Considering that the mixing in bioreactors is done 6 times a day for 4 to 7 minutes, it follows that the biomass speed in bioreactors is not compared to the mixer speed. Therefore, in an anaerobic process, the speed of methanogenous mixing should be zero and the mixing performance should be maximum, as it should be directly proportional to the biogas volume obtained in bioreactors. Therefore, it is necessary to find a solution to the problem of optimal mixing in bioreactors.

III. SOLUTION

A mathematical model is considered that provides an increase in bioreactor productivity in the process of biomass mixing [19]. The mixing performance of a winged bioreactor mixer is calculated by the formula [20]:

$$\mathrm{U_a} = 94,2 \cdot \pi \cdot \left(D^2 - d^2\right) \cdot n \cdot L_{\text{к}} \cdot \mathrm{k_T} \cdot \mathrm{k} \tag{1}$$

Here D – is the diameter of mixer blade (m); d is the diameter of bioreactor drum (m); n– is the number of revolutions of the mixer shaft (rpm); $L_{\text{к}}$ is the pitch of the mixer blade (m); k_m is the bioreactor fill factor $(k_T = 96...98)$) [19,20]; $k_{\text{иш}}$ - coefficient of friction of biomass $(k_{иш} = 0,09...0,19)$.

The quality of organic waste mixing in the bioreactor (a speed of 4 ... 6 km/h is accepted as the optimal speed for biomass mixing in the bioreactor) affects the volume of biogas obtained in the process. For high-quality mixing, the average speed of the mixer wing should not exceed the level of demand in methanogenesis. Otherwise, the centrifugal force acting on the particles of the mixed substance will be greater than the friction force. This leads to the substance adhesion to the walls of the bioreactor. The state of one part of the biomass in one stage of the bioreactor and the acting forces are shown in Fig. 1. In order for the biomass particles not to disperse throughout the entire volume, its inertia force must satisfy the following condition:

$$\mathrm{F_{ИМ}} = \left(\mathrm{G} + \mathrm{Q}\right) \cdot f \tag{2}$$

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Here $F_{ин}$- is the inertia force of biomass particles; G is the mass of biomass particles located on the mixer blade, kg;

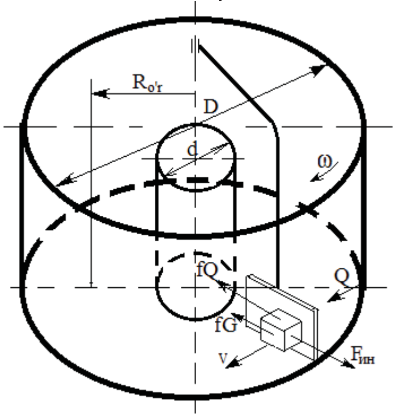


Fig. 1. Mixing scheme in a bioreactor

Q is the force acting on the mixture from the side of the mixer blade: $Q = f \cdot G$ is the coefficient of mixture friction on the surface of the mixer blade $(f = 0,14...0,59)$.

The inertia force of the biomass particles in the bioreactor is calculated by the formula:

$$F = \frac{G}{g} \cdot \omega^2 R \quad (3)$$

From (2) and (3) the following relationship is written:

$$f \cdot G + f \cdot G^2 = G \cdot \omega^2 \cdot \frac{R}{g} \quad (4)$$

From here the angular velocity is determined:

$$\omega = \sqrt{g \cdot \frac{f \cdot (1+f)}{R}} \quad (5)$$

Here R –is the radius of the stage where the biomass of the bioreactor is mixed (m).

The diameter of the bioreactor in this stage is calculated by the formula

$$D = \sqrt{\frac{4 \cdot V}{\pi \cdot h}} \quad (6)$$

Here V –is the biomass volume in a stage (m^3); h is the height of the biomass mixed in the stage (m). If the mixing of biomass in the bioreactor is continuous, then the productivity of the bioreactor is calculated by the formula:

$$U_a = 94,2 \cdot \pi \cdot \left(D^2 - d^2\right) \cdot n \cdot z \cdot L_K \cdot k_T \cdot k \quad (7)$$

Here k – is the coefficient of biomass displacement on the surface of the mixer blade. The length L of the mixer using the diameter D is calculated by the formula[13,14]:

$$L = m \cdot D \quad (8)$$

Here $m = 2,7...3$. In this model, the program describing the patterns of change in bioreactor productivity depending on the values of the bioreactor diameter $D = 3,4,5$ has the following form:

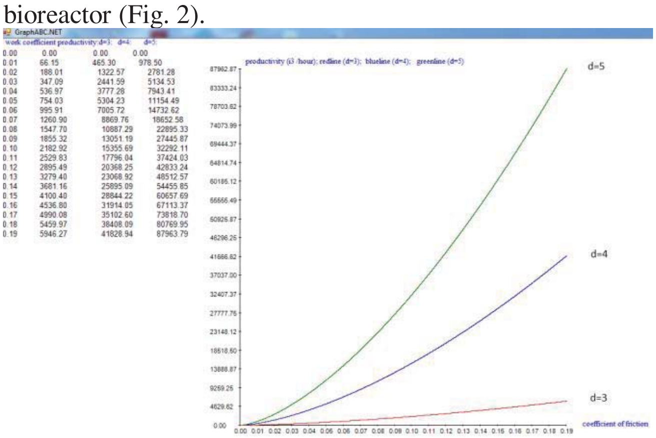
```
Uses graphABC;
type mas=array[1..100000] of real;
var
w,f,u,u0,u3,n:mas;i,y,y2,y3,x,x0,y0,xleft,xright,yleft,yright,
ww,h,k,m : integer;

u3max,u3min,u0max,u0min,u1,num,umin,umax,ki,kt,lq,g,r,
b,a,d,d1,d2,d3,d0,dx,mx,dy,my,u01,u31: real;
  s: string;
procedure pmax(u:mas;varumax,umin:real);
  var k: integer;
  begin
  umin:=u[1];
  umax:=u[1];
   for k:=2 to m do
begin
   if umin>=u[k]
     then umin:=u[k];
   if umax<=u[k]
     then umax:=u[k];
   end;
   end;
begin ww:=1000; h:=700;
  SetWindowSize(Ww, H);
  xLeft:=400;
  yLeft:=50;
  xRight:=ww-50;
  yRight:=H-50;
  g:=0.001; d1:=3; d2:=2.8; d0:=4; d3:=5; kt:=96; r:=d1/2;
lq:=2.7*d1; i:=5000; dx:=0.01/i;
  writeln('work coefficient productivity:d=3:   d=4:
d=5:');
  a:=0; b:=0.19; m:=trunc((b-a)/dx)+1;  ki:=a ;d:=b;
  for k:=1 to round(m/i)+1  do
begin
   f[k]:=ki;
   w[k]:=sqrt(g*f[k]*(1+f[k])/r);
   n[k]:=w[k]/(2*pi);
   u0[k]:=94.2*60*pi*(sqr(d0)-sqr(d2))*n[k]*lq*kt*ki;
   u[k]:=94.2*60*pi*(sqr(d1)-sqr(d2))*n[k]*lq*kt*ki;
   u3[k]:=94.2*60*pi*(sqr(d3)-sqr(d2))*n[k]*lq*kt*ki;
   writeln(ki:4:2,'':10,u[k]:5:2,'':15,u0[k]:5:2,'':10,u3[k]:5:2);
   ki:=ki+dx*i;
   end;
   pmax(u0,u0max,u0min); pmax(u,umax,umin);
pmax(u3,u3max,u3min);
     if u0max>umax
       then if u0max>u3max
       then umax:=u0max
       else umax:=u3max
       else if umax>u3max
       then umax:=umax else umax:=u3max;
   dy:=(umax-umin)/m; mx:=(xRight-xLeft)/(b-a);
my:=(yRight-yLeft)/(umax-umin); x0:=xLeft; y0:=yRight;
line(xLeft,y0,xRight,y0); line(x0, yLeft, x0, yRight);
  SetFontSize(8);  SetFontColor(clBlack);
  TextOut(xRight+15,y0-5,'coefficient of friction');
  TextOut(x0,yLeft-15,' productivity (i3 /hour); redline
(d=3);  blueline (d=4);   greenline (d=5)');
            for    k:=1 to round(m/i)+1  do
begin num:=a+(k-1)*dx*i; x:=xleft+round(mx*(num-a));
   Line(x,y0 -1,x,y0 +1); str(Num:5:2,s);
   TextOut(x-TextWidth(s) div 2,y0+3,s)
end;
```

```
   m:=round((umax-umin)/dy)+1;
   for k := 1 to round(m/i)+1 do
begin num:=umin+(k-1)*dy*i; y:=y0-round(my*(num-umin));
Line(x0-2,y,x0+2,y); str(num:6:2,s);
TextOut(x0-50,y-TextHeight(s)div 2,s);
end;
   ki:=a;  for  k:=1 to m  do
begin f[k]:=ki;  w[k]:=sqrt(g*f[k]*(1+f[k])/r);
n[k]:=w[k]/(2*pi);
u0[k]:=94.2*60*pi*(sqr(d0)-sqr(d2))*n[k]*lq*kt*ki;
u[k]:=94.2*60*pi*(sqr(d1)-sqr(d2))*n[k]*lq*kt*ki;
u3[k]:=94.2*60*pi*(sqr(d3)-sqr(d2))*n[k]*lq*kt*ki;
 u01:=u0[k];    u1:=u[k]; u31:=u3[k];
x:=(xleft+round(ki*mx));
y2:=(yright-round(u01*my));
   if(y2>=yleft) and (y2<=yRight)
    then  setpixel(x+1,y2,clblue); y:=(yright-round(u1*my));
   if(y>=yleft) and (y<=yRight)
    then  setpixel(x+1,y,clred); y3:=(yright-round(u31*my));
   if(y3>=yleft) and (y3<=yRight)
    then  setpixel (x+1,y3,clgreen); ki:=ki+dx
end;
end.
```

Program result has the form:

Mixer performance increases with an increase in the bioreactor (Fig. 2).



The program shows that at mixing in a bioreactor, the optimal mixing speed of the blades is of 3.5 km/h. At the same time, the amount of biogas at the highest mixing rate is 0.48 m^3/day. When the speed changes to 3.5 km/h, the amount of biogas decreases by 15%. The program determines the optimal value of the bioreactor diameter, used in production. With this device, the maximum amount of biogas was produced in the experimental production site located in the Karaulbazar district of the Bukhara region. These data are proved by the Certificate No. 22 of 05/13/2019 of the MChZ “UzZHAMOALOIYKHA”.

IV. Conclusions

The program shows that at mixing in a bioreactor, the optimal mixing speed of the blades is of 3.5 km/h. At the same time, the amount of biogas at the highest mixing rate is 0.48 m^3/day. When the speed changes to 3.5 km/h, the amount of biogas decreases by 15%. The program determines the optimal value of the bioreactor diameter, used in production. With this device, the maximum amount of biogas was produced in the experimental production site located in the Karaulbazar district of the Bukhara region. These data are proved by the Certificate No. 22 of 05/13/2019 of the MChZ “UzZHAMOALOIYKHA”.

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