

Research Article

Kinetic Parameter Optimization and By-product Analysis in N-butane Oxidation to Maleic Anhydride in an Industrial Fixed-bed Reactor

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Abstract

Maleic anhydride is a key intermediate in the chemical industry, predominantly produced through the partial oxidation of n-butane over vanadium-phosphorus-oxide (VPO) catalysts. This reaction is accompanied by side reactions that lead to the formation of undesired by-products, primarily CO and CO₂. In this work, a previously developed mathematical model of a fixed-bed tubular reactor was extended to include a catalyst activity function accounting for catalyst deactivation, and the kinetic parameters were optimized using experimental data from an industrial reactor at Koksara d.o.o. Lukavac. The model describes the partial oxidation of n-butane to maleic anhydride through multiple reactions, with reaction rates expressed as functions of temperature, partial pressures, and catalyst activity. Numerical simulations were performed using MATLAB, employing a nonlinear least-squares solver to minimize the deviation between the predicted and measured temperature profiles along the reactor. The validated model showed good agreement with experimental data, demonstrating its capability to accurately simulate reactor behavior under typical industrial conditions. Parametric studies were conducted to analyze the effects of inlet n-butane and oxygen flow rates, reaction mixture temperature, and pressure on the formation of CO and CO₂. The results indicate that by-product formation is strongly influenced by the oxygen/n-butane ratio, temperature, pressure, and the catalyst oxidation state. Higher oxygen flow rates and elevated temperatures increase CO and CO₂ formation, while lower values reduce their production. Changes in n-butane flow have a minor effect on CO₂, but more pronounced effects on CO due to the interplay between partial and complete oxidation at different catalyst sites. Increasing the inlet pressure enhances by-product formation by increasing reactant concentrations, whereas reduced pressure decreases CO and CO₂ formation. The developed model provides a practical tool for understanding and optimizing industrial maleic anhydride production. It offers insights into the effects of key process parameters on by-product formation, supporting improved reactor operation, reduced trial-and-error experimentation, and more efficient industrial process design.

Keywords

Maleic Anhydride, N-butane Oxidation, Fixed-bed Tubular Reactor, VPO Catalyst, Mathematical Modeling, Kinetic Parameters, By-product Formation

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1. Introduction

Maleic anhydride is an important intermediate in the chemical industry, today mostly produced via the oxidation of *n*-butane over vanadium-phosphorus-oxide (VPO) catalysts. The synthesis of maleic anhydride from *n*-butane and oxygen involves, in addition to the main reaction, several side reactions that contribute to the formation of undesired products, primarily CO and CO₂, and to a lesser extent acrylic acid. Initially, maleic anhydride was produced by the partial oxidation of benzene using a vanadium-molybdenum-oxide catalyst. This process involved the oxidation of benzene with air. Over time, *n*-butane replaced benzene for the production of maleic anhydride, first implemented by Monsanto in 1974 [1]. Compared with benzene as a reactant, the partial oxidation of *n*-butane to maleic anhydride is more economically efficient and environmentally friendly [2]. The conversion of *n*-butane to maleic anhydride occurs through multiple steps, during which some undesired by-products are also formed [3, 4] studied several reactor configurations with the aim of improving the productivity of maleic anhydride. Fixed-bed, fluidized-bed, and circulating fluidized-bed reactors are the most commonly used reactor types for maleic anhydride production. More than half of the globally produced maleic anhydride is used for the production of unsaturated polyester resins, as well as for the manufacture of copolymers (such as styrene-maleic anhydride and acrylic anhydride), paints, lubricants, pesticides, and other organic compounds [5]. Mathematical modeling represents a valuable tool for the simulation and design of process equipment in the chemical and process industries, as well as for determining the conditions for optimal process performance. The industrial significance of such studies lies in the enhanced understanding of the process behavior, which allows for better operational decisions and reactor design. A well-developed mathematical model of a fixed-bed tubular reactor provides a powerful framework for reactor design, optimization, and operation. However, no universal mathematical model exists for fixed-bed tubular reactors; the most appropriate model is selected based on the characteristics of the system, the availability of parameters, and the feasibility of solving the model equations. To achieve a reliable model, minimal assumptions should be made, which depends heavily on the availability of industrial data for comparison between simulation predictions and actual measured data. Studies on the modeling of tubular reactors with a fixed bed of catalyst are reported [6-15]. Modeling of reactors with a fluidized bed of catalyst is presented [16-24]. Membrane reactors applied for the oxidation of *n*-butane to maleic anhydride are analyzed [25-28]. Detailed modeling of *n*-butane oxidation to maleic anhydride enhances process understanding and supports optimization efforts, but existing kinetic models do not adequately describe the formation of key by-products CO and CO₂ [29]. In this study, a previously developed mathematical model of a tubular fixed-bed reactor from [15] was adopted

and extended by introducing a catalyst activity function to account for catalyst deactivation. The kinetic model was employed, and its parameters were optimized using experimental data obtained from an industrial reactor [9]. The main objectives of the present work are to develop a mathematical model capable of numerically simulating the partial oxidation of *n*-butane to maleic anhydride in an industrial fixed-bed tubular reactor, to verify the model against experimental data, and to analyze the effects of inlet *n*-butane and air/oxygen flow rates, temperature, and pressure of the reaction mixture on the formation of CO and CO₂. The kinetic model [9] was adopted as the basis for describing the reaction mechanism. This comprehensive approach, integrating industrial data with detailed reactor modeling, provides a rare and valuable contribution to the literature, as most previous studies have been limited to laboratory or pilot-scale systems. The validated model serves as a practical tool for improving plant operation, minimizing costly trial-and-error experiments, and enhancing process understanding for industrial maleic anhydride synthesis.

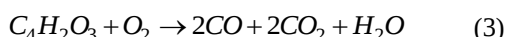
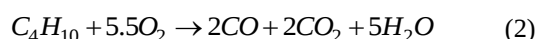
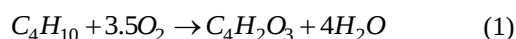
2. Materials and Method

2.1. Reactor and Experimental Data

The analysis was based on measured data obtained from an industrial fixed-bed tubular reactor used for the oxidation of *n*-butane to maleic anhydride at Koksara d.o.o. Lukavac. Only general information about the reactor and process is presented in this study due to data confidentiality. The reactor operates under typical industrial conditions of temperature, pressure, and feed composition, representative of large-scale maleic anhydride production. For this study, industrial data from a fixed-bed tubular reactor packed with a vanadium-phosphorus oxide (VPO) catalyst were employed. The reactor consists of a large number of parallel tubes, each filled with catalyst pellets, and cooled by molten salt on the shell side. The catalyst and reactor configuration are representative of typical industrial operation, while specific geometric details and catalyst porosity are omitted to maintain confidentiality. The following process data were utilized in this study: temperature and pressure of the reaction mixture at the reactor inlet, reactant flow rates at the inlet, temperature profile along the reactor height, temperature and pressure of the reaction mixture at the reactor outlet, and outlet gas composition (mole fractions of *n*-butane, CO, and CO₂).

2.2. Kinetic Model

The chemical reactions (1), (2), and (3) are reported in [12], originally presented in [9]:



The investigated kinetic model describing the partial oxidation of *n*-butane to maleic anhydride [9]. The reaction rates are expressed as follows:(3)

$$r_1 = \frac{k_1 \cdot p_1^{\alpha_1}}{(1 + K_2 \cdot p_2)} \quad (4)$$

$$r_2 = \frac{k_2 \cdot p_2}{(1 + K_2 \cdot p_2)^2} \quad (5)$$

$$r_3 = k_3 \cdot p_1^{\alpha_3} \quad (6)$$

where r_1 - reaction rate of reaction (1) (mol/(s m³)), r_2 - reaction rate of reaction (2) (mol/(s m³)), r_3 - reaction rate of reaction (3) (mol/(s m³)), k_1 - value of the rate constant of reaction (1) ((kmol atm^{0.54}/(kg s))), k_2 - value of the rate constant of reaction (2) (kmol/(kg s atm)), k_3 - value of the rate constant of reaction (3) (kmol/(kg s atm^{0.54})), K_2 - maleic anhydride adsorption rate constant (1/atm), α_1 - exponent in rate equation (1) (-), α_3 - exponent in rate equation (3) (-), p_1 - partial pressure of *n*-butane (atm), p_2 - partial pressure of maleic anhydride (atm).

The rate constants were reparameterized as:

$$k_{jT} = k_{j673} \exp \left[\frac{E_j}{673 \cdot R} \cdot \left(1 - \frac{673}{T} \right) \right] \quad \text{where } j \text{ refers to}$$

equations (1), (2), and (3) (7).

Where k_{jT} - value of the rate constant of equation j at the temperature T (various units), k_{j673} - value of the rate constant k_j at the reference temperature of 673 K (various units), E_j - activation energy of reaction j (J/mol), R - universal gas constant (J/(mol K)), T - Temperature (K).

The kinetic parameters were optimized using experimental data obtained from the industrial reactor, by minimizing the deviation between simulated and measured temperature profiles along the reactor.

2.3. Mathematical Model

The mathematical model with the inclusion of catalyst activity and the residence time of the reaction mixture in the reactor in the present study [15].

The catalyst activity is represented by the following equation [30]:

$$\frac{dac}{dt} = -k_d \cdot e^{\left(\frac{-E_{deac}}{R} \cdot \left(\frac{1}{T} - \frac{1}{T_{ref}} \right) \right)} \cdot ac^{md} \quad (8)$$

where ac - catalyst activity (-), t - residence time of the reaction mixture in the reactor (s), k_d - catalyst deactivation constant (= 0.017 1/s, [13]), E_{deac} - catalyst deactivation energy (= 125 kJ/kmol, [8]), md - deactivation order (-).

The residence time of the reaction mixture in the reactor is expressed by the following equation [31]:

$$t = \frac{V}{v} \quad (9)$$

where t - residence time of the reaction mixture (s), V - reactor volume (m³), v - volumetric flow rate of the reaction mixture (m³/s).

The volumetric flow rate of the reaction mixture is expressed by the following equation [32]:

$$v = v_0 \cdot \frac{F_T}{F_{T0}} \cdot \frac{P_0}{P} \cdot \frac{T}{T_0} \quad (10)$$

where: v_0 - volumetric flow rate of the reaction mixture at the reactor inlet (m³/s), F_T - total molar flow rate of the reaction mixture (kmol/s), F_{T0} - total molar flow rate of the reaction mixture at the reactor inlet (kmol/s), P_0 - pressure of the reaction mixture at the reactor inlet (bar), P - pressure of the reaction mixture at the reactor outlet (bar), T - temperature of the reaction mixture at the reactor outlet (K), T_0 - temperature of the reaction mixture at the reactor inlet (K).

The reaction rate considering catalyst deactivation is expressed by the following equation [33]:

$$r'_j = ac \cdot r_j \quad (11)$$

where r'_j - reaction rate with catalyst deactivation (kmol/(kg s)) for reactions $j = 1, 2, 3$.

2.4. Numerical Solution and Parameter Optimization

Based on experimental measurements (temperature and pressure of the reaction mixture at the reactor inlet, reactant flow rates at the reactor inlet, temperature of the reaction mixture along the reactor length, temperature and pressure of the reaction mixture at the reactor outlet, and outlet concentrations of *n*-butane, carbon monoxide, and carbon dioxide) obtained from an industrial fixed-bed tubular reactor, the kinetic parameters were optimized using a mathematical model. The numerical software package MATLAB was used for the numerical solution of the system of mathematical model equations. A nonlinear least-squares solver (lsqcurvefit)

was employed to determine the kinetic parameters of the model. The system of ordinary differential equations was solved numerically using the MATLAB ode45 solver (based on an explicit fourth- and fifth-order Runge-Kutta formula). The algorithm was implemented in the numerical software package MATLAB (Figure 1). Initial guesses for the kinetic parameters, including pre-exponential factors, activation energies, and reaction-specific constants, were defined. Fixed process variables were simultaneously specified, encompassing reactor geometry, catalyst characteristics, and operating conditions such as temperature, pressure, and inlet flow rates. The experimental target, the temperature profile along the reactor, was also defined. Secondary parameters required for reactor evaluation were calculated from the known inputs. These included engineering variables derived from the reactor configuration and catalyst properties, which facilitated subsequent solution of the reactor model. The core of the algorithm was an iterative procedure that refined the kinetic parameters to minimize the discrepancy between model predic-

tions and experimental data: At each iteration, the complete reactor model was solved using the current kinetic parameters, calculating the spatial profiles of temperature, pressure, and composition along the reactor length. The outlet temperature predicted by the model was compared with the measured values, and the objective function, defined as the sum of squared deviations between simulated and experimental temperatures, was evaluated. The MATLAB nonlinear least-squares solver (lsqcurvefit) automatically adjusted the kinetic parameters to minimize the objective function. The iterative process continued until convergence, yielding the optimized set of kinetic parameters that provided the best agreement between the theoretical model and experimental observations. Variable definitions in Figure 1 follow the model [15]. As the criterion for agreement between the model-predicted and experimental values, the following objective function was selected: the sum of squared absolute differences between the simulated and experimental reaction mixture temperatures along the reactor height.

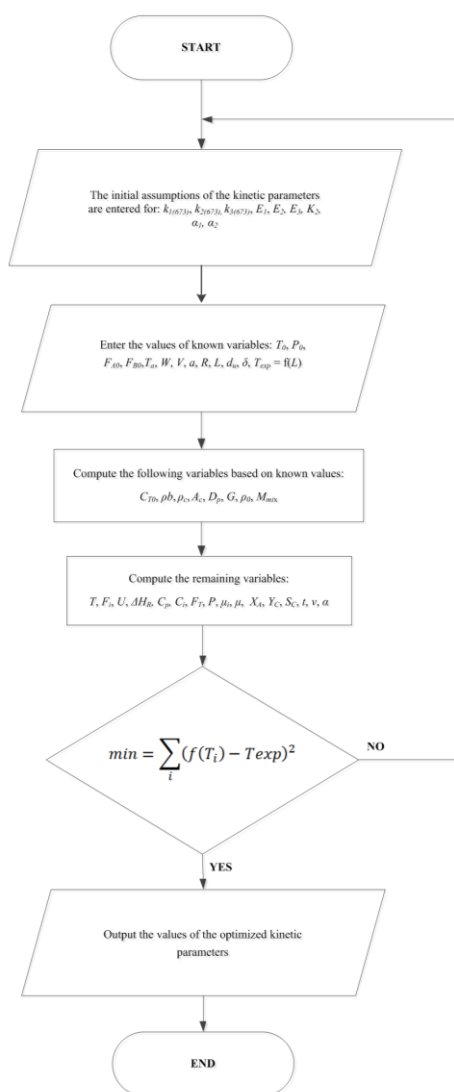


Figure 1. Algorithm for kinetic parameter optimization.

3. Results and Discussion

Table 1 presents a comparison between the kinetic parameters [9] and the optimized kinetic parameters obtained in this study.

Table 1. Comparison of existing kinetic parameters with optimized kinetic parameters in the kinetic model [9].

Reaction	Kinetic parameters [9]				
	E_j (J/mol)	k_{j673} (various units)	α_1 (-)	α_3 (-)	K_2 (1/atm)
1	93100	$0.96 \cdot 10^{-6}$	0.54	-	310
2	155000	$0.29 \cdot 10^{-6}$	-	-	310
3	93100	$0.15 \cdot 10^{-6}$	-	0.54	-

Table 1. Continued.

Reaction	Optimized kinetic parameters (this study)				
	E_j (J/mol)	k_{j673} (various units)	α_1 (-)	α_3 (-)	K_2 (1/atm)
1	64064	$5.3056 \cdot 10^{-7}$	0.34803	-	330.15
2	215030	$3.1596 \cdot 10^{-5}$	-	-	330.15
3	64064	$5.0809 \cdot 10^{-6}$	-	0.34803	-

Smaller deviations between the kinetic parameters are observed for the parameters α_1 , α_3 , and K_2 , while larger deviations are present for the remaining kinetic parameters. The good agreement for α_1 , α_3 , and K_2 can be attributed to the fact that the original study employed a fixed-bed reactor, although under significantly different operating conditions compared to the industrial fixed-bed tubular reactor used in this work, which may explain the deviations observed for E_j and k_{j673} . Similar to the explanation in [28] for differences in kinetic parameters arising from varying n-butane to oxygen ratios, the discrepancies between the kinetic parameters in the present study and the kinetic model in [9] can be attributed to the use of different inlet process conditions. [34] determined activation energies for the oxidation of n-butane to maleic anhydride over two different catalysts (VPO and VWPO). The activation energies for the formation and combustion of maleic anhydride were lower for the VWPO catalyst compared to the VPO catalyst, which was explained by a higher average oxidation state of the VWPO catalyst. In the present study, the activation energies for the formation and decomposition of maleic anhydride are lower than the values reported in [9], which may be due to a higher average oxidation state of the catalyst used here compared to that used in the original study. Considering that the sum of squares of the

absolute differences between the simulated values obtained using the optimized kinetic parameters and the measured values from the industrial fixed-bed tubular reactor of the reaction mixture temperature along the reactor height served as the objective function, Figure 2 present a comparison between the simulated and measured reaction mixture temperatures along the reactor height resulting from the optimization of the kinetic parameters.

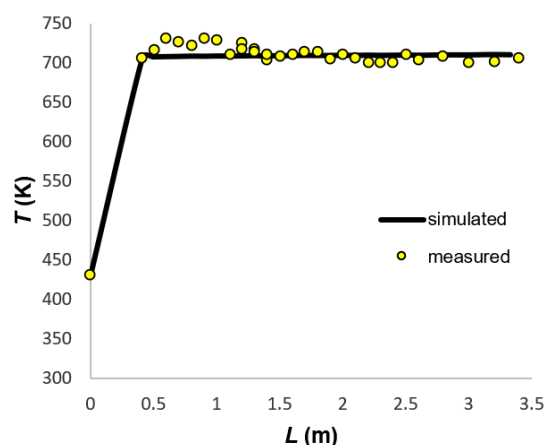


Figure 2. Algorithm for kinetic parameter optimization.

By using the optimized kinetic parameter values, satisfactory agreement was achieved between the simulated and measured reaction mixture temperatures along the reactor height in the industrial fixed-bed tubular reactor. This indicates that the nonlinear least-squares solver (lsqcurvefit) successfully minimized the sum of squares of the absolute

differences between the simulated and measured reaction mixture temperatures along the reactor height during the optimization of the kinetic parameters.

Tables 2-5 show the effects of variations in n-butane and oxygen inlet flow rates, reaction mixture inlet temperature and pressure on the formation of CO and CO₂.

Table 2. Influence of n-butane flow rate changes on the formation of CO and CO₂ in the fixed-bed reactor.

n-C ₄ H ₁₀ flow rate change (%)	CO ₂ formation change (%)	CO formation change (%)
-20	-1.62	6.01
-10	-0.71	3.27
0	0	0
+10	0.58	-2.01
+20	1.04	-6.84

The observed changes in CO₂ formation due to variations in n-butane flow rate can be explained by the effect of the oxygen/butane ratio on oxidation reactions. A low oxygen availability, the reaction environment becomes more reducing, which can enhance the oxidation of intermediates such as maleic anhydride to CO₂ by available electrophilic oxygen species [1]. Conversely, at very high oxygen/butane ratios, the vanadium oxidation state increases, which may also promote overoxidation to CO₂. Therefore, the minor increase or decrease in CO₂ formation with changes in butane flow is likely due to the interplay between oxygen availability, electrophilic oxygen species, and the catalyst oxidation state. As seen in Table 2, the changes in CO₂ formation are relatively small, indicating that the system remains near steady-state oxidation conditions for the investigated flow rates. This limited dependence of CO₂ formation on the butane concentration is consistent with the findings [36], confirming that CO₂ formation is practically unaffected with hydrocarbon feed con-

centration. This behavior may also reflect a slight reduction of the VPO catalyst surface under low oxygen/butane ratios [1], leading to a slow deactivation characterized by a minor decrease in maleic anhydride selectivity and a slight increase in CO₂ formation. The influence on CO formation is likely related to the same factors: the oxygen/butane ratio and the dynamic oxidation state of the catalyst. At lower oxygen availability, partial oxidation tends to favor CO production, whereas at higher oxygen concentrations, the more oxidized catalyst surface can shift carbon conversion towards CO₂, reducing CO formation. No studies were found in the literature specifically analyzing the effect of variations in n-butane flow at the reactor inlet on CO formation, so these observations are based on the present simulations. Thus, the observed changes in CO are probably a consequence of the interplay between partial and complete oxidation and the evolving catalyst state under different oxygen-to-butane ratios.

Table 3. Influence of oxygen flow rate changes on the formation of CO and CO₂ in the fixed-bed reactor.

O ₂ flow rate change (%)	CO ₂ formation change (%)	CO formation change (%)
-20	-2.68	-4.71
-10	-1.04	-2.27
0	0	0
+10	1.68	2.89
+20	3.11	5.01

As shown in Table 3, the formation rates of CO and CO₂ increase slightly with increasing oxygen flow rate, indicating that higher O₂ availability enhances the extent of oxidation reactions. However, these changes do not significantly affect the overall selectivity towards maleic anhydride. This behavior is consistent with the findings [36], which reported that CO and CO₂ formation exhibit only a weak dependence on oxygen concentration, without substantially altering the selectivity of the main oxidation reaction. Both CO and CO₂ formation rates increase with O₂ concentration, suggesting that the catalytic oxidation occurs primarily on the catalyst surface rather than via homogeneous gas-phase reactions. The data in Table 3 confirm that the reaction remains surface-catalyzed, and the O₂ concentration influences the extent of CO and CO₂ production without promoting gas-phase oxidation. The observed modest changes in CO and CO₂ formation with varying oxygen flow further indicate that the

reaction pathway is predominantly controlled by the catalyst surface and its oxidation state, rather than by the gas-phase composition. The slight variations observed in CO and CO₂ formation with changing O₂ flow rate can be explained by the presence of different types of active sites on the VPO catalyst. [37] identified two categories of active sites on this catalyst: selective sites that facilitate the oxidation of n-butane to maleic anhydride, and nonselective sites responsible for the formation of carbon oxides from both n-butane and maleic anhydride. Therefore, the increase in O₂ availability primarily enhances the activity of nonselective sites, resulting in a modest increase in CO and CO₂ formation without significantly affecting overall selectivity toward maleic anhydride. This interpretation is consistent with the behavior observed in our results, where the CO and CO₂ formation rates increased slightly with higher O₂ flow, while selectivity to the main product remained nearly unchanged.

Table 4. Influence of inlet reaction mixture temperature on CO and CO₂ formation.

Reaction mixture temperature at the reactor inlet change (%)	CO ₂ formation change (%)	CO formation change (%)
-20	-2.98	-6.99
-10	-5.14	-3.04
0	0	0
+10	4.45	5.5
+20	8.07	9.01

As shown in Table 3, increasing the reactor inlet temperature leads to higher formation of both CO and CO₂. The observed trend indicates that the activation energies for CO and CO₂ formation are higher than that for maleic anhydride [1], which explains the relative increase of these by-products at elevated temperatures. The CO/CO₂ ratio also tends to increase with rising temperature [35]. Higher temperatures accelerate the oxidation of intermediates and reactant mole-

cules, promoting CO and CO₂ formation. Moreover, the rate of side oxidation reactions leading to CO and CO₂ formation increases more significantly than the main reaction [36], which is consistent with the simulated and experimental data presented in Table 3. Overall, these results demonstrate that temperature has a pronounced effect on the partial oxidation pathways, enhancing the formation of CO and CO₂ without substantially altering the selectivity toward maleic anhydride.

Table 5. Influence of inlet reaction mixture pressure on CO and CO₂ formation.

Reaction mixture pressure at the reactor inlet change (%)	CO ₂ formation change (%)	CO formation change (%)
-20	-4.54	-5.46
-10	-1.98	-2.11
0	0	0
+10	3.11	4.01
+20	6.98	7.87

An increase in the inlet pressure generally leads to higher CO and CO₂ formation, while a decrease in pressure reduces their production. This behavior can be explained by the effect of pressure on reactant concentrations: higher pressure increases the concentration of n-butane and oxygen in the reaction mixture, thereby enhancing the rates of side oxidation reactions producing CO and CO₂. Conversely, lower pressure decreases reactant concentrations and slows down these side reactions. To the best of our knowledge, no studies have explicitly investigated the effect of reaction mixture pressure on CO and CO₂ formation in the partial oxidation of n-butane to maleic anhydride or similar systems. Therefore, these results provide new insights into the influence of reactor pressure as a process parameter for controlling side-product formation. Overall, while pressure impacts CO and CO₂ production, its effect is generally less pronounced compared to temperature, reactant flow rates, or catalyst characteristics. Despite the good agreement between the simulated and measured data, the presented model has certain limitations. The catalyst deactivation is described using a simplified empirical function that assumes uniform deactivation throughout the catalyst bed. In reality, deactivation may vary along the reactor height due to local variations in temperature, reactant concentration, and catalyst oxidation state. Furthermore, the model does not account for potential mass and heat transfer limitations within catalyst pellets or tube-to-tube variations in the industrial reactor. Side reactions leading to minor by-products such as acrylic acid are also not explicitly modeled, which may slightly affect the predicted selectivity. These simplifications were necessary to allow numerical optimization of kinetic parameters based on available industrial data, but they should be considered when extrapolating the model to different operating conditions or reactor designs.

4. Conclusions

In this study, a mathematical model of an industrial fixed-bed tubular reactor with a VPO catalyst for the partial oxidation of n-butane to maleic anhydride was developed and validated. Optimization of kinetic parameters using experimental data allowed a good agreement between the simulated and measured temperature profiles along the reactor. The analysis of process parameters on the formation of by-products CO and CO₂ showed that these reactions are strongly surface-catalyzed and depend on the oxygen/n-butane ratio, temperature, pressure, and the catalyst oxidation state. Increased oxygen flow and higher temperature lead to higher CO and CO₂ formation, while lower flows and temperatures reduce their production. The influence of n-butane flow on CO₂ formation is relatively small, whereas CO shows more pronounced variations, likely due to the balance between partial and complete oxidation at different types of active sites on the catalyst. An increase in the reaction mixture pressure generally enhances CO and CO₂ formation,

while a decrease in pressure reduces their production, which can be explained by changes in reactant concentration. To the best of our knowledge, no studies have directly investigated the effect of reaction mixture pressure on CO and CO₂ formation in n-butane oxidation, making these results a novel contribution to understanding the process. The results indicate that, although by-product formation varies with changes in process parameters, the overall maleic anhydride production remains largely stable across a wide range of operating conditions. These findings emphasize the importance of optimizing inlet parameters and controlling the oxidation state of the catalyst to minimize by-product formation. These conclusions provide a better understanding of n-butane oxidation kinetics in industrial reactors and offer a basis for future process optimization and by-product management in industrial maleic anhydride production.

Abbreviations

VPO	Vanadium-Phosphorus-Oxide
VWPO	Vanadium-Wolfram-Phosphorus-Oxide

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Author Contributions

Ervin Karic: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing - original draft.

Ivan Petric: Formal Analysis, Investigation, Supervision, Validation, Writing - review & editing.

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Data Availability Statement

The data are available from the corresponding author upon reasonable request and with the permission of the company.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



Ervin Karic is an Assistant Professor at the University of Tuzla, Faculty of Technology, Department of Chemical Engineering. He enrolled in the Chemical Engineering program at the University of Tuzla in 2008/2009 and in 2012 graduated with a first-cycle average grade of 9.059. He completed his Master's studies in Chemical Engineering and Technology in 2016 with an average grade of 10.00 and obtained his PhD in Chemical Engineering in 2021, also with an average grade of 10.00. He has participated in several research projects and is currently the principal investigator of an ongoing research project. Dr. Karic is the author and co-author of numerous scientific publications in the field of Chemical Engineering. He actively contributes to the academic community through teaching, supervision of graduate students, and participation in national and international scientific collaborations.



Ivan Petric is a Full Professor at the University of Tuzla, Faculty of Technology, Department of Chemical Engineering. He received his PhD in Process Engineering from the University of Tuzla in 2007, following a Master of Science in Process Engineering in 2001 and a Diploma in Technology in 1996 from the same institution. Prof. Petric has led several national research projects and is currently the head of the Department of Chemical Engineering and Technology. He is the author and co-author of numerous scientific publications in the field of Chemical Engineering. Prof. Petric has supervised many students at the undergraduate, Master's, and Doctoral levels.

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Ervin Karic: Chemical Reactor Design and Optimization, Reaction Engineering, Process Simulation and Modeling, Heat Transfer Operations, Process Equipment Engineering, Material and Energy Balances, Composting Process Optimization, Organic Waste Treatment and Management.

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