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Analysis of Kinetic and Operational Parameters in a Structured Model for Acrylic Acid Production through Experimental Design

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Abstract In biotechnological processes, a great number of factors can influence the income productivity and conversion. Normally, it is not evident which of these factors are the most important and how they interact. In this work, multivariate analysis techniques are used as experimental design coupled to a detailed deterministic model to identify the parameters with the most significant impact on the model to represent well the acrylic acid production process. It is proposed as an alternative process, having sugarcane as feedstock, to the petrochemical-based ones that have significant environmental impacts for their production. To increase the competitiveness of renewable acrylic-acid-based process, it is necessary to find out working conditions near the optimal region, which is not an easy task, as the process is multivariable and non-linear. The mapping of the dynamics of the developed process is made using techniques of factorial design together with the methodology of Plackett–Burman. It is shown that it is possible to increase the process performance by choosing optimized conditions for the reactor operation.

Keywords Experimental design · Plackett–Burman design · Factorial design · Biotechnological process · Acrylic acid · Structured model

Nomenclature

AA	acrylic acid concentration
D_{Ai}	diffusivity
D_{az}	axial dispersion coefficient
D_p	particle diameter
D_r	reactor diameter
F_{in}	feed rate
k	factors number
K_A, $K_{A''}$	inhibition constant related with the product
k_i	rate constant for reaction

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K_i	affinity constant
K_{ji}	inhibition constant
L	reactor length
p	level of fractionation
R_i	reaction rate
S_i	extracellular concentration
S_{in}	feed glucose concentration
u	superficial velocity
X_{in}	feed biomass concentration
X_i	active cell material
X_{LADH}	lactate dehydrogenase
ε	porosity
η	effectiveness factor

Introduction

In biotechnological process, a great number of factors can influence income, productivity, and conversion. Normally, it is not evident which of these factors are the most important and how they interact. This knowledge are important in an early design stage so that better process can be developed especially in terms of high production and lower environmental impact and also to define suitable operating strategies. A way to do this is to use multivariate analysis techniques as experimental design coupled to a detailed model so that several operation scenarios may be investigated. A central point in this exercise is to have a good process model, and in this sense, the knowledge of the kinetic parameters is essential.

Design of experiments is a powerful technique used for discovering a set of process factors that are most important to the process and then determine at what levels these factors must be kept to optimize the process performance [1].

This work presents an analysis of kinetic parameters, used in a dynamic structured model for the acrylic acid production process. Through this procedure, it was possible to identify the parameters with the most significant impact on the model to represent well the process of acrylic acid production.

First, an experimental design was performed to identify the key kinetics parameters that affect the response of interest (acrylic acid concentration in the steady state). For identification of these parameters, the methodology Plackett–Burman was used.

Plackett–Burman [2] is a tool for this initial screening, as it makes it possible to determine the influence of various factors with only a small number of trials, instead of using more extensive factorial design, which would furnish more complete information but which involves unfeasible complexity.

After identifying the key kinetics parameters, a full factorial was applied to identify and quantify the interactions among the key parameters and to understanding how these interactions take place. To identify the effects of the operational parameters on the acrylic acid production, a fractional factorial was applied.

Mathematical Modeling

A deterministic mathematical model for simulating the biotechnological synthesis of acrylic acid was developed in a previous study [3] to explore an alternative process. The proposed

process makes it possible to obtain acrylic acid continuously from the sugarcane fermentation. The reactor is continuously operated, and the challenge is to define operating strategy and conditions to achieve the product within the desired specifications. The kinetic model is based on the concepts of structured representation and adapted from a structured growth model developed by Lei et al. [4] and a structured model for ethanol production developed by Stremel [5].

A continuous bioreactor type plug flow reactor (PFR) with immobilized cell of *Saccharomyces cerevisiae* in spherical particle was used in the work to take into account the variations of concentrations at the reactor length and inside spherical particle.

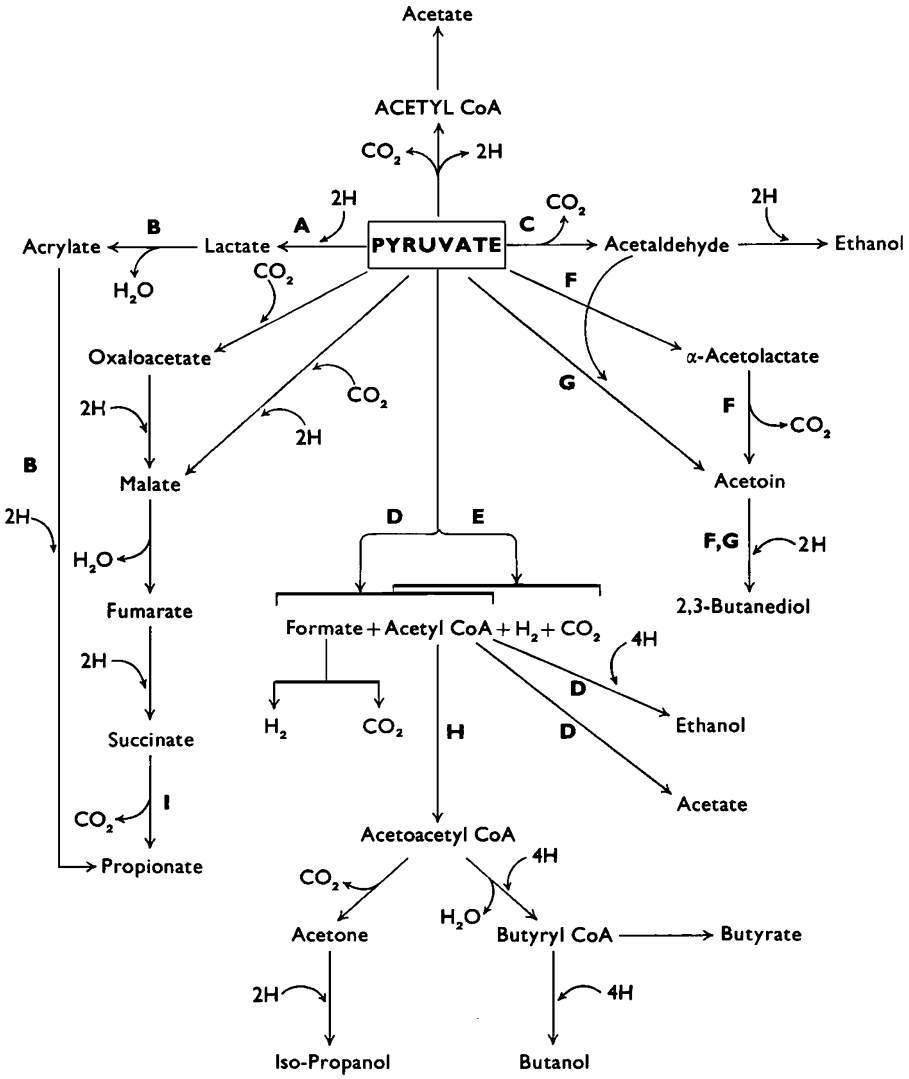


Fig. 1 Glycolytic route. Pyruvate formed by catabolism of glucose is further metabolized by pathways, which are characteristic of particular organism (see [7])

In *S. cerevisiae*, the major flux of pyruvate metabolism is to ethanol, by way of pyruvate decarboxylase and alcohol dehydrogenase. Providing an alternative route for regenerating NAD^+ through lactate dehydrogenase, which catalyzes the reduction of pyruvate to lactate, can theoretically replace ethanolic fermentation [6].

The bioreactor behavior is based on mass balances for the key chemical species of the fermentative process. The reaction stoichiometric considered was

$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{lactate}}{2C_3H_6O_3}$$

$$\underset{\text{lactate}}{C_3H_6O_3} \rightarrow \underset{\text{acrylic acid}}{C_3H_4O_2 + H_2O}$$

Figure 1 shows the scheme of the metabolic pathway for obtaining the acrylic acid. Several parallel and consecutive reactions take place and are necessary to find out operating conditions, which allow the desired product to be obtained.

Figure 2 shows a representative metabolic route involved in the process of acrylic acid production and also the reaction rates (see Table 1).

Table 1 shows the reaction rates used in the mathematical model and the kinetic parameters that are analyzed in this work.

The reaction rate (R_1) describes the glucose uptake and glycolytic pathway, and it is represented by two Michaelis–Menten equations [4].

R_2 represents the cell growth (biomass formation) from glucose with inhibition by lactate. The biomass formed is converted into active cellular material. The reaction rates (R_3) and (R_4) describe the lactate and acrylic acid formation, respectively.

Equation (R_5) corresponds to the biomass formation from lactate, where a glucose inhibition term is included in the equation. Equation (R_6) describes the formation of lactate dehydrogenase from active component in the cell material (X_a). An acrylic acid inhibition term was added in this equation. Equation (R_7) shows the degradation rate of the active compartment and depends of the glucose and acrylic acid present in the medium. These reaction rates and the kinetic parameters values were obtained from Lei et al. [4] and modified to describe the acrylic acid production process.

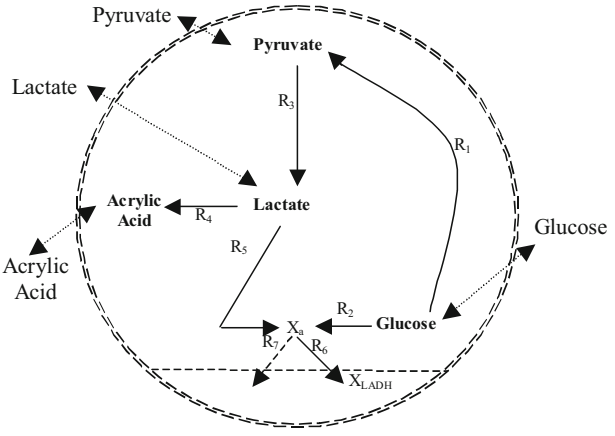


Fig. 2 Representative metabolic route

Table 1 Reaction rates.

Reactions
$R_1 = k_1 \frac{S_{\text{glucose}}}{S_{\text{glucose}}+K_1} X_a + k_{1a} \frac{S_{\text{glucose}}}{S_{\text{glucose}}+K_{1a}} X_a$
$R_2 = k_2 \frac{S_{\text{glucose}}}{S_{\text{glucose}}+K_2} \frac{1}{1+\left(\frac{S_{\text{lactate}}}{K_{2i}}\right)} X_a$
$R_3 = k_3 \frac{S_{\text{pyruvate}}}{S_{\text{pyruvate}}+K_3} X_a$
$R_4 = k_4 \frac{S_{\text{lactate}}}{S_{\text{lactate}}+K_4} X_a$
$R_5 = k_5 \frac{S_{\text{lactate}}}{S_{\text{lactate}}+K_5} \left(\frac{1}{1+K_{5i}S_{\text{glucose}}}\right) X_a$
$R_6 = k_6 \left(\frac{S_{\text{glucose}}}{S_{\text{glucose}}+K_6} + \frac{S_{\text{lactate}}}{S_{\text{lactate}}+K_{6a}}\right)\left(\frac{1}{K_{6i}S_{\text{acrylic acid}}+1}\right) X_a$
$R_7 = \left(k_7 \frac{S_{\text{glucose}}}{S_{\text{glucose}}+K_7} + k_{7a} \frac{S_{\text{acrylic acid}}}{S_{\text{acrylic acid}}+K_{7a}}\right) X_a$

Table 2 Mass balance for fluid and solid phase.

Reactions
Fluid phase
$\frac{\partial S_{\text{glucose}}}{dt} = D_{az}\left(\frac{\partial^2 S_{\text{glucose}}}{\partial z^2}\right) - u\left(\frac{\partial S_{\text{glucose}}}{\partial z}\right) + \frac{1-\varepsilon}{\varepsilon}\eta\left[(R_1 - R_2)_e^{-K_A S_{\text{acrylic acid}}} X\right]$
$\frac{\partial S_{\text{pyruvate}}}{dt} = D_{az}\left(\frac{\partial^2 S_{\text{pyruvate}}}{\partial z^2}\right) - u\left(\frac{\partial S_{\text{pyruvate}}}{\partial z}\right) + \frac{1-\varepsilon}{\varepsilon}\eta\left[(0.978R_1 - R_3)_e^{-K_A S_{\text{acrylic acid}}} X\right]$
$\frac{\partial S_{\text{lactate}}}{dt} = D_{az}\left(\frac{\partial^2 S_{\text{lactate}}}{\partial z^2}\right) - u\left(\frac{\partial S_{\text{lactate}}}{\partial z}\right) + \frac{1-\varepsilon}{\varepsilon}\eta\left[(1.023R_3 - R_4 - R_5)e^{-K_A S_{\text{acrylic acid}}} X\right]$
$\frac{\partial S_{\text{acrylic acid}}}{dt} = D_{az}\left(\frac{\partial^2 S_{\text{acrylic acid}}}{\partial z^2}\right) - u\left(\frac{\partial S_{\text{acrylic acid}}}{\partial z}\right) + \frac{1-\varepsilon}{\varepsilon}\eta\left[(0.8R_4 - R_7)e^{-K_A S_{\text{acrylic acid}}} X\right]$
Solid phase
$\frac{\partial S_{\text{glucose}}}{\partial t} = \frac{D_{Ag}}{R^2}\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial S_{\text{glucose}}}{\partial r}\right) + (R_1 + R_2)_e^{-K_A S_{\text{acrylic acid}}} X$
$\frac{\partial S_{\text{pyruvate}}}{\partial t} = \frac{D_{Ap}}{R^2}\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial S_{\text{pyruvate}}}{\partial r}\right) + (0.978R_1 - R_3)_e^{-K_A S_{\text{acrylic acid}}} X$
$\frac{\partial S_{\text{lactate}}}{\partial t} = \frac{D_{Al}}{R^2}\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial S_{\text{lactate}}}{\partial r}\right) + (1.023R_3 - R_4 - R_5)_e^{-K_A S_{\text{acrylic acid}}} X$
$\frac{\partial S_{\text{acrylic acid}}}{\partial t} = \frac{D_{Aaa}}{R^2}\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial S_{\text{acrylic acid}}}{\partial r}\right) + (0.8R_4 - R_7)_e^{-K_A S_{\text{acrylic acid}}} X$
$\frac{\partial X}{\partial t} = (0.732R_2 - 0.821R_5)X\left(1 - \frac{X}{X_{sat}}\right) e^{-K_A{}'' S_{acrylic\ acid}} - k_d X$
$\frac{\partial X_a}{\partial t} = (0.732R_2 - 0.821R_5 - R_6 - R_7) - (0.732R_2 + 0.821R_5)X_a$
$\frac{\partial X_{\text{LADH}}}{\partial t} = R_6 - (0.732R_2 + 0.821R_5)X_{\text{LADH}}$

The model consists of a set of partial differential equations describing the acrylic acid, lactate and pyruvate production, cellular growth, and glucose consumption (see Table 2).

Table 2 shows the mass balance of the main components of the process in the fluid and solid phase. The whole set of equations is solved coupling the Orthogonal Collocation Method to discretize the radial ordinates with the Method of Lines to integrated the system of equations by a stiff integrator. This work is only a theoretical study, as a predictive tool, and all presented data were simulated.

Experimental Design and Results

In the development of new process and product, the number of potential factor or variables is often excessively large. Experimental design are useful to reduce the number of variable to a manageable size so that further experiments can be performed using these key variables for a better understanding of the process/product [1].

A large number of kinetics parameters are involved in the definition of the best operating conditions to achieve the acrylic acid, taking into account all others possible products. Bearing this in mind, 24 parameters are chosen as necessary to be investigated to produce acrylic acid.

For studying such 24 kinetic parameters, Plackett–Burman design with 32 runs and 31 degrees of freedom was selected. The different parameters (variables) were prepared in two

Table 3 Kinetic parameters used in the experimental design and their levels.

Parameters	Values	
	Low level (−1)	High level (+1)
k_1	1.92	2.88
k_{1a}	0.4672	0.7008
k_2	2.64	3.96
k_3	4.16	6.24
k_4	3.40	5.10
k_5	0.96	1.44
k_6	0.024	0.036
k_7	0.032	0.048
k_{7a}	0.0032	0.0048
K_1	0.0008	0.0012
K_{1a}	0.00928	0.01392
K_2	2.32	3.48
K_3	2.56	3.84
K_4	1.68	2.52
K_5	1.88	2.82
K_6	1.56	2.34
K_{6a}	10.40	15.60
K_7	0.016	0.024
K_{7a}	0.00072	0.00108
K_{2i}	0.072	0.108
K_{5i}	1.584	2.376
K_{6i}	2.0	3.0
K_A[a]	0.072	0.108
$K_{A''}$[a]	0.152	0.228

[a] The parameters K_A and $K_{A''}$ do not appear in Table 1, but they are included in the mass balance realized inside of the particle (see Table 2).

levels, (−1) for low level and (+1) for high level. Seven dummy variables are used to estimate the standard error during analysis of data. The kinetic parameters analyzed in this study and their levels (low and high) are shown in Table 3. The values shown in Table 3 were obtained through simulation realized in the process model of acrylic acid production.

Statistica software was used to generate the matrix of the parameters values and simulation program based on a detailed model described in "Mathematical Modeling", written in Fortran language, was used to generate the desired process response. The simulations were conducted according to the 32-run Plackett–Burman design for the 24 kinetic variables, specified in Table 3. Each simulation (test) generates a result of acrylic acid concentration in the steady state (desired response).

The Pareto chart (Fig. 3) was used for identifying which estimated effects are the most important in the rote to obtain acrylic acid and to identify possible interaction effects showed later on.

Figure 3 depicts that of the 24 parameters analyzed, 10 parameters, K_A (inhibition constant by product), $K_{A'}$ (inhibition constant by product related with cell), $k_{1,}$ k_{1a}, k_2, k_4 (specifics reaction rates), K_3, K_4, K_5 (affinity constants), and K_{5i} (inhibition constant) were statistically significant for acrylic acid concentration at 99% of confidence level (the dot line is the reference). These results also can be visualized in Table 4, where the results of the analysis of variance (ANOVA) for the 32-run Plackett–Burman design are shown.

As the number of significant parameters identified in the first experimental design is high, a new Plackett–Burman design was chosen to screen the most significant parameters between the ten parameters identified before.

For this study, a Plackett–Burman design with 16 runs and 15 degrees of freedom was selected. Pareto chart (Fig. 4) was used for show the obtained results.

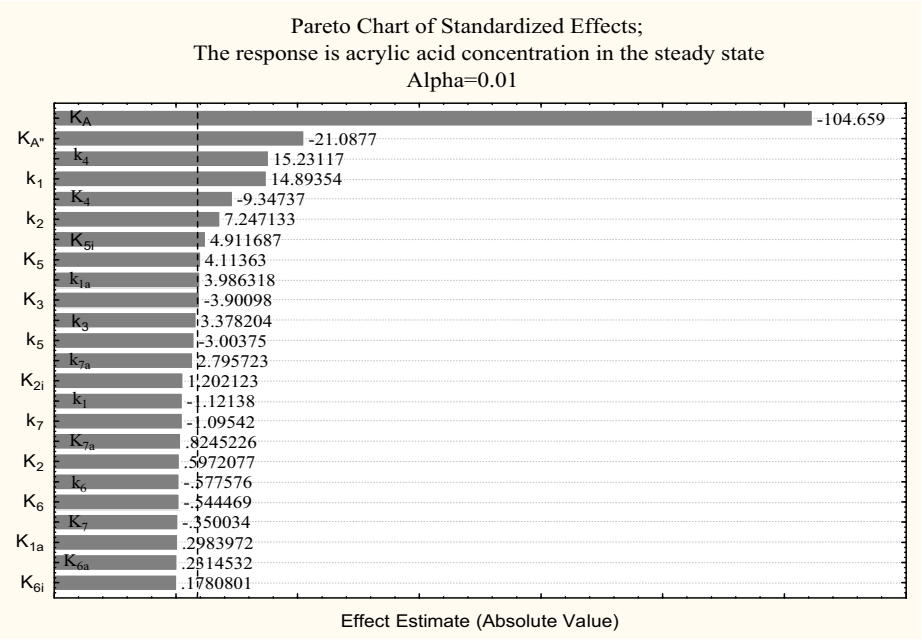


Fig. 3 Pareto chart of effects for acrylic acid concentration from 32-run Plackett–Burman design

Table 4 The results of the ANOVA for 32-run Plackett–Burman design.

Factor	Sum of squares	*df*	Mean square	*F* value	*p* value
k_1[a]	19.6748	1	19.6748	221.82	0.000001
k_{1a}[a]	1.385	1	1.3845	15.89	0.005281
k_2[a]	4.576	1	4.576	52.52	0.000170
K_3	0.994	1	0.994	11.41	0.01179
k_4[a]	20.213	1	20.213	231.99	0.000001
K_5	0.786	1	0.786	9.02	0.019837
K_6	0.0291	1	0.0291	0.33	0.58164
K_7	0.105	1	0.105	1.20	0.309583
K_{7a}	0.6810	1	0.6810	7.82	0.02669
K_1	0.110	1	0.1096	1.26	0.29912
K_{1a}	0.008	1	0.008	0.09	0.774063
K_2	0.031	1	0.0311	0.36	0.569174
K_3[a]	1.326	1	1.326	15.22	0.005891
K_4[a]	7.613	1	7.613	87.37	0.000033
K_5[a]	1.474	1	1.474	16.92	0.004495
K_6	0.026	1	0.026	0.30	0.60302
K_{6a}	0.005	1	0.005	0.05	0.82358
K_7	0.011	1	0.011	0.12	0.736609
K_{7a}	0.059	1	0.059	0.68	0.43683
K_A[a]	954.344	1	954.344	10953.43	0.00000
$K_{A''}$[a]	38.745	1	38.745	444.69	0.00000
K_{2i}	0.126	1	0.126	1.45	0.2684
K_{5i}[a]	2.102	1	2.102	24.12	0.001730
K_{6i}	0.003	1	0.003	0.03	0.863704
Error	0.610	7	0.0871		

[a] Significant parameters

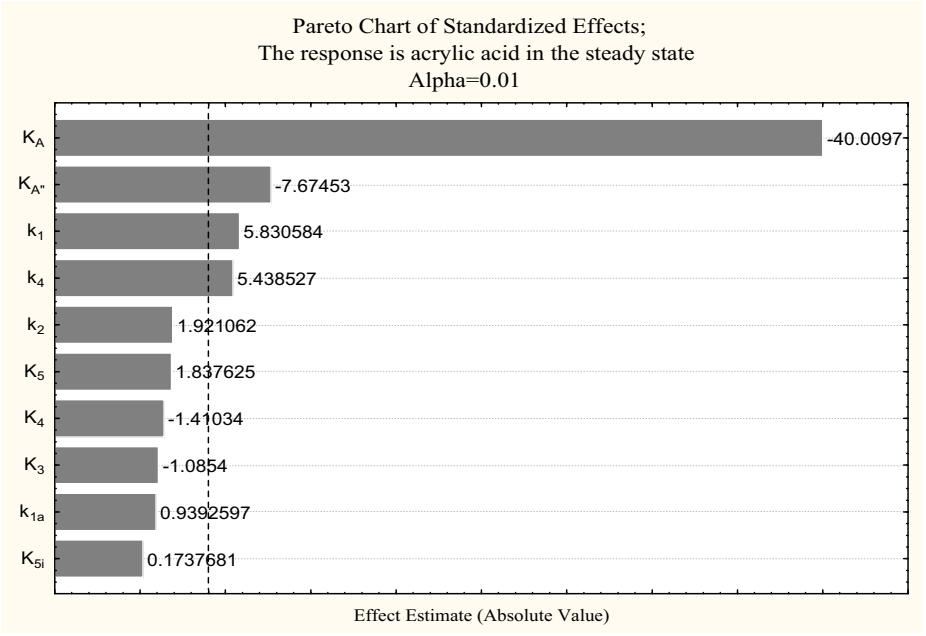


Fig. 4 Pareto chart of effects for acrylic acid concentration from 16-run Plackett–Burman design

Table 5 Coded units of parameters and response obtained from 2^4 full factorial design.

Test	Parameters				Response AA
	k_1	k_4	K_A	$K_{A''}$	
1	−1	−1	−1	−1	45.7547
2	1	−1	−1	−1	47.1526
3	−1	1	−1	−1	47.1336
4	1	1	−1	−1	49.4629
5	−1	−1	1	−1	35.5647
6	1	−1	1	−1	36.1339
7	−1	1	1	−1	36.9125
8	1	1	1	−1	37.9857
9	−1	−1	−1	1	43.7080
10	1	−1	−1	1	45.3416
11	−1	1	−1	1	44.8187
12	1	1	−1	1	47.4619
13	−1	−1	1	1	33.0871
14	1	−1	1	1	34.0245
15	−1	1	1	1	34.1258
16	1	1	1	1	35.6197

Figure 4 depicts that of the ten parameters analyzed, four parameters, K_A (inhibition constant by product), $K_{A'}$ (inhibition constant by product related with cell), k_1, and k_4 (specifics reaction rates) were statistically significant for acrylic acid concentration at 99% of confidence level. After identifying the key parameters, a full factorial design (2^k) was

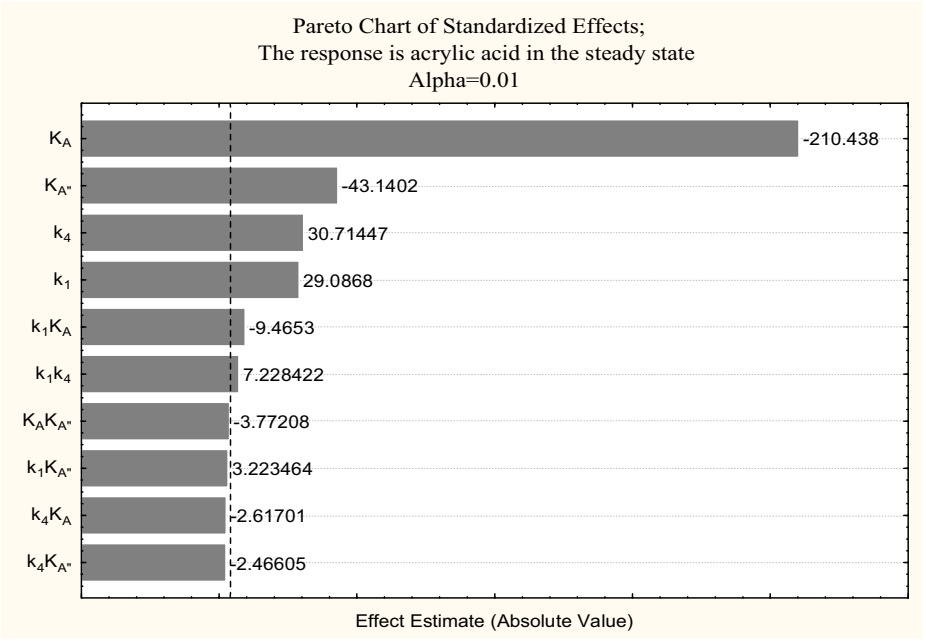
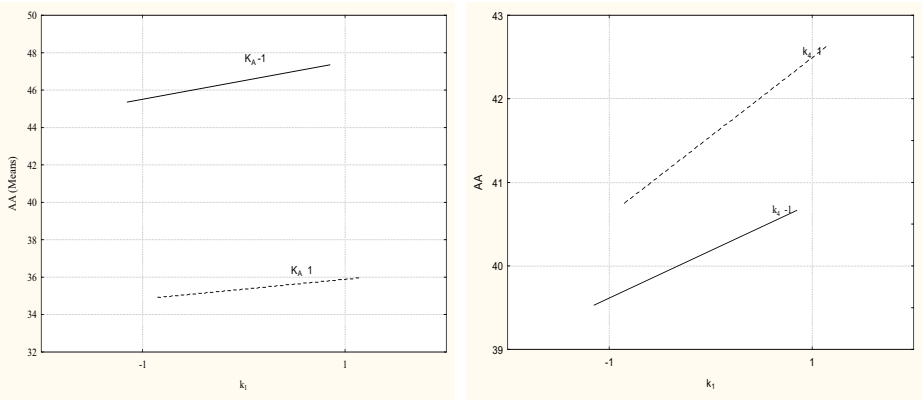


Fig. 5 Pareto chart of effects for acrylic acid concentration, from full factorial design (2^4)



a Interaction between k_1 and k_4 **b** Interaction between k_1K_A

Fig. 6 **a** Influence of the interactions between k_1 and k_4 in the acrylic acid concentration (mean value). **b** Influence of the interactions between k_1 and K_A in the acrylic acid concentration (mean value)

used to identify and to quantify the possible interactions among the key parameters. The understanding of such interactions is very important to achieve high conversion in the desired product and can be used for instance to design an optimum substrate besides the definitions of suitable operating conditions to met the objective (acrylic acid production). To do this, a full factorial design of two-level (2^4) coupled to the detailed process model was used. Four variables (k_1, k_4, K_A, and $K_{A''}$) in 16 runs were investigated in this design stage. Table 5 shows the coded units of parameters and the obtained response in each simulation (column 6). The obtained results from the 2^4 full factorial design was shown in the Pareto chart (Fig. 5).

Figure 5 also depicts that all the key parameters (k_1, k_4, K_A, and $K_{A''}$) and two interactions (k_1k_4 and k_1K_A) are statistically significant at 99% confidence level.

Figure 6a shows interaction plot between (k_1) and ($K_{A)}$. Through the chart, it is possible to realize that the effect of ($k_{1)}$ in the response (acrylic acid concentration in the steady state) is different at different levels of ($K_{A)}$. The maximum acrylic acid concentration is

Table 6 The results of the ANOVA for 2^4 full factorial design.

Factor	Sum of squares	*df*	Mean square	Coeff. estimate	*F* value	*p* value
k_1[a]	9.1170	1	9.1170	0.75486	846.04	0.000001
k_4[a]	10.1659	1	10.1659	0.79720	943.38	0.000001
K_A[a]	477.2062	1	477.2062	−5.46126	44384.11	0.000000
$K_{A''}$[a]	20.0555	1	20.0555	−1.11957	1861.08	0.000000
k_1k_4[a]	0.5630	1	0.5630	0.18759	52.25	0.000791
k_1k_A[a]	0.9654	1	0.9654	−0.24564	89.59	0.000222
$K_1k_{A''}$	0.1120	1	0.1120	0.08366	10.39	0.023375
K_4k_A	0.0738	1	0.0738	−0.06792	6.85	0.047268
$K_4K_{A''}$	0.0655	1	0.0655	−0.06406	6.08	0.056805
$K_AK_{A''}$	0.1533	1	0.1533	−0.09789	14.23	0.012995
Error	0.0539	5	0.0108	Mean=40.8930		

[a] Significant parameters

Table 7 Operational and design parameters used in the experimental design and their levels.

Parameters	Values	
	Low level (−)	High level (+)
S_{in}	80	120
F_{in}	0.032	0.048
X_{in}	16	24
D_p	0.024	0.036
D_r	0.4	0.6
L	1.6	2.4

achieved when the ($k_{1)}$ is high and ($K_{A)}$ value is low. Figure 6b shows an interaction plot between (k_1) and (k_4). Through this figure, it is possible to visualize that the maximum acrylic acid concentration is achieved when (k_1) and (k_4) value is high. This can be used to guide the operator in the search for operating conditions and to design the substrate. Furthermore, this information can be used to have insights on how possible changes in the microorganism genetics should be made to potentialize the acrylic acid production. In Table 6, the results of the ANOVA for the 2^4 full factorial designs are shown.

To analyze the operational parameters used in the acrylic acid production process, a fractional factorial design of two-level (2^{k-p}) with two level of fractionation was used. In this experimental design, six variables (S_{in}, F_{in}, X_{in}, D_p, D_r, and L) were investigated in 16 runs. The values of such parameters are shown in Table 7, whereas Table 8 depicts the coded units of parameters and the obtained response in each simulation (column 8). The obtained results are shown in Pareto chart (Fig. 7).

As can be seen through the analyses of Fig. 7, it is possible to observe that the parameters, F_{in} (feed rate), X_{in} (feed biomass concentration), D_r (reactor diameter), and L (reactor length) are statistically significant at 99% confidence level. Two first variables are possible to be used as operating variables, but the last two (reactor diameter and length) are design variables that have to be chosen in a early design stage. If this investigation is not

Table 8 Coded units of parameters and response obtained from 2^{6-2} fractional factorial design.

Test	Parameters						Response
	S_{in}	F_{in}	X_{in}	D_p	D_r	L	AA
1	−1	−1	−1	−1	−1	−1	34.2994
2	1	−1	−1	−1	1	−1	41.2667
3	−1	1	−1	−1	1	1	42.1471
4	1	1	−1	−1	−1	1	34.9833
5	−1	−1	1	−1	1	1	47.6661
6	1	−1	1	−1	−1	1	40.4901
7	−1	1	1	−1	−1	−1	32.4330
8	1	1	1	−1	1	−1	39.6531
9	−1	−1	−1	1	−1	1	37.8220
10	1	−1	−1	1	1	1	45.2582
11	−1	1	−1	1	1	−1	36.9228
12	1	1	−1	1	−1	−1	30.8105
13	−1	−1	1	1	1	−1	42.6191
14	1	−1	1	1	−1	−1	35.2548
15	−1	1	1	1	−1	1	36.0530
16	1	1	1	1	1	1	43.7811

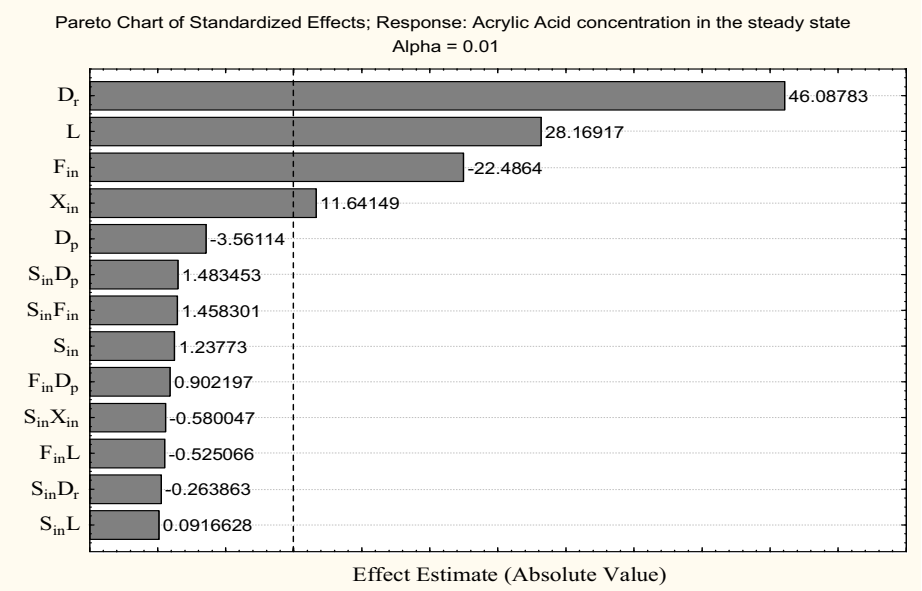


Fig. 7 Pareto chart of effects of initial and operation conditions from fractional factorial design (2^{6-2})

carried out, it is possible to have a process with lower operational performance, as changes in the operational may not be enough to drive the process to high operational performance. At this point, it is worthwhile to mention that the economical success of this alternative acrylic acid production process depends upon the achievement of high concentrations, as the downstream operations are complex and expensive, and the conventional process, even environmentally aggressive, are well established nowadays.

Through these experimental designs, it is possible to identify the optimal values of the parameters to increase the acrylic acid concentration from biotechnological process (inside of value range established for this process). Table 9 shows the optimal condition settings of factors.

Conclusions

In this work, the kinetics and operational parameters used in the acrylic acid production from biotechnological process were analyzed, bearing in mind that high operational

Table 9 Optimal values for analyzed parameters.

Factors	Optimal level
K_1	2.88
K_4	5.10
K_A	0.072
$K_{A''}$	0.152
F_{in}	0.032
X_{in}	24
D_r	0.6
L	2.4

performance are required to become this alternative process competitive with the well-established conventional ones. The appeal of the environmental less aggressive and renewable feedstock-based process is, nowadays, a target to be met; however, economical considerations have to be made. This is an issue that can be suitably dealt with through simulation tools as has been extensively made in other industry (as car makers using computational fluid dynamics to find out the best vehicle design). In this work, a procedure was proposed and used based on the experimental design that allows designing and operating the alternative process to obtain acrylic acid. This was made in two stages. First, using the methodology of Plackett–Burman design, it was possible to evaluate the kinetic parameters and identify the parameters that have significant impact in the acrylic acid production process.

Later on, through fractional factorial design, the operational parameters with a significant impact in the process were identified. In addition, it was possible to identify the optimal values for kinetic and operational parameters. The optimal values of such parameters identified in these experimental designs are able to drive the process to maximize the acrylic acid concentration.

The acrylic acid synthesis from fermentative process is a recent subject with very few works published in the literature without conclusive kinetic data of the process. Therefore, it is valuable to identify the effect of the kinetic parameters values to trace guidelines to process design and operation and to gain some insights on how genetic modifications should be made in the microorganism to met specific objectives, in this case, to enhance the acrylic acid conversion. Besides that, extensive simulation can be made allowing an understanding of the process features, which is useful to take decisions at an early design stage.

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