COMPUTER MODEL FOR BAKERS' YEAST PRODUCTION

By

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ABSTRACT

This paper concerns modelling of fermentation for bakers' yeast (Saccharomyces Cerevisiae) production using sugar cane blackstrap molasses as a feed. The problem constitutes of expressing physical phenomena, mathematically, as function of operating conditions.

The program developed is easy to run and does not cost much in terms of preparations. With this program different operating conditions were tested and results show that available equations are not exhaustive. Thus more research is recommended.

1. INTRODUCTION

Bakers' yeast growth requires carbon source and oxygen as major components. Carbon sources in use are petroleum products e.g. ethylene and agricultural products. Supply of agricultural products is difficult to maintain for they fluctuate with environmental conditions. However, agricultural products are more easily metabolized by microorganisms than the petroleum products. Thus, agricultural products, here sugar cane blackstrap molasses, has been chosen for modelling.

Oxygen is sparsely soluble in fermentation broth and its mass transfer rate is small. The mass transfer coefficient can be improved by using multiple impellers, changing reactors geometry, supplying pure oxygen and increasing agitation speed.

2. Development of the Model

Models of varying degree of complexity do exist. In this paper focus is made on lumped parameter model. This model expresses the specific growth rate as a function of the abiotic medium.

This paper covers only stirred tank reactor which is represented in Fig. 1 and can be run as batch, fed-batch or continuous reactor. The reaction which takes place can be represented, generally as:

$$CH_aO_b + \alpha_1 NH_3 + \beta(+essentialNutrients) \rightarrow y_b CH_cO_dN_e ash + u_d CO_2 + y_w H_2O$$

where a, b, c, d, e are constants.

Mass balance of all models of stirred tank reactor i.e. batch, semi - batch and continuous are as follows :

Cell mass

$$\frac{dX}{dt} = (\mu - \alpha_2)X - D_2X + D_1X_o \qquad (1)$$

Substrate :

$$\frac{dS}{dt} = D_1S_o - D_2S + M_sX - \mu\frac{X}{Y_s} \qquad (2)$$

where

$$D_1 = \frac{F_1}{V} \wedge D_2 = \frac{F_2}{V}$$

for batch operation D_1 $D_2 = 0$, fed-batch $D_1 > 0$, $D_2 = 0$ and for continuous system $D_1 = D_2 > 0$.

Specific growth rate, can be expressed as function of the limiting substrate:

$$\mu = \frac{\mu\max . C_o}{K_o + C_o} \qquad (3)$$

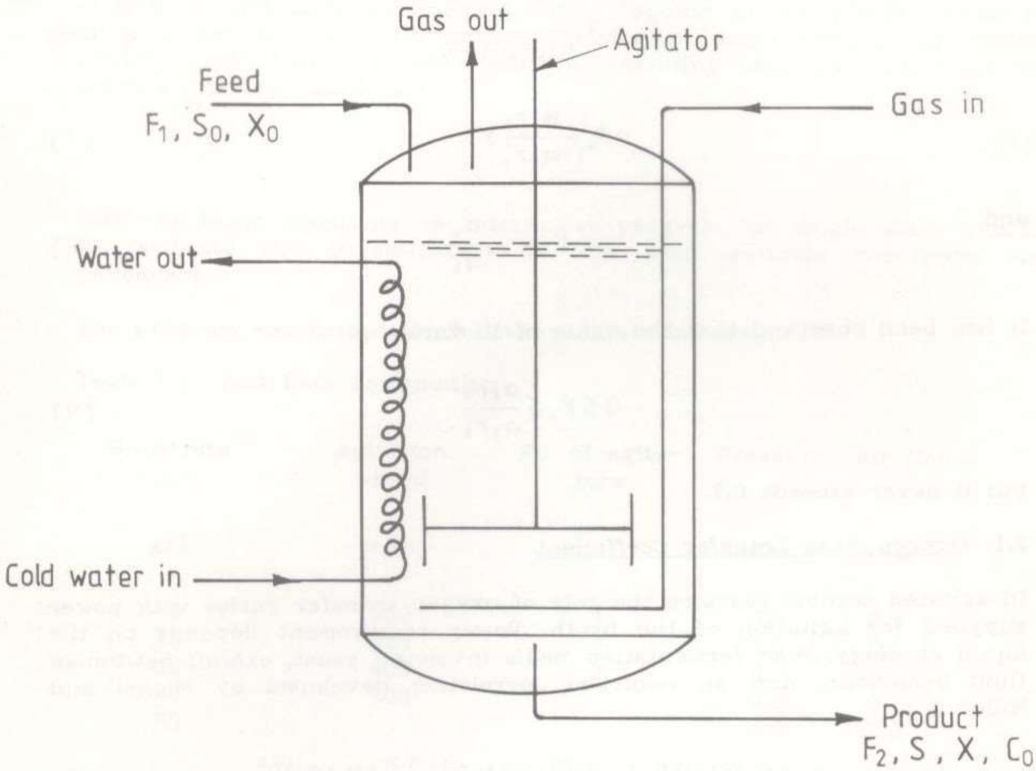

Fig.1 : Stirred Tank Reactor

In aerobic fermentation air stream flows into the reactor to provide the necessary oxygen for growth. The dissolved oxygen is given by the equation below:

$$\frac{dC_o}{dt} = k_L a\left(C*_o - C_o\right) - Q_{o_2} X - D_1 C_o \tag{4}$$

where

$$Q_{o2} = \frac{\mu}{Y_o} + m_o \tag{5}$$

$$Y_o = 3\frac{\theta_b}{2a_b r_b\left(1-\theta_b\right)} \tag{6}$$

$$\theta_b = \frac{a_b r_b}{a_s r_s} Y_s \tag{7}$$

and

$$Y_s = y_b \frac{a_s}{a_b} \tag{8}$$

It has been observed that the value of Y_s varies as

$$0 \le Y_s \le \frac{a_s r_s}{a_b r_b} \tag{9}$$

but it never exceeds 0.7.

2.1 Oxygen Mass Transfer Coefficient

In agitated aerobic reactors the rate of oxygen transfer varies with power supplied for agitation of the broth. Power requirement depends on the liquid rheology. Most fermentation media involving yeast, exhibit Newtonian fluid behaviour. And an empirical correlation developed by Michel and Miller is :

$$p_g = 0.0312P.Fr^{-0.064}\left(Q/ND_i^3\right)^{-0.38}\left(H/D_t\right)^{0.8} \tag{10}$$

where

$$p = N_o D_i^5 N^3 \tag{11}$$

and

$$N_o = 5-6(Oosterhuis\ \ et AL.(1983))$$

A number of correlations for expressing oxygen transfer have been developed. Among them Richards' correlation is adopted for laboratory scale fermenters (6 - 27L) whereas Fukuda - Richards correlation is adopted for pilot scales (100 -42,000L)

$$k_l a = K.\left(\frac{P_g}{V}\right)^{0.4} N^{0.5} V^{0.5} - Richards(1961) correlation \quad (12)$$

$$k_l a = (2.0 + 2.8 Ni)\left(\frac{P_g}{V}\right)^{0.56} V^{0.7} N^{0.4} Fukuda/Richards correlation. \quad (13)$$

2.2 Solubility of Oxygen

Fermentation broth contains a mixture of organic and inorganic solutes. Equilibrium oxygen concentration in such situation can be obtained by log - additive approach (Schumpe (1985), Popovic et AL (1979)). However, since it is very difficult to measure oxygen concentration analytically, activity coefficient is measure instead. Assuming ideal gas conditions the solubility is expressed as :

$$C_o^* = \frac{M_g P_o}{RT} P_a \quad (14)$$

With the basic equations an interactive program for single stage reactor to facilitate the investigation on the most suitable conditions was developed.

The program. was tested for following data combinations :

Table 1 : Test Data Combination

Substrate Conc.	Agitation speed	No. of agita-tors	Pressure	Air flow
g/1	rpm	-	Bar	VVm
5	200	1	1.1	0,2
10	300	2	2.0	0,5
20	400	3	3.0	
40	500		4.0	0.7
60			5.0	1,0

3. MODELLING RESULTS AND DISCUSSION

The results are shown in figures 2 - 5.
In Fig. 2 it can be seen that the mass transfer coefficient increases with number of impellers for Fukuda/Richards correlation whereas Richards correlation shows no effect. Number of Impellers however, is limited by liquid height. And an economical maximum in use is 3 impellers.

Fig. 3 shows that increase in agitation speed favours mass transfer as this increase turbulence. Effectiveness of mixing, however, varies with type of agitator. Thus further investigations and establishment of equations for various types of agitators are called for.

Increase in inlet air flowrate favours mass transfer coefficient as shown in Fig. 4. Nevertheless, restriction must be made to avoid flooding.

Availability of oxygen for bioprocess is highly affected by the pressure of the inlet air. Increase in the air pressure increase the oxygen depletion time and biomass yield as shown in Fig. 5. Since fermenters are operated at ambient pressure then increase in inlet air pressure will diminish residence time of the gas in the reactor thus decreasing oxygen mass transfer. Alternatively, pure oxygen has to be used. And it might be worth investigating the feasibility of fermentation in pressure vessels.

CONCLUSION

With above remarks it can be concluded that:

- Oxygen transfer is very small especially if air is supplied. Growth stops the moment oxygen concentration becomes lower than biomass demand.
- Existing mass transfer equations are not exhaustive. As such different types of agitators for example, cannot be tested for suitability. Hence more research on such lines is required.
- Specific death rates as expressed by Arrhenius equation, does not take into account the effect of limiting nutrient concentration. Hence it looks unrealistic.

Reference

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NOMENCLATURE

a_b	weight fraction of carbon in organic substrate	–
a_s	weight fraction of acarbon in biomass	–
C_o	Oxygen Concentration	kg/m^3
D_1,D_2	Dilution rate	h^{-1}
D_i	Diameter of Impeller	m
F_1,F_2	Volumetric Flowrate of liquid phase	m^3h^{-1}
F_r	Froude number	–
H	Height of liquid	m
k_La	overall mass transfer Coefficient	kg $m^{-3}h^{-1}at\ m^{-1}$
K	Constant	–
K_o	Saturation Constant for Monod kinetic model	kg m^{-3}
m^o	Maintenance Coefficient based on oxygen	gmol O_2(g biomass.h)$^{-1}$
m_s	Maintenance Coefficient based on substrate	g substrate(g biomass.h)$^{-1}$
M^g	Molecular weight of gas	gmol
N	Impeller speed	rpm
Ni	Number of Impeller	–
N_o	Power Number	–
P	Non-gassed Power Supply	W
P_g	Gassed power	W
P_o	Partial Pressure of Oxygen	P_a
Q	Volumetric gas Flowrate	m^3h^{-1}
Q_{o2}	Specific Rate of Oxygen Consumption	gmol O_2(g biomass.h)$^{-1}$
r_b	Reduction potential of organic substrate	–
r_s	Reduction potential of biomass	–
R	Universal Gas Constant	kJ(kmol.K)$^{-1}$
Re	Reynolds Number	–
S	Organic substrate concentration	kg m^{-3}
S_o	Substrate concentration in feed medium	kg m^{-3}
t	Time h; temperature	°C
T	Temperature	°K
V	Fermenter Volume	m^3
X	Biomass concentration	kg m^{-3}
X_o	Biomass concentration in the feed medium	kg m^{-3}
y_b	Biomass stoichiometric constant	–
Y_o	Biomass yield based on oxygen	g biomass(g mol O_2)$^{-1}$
Y_s	Biomass yield based on substrate	g biomass(g substrate)$^{-1}$

Greek Letters

α_1	Stoichiometric coefficient	mol
α_2	Specific growth rate	h-1
μ	Specific growth rate h^{-1}; Viscosity	cP
θ_b	Constant	-
β	Stoichiometric coefficient	mol

Superscripts

*Equilibrium concentration

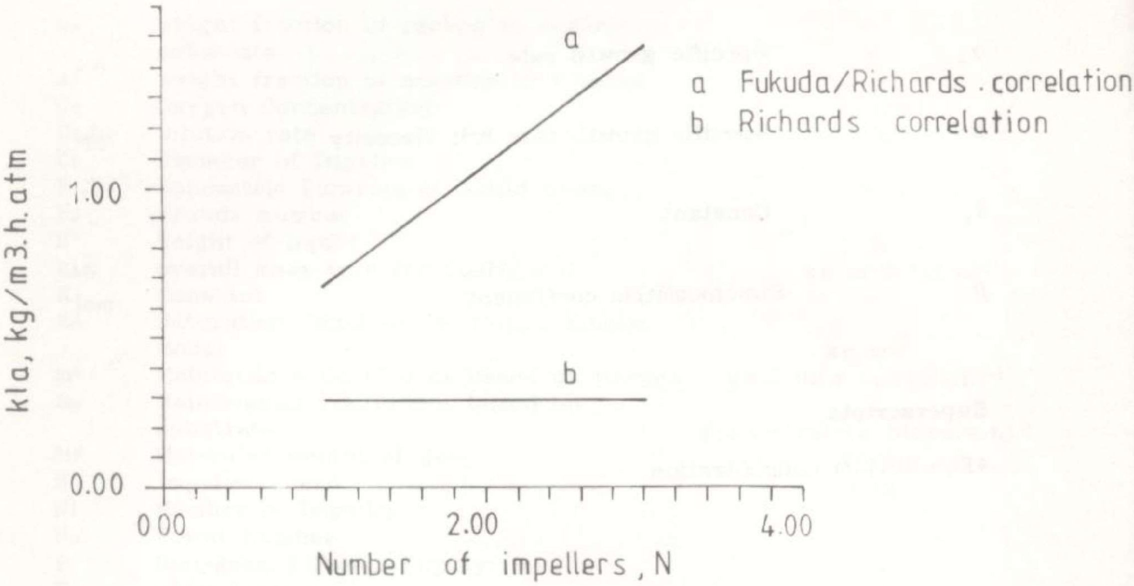

Fig 2 Effect of Numberof Impellers on the Mass Transfer Coefficient

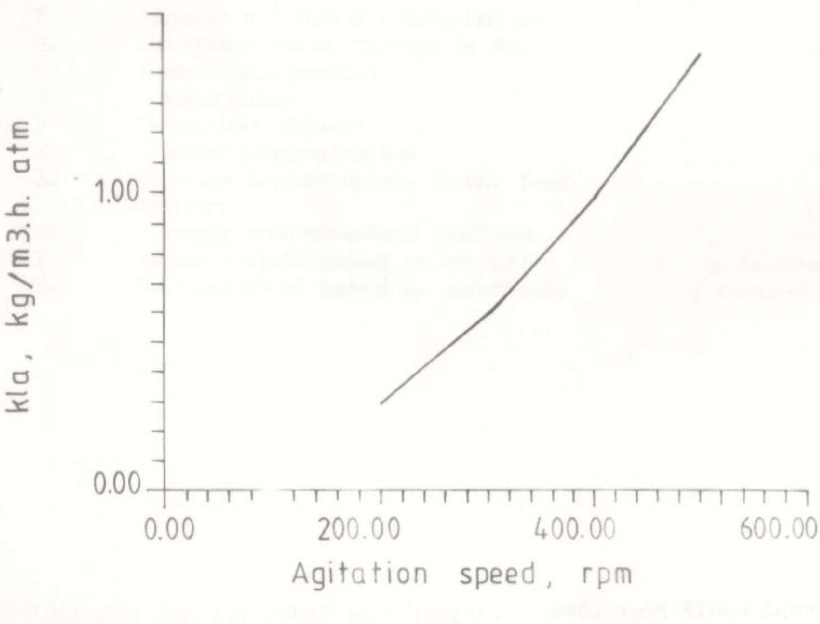

Fig 3 Effect of Agi tion Speed on Mass Transfer Coefficient

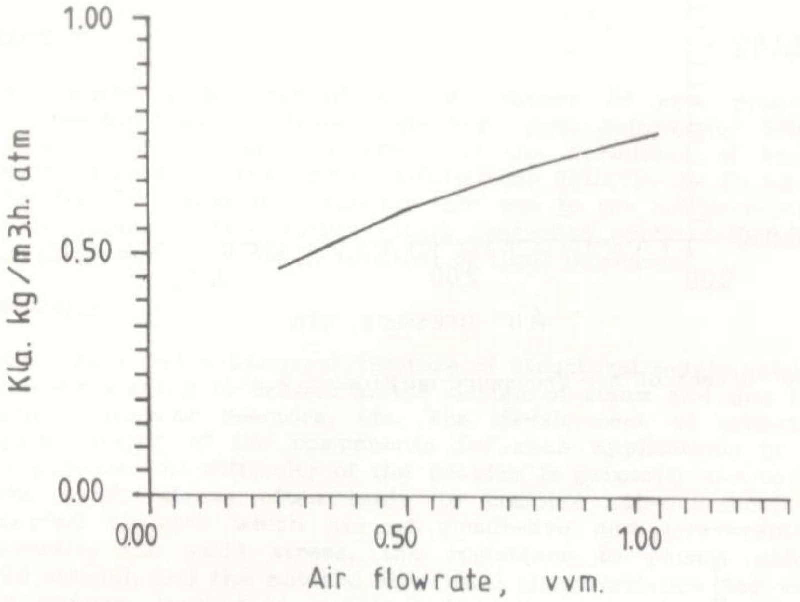

Fig. 4 Effect of Air Flowrate on Mass Transfer Coefficient.