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DEVELOPMENT OF AN INTEGRATED FERMENTATION PERVAPORATION MODEL FOR BIOETHANOL PRODUCTION

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The continuous fermentation process where ethanol is selectively removed from the broth is an efficient technique for optimising the bioethanol productivity and limiting the inhibitory effect of both end product and substrate. However, the application of this approach may increase the concentration of minor secondary products to the point where they become toxic to the yeast. Despite that several studies have reported the significant inhibitory effect of byproducts, there is currently no fermentation model that considers the inhibitory effect of these byproducts.

In this study, an integrated model of a fermentation-pervaporation system was developed considering the effect of the interaction between both processes with special attention has been devoted to the inhibitory effect of byproducts. Firstly, a modified Monod model for the alcoholic fermentation process was developed. Then, the optimization and modelling of the pervaporation process for ethanol recovery were conducted. Finally, the integrated model of alcoholic fermentation coupled with a pervaporation system for ethanol recovery was developed and validated.

The findings showed that glycerol, acetic acid and succinic acid were the main byproducts during the fermentation process. It was also noted that the concentration of these byproducts linearly increased with the increase of glucose concentration in the range of 25-250 g/L. A modified Monod model concerning the inhibitory effect of these byproducts was suggested where the specific growth coefficient exponentially decreased with the increase of byproducts concentration in the fermentation broth. The suggested model showed a good agreement with the experimental data and higher accuracy compared to the conventional Monod model.

In optimization of the pervaporation process, the ethanol feed concentration and the permeate pressure positively affected the selectivity, while the feed temperature and the feed flow rate showed a negative effect. The results also revealed that all the four studied factors had a positive effect on the total flux in the selected range. In addition, A solution-diffusion model has been developed and validated using the fermentation broth as a feed solution where it showed high accuracy with R^2 higher than 0.96 for predicting the permeate total flux.

A full model was developed by the integration of the modified Monod model and the solution-diffusion model of the pervaporation process considering the interactions between both processes. The suggested model could accurately predict the biomass concentration, glucose concentration, and ethanol concentration in the fermentation broth simultaneously with predicting the total permeate flux, ethanol flux, and water flux in the collected permeate during a long-term continuous fermentation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMODELAN SISTEM PENAPAIAN ALKOHOL BERSEPADU DENGAN PEMISAHAN PENYEJATAN UNTUK MENAPIS BIOETANOL

Oleh

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Januari 2021

Pengerusi : Profesor Zurina binti Zainal Abidin, PhD
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Penapaian secara berterusan di mana etanol dikeluarkan secara selektif dari kaldu adalah ideal untuk mengoptimumkan produktiviti bioetanol dan menghadkan kesan perencatan daripada produk akhir dan juga daripada substrat. Namun, proses ini boleh menyebabkan produk sampingan sekunder bertambah sehingga menjadi toksik kepada ragi. Namun begitu, walaupun kesan perencatan dari produk sampingan telah dilaporkan dalam beberapa kajian yang lepas, tiada lagi model penapaian yang melibatkan kesan perencatan daripada produk sampingan.

Dalam kajian ini, model sistem penapaian-penyejatan yang lengkap telah dihasilkan dengan mengambilkira interaksi antara proses penapaian dan penyejatan dengan perhatian istimewa telah diberikan kepada kesan perencatan daripada produk sampingan. Pertama, model baharu Monod yang telah diubahsuai untuk proses penapaian alkohol telah dihasilkan. Kemudian, pengoptimuman dan pemodelan proses penyejatan untuk menapis etanol telah dilakukan. Akhirnya, model lengkap penapaian alkohol yang digabungkan dengan sistem penyejatan untuk menapis ethanol telah dihasilkan dan disahkan.

Hasil kajian telah menunjukkan bahawa gliserol, asid asetik dan asid sukina adalah produk sampingan utama semasa proses penapaian. Terdapat juga pemerhatian bahawa kepekatan produk sampingan ini turut meningkat secara linear mengikut peningkatan kepekatan glukosa dalam julat 25-250 g/L. Model baharu Monod yang telah diubahsuai dengan mengambilkira kesan perencatan produk sampingan adalah disarankan, di mana pekali pertumbuhan spesifik menurun secara eksponen dengan peningkatan kepekatan produk sampingan dalam penapaian kaldu. Model baharu ini telah menunjukkan persamaan yang baik dengan data eksperimen dan ketepatan yang lebih tinggi berbanding dengan model Monod konvensional.

Kajian pengoptimuman mengenai kesan keadaan operasi dalam proses penyejatan menunjukkan bahawa kepekatan suapan ethanol dan tekanan telapan mempunyai kesan positif yang ketara pada pemilihan. Sebaliknya, kesan negatif suhu suapan dan kadar aliran suapan pada pemilihan telah direkodkan. Selain itu, keempat-empat faktor telah menunjukkan kesan positif pada jumlah fluks dalam julat yang dipilih. Di samping itu, model larutan-resapan telah dihasilkan dan disahkan menggunakan penapaian kaldu dan menunjukkan ketepatan tinggi dengan R^2 lebih tinggi daripada 0.96 untuk meramalkan jumlah fluks telapan.

Model lengkap telah dihasilkan dengan persepaduan model Monod yang telah diubah suai dan model larutan-resapan untuk proses penyejatan dengan mempertimbangkan interaksi antara kedua-dua proses tersebut. Model yang dicadangkan mempunyai kemampuan untuk meramal kepekatan biomas, kepekatan glukosa, dan kepekatan ethanol dalam penapaian kaldu secara serentak dengan meramalkan jumlah fluks telapan, fluks ethanol, dan fluks air dalam telapan yang terkumpul semasa penapaian secara berterusan dalam jangka panjang.

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LIST OF ABBREVIATIONS

AC	Activated Carbon
ADP	Adenosine Tri-Phosphate
ANOVA	Analysis of Variance
ATP	Adenosine Tri-Phosphate
CCD	Central Composite Design
CV	Coefficient of Variation
CoA	Coenzyme A
CS	Chitosan
DF	Degree of Freedom
GSEF	Gas Stripping Ethanol Fermentation
HEC	Hydroxy Ethyl Cellulose
HPLC	High Performance Liquid Chromatography
MAPE	Mean Absolute Percentage Error
MAVS	Membrane Assisted Vapor Stripping
MBRs	Membrane Bio-Reactors
MMMs	Mixed Matrix Membranes
NADH	Nicotinamide Adenine Dinucleotide + Hydron
NAD	Nicotinamide Adenine Dinucleotide
NREL	National Renewable Energy Laboratory
NRTL	Non-Random-Two-Liquid
OD	Optical Density
PAA	Poly Acrylic Acid
PAN	Poly Acrylo-Nitrile

PDMS	Poly Di-Methyl Siloxane
PI	Poly Imide
POMS	Poly Octyl Methyl Siloxane
PRESS	Predicted Error Sum of Squares
PTFE	Poly Tetra Fluoro Ethylene
PTMSP	Poly [1-(Tri-Methyl-Silyl)-1-Propyne
PV	Pervaporation
PVA	Poly (Vinyl Alcohol)
PVDF	Poly (Vinylidene Fluoride)
PVI	Poly (2-Vinyl-Imidazoline)
RSM	Response Surface Methodology
SDS	Sodium Dodecyl Sulfate
SSF	Simultaneous Saccharification and Fermentation
UNIQUAC	Universal Quasichemical
USA	United States American
VHG	Very High Gravity
YEP	Yeast Extract Peptone
YNP	Yeast Nitrogen Base
YPD	Yeast Peptone Dextrose
3D	Three Dimensions

CHAPTER 1

INTRODUCTION

1.1 Background

In the past decades, the industrial revolution has remarkably increased the demand for energy that is derived from conventional fossil fuel resources such as coal, oil and natural gas. Growing concerns over the consequences of climate change may severely limit future access to fossil fuels. A forced choice between energy and environment could precipitate a major economic crisis, an environmental crisis, or both. Averting such a crisis will be difficult because fossil energy resources are an essential part of the world's energy supply and climate change is mainly driven by the build-up of carbon dioxide in the atmosphere (Hester et al., 2010). Nevertheless, fossil fuels will be substituted partially by new energy sources that can fulfil the energy needs of humanity and overcome the environmental challenges resulting from the extensive use of fossil fuels. In this regard, biofuels provide an excellent alternative to traditional fossil fuel-derived energy sources, as they can be produced from abundant supplies of renewable biomass (Davis et al., 2000).

Biofuels are produced directly or indirectly from natural feedstocks, which include vegetables, raw materials, and animal waste. There are two main industrial sectors in biofuel production, namely bioethanol and biodiesel (Correa et al., 2017). Bioethanol can be produced by the fermentation of sugars, whereas biodiesel is derived from vegetable or animal fat through the process of transesterification. Brazil and the USA are the two largest biofuel producers in the world (Alonso-Pippo et al., 2013).

The biofuel industry is facing several challenges to substitute totally and limit the use of fossil fuels and meet the market demand. The availability of an efficient separation and purification technique is one of these major challenges, as it typically represents at least 40% (up to 80%) of bioethanol production cost (Le et al., 2011). Moreover, the product (ethanol) inhibition is another limiting factor for the efficient production of ethanol (Garhyan et al., 2004). It was previously reported that yeast cells do not grow in ethanol concentration above 11 wt.% where the ethanol-producing capability of the cells is totally blocked at a concentration of 10 wt.% (Luong, 1985).

Fermentation and purification are the major steps during bioethanol production. Ethanol and total water are the major components of the broth after fermentation. Separation is necessary to purify the ethanol from the fermentation broth (Tian et al., 2013). Distillation has been used as the main purification method for ethanol recovery for many years (Lei et al., 2003). Distillation has a lot of advantages that place it as the preferred choice for industrial application due to: high alcohol recovery (99+ %), sufficient energy efficiency at moderate feed concentrations, and easy simulation process with different available software programs. On the other hand, distillation has some negative aspects such as the high energy consumption and costs, the high operating temperatures which cause the deactivation of proteins and enzymes, and the need for additional separation to reach product dryness specifications (Vane, 2008).

Therefore, developing new separation techniques become a hot issue to improve biofuels production efficiency, and reduce energy consumption (Nigiz et al., 2013). Bioethanol recovery techniques from fermentation broth were classified by Serra et al. (Serra et al., 1987) into conventional or modified conventional systems (distillation system) and nonconventional systems (non-distillation systems).

The non-conventional systems are recently proposed as alternatives for ethanol recovery with energy saving and low investments such as pervaporation, vacuum stripping, gas stripping, solvent extraction, adsorption and various hybrid processes were mostly developed during the 70's when there was the interest to produce chemicals using less fossil fuel (Offeman et al., 2005).

In the last decade, the application of membrane technology for biological separation processes have flourished throughout the world because it overcomes several constraints associated with conventional techniques. Membrane systems have several advantages over conventional separation processes such as distillation, adsorption, and extraction (Schmidt et al., 1997). Pervaporation technology is currently developed to be integrated with the fermentation process for bioethanol recovery during the continuous alcoholic fermentation process. Fermentation systems operated in continuous mode offer several advantages compared to batch processes, generally resulting in enhanced volumetric productivity and, consequently, smaller bioreactor volumes and lower investment and operational costs (Ivanova et al., 2011). In this context, several studies have been conducted to develop new designs of bioreactors and new membrane modules to optimize bioethanol production; parallelly, researchers turned their focus towards using computing methods to optimize the bioethanol production process. Mathematical model–based simulations of actual bioreactor runs suggest how process variables such as substrate and product concentrations change and how nutrient feeding should be "tuned" with respect to time, pattern, concentration, and composition to elicit the desired response. Insights gained from modelling can guide us in the adjustment of a process, reducing the number of characterization rounds required. Furthermore, comparing actual experimental results with model predictions helps improve the models themselves.

Many aspects complicate the modelling of the bioprocess since the fermentation process has both non-linear and dynamic properties, and the metabolic processes of the microorganisms are very complicated and cannot be modelled precisely. The most important properties of a biological mathematical model were defined in the Edwards and Wilke' that postulates: (a) it is capable to represent all the culture phases; (b) it is flexible enough to approximate different data types without the insertion of significant distortions; (c) it must be continuously derivable; (d) it must be easy to operate, once the parameters evaluated; (e) each model parameter is to have a physic significance and must be easy to evaluate (Bellgardt, 2000).

Although the continuous operation is known to be advantageous over the batch process in term of reducing operational costs, it has not yet enjoyed the same measure of acceptance in the industry as that of the batch operation. Some of the major hindrances to the industrial applications of continuous fermentation are susceptibility to contaminations and complex operational problems like a nonlinear process that is difficult to control (O'Brien et al., 2000). Kinetic modelling may be regarded as an important tool in developing an efficient ethanol fermentation process, since models help in process control, reducing process costs, and optimization of the performance of biotechnological processes.

1.2 Problem Statement

Besides the complexity of fermentation modelling itself, coupling the alcoholic fermentation with a separation system such as pervaporation separation for ethanol recovery implies another challenge to developing an 'integrated model' of the fermentation-pervaporation system. The current models do not ideally represent the integrated system since it is standard models describing the fermentation process and pervaporation process as separate units. Thus, modified models should be developed specifically for the modelling of a fermentation-pervaporation integrated system by taking into account the effects of the interaction between both processes.

In this regard, several issues have been highlighted in the present study to be addressed. First of all, it is known that ethanol is selectively removed from the fermentation broth during continuous fermentation using a separation process such as pervaporation which eliminates the ethanol inhibitory effect. On the other hand, this process can concentrate minor secondary products to the point where they become toxic to the yeast. The inhibitory effect of byproducts on the fermentation process has been confirmed in previous studies (Maiorella et al., 1983), However, most available fermentation models highlighted the inhibitory effect of ethanol (Brown et al., 1981; Ghose et al., 1979; Luong, 1985; Palmqvist et al., 2000; Q. Zhang et al., 2015), the inhibitory effect of substrate (Ghose et al., 1979; Mota et al., 1984; Starzak et al., 1994; Q. Zhang et al., 2015), and inhibition effect of cell density on the growth called '' self-inhibition ''(Contois, 1959; Mazzoleni et al., 2015), whereas of inhibition effect of byproducts did not receive the same attention. Thus, a vital part of the present study was devoted to developing a new modified Monod model which takes into account the inhibitory effect of byproducts.

Indeed, defining the optimal operating conditions of a process plays an important role to enhance its performance and productivity. While the optimal conditions of the fermentation process using *S. cerevisiae* yeast have been well-known for several decades ago, there no agreement about the optimal conditions of the pervaporation process due to the differences in the properties of the used membrane, the selected range of factors, and the characteristics of the components of the experimental setup. Therefore, using Response Surface Methodology (RSM) approach for the optimization of ethanol pervaporation process was used due to the reliability RSM approach compared to the one-factor-at-a-time approach which does not consider the interactions between variables during the optimization process.

In addition, the majority of studies investigating the modelling of pervaporation for ethanol recovery have used the ethanol/water mixture as a feed whereas the fermentation broth normally contains other metabolites which may influence the pervaporation separation performance (Hietaharju et al., 2019; Kanse et al., 2017; Qiu et al., 2019). Using ethanol/water standard solution is understood as it allows better control of the operating conditions, however, the fermentation broth should be used during the validation of the model for more reliability.

The integration biological fermentation model and pervaporation separation model is a very challenging step. The notion of 'integrated model' provides a platform to infuse the researches from two different fields biological process modelling and separation modelling for bioethanol production and recovery in a harmonized way and hence provokes interconnected investigations from both fields. The previous studies have focused more on the interaction between both process in term of productivity of performance, for example, the effect of product removal by a pervaporation on ethanol fermentation (Miyazawa et al., 1998), or the effect of fermentation broth components on the pervaporation process (García et al., 2009) whereas a lack in studies discussing an integrated model for the integrated fermentation-pervaporation system was noted. The few reported modelling studies have considered the conventional modelling approach of continuous fermentation at a fixed dilution rate ignoring the fact that output flux is variable due to the change of the ethanol concentration in fermentation broth and its effect on the pervaporation process performance. These issues and points will be fully covered in the present study.

1.3 Objectives

The major objective of this study is to develop an integrated model of a fermentation-pervaporation system. This will include the following secondary objectives and tasks:

1. To develop a modified Monod model for bioethanol fermentation process with the incorporation of byproducts inhibitory effects.

2. To model pervaporation process based on solution- diffusion mechanism.

3. To develop an integrated model based on a continuous combined fermentation-pervaporation system for bioethanol production.

1.4 Scope of Study

The presented work is focused on the modelling of a fermentation-pervaporation system by taking the effect of the interactions on both fermentation and pervaporation processes. Firstly, a preliminary investigation was conducted to evaluate the amount of byproducts formation during the alcoholic fermentation and study the effect of initial substrate concentration on the formation of these byproducts. Based on this investigation, an experimental design was set to determine the effect of these byproducts during the alcoholic fermentation to end up with a new Modified Monod model for the alcoholic fermentation with taking the byproducts inhibitory effect into account.

Secondly, RSM approach was used to optimize the pervaporation process and study the effect of temperature, feed concentration, flow rate and vacuum pressure which may be dependent on each other and it was needed to consider their interactions in this study. Besides the RSM model, a solution-diffusion model will be developed to predict the total flux and separation factor during the pervaporation process, and the developed model will be validated against experimental data using the fermentation broth for more reliability and to assess the ability to integrate the model with the fermentation process.

Finally, an integrated mathematical model to describe the fermentation-pervaporation system was built based on the developed models. The obtained model was validated against experimental data and then compared to previous models reported in the literature to assess its performance.

In the present study, the proposed models were developed assuming that the fouling of the membrane is negligible during the pervaporation process. Although that this assumption is valid for the present study due to the use of glucose solution as a feed of the fermentation process, the fouling problem was reported as the most factor reducing the permeation flux during the pervaporation process (Kamelian et al., 2020; Sun et al., 2020; Zhao et al., 2021; Zhu et al., 2020). Therefore, the application of the suggested integrated model in this study is only limited in the cases where the fouling factors are not significant. Thus, it is suggested to take the fouling phenomena into account in the modelling of the integrated fermentation-pervaporation system especially in the presence of foulants particles in the feed. Moreover, the solution-diffusion model in the present work does not consider the variation of feed concentration along with the module. Therefore, this model is suitable only for flat sheets or small membrane modules as the feed concentration varies along the x-direction for the large modules.

1.5 Outline of Thesis

The presented thesis is divided into five chapters. Chapter one covers the introduction, problem statement, objectives, scope and thesis structure. Chapter two presents the theory and literature review closely related to this work including principles, mechanism, and modelling of both fermentation and pervaporation process and the integration of these process for bioethanol production. Chapter three includes the different materials and methods used in the presented study and describe the experimental design of different stages of the project. Chapter four presented the obtained results and discussed the findings. Conclusions have summarized in chapter five which involves some recommendations for future works as well.

REFERENCES

Abrams, D. S., & Prausnitz, J. M. (1975). Statistical thermodynamics of liquid mixtures: a new expression for the excess Gibbs energy of partly or completely miscible systems. AIChE journal, 21(1), 116-128.

Aiba, S., Shoda, M., & Nagatani, M. (2000). Kinetics of product inhibition in alcohol fermentation. Biotechnology and bioengineering, 67(6), 671-690.

Aiyar, A., & Luedeking, R. (1966). A kinetic study of the alcoholic fermentation of glucose by S*accharomyces cereviseae*. Paper presented at the Chem. Eng. Prog. Symp. Ser.

Alonso-Pippo, W., Luengo, C. A., Alberteris, L. A. M., del Pino, G. G., & Junior, S. D. (2013). Practical implementation of liquid biofuels: The transferability of the Brazilian experiences. Energy Policy, 60, 70-80.

Amin, G., Van den Eynde, E., & Verachtert, H. (1983). Determination of by-products formed during the ethanolic fermentation, using batch and immobilized cell systems of *Zymomonas mobilis* and *Saccharomyces bayanus*. European journal of applied microbiology and biotechnology, 18(1), 1-5.

Anderson, M. J., & Whitcomb, P. J. (2016). RSM simplified: optimizing processes using response surface methods for design of experiments: Productivity press.

Arikawa, Y., Kuroyanagi, T., Shimosaka, M., Muratsubaki, H., Enomoto, K., Kodaira, R., & Okazaki, M. (1999). Effect of gene disruptions of the TCA cycle on production of succinic acid in Saccharomyces cerevisiae. Journal of bioscience and bioengineering, 87(1), 28-36.

Aroujalian, A., Belkacemi, K., Davids, S. J., Turcotte, G., & Pouliot, Y. (2003). Effect of protein on flux and selectivity in pervaporation of ethanol from a dilute solution. Separation Science and Technology, 38(12-13), 3239-3247.

Aroujalian, A., & Raisi, A. (2009). Pervaporation as a means of recovering ethanol from lignocellulosic bioconversions. Desalination, 247(1-3), 509-517.

Azimi, H., Thibault, J., & Tezel, F. H. (2019). Separation of Butanol Using Pervaporation: A Review of Mass Transfer Models. Journal of Fluid Flow, Heat and Mass Transfer (JFFHMT), 5(4), 53-82.

Bai, F., Anderson, W., & Moo-Young, M. (2008). Ethanol fermentation technologies from sugar and starch feedstocks. Biotechnology advances, 26(1), 89-105.

Baker, R. W. (2012). Membrane technology and applications: John Wiley & Sons.

Barnett, J. A. (2005). Glucose catabolism in yeast and muscle. Comprehensive Biochemistry, 44, 1-132.

Basile, A., Figoli, A., & Khayet, M. (2015). Pervaporation, vapour permeation and membrane distillation: principles and applications: Elsevier.

Basile, A., & Nunes, S. P. (2011). Advanced membrane science and technology for sustainable energy and environmental applications: Elsevier.

Baudot, A., & Marin, M. (1997). Pervaporation of aroma compounds: Comparison of membrane performances with vapour-liquid equilibria and engineering aspects of process improvement. Food and Bioproducts Processing, 75(2), 117-142.

Beckner, M., Ivey, M. L., & Phister, T. G. (2011). Microbial contamination of fuel ethanol fermentations. Letters in applied microbiology, 53(4), 387-394.

Bellgardt, K. (2000). Bioreaction Engineering. Ed. K. Schugerl, and KH Bellgardt, Springer Verlag, Berlin, 1-18.

Bello, R., Souza, O., Sellin, N., Medeiros, S., & Marangoni, C. (2012). Effect of operating variables on the pervaporation of ethanol produced by lignocellulosic residue. Procedia Engineering, 42, 512-520.

Bello, R. H., Linzmeyer, P., Franco, C. M. B., Souza, O., Sellin, N., Medeiros, S. H. W., & Marangoni, C. (2014). Pervaporation of ethanol produced from banana waste. Waste management, 34(8), 1501-1509.

Bettens, B., Verhoef, A., van Veen, H. M., Vandecasteele, C., Degrève, J., & Van der Bruggen, B. (2010). Pervaporation of binary water–alcohol and methanol–alcohol mixtures through microporous methylated silica membranes: Maxwell–Stefan modeling. Computers & Chemical Engineering, 34(11), 1775-1788.

Blackmore, L. (2016). Autonomous precision landing of space rockets. Paper presented at the in Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2016 Symposium.

Bowen, W. R., & Jenner, F. (1995). Theoretical descriptions of membrane filtration of colloids and fine particles: an assessment and review. Advances in Colloid and Interface Science, 56, 141-200.

Brexó, R. P., & Sant'Ana, A. S. (2017). Impact and significance of microbial contamination during fermentation for bioethanol production. Renewable and Sustainable Energy Reviews, 73, 423-434.

Brown, S., Oliver, S., Harrison, D., & Righelato, R. (1981). Ethanol inhibition of yeast growth and fermentation: differences in the magnitude and complexity of the effect. European journal of applied microbiology and biotechnology, 11(3), 151-155.

Buchner, E. (1907). Cell-free fermentation. Nobel Lecture, 103-120.

Bui, S., Verykios, X., & Mutharasan, R. (1985). In situ removal of ethanol from fermentation broths. 1. Selective adsorption characteristics. Industrial & Engineering Chemistry Process Design and Development, 24(4), 1209-1213.

Cai, D., Hu, S., Chen, C., Wang, Y., Zhang, C., Miao, Q., . . . Tan, T. (2016). Immobilized ethanol fermentation coupled to pervaporation with silicalite-1/polydimethylsiloxane/polyvinylidene fluoride composite membrane. Bioresource technology, 220, 124-131.

Canchola, J., Tang, S., Hemyari, P., Paxinos, E., & Marins, E. (2017). Correct use of percent coefficient of variation (cv) formula for log-transformed data. MOJ Proteomics Bioinform, 6(4), 316-317.

Cannilla, C., Bonura, G., & Frusteri, F. (2017). Potential of pervaporation and vapor separation with water selective membranes for an optimized production of biofuels—a review. Catalysts, 7(6), 187.

Caro, I., Perez, L., & Cantero, D. (1991). Development of a kinetic model for the alcoholic fermentation of must. Biotechnology and bioengineering, 38(7), 742-748.

Carvalho-Netto, O. V., Carazzolle, M. F., Mofatto, L. S., Teixeira, P. J., Noronha, M. F., Calderón, L. A., . . . Pereira, G. A. (2015). Saccharomyces cerevisiae transcriptional reprograming due to bacterial contamination during industrial scale bioethanol production. Microbial cell factories, 14(1), 13.

Cath, T. Y., Elimelech, M., McCutcheon, J. R., McGinnis, R. L., Achilli, A., Anastasio, D., . . . Hancock, N. T. (2013). Standard methodology for evaluating membrane performance in osmotically driven membrane processes. Desalination, 312, 31-38.

Chen, J., Zhang, H., Wei, P., Zhang, L., & Huang, H. (2014). Pervaporation behavior and integrated process for concentrating lignocellulosic ethanol through polydimethylsiloxane (PDMS) membrane. Bioprocess and biosystems engineering, 37(2), 183-191.

Choi, H., Zhang, K., Dionysiou, D. D., Oerther, D. B., & Sorial, G. A. (2005). Influence of cross-flow velocity on membrane performance during filtration of biological suspension. Journal of Membrane Science, 248(1-2), 189-199.

Cinelli, B. A., Freire, D. M., & Kronemberger, F. A. (2019). Membrane distillation and pervaporation for ethanol removal: are we comparing in the right way? Separation Science and Technology, 54(1), 110-127.

Contois, D. (1959). Kinetics of bacterial growth: relationship between population density and specific growth rate of continuous cultures. Microbiology, 21(1), 40-50.

Converti, A., Zilli, M., Rovatti, M., & Del Borghi, M. (1995). Effects of glycerol on alcohol fermentation. Inhibition mechanism and diffusion limitations. Bioprocess Engineering, 13(5), 257-263.

Cooney, C., & Makiguchi, N. (1967). Continuous Culture 6. SCI London, 146-157.

Correa, D. F., Beyer, H. L., Possingham, H. P., Thomas-Hall, S. R., & Schenk, P. M. (2017). Biodiversity impacts of bioenergy production: Microalgae vs. first generation biofuels. Renewable and Sustainable Energy Reviews, 74, 1131-1146.

Crabtree, H. G. (1929). Observations on the carbohydrate metabolism of tumours. Biochemical journal, 23(3), 536.

Crespo, J. G., & Böddeker, K. W. (2013). Membrane processes in separation and purification (Vol. 272): Springer Science & Business Media.

Cysewski, G. R., & Wilke, C. R. (1977). Rapid ethanol fermentations using vacuum and cell recycle. Biotechnology and bioengineering, 19(8), 1125-1143.

Dadi, D., Beyene, A., Simoens, K., Soares, J., Demeke, M., Thevelein, J., . . . Van der Bruggen, B. (2018). Valorization of coffee byproducts for bioethanol production using lignocellulosic yeast fermentation and pervaporation. International Journal of Environmental Science and Technology, 15(4), 821-832.

Davis, M. S., Solbiati, J., & Cronan, J. E. (2000). Overproduction of acetyl-CoA carboxylase activity increases the rate of fatty acid biosynthesis in Escherichia coli. Journal of Biological Chemistry, 275(37), 28593-28598.

De Deken, R. (1966). The Crabtree effect: a regulatory system in yeast. Microbiology, 44(2), 149-156.

de Vrije, T., Budde, M., van der Wal, H., Claassen, P. A., & López-Contreras, A. M. (2013). “In situ” removal of isopropanol, butanol and ethanol from fermentation broth by gas stripping. Bioresource technology, 137, 153-159.

Delgado, J., Águeda, V., Uguina, M., Sotelo, J., García-Sanz, A., & García, A. (2015). Separation of ethanol–water liquid mixtures by adsorption on BPL activated carbon with air regeneration. Separation and purification technology, 149, 370-380.

Di Luccio, M., Borges, C. P., & Alves, T. L. (2002). Economic analysis of ethanol and fructose production by selective fermentation coupled to pervaporation: effect of membrane costs on process economics. Desalination, 147(1-3), 161-166.

Diwekar, U. (2011). Batch distillation: simulation, optimal design, and control: CRC Press.

Dobrak, A., Figoli, A., Chovau, S., Galiano, F., Simone, S., Vankelecom, I., . . . Van der Bruggen, B. (2010). Performance of PDMS membranes in pervaporation: effect of silicalite fillers and comparison with SBS membranes. Journal of colloid and interface science, 346(1), 254-264.

Dodić, J. M., Vučurović, D. G., Dodić, S. N., Grahovac, J. A., Popov, S. D., & Nedeljković, N. M. (2012). Kinetic modelling of batch ethanol production from sugar beet raw juice. Applied energy, 99, 192-197.

Drioli, E., & Giorno, L. (2010). Comprehensive membrane science and engineering (Vol. 1): Newnes.

Duskova, M., Borovikova, D., Herynkova, P., Rapoport, A., & Sychrova, H. (2015). The role of glycerol transporters in yeast cells in various physiological and stress conditions. FEMS microbiology letters, 362(3), 1-8.

Ebneyamini, A., Azimi, H., Tezel, F. H., & Thibault, J. (2017). Modelling of mixed matrix membranes: Validation of the resistance-based model. Journal of Membrane Science, 543, 361-369.

Ezeji, T., Qureshi, N., & Blaschek, H. (2003). Production of acetone, butanol and ethanol by Clostridium beijerinckii BA101 and in situ recovery by gas stripping. World Journal of Microbiology and Biotechnology, 19(6), 595-603.

Fan, S., Liu, J., Tang, X., Wang, W., Xiao, Z., Qiu, B., . . . Wang, Y. (2019). Process operation performance of PDMS membrane pervaporation coupled with fermentation for efficient bioethanol production. Chinese Journal of Chemical Engineering, 27(6), 1339-1347.

Flynn, E. J. (2013). Advanced polymer membrane development in pervaporation dehydration and lateral flow diagnostics.

Fouad, E. A., & Feng, X. (2009). Pervaporative separation of n-butanol from dilute aqueous solutions using silicalite-filled poly (dimethyl siloxane) membranes. Journal of Membrane Science, 339(1-2), 120-125.

Fujita, H., Qian, Q., Fujii, T., Mochizuki, K., & Sakoda, A. (2011). Isolation of ethanol from its aqueous solution by liquid phase adsorption and gas phase desorption using molecular sieving carbon. Adsorption, 17(5), 869-879.

García, M., Sanz, M. T., & Beltrán, S. (2009). Separation by pervaporation of ethanol from aqueous solutions and effect of other components present in fermentation broths. Journal of Chemical Technology & Biotechnology, 84(12), 1873-1882.

Garhyan, P., & Elnashaie, S. (2004). Utilization of mathematical models to investigate the bifurcation and chaotic behavior of ethanol fermentors. Mathematical and computer modelling, 39(4-5), 381-427.

Gasmi, N., Jacques, P.-E., Klimova, N., Guo, X., Ricciardi, A., Robert, F., & Turcotte, B. (2014). The switch from fermentation to respiration in Saccharomyces cerevisiae is regulated by the Ert1 transcriptional activator/repressor. Genetics, 198(2), 547-560.

Gaykawad, S. S., Zha, Y., Punt, P. J., van Groenestijn, J. W., van der Wielen, L. A., & Straathof, A. J. (2013). Pervaporation of ethanol from lignocellulosic fermentation broth. Bioresource technology, 129, 469-476.

Gerson, D. F., Kole, M. M., Ozum, B., & Oguztoreli, M. (1988). Substrate concentration control in bioreactors. Biotechnology and Genetic Engineering Reviews, 6(1), 67-150.

Ghose, T., & Tyagi, R. (1979). Rapid ethanol fermentation of cellulose hydrolysate. II. Product and substrate inhibition and optimization of fermentor design. Biotechnology and bioengineering, 21(8), 1401-1420.

González-Marcos, J. A., López-Dehesa, C., & González-Velasco, J. R. (2004). Effect of operation conditions in the pervaporation of ethanol–water mixtures with poly (1-trimethylsilyl-1-propyne) membranes. Journal of applied polymer science, 94(4), 1395-1403.

Hassan, I., Ennouri, M., Lafforgue, C., Schmitz, P., & Ayadi, A. (2013). Experimental study of membrane fouling during crossflow microfiltration of yeast and bacteria suspensions: towards an analysis at the microscopic level. Membranes, 3(2), 44-68.

Heintz, A., & Stephan, W. (1994). A generalized solution—diffusion model of the pervaporation process through composite membranes Part II. Concentration polarization, coupled diffusion and the influence of the porous support layer. Journal of Membrane Science, 89(1-2), 153-169.

Hester, R. E., & Harrison, R. M. (2010). Carbon capture: sequestration and storage (Vol. 29): Royal Society of Chemistry.

Hietaharju, J., Kangas, J., & Tanskanen, J. (2019). Analysis of the permeation behavior of ethanol/water mixtures through a polydimethylsiloxane (PDMS) membrane in pervaporation and vapor permeation conditions. Separation and purification technology, 227, 115738.

Hind, H. L. (1932). THEORIES OF FERMENTATION AND THEIR PRACTICAL APPLICATION. Journal of the Institute of Brewing, 38(4), 391-402.

Holsbeeks, I., Lagatie, O., Van Nuland, A., Van de Velde, S., & Thevelein, J. M. (2004). The eukaryotic plasma membrane as a nutrient-sensing device. Trends in biochemical sciences, 29(10), 556-564.

Holzberg, I., Finn, R., & Steinkraus, K. H. (1967). A kinetic study of the alcoholic fermentation of grape juice. Biotechnology and bioengineering, 9(3), 413-427.

Hoskisson, P. A., & Hobbs, G. (2005). Continuous culture–making a comeback? Microbiology, 151(10), 3153-3159.

Huang, H.-J., Ramaswamy, S., Tschirner, U. W., & Ramarao, B. (2008). A review of separation technologies in current and future biorefineries. Separation and purification technology, 62(1), 1-21.

Huang, H., Qureshi, N., Chen, M.-H., Liu, W., & Singh, V. (2015). Ethanol production from food waste at high solids content with vacuum recovery technology. Journal of agricultural and food chemistry, 63(10), 2760-2766.

Huang, R., & Rhim, J. (1991). Separation characteristics of pervaporation membrane separation processes Pervaporation Membrane Separation Processes (pp. 111-180): Elsevier Amsterdam.

Huang, R. Y. (1991). Pervaporation Membrane Sepration Processes. Membrane Science and Technology Series 1, 111.

Huberts, D. H., Niebel, B., & Heinemann, M. (2012). A flux-sensing mechanism could regulate the switch between respiration and fermentation. FEMS yeast research, 12(2), 118-128.

Humphrey, A. (1979). Fermentation process modeling: an overview. Annals of the New York Academy of Sciences, 326(1), 17-33.

Hwang, S.-T., Kammermeyer, K., & Weissberger, A. (1975). Membranes in separations (Vol. 7): Wiley New York.

Ismail, A. F., Khulbe, K. C., & Matsuura, T. (2015). Membrane modules and process design Gas Separation Membranes (pp. 221-240): Springer.

Ivanova, V., Petrova, P., & Hristov, J. (2011). Application in the ethanol fermentation of immobilized yeast cells in matrix of alginate/magnetic nanoparticles, on chitosan-magnetite microparticles and cellulose-coated magnetic nanoparticles. arXiv preprint arXiv:1105.0619.

Jaimes, J. H. B., Alvarez, M. E., Rojas, J. V., & Maciel Filho, R. (2014). Pervaporation: promissory method for the bioethanol separation of fermentation. Chem. Eng, 38.

Jia, W., Sun, W., Xia, C., Yang, X., Cao, Z., & Zhang, W. (2017). Copolymerization modification of poly (vinyltriethoxysilane) membranes for ethanol recovery by pervaporation. RSC advances, 7(86), 54441-54452.

Jiraratananon, R., Chanachai, A., Huang, R., & Uttapap, D. (2002). Pervaporation dehydration of ethanol–water mixtures with chitosan/hydroxyethylcellulose (CS/HEC) composite membranes: I. Effect of operating conditions. Journal of Membrane Science, 195(2), 143-151.

Jyoti, G., Keshav, A., & Anandkumar, J. (2015). Review on pervaporation: theory, membrane performance, and application to intensification of esterification reaction. Journal of Engineering, 2015.

Kaewkannetra, P., Chutinate, N., Moonamart, S., Kamsan, T., & Chiu, T. Y. (2012). Experimental study and cost evaluation for ethanol separation from fermentation broth using pervaporation. Desalination and Water Treatment, 41(1-3), 88-94.

Kamelian, F. S., Mohammadi, T., Naeimpoor, F., & Sillanpää, M. (2020). One-Step and Low-Cost Designing of Two-Layered Active-Layer Superhydrophobic Silicalite-1/PDMS Membrane for Simultaneously Achieving Superior Bioethanol Pervaporation and Fouling/Biofouling Resistance. ACS Applied Materials & Interfaces.

Kanse, N. G., & Dawande, S. (2017). Separation of ethanol/water (azeotropic mixture) by pervaporation using PVA membrane. Materials Today: Proceedings, 4(9), 10520-10523.

Khatinzadeh, G., Mahdyarfar, M., Mehdizadeh, A., Esmailzadeh, A., & Sattari, A. (2016). Effects of permeate pressure and feed flow rate on benzene dehydration by pervaporation. Journal of Petroleum Science and Technology, 6(2), 30-36.

Kim, S., & Kim, H. (2016). A new metric of absolute percentage error for intermittent demand forecasts. International Journal of Forecasting, 32(3), 669-679.

Klinke, H. B., Thomsen, A., & Ahring, B. K. (2004). Inhibition of ethanol-producing yeast and bacteria by degradation products produced during pre-treatment of biomass. Applied microbiology and biotechnology, 66(1), 10-26.

Klinov, A. V., Akberov, R. R., Fazlyev, A. R., & Farakhov, M. I. (2017). Experimental investigation and modeling through using the solution-diffusion concept of pervaporation dehydration of ethanol and isopropanol by ceramic membranes HybSi. Journal of Membrane Science, 524, 321-333.

Kollerup, F., & Daugulis, A. J. (1986). Ethanol production by extractive fermentation–solvent identification and prototype development. The Canadian Journal of Chemical Engineering, 64(4), 598-606.

Kreis, P., & Górak, A. (2006). Process analysis of hybrid separation processes: Combination of distillation and pervaporation. Chemical Engineering Research and Design, 84(7), 595-600.

Kujawska, A., Kujawski, J., Bryjak, M., & Kujawski, W. (2015). ABE fermentation products recovery methods—a review. Renewable and Sustainable Energy Reviews, 48, 648-661.

Le, N. L., Wang, Y., & Chung, T.-S. (2011). Pebax/POSS mixed matrix membranes for ethanol recovery from aqueous solutions via pervaporation. Journal of Membrane Science, 379(1-2), 174-183.

Lee, H.-J., Cho, E. J., Kim, Y.-G., Choi, I. S., & Bae, H.-J. (2012). Pervaporative separation of bioethanol using a polydimethylsiloxane/polyetherimide composite hollow-fiber membrane. Bioresource technology, 109, 110-115.

Lei, Z., Li, C., & Chen, B. (2003). Extractive distillation: a review. Separation & Purification Reviews, 32(2), 121-213.

Li, Q., Cheng, L., Shen, J., Shi, J., Chen, G., Zhao, J., . . . Jin, W. (2017). Improved ethanol recovery through mixed-matrix membrane with hydrophobic MAF-6 as filler. Separation and purification technology, 178, 105-112.

Lipnizki, F., & Trägårdh, G. (2001). Modelling of pervaporation: models to analyze and predict the mass transport in pervaporation. Separation and Purification Methods, 30(1), 49-125.

Liu, H.-s., & Hsien-Wen, H. (1990). Analysis of gas stripping during ethanol fermentation—I. In a continuous stirred tank reactor. Chemical Engineering Science, 45(5), 1289-1299.

Longobardi, G. (1994). Fed-batch versus batch fermentation. Bioprocess and biosystems engineering, 10(5), 185-194.

Luedeking, R., & Piret, E. L. (1959). Transient and steady states in continuous fermentaion. Theory and experiment. Journal of biochemical and microbiological technology and engineering, 1(4), 431-459.

Luong, J. (1985). Kinetics of ethanol inhibition in alcohol fermentation. Biotechnology and bioengineering, 27(3), 280-285.

Lyu, J., Wen, X., Kumar, U., You, Y., Chen, V., & Joshi, R. (2018). Separation and purification using GO and r-GO membranes. RSC advances, 8(41), 23130-23151.

Maiorella, B., Blanch, H. W., & Wilke, C. R. (1983). By-product inhibition effects on ethanolic fermentation by Saccharomyces cerevisiae. Biotechnology and bioengineering, 25(1), 103-121.

Marín, M. R. (1999). Alcoholic fermentation modelling: current state and perspectives. American Journal of Enology and Viticulture, 50(2), 166-178.

Marriott, J., & Sørensen, E. (2003). A general approach to modelling membrane modules. Chemical Engineering Science, 58(22), 4975-4990.

Mata-Alvarez, J., & Mitchell, D. A. (2009). Mathematical Modeling in Biotechnology. BIOTECHNOLOGY-Volume II: Fundamentals in Biotechnology, 2, 102.

Mazzoleni, S., Landi, C., Cartenì, F., de Alteriis, E., Giannino, F., Paciello, L., & Parascandola, P. (2015). A novel process-based model of microbial growth: self-inhibition in Saccharomyces cerevisiae aerobic fed-batch cultures. Microbial cell factories, 14(1), 109.

Menezes, J. C., Alves, S. S., Lemos, J. M., & de Azevedo, S. F. (1994). Mathematical modelling of industrial pilot-plant penicillin-G fed-batch fermentations. Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental AND Clean Technology, 61(2), 123-138.

Minier, M., & Coma, G. (1981). Production of ethanol by coupling fermentation and solvent extraction. Biotechnology letters, 3(8), 405-408.

Minteer, S. (2016). Alcoholic fuels: CRC Press.

Miyazawa, I., & Kokugan, T. (1998). Effect of product removal by a pervaporation on ethanol fermentation. Journal of fermentation and Bioengineering, 86(5), 488-493.

Monod, J. (1950). La technique de culture continue: theorie et applications.

Monsalve-Bravo, G. M., & Bhatia, S. K. (2018). Modeling permeation through mixed-matrix membranes: a review. Processes, 6(9), 172.

Montgomery, D. C. (2017). Design and analysis of experiments: John wiley & sons.

Morales-Sánchez, D., Kim, Y., Terng, E. L., Peterson, L., & Cerutti, H. (2017). A multidomain enzyme, with glycerol-3-phosphate dehydrogenase and phosphatase activities, is involved in a chloroplastic pathway for glycerol synthesis in Chlamydomonas reinhardtii. The Plant Journal, 90(6), 1079-1092.

Mota, M., Strehaiano, P., & Goma, G. (1984). Studies on conjugate effects of substrate (glucose) and product (ethanol) on cell growth kinetics during fermentation of different yeast strains. Journal of the Institute of Brewing, 90(6), 359-362.

Moulin, G., Boze, H., & Galzy, P. (1980). Inhibition of alcoholic fermentation by substrate and ethanol. Biotechnology and bioengineering, 22(11), 2375-2381.

Mulder, M. (1991). Thermodynamic principles of pervaporation. Pervaporation membrane separation processes. Chapter 4, 225-250.

Mulder, M., & Smolders, C. (1984). On the mechanism of separation of ethanol/water mixtures by pervaporation I. Calculations of concentration profiles. Journal of Membrane Science, 17(3), 289-307.

Mulder, M., & Smolders, C. (1991). Mass transport phenomena in pervaporation processes. Separation Science and Technology, 26(1), 85-95.

Nasiri, H., & Aroujalian, A. (2010). A novel model based on cluster formation for pervaporation separation of polar components from aqueous solutions. Separation and purification technology, 72(1), 13-21.

Negelein, E., & Wulff, H. (1937). Diphosphopyridinproteid, Alkohol, Acetaldehyd. Biochem. Z, 293(351), 62.

Nelson, D. L., Lehninger, A. L., & Cox, M. M. (2008). Lehninger principles of biochemistry: Macmillan.

Nguyen, V. D., Auresenia, J., Kosuge, H., Tan, R. R., & Brondial, Y. (2011). Vacuum fermentation integrated with separation process for ethanol production. Biochemical engineering journal, 55(3), 208-214.

Nguyen, V. D., Kosuge, H., Auresenia, J., Tan, R., & Brondial, Y. (2009). Effect of vacuum pressure on ethanol fermentation. J Appl Sci, 9, 3020-3026.

Nigiz, F. U., & Hilmioglu, N. D. (2013). Bioethanol Production by Pervaporation Membrane Bioreactor. Journal of Selcuk University Natural and Applied Science, 258-264.

Noble, R. D., & Stern, S. A. (1995). Membrane separations technology: principles and applications (Vol. 2): Elsevier.

O'Brien, D. J., Roth, L. H., & McAloon, A. J. (2000). Ethanol production by continuous fermentation–pervaporation: a preliminary economic analysis. Journal of Membrane Science, 166(1), 105-111.

Obotey Ezugbe, E., & Rathilal, S. (2020). Membrane technologies in wastewater treatment: a review. Membranes, 10(5), 89.

Offeman, R. D., Stephenson, S. K., Franqui, D., Cline, J. L., Robertson, G. H., & Orts, W. J. (2008). Extraction of ethanol with higher alcohol solvents and their toxicity to yeast. Separation and purification technology, 63(2), 444-451.

Offeman, R. D., Stephenson, S. K., Robertson, G. H., & Orts, W. J. (2005). Solvent extraction of ethanol from aqueous solutions. I. Screening methodology for solvents. Industrial & engineering chemistry research, 44(17), 6789-6796.

Okada, T., & Matsuura, T. (1991). A new transport model for pervaporation. Journal of Membrane Science, 59(2), 133-149.

Okada, T., Yoshikawa, M., & Matsuura, T. (1991). A study on the pervaporation of ethanol/water mixtures on the basis of pore flow model. Journal of Membrane Science, 59(2), 151-168.

Oliveira, S., Oliveira, R., Tacin, M., & Gattás, E. (2016). Kinetic modeling and optimization of a batch ethanol fermentation process. J Bioprocess Biotech, 6(266), 2.

Ong, Y. K., Shi, G. M., Le, N. L., Tang, Y. P., Zuo, J., Nunes, S. P., & Chung, T.-S. (2016). Recent membrane development for pervaporation processes. Progress in Polymer Science, 57, 1-31.

Outram, V., Lalander, C. A., Lee, J. G., Davies, E. T., & Harvey, A. P. (2017). Applied in situ product recovery in ABE fermentation. Biotechnology progress, 33(3), 563-579.

Özilgen, M., Celik, M., & Bozoḡlu, T. (1991). Kinetics of spontaneous wine production. Enzyme and microbial technology, 13(3), 252-256.

Palmqvist, E., & Hahn-Hägerdal, B. (2000). Fermentation of lignocellulosic hydrolysates. II: inhibitors and mechanisms of inhibition. Bioresource technology, 74(1), 25-33.

Parnes, O. (2003). From agents to cells: Theodor Schwann's research notes of the years 1835–1838 Reworking the Bench (pp. 119-140): Springer.

Peebo, K., & Neubauer, P. (2018). Application of continuous culture methods to recombinant protein production in microorganisms. Microorganisms, 6(3), 56.

Pereira, C., Habert, A., Nobrega, R., & Borges, C. (1998). New insights in the removal of diluted volatile organic compounds from dilute aqueous solution by pervaporation process. Journal of Membrane Science, 138(2), 227-235.

Pfeiffer, T., Schuster, S., & Bonhoeffer, S. (2001). Cooperation and competition in the evolution of ATP-producing pathways. Science, 292(5516), 504-507.

Pirt, S. J. (1975). Principles of microbe and cell cultivation: Blackwell Scientific Publications.

Qiu, B., Wang, Y., Fan, S., Liu, J., Jian, S., Qin, Y., . . . Wang, W. (2019). Ethanol mass transfer during pervaporation with PDMS membrane based on solution-diffusion model considering concentration polarization. Separation and purification technology, 220, 276-282.

Racker, E. (1974). History of the Pasteur effect and its pathobiology. Molecular and cellular biochemistry, 5(1-2), 17-23.

Rautenbach, R., Herion, C., & Meyer-Blumentoth, U. (1991). Pervaporation membrane separation processes. Membrane science and technology series, 1, 181-191.

Remize, F., Roustan, J., Sablayrolles, J., Barre, P., & Dequin, S. (1999). Glycerol overproduction by engineered Saccharomyces cerevisiae wine yeast strains leads to substantial changes in by-product formation and to a stimulation of fermentation rate in stationary phase. Appl. Environ. Microbiol., 65(1), 143-149.

Renon, H., & Prausnitz, J. M. (1968). Local compositions in thermodynamic excess functions for liquid mixtures. AIChE journal, 14(1), 135-144.

Rich, J. O., Leathers, T. D., Bischoff, K. M., Anderson, A. M., & Nunnally, M. S. (2015). Biofilm formation and ethanol inhibition by bacterial contaminants of biofuel fermentation. Bioresource technology, 196, 347-354.

Richardson, J. F., Harker, J. H., & Backhurst, J. R. (2002). Coulson & Richardson's Chemical Engineering (Vol. 2): Butterworth-Heinemann London.

Riley, R., Lyons, C., Milstead, C., Seroy, M., & Tagami, M. (1976). Research and Development on a Spiral-Wound Membrane System for Single-Stage Seawater Deslination.

Robinson, R. K. (2014). Encyclopedia of food microbiology: Academic press.

Rottenberg, H. (1979). [64] The measurement of membrane potential and ΔpH in cells, organelles, and vesicles Methods in enzymology (Vol. 55, pp. 547-569): Elsevier.

Rubio-Texeira, M., Van Zeebroeck, G., Voordeckers, K., & Thevelein, J. M. (2010). Saccharomyces cerevisiae plasma membrane nutrient sensors and their role in PKA signaling. FEMS yeast research, 10(2), 134-149.

Russell, J. (1992). Another explanation for the toxicity of fermentation acids at low pH: anion accumulation versus uncoupling. Journal of applied bacteriology, 73(5), 363-370.

Salsani, A., Daneshian, J., Shariati, S., Yazdani-Chamzini, A., & Taheri, M. (2014). Predicting roadheader performance by using artificial neural network. Neural Computing and Applications, 24(7-8), 1823-1831.

Samei, M., Iravaninia, M., Mohammadi, T., & Asadi, A. A. (2016). Solution diffusion modeling of a composite PVA/fumed silica ceramic supported membrane. Chemical Engineering and Processing-Process Intensification, 109, 11-19.

Santos, E. L. I., Rostro-Alanís, M., Parra-Saldívar, R., & Alvarez, A. J. (2018). A novel method for bioethanol production using immobilized yeast cells in calcium-alginate films and hybrid composite pervaporation membrane. Bioresource technology, 247, 165-173.

Schiffmann, P., & Repke, J.-U. (2011). Design of pervaporation modules based on computational process modelling Computer Aided Chemical Engineering (Vol. 29, pp. 397-401): Elsevier.

Schmidt, S. L., Myers, M. D., Kelley, S. S., McMillan, J. D., & Padukone, N. (1997). Evaluation of PTMSP membranes in achieving enhanced ethanol removal from fermentations by pervaporation Biotechnology for Fuels and Chemicals (pp. 469-482): Springer.

Serra, A., Poch, M., & Sola, C. (1987). A survey of separation systems for fermentation ethanol recovery. Process biochemistry, 22(5), 154-158.

Shafiei Amrei, S., Asghari, M., Esfahanian, M., & Zahraei, Z. (2020). Highly selective carbon nanotube-coupled graphene oxide-incorporated polydimethylsiloxane membrane for pervaporative membrane bioreactor ethanol production. Journal of Chemical Technology & Biotechnology, 95(5), 1604-1613.

Shah, D. S. (2001). Pervaporation of solvent mixtures using polymeric and zeolitic membranes: separation studies and modeling.

Slater, C. S., Schurmann, T., MacMillian, J., & Zimarowski, A. (2005). Membrane pervaporation-An experimental experience in novel separations for green engineering. Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Sluiter, A., Hames, B., Ruiz, R., Scarlata, C., Sluiter, J., & Templeton, D. (2006). Determination of sugars, byproducts, and degradation products in liquid fraction process samples. Golden: National Renewable Energy Laboratory.

Soltanieh, M., & Gill, W. N. (1982). Analysis and design of hollow fiber reverse osmosis systems. Chemical engineering communications, 18(5-6), 311-330.

Spitzen, J. W. (1990). Pervaporation: Membranes and models for the dehydration of ethanol.

Starzak, M., Kryzstek, L., Nowicki, L., & Michalski, H. (1994). Macroapproach kinetics of ethanol fermentation by Saccharomyces cerevisiae: experimental studies and mathematical modelling. The Chemical Engineering Journal and the Biochemical Engineering Journal, 54(3), 221-240.

Stouthamer, A. (1979). The search for correlation between theoretical and experimental growth yields Vol. 21: Baltimore: University Park Press.

Strehaiano, P., Mota, M., & Goma, G. (1983). Effects of inoculum level on kinetics of alcoholic fermentation. Biotechnology letters, 5(2), 135-140.

Sukitpaneenit, P., Chung, T.-S., & Jiang, L. Y. (2010). Modified pore-flow model for pervaporation mass transport in PVDF hollow fiber membranes for ethanol–water separation. Journal of Membrane Science, 362(1-2), 393-406.

Sun, X., Dang, G., Ding, X., Shen, C., Liu, G., Zuo, C., . . . Jin, W. (2020). Production of alcohol-free wine and grape spirit by pervaporation membrane technology. Food and Bioproducts Processing, 123, 262-273.

Svang-Ariyaskul, A., Huang, R., Douglas, P., Pal, R., Feng, X., Chen, P., & Liu, L. (2006). Blended chitosan and polyvinyl alcohol membranes for the pervaporation dehydration of isopropanol. Journal of Membrane Science, 280(1-2), 815-823.

Thierie, J., & Penninckx, M. (2009). Crabtree Effect. Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation, and Cell Technology, 1-18.

Thongsukmak, A., & Sirkar, K. (2009). Extractive pervaporation to separate ethanol from its dilute aqueous solutions characteristic of ethanol-producing fermentation processes. Journal of Membrane Science, 329(1-2), 119-129.

Tian, M., & Row, K. H. (2013). Separation of glucose and bioethanol in biomass with current methods and sorbents. Journal of chromatographic science, 51(8), 819-824.

Todaro, C. M., & Vogel, H. C. (2014). Fermentation and biochemical engineering handbook: William Andrew.

Torija, M. J., Beltran, G., Novo, M., Poblet, M., Rozès, N., Mas, A., & Guillamón, J. M. (2003). Effect of organic acids and nitrogen source on alcoholic fermentation: study of their buffering capacity. Journal of agricultural and food chemistry, 51(4), 916-922.

Trinh, L. T. P., Cho, E. J., Lee, Y. J., Bae, H.-J., & Lee, H.-J. (2013). Pervaporative separation of bioethanol produced from the fermentation of waste newspaper. Journal of Industrial and Engineering Chemistry, 19(6), 1910-1915.

Vane, L. M. (2005). A review of pervaporation for product recovery from biomass fermentation processes. Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology, 80(6), 603-629.

Vane, L. M. (2008). Separation technologies for the recovery and dehydration of alcohols from fermentation broths. Biofuels, Bioproducts and Biorefining, 2(6), 553-588.

Vane, L. M., Alvarez, F. R., Rosenblum, L., & Govindaswamy, S. (2012). Efficient ethanol recovery from yeast fermentation broth with integrated distillation–membrane process. Industrial & engineering chemistry research, 52(3), 1033-1041.

Vankelecom, I. F., Depre, D., De Beukelaer, S., & Uytterhoeven, J. B. (1995). Influence of zeolites in PDMS membranes: pervaporation of water/alcohol mixtures. The Journal of Physical Chemistry, 99(35), 13193-13197.

Verduyn, C. (1992). Physiology of yeasts in relation to biomass yields Quantitative Aspects of Growth and Metabolism of Microorganisms (pp. 325-353): Springer.

Walsh, P., Liu, C., Findley, M., Liapis, A., & Siehr, D. (1983). Ethanol separation from water in a two-stage adsorption process. Paper presented at the Biotechnol. Bioeng. Symp.;(United States).

Wang, H., Tang, S., Ni, Y., Zhang, C., Zhu, X., & Zhao, Q. (2020). Covalent cross-linking for interface engineering of high flux UiO-66-TMS/PDMS pervaporation membranes. Journal of Membrane Science, 598, 117791.

Wang, Z., Wu, Z., & Tang, S. (2009). Extracellular polymeric substances (EPS) properties and their effects on membrane fouling in a submerged membrane bioreactor. Water research, 43(9), 2504-2512.

Watanabe, K., & Kyo, S. (1992). Pervaporation performance of hollow-fiber chitosan-polyacrylonitrile composite membrane in dehydration of ethanol. Journal of chemical engineering of Japan, 25(1), 17-21.

Wei, W., Xia, S., Liu, G., Dong, X., Jin, W., & Xu, N. (2011). Effects of polydimethylsiloxane (PDMS) molecular weight on performance of PDMS/ceramic composite membranes. Journal of Membrane Science, 375(1-2), 334-344.

Wijmans, J. G., & Baker, R. W. (1995). The solution-diffusion model: a review. Journal of Membrane Science, 107(1-2), 1-21.

Williams, S. J. (2016). Experimental and Modeling Study on Pervaporation Separation of Ethanol and Water Mixture by Polycrystalline MFI Zeolite Membranes. Arizona State University.

Xie, Z., Ng, D., Hoang, M., Duong, T., & Gray, S. (2011). Separation of aqueous salt solution by pervaporation through hybrid organic–inorganic membrane: effect of operating conditions. Desalination, 273(1), 220-225.

Xu, T.-J., & Ting, Y.-P. (2004). Optimisation on bioleaching of incinerator fly ash by Aspergillus niger–use of central composite design. Enzyme and microbial technology, 35(5), 444-454.

Xue, C., Yang, D., Du, G., Chen, L., Ren, J., & Bai, F. (2015). Evaluation of hydrophobic micro-zeolite-mixed matrix membrane and integrated with acetone–butanol–ethanol fermentation for enhanced butanol production. Biotechnology for biofuels, 8(1), 105.

Yeom, C., & Huang, R. (1992). Modelling of the pervaporation separation of ethanol-water mixtures through crosslinked poly (vinyl alcohol) membrane. Journal of Membrane Science, 67(1), 39-55.

Yi, S., & Wan, Y. (2017). Separation performance of novel vinyltriethoxysilane (VTES)-g-silicalite-1/PDMS/PAN thin-film composite membrane in the recovery of bioethanol from fermentation broths by pervaporation. Journal of Membrane Science, 524, 132-140.

Ylitervo, P., Akinbomi, J., & Taherzadeh, M. J. (2013). Membrane bioreactors' potential for ethanol and biogas production: a review. Environmental technology, 34(13-14), 1711-1723.

Yoshida, S., & Yokoyama, A. (2012). Identification and characterization of genes related to the production of organic acids in yeast. Journal of bioscience and bioengineering, 113(5), 556-561.

Zentou, H., Abidin, Z. Z., Yunus, R., Biak, A., Radiah, D., & Korelskiy, D. (2019). Overview of Alternative Ethanol Removal Techniques for Enhancing Bioethanol Recovery from Fermentation Broth. Processes, 7(7), 458.

Zentou, H., Zainal Abidin, Z., Yunus, R., Awang Biak, D. R., Abdullah Issa, M., & Yahaya Pudza, M. (2021). A New Model of Alcoholic Fermentation under a Byproduct Inhibitory Effect. ACS omega, 6(6), 4137-4146.

Zhan, X., Li, J.-d., Huang, J.-q., & Chen, C.-x. (2009). Pervaporation properties of PDMS membranes cured with different cross-linking reagents for ethanol concentration from aqueous solutions. Chinese Journal of Polymer Science, 27(04), 533-542.

Zhang, A., & Xun, C. (2008). Improve ethanol yield through minimizing glycerol yield in ethanol fermentation of Saccharomyces cerevisiae. Chinese Journal of Chemical Engineering, 16(4), 620-625.

Zhang, J., Liu, H.-j., & Liu, D.-h. (2005). Effect of different types of gas in gas stripping ethanol fermentation (GSEF). CHINESE JOURNAL OF PROCESS ENGINEERING, 5(3), 349.

Zhang, Q., Wu, D., Lin, Y., Wang, X., Kong, H., & Tanaka, S. (2015). Substrate and product inhibition on yeast performance in ethanol fermentation. Energy & fuels, 29(2), 1019-1027.

Zhang, W., Xia, C., Li, L., Ren, Z., Liu, J., & Yang, X. (2014). Preparation and application of a novel ethanol permselective poly (vinyltriethoxysilane) membrane. RSC advances, 4(28), 14592-14596.

Zhao, P., Yao, B., Meng, J., Zhang, R., Cao, B., & Li, P. (2021). Studies on the fouling behavior and cleaning method of pervaporation desalination membranes for reclamation of reverse osmosis concentrated water. Separation and Purification Technology, 119034.

Zhou, H., Shi, R., & Jin, W. (2014). Novel organic–inorganic pervaporation membrane with a superhydrophobic surface for the separation of ethanol from an aqueous solution. Separation and purification technology, 127, 61-69.

Zhu, H., Li, X., Pan, Y., Liu, G., Wu, H., Jiang, M., & Jin, W. (2020). Fluorinated PDMS membrane with anti-biofouling property for in-situ biobutanol recovery from fermentation-pervaporation coupled process. Journal of Membrane Science, 609, 118225.

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LIST OF PUBLICATIONS

Zentou, H., Abidin, Z. Z., Yunus, R., Biak, D. R. A., & Issa, M. A. A New Model of Alcoholic Fermentation Under Byproducts Inhibitory Effect. Omega ACS.2021(https://pubs.acs.org/doi/abs/10.1021/acsomega.0c04025)

Zentou, H., Abidin, Z. Z., Yunus, R., Biak, D. R. A., & Issa, M. A. Optimization and modeling of the performance of polydimethylsiloxane for pervaporation of ethanol-water mixture. Journal of Applied PolymerScience.2020,50408. (https://onlinelibrary.wiley.com/doi/abs/10.1002/app.50408)

Zentou, H.; Zainal Abidin, Z.; Yunus, R.; Awang Biak, D.R.; Zouanti, M.; Hassani, A. Modelling of Molasses Fermentation for Bioethanol Production: A Comparative Investigation of Monod and Andrews Models Accuracy Assessment. Biomolecules 2019, 9, 308. (https://www.mdpi.com/2218-273X/9/8/308)

Zentou H, Abidin ZZ, Robiah Yunus, Biak DRA, Korelskiy D. Overview of Alternative Ethanol Removal Techniques for Enhancing Bioethanol Recovery from Fermentation Broth. Processes. 2019 Jul;7(7):458. (https://www.mdpi.com/2227-9717/7/7/458)

Zentou, H., Rosli, N. S., & Gomes, C. (2019). The Viability of Biofuels in Developing Countries: Successes, Failures and Challenges. Iranian Journal of Chemistry and Chemical Engineering (IJCCE).(https://iranjournals.nlai.ir/1295/article_637845_38a278b771842069a8515a4dada458cb.pdf)

Zentou, H., Abidin, Z. Z., Zouanti, M., & Greetham, D. (2017). Effect of operating conditions on molasses fermentation for bioethanol production. International Journal of Applied Engineering Research,12(15),5202-5506. (https://www.ripublication.com/ijaer17/ijaerv12n15_%20(68).pdf)

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