Mixing and Stiring in Aerated Stirred Tank Bioreactor

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Abstract:
Fermentation is a metabolic process carried out by microorganisms like yeast or bacteria and involves the conversion of sugars into other compounds such as acids, gases, or alcohol. This process is widely used in food production, and also utilized in industrial processes to produce various chemicals and pharmaceuticals. It is a fundamental aspect of biotechnology, food science, and microbiology, playing a crucial role in the production of many everyday products.

Mixing is crucial in fermentation to ensure even distribution of nutrients, oxygen supply for aerobic processes, efficient contact between microorganisms and substrate, heat dissipation, and prevention of stratification, ultimately leading to optimal product quality and yield. This book provides a deeper understanding on the various mechanisms employed for agitation in stirred tank fermenters, such as impellers, baffles, and spargers. Also, analyzing the power consumption associated with stirring and mixing operations, including factors such as impeller design, rotational speed, and viscosity of the fermentation broth.

The primary aim of this book is to be a comprehensive volume for stirring and mixing topic, ensuring that students not only grasp the fundamentals but also explore into the depths of understanding. With clear explanations and comprehensive notes, this book attempt to clarify the path toward mastery in this interesting topic.

Keywords: Fermentation, harmaceuticals, stirring, bioprocess performance

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PREFACE

Fermentation is a metabolic process carried out by microorganisms like yeast or bacteria and involves the conversion of sugars into other compounds such as acids, gases, or alcohol. This process is widely used in food production, and also utilized in industrial processes to produce various chemicals and pharmaceuticals. It is a fundamental aspect of biotechnology, food science, and microbiology, playing a crucial role in the production of many everyday products.

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INTRODUCTION

"Mixing and Stirring in Aerated Stirred Tank Bioreactors" is primarily dedicated to comprehending and refining the details of stirring and mixing operations within aerated stirred tank batch fermenters, critical for enhancing microbial cultivation efficiency and bioprocess performance.

The first chapter serves as an introduction to bioreactors and their varied types, elucidating their respective functions. It also offers a concise overview of aerated stirred tank batch bioreactors, the focal point of this book. Subsequent chapters explore into the nuances of stirring and mixing, describe on the processes and mechanisms involved, and shedding light on the consequences of inadequate mixing.

Chapter three navigates through the agitation components within stirred tank fermenters, including impellers, spargers, and baffles. It further explores the fluid dynamics within the fermenter, analyzing flow patterns, turbulence, and shear stress distribution to optimize mixing efficiency.

The subsequent chapter studies the power consumption entailed in stirring and mixing operations, examining factors such as impeller design, rotational speed, and fermentation broth viscosity. Additionally, it provides comprehensive insights into mixing time and residence time distribution, facilitating the evaluation of homogeneity attainment within the fermentation broth.

The final chapter, explore into mass transfer, elucidating the transfer of mass from oxygen bubbles to cells. This encompasses the calculation of parameters such as oxygen transfer rate (OTR), oxygen uptake rate (OUR), and $K_L a$. It elucidates the pivotal role of mixing in facilitating heat transfer within the fermenter, thereby maintaining optimal temperature conditions crucial for microbial growth and metabolic activity.

Collectively, these chapters form a comprehensive framework for understanding and optimizing bioreactor operations, paving the way for enhanced efficiency and productivity in various biotechnological applications.

CHAPTER 1

INTRODUCTION TO BIOREACTOR

1.1 BIOREACTORS AND THEIR TYPES

A fermentation tank, also known as a bioreactor, provides an enclosed environment for the controlled growth of microorganisms, facilitating optimal conditions for maximum production of desired products while preventing contamination. The organisms within it thrive under ideal pH, temperature, oxygen, and other environmental conditions. In the chemical industry, such vessels are referred to as reactors, and fermenters are a specific type of bioreactor.

Bioreactors come in various types based on their shape, aeration capability (aerated or anaerobic), and operation mode (batch or continuous). Table 1 summarizes the different types of bioreactors along with their descriptions, advantages, and applications. Typically, bioreactors are cylindrical vessels with hemispherical tops and/or bottoms, ranging in size from a few liters to cubic meters. They are commonly constructed from stainless steel or glass. Unlike traditional composting systems, bioreactors allow for more precise measurement and control of various parameters throughout the fermentation process. The size of bioreactors varies significantly, spanning from micro-scale (a few cubic millimeters) to plant-scale (up to 500 m^3). Examples include shake flasks (100-1000 ml), laboratory fermenters (1-50 liters), pilot-scale units (0.3-10 m^3), and industrial-scale facilities. For instance, a stirred tank bioreactor is designed to enhance oxygen transfer and carbon dioxide removal through increased surface area, critical for supporting microbial cultures.

CHAPTER 2

STIRRING AND MIXING

2.1 INTRODUCTION

Mixing is fundamental in bioprocessing; it eliminate non-uniformities in fluid properties such as concentration and temperature. Whereas, the agitation process in fermentation plays crucial roles by ensuring uniformity in the broth, preventing concentration gradients, and enhancing mass transfer. In the fermentation process, mixing serves as a crucial tool to ensure the contents of the vessel, often called the broth or liquid, are evenly distributed. Just filling the fermenter with a nutrient-rich medium is not enough. Without proper mixing, cells may quickly deplete nutrients in their immediate area, subsequently leading to uneven growth.

Mixing accomplishes this by moving materials around and allowing components to blend. Complete mixing is achieved when every part of the vessel has an equal chance of containing any particular component. Mixing is usually carried out in a cylindrical stirred tank bioreactor, where the base of the tank is rounded at the edges rather than angled (Figure 2). The purpose of this is to eliminates sharp corners and pockets into which fluid currents may not penetrate and discourage formation of stagnant regions. The efficiency of mixing in stirred tanks is influenced by the shape of their base. Figure 3 illustrates various base shapes used in these tanks.

CHAPTER 3

AGITATION COMPONENTS: AGITATOR/IMPELLER, AIR SPARGER AND BAFFLE

Mixing is an essential part of fermentation processes. There are two sources of fluid-mixing energy in a fermentation process; mixing impellers provide circulation of fluids through the tank, and the expansion and velocity of air passing through a fermenter imparts fluid motion. The diagram in Figure 4 illustrates a bioreactor equipped with mixing apparatus, including an impeller, air sparger and baffle, to ensure effective mixing.

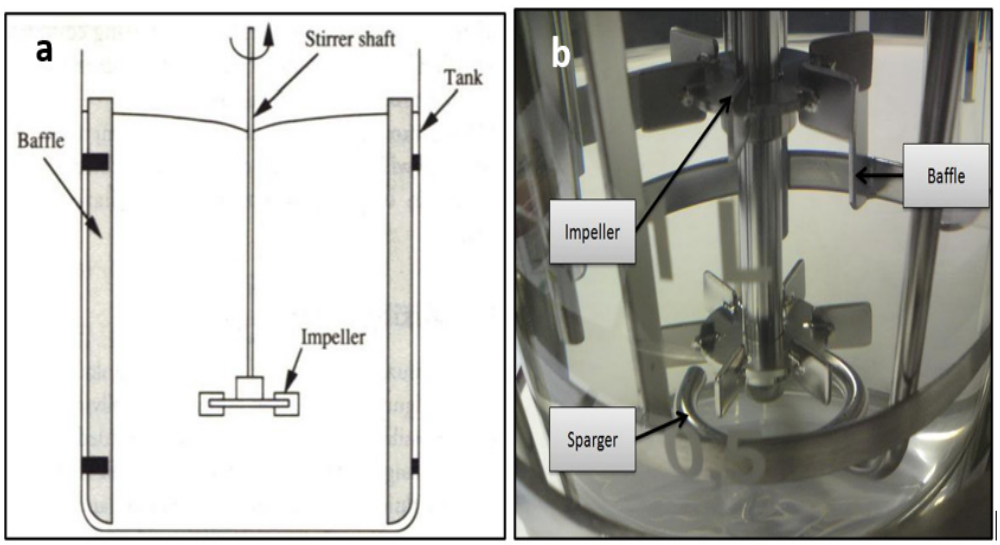


Figure 3.1: (a) Typical configuration of a stirred tank, (b) The main three (3) mixing equipment in a stirred tank: (i) Impeller; (ii) Sparger and (iii) Baffle.

(Figure 4(a) was adapted from Pauline M. Doran (2013), whereas Figure 4(b) was self-captured in the laboratory)

CHAPTER 4

POWER REQUIREMENT FOR MIXING

4.1 INTRODUCTION

Stirrer power requirements in bioreactors play a crucial role in determining the efficiency and cost-effectiveness of bioprocess operations. The power needed to drive the stirrers is influenced by various factors such as the size of the bioreactor, the viscosity of the fluid being stirred, the desired mixing intensity, and the design of the stirrer itself.

In general, larger bioreactors require more power to achieve proper mixing compared to smaller ones. This is because larger volumes of fluid present higher resistance to movement, requiring stronger agitation to ensure uniform mixing. Additionally, highly viscous fluids, such as those containing high concentrations of biomass or certain chemicals, also require more power to overcome the resistance to flow. The design of the stirrer, including the shape and size of the impeller blades, also affects power requirements. Different impeller designs are suited for different applications, with some being more efficient at mixing viscous fluids or creating high levels of turbulence.

To calculate the power required for stirring in a bioreactor, factors such as the speed of the stirrer, the torque on the stirrer shaft, and any losses due to friction in the motor gearbox and seals must be considered. This power requirement can be determined experimentally by measuring the induced torque on the stirrer shaft. Overall, understanding stirrer power requirements is essential for optimizing bioprocess operations, as it directly impacts energy consumption, process efficiency, and ultimately, the economic viability of bioreactor-based production processes. Table 8 summarizes the factors for efficient mixing while minimizing energy consumption.

CHAPTER 5

MASS TRANSFER

5.1 INTRODUCTION

Mass transfer in bioreactors is a fundamental process that plays a pivotal role in numerous biotechnological applications, encompassing fermentation, cell culture, and microbial growth. It involves the movement of mass, such as oxygen, nutrients, and waste products, between different phases within the bioreactor system, including gas-liquid, liquid-solid, or liquid-liquid interfaces. Efficient mass transfer is essential for providing essential nutrients to cells, facilitating metabolic processes, and removing metabolic by-products, thereby influencing cell growth, viability, and productivity. Understanding and optimizing mass transfer phenomena are critical for enhancing bioreactor performance, improving process efficiency, and maximizing the yield and quality of desired biotechnological products. The efficient mass transfer in bioreactor system is very important due to:

i. Cellular Metabolism
   Cells within a bioreactor require a continuous supply of nutrients and oxygen to sustain their metabolic activities. Mass transfer ensures the delivery of essential nutrients and oxygen to the cells, facilitating cell growth, proliferation, and metabolism. Adequate mass transfer rates directly influence the rate of cellular metabolism and, consequently, the production of desired biotechnological products.

ii. Oxygen Supply
   Oxygen is a crucial substrate for aerobic organisms and plays a vital role in various cellular processes, including energy production through respiration. Efficient mass transfer of oxygen from the gas phase to the liquid phase ensures an adequate supply of oxygen to cells, preventing oxygen limitation and enabling optimal growth and metabolism.

CONCLUSION

In core, "Mixing and Stirring in Aerated Stirred Tank Bioreactors" serves as a detailed guidebook dedicated to resolving the details of stirring and mixing operations within aerated stirred tank batch fermenters, pivotal for increasing microbial cultivation efficiency and overall bioprocess performance.

Understanding stirring and mixing operations in aerated stirred tank batch fermenters enhances efficiency in microbial cultivation and bioprocess performance, leading to increased productivity. This optimization ensures homogeneity in the fermentation broth, resulting in higher-quality products meeting industry standards. Additionally, it reduces costs by decreasing energy consumption and resource utilization. Knowledge of power consumption and agitation components enables better process control, aiding in informed decision-making for maximizing productivity. Understandings into mass transfer dynamics drive technological advancements in bioreactor design, fostering more efficient and sustainable systems. Ultimately, leveraging this knowledge enhances industry competitiveness by improving efficiency, reducing costs, and delivering high-quality products, positioning bioprocess industries for success.

In summary, the insights provided in this book offer a range of benefits, from enhancing efficiency and product quality to reducing costs and driving technological advancements, ultimately positioning bioprocess industries for success in a competitive landscape.

BIBLIOGRAPHY

Asenjo J.A, Merchuk J.C 1996. Bioreactor System Design, Marcel Dekker, INC., New York.

Bailey, James E., and David F. Ollis. "Biochemical engineering fundamentals." McGraw-Hill, 1986.

Blanch, Harvey W., and Douglas S. Clark. "Biochemical engineering." CRC Press, 1997.

Bates R. L, Fondy P. L, and Corpstein R.R. 1963. An examination of some geometric parameters of impeller power. Ind. Eng. Chem. Process Des. Dev. 2, 310-314

Chisti, Y. 2006. Bioreactor design. Basic Biotechnology: Third Edition, m, 181–200. https://doi.org/10.1017/CBO9780511802409.009

Edward L. Paul, Victor A. Atiemo-Obeng, Suzanne M. Kresta, Edward L. Paul, Victor A. Atiemo- Obeng, Suzanne M. Kresta, (2004) *Handbook of Industrial Mixing*. 1st edn. Wiley. Available at: https://www.perlego.com/book/2768849/handbook-of-industrial-mixing-science-and-practice-pdf (Accessed: 05 April 2024).

Ghosh, B., Bhattacharya, D., & Mukhopadhyay, M. 2018. Use of Fermentation Technology for Value-Added Industrial Research. Principles and Applications of Fermentation Technology, August, 141–161. https://doi.org/10.1002/9781119460381.ch8

Harvey P. S. Greaves M. 1982. Turbulent-Flow in an Agitated Vessel.2. Numerical-Solution and Model Predictions Transactions of the Institution of Chemical Engineers 60 (4), 201-210.

Holland F.A. and Chapman F.S. 1966. Liquid Mixing and Processing in Stirred Tanks, Reinhold, New York.

Jaibiba, P., Vignesh, S. N., & Hariharan, S. 2020. Working principle of typical bioreactors. In Bioreactors. INC. https://doi.org/10.1016/B978-0-12-821264-6.00010-3

Kaiser, S. C., Werner, S., Jossen, V., Blaschczok, K., & Eibl, D. 2018. Power input measurements in stirred bioreactors at laboratory scale. Journal of Visualized Experiments, 2018(135), 1–11. https://doi.org/10.3791/56078

Kuila A and Sharma V. 2018. In Principles and Applications of Fermentation Technology. https://doi.org/10.1002/9781119460381

Mandenius, C.-F. 2016. Challenges for Bioreactor Design and Operation. Bioreactors, 1–34. https://doi.org/10.1002/9783527683369.ch1

Metzner A.B, Feehs, Lopez Ramos H., Otto R.E, and Tuthill J.D. 1961. Agitation of viscous Newtonian and non-Newtonian fluids. AIChE J. 7, 3-9.

Muniraj, I. K., Desikan, R., & Subburamu, K. 2019. Perspectives and Prospects of Fermentation Technology. Advances in Food Bioproducts and Bioprocessing Technologies, July 2020, 217–232. https://doi.org/10.1201/9780429331817-10

Mohammed Abld, Catherine Xuereb, Joël Bertrand. 1994. Modeling of the 3D hydrodynamics of 2- blade impellers in stirred tanks filled with a highly viscous fluid. The Canadian Journal of Chemical Engineering 72(2):184 – 193. http://dx.doi.org/10.1002/cjce.5450720202.

Ng K. Fentiman N. J. Lee K. C. et al. (1998) Assessment of sliding mesh CFD predictions and LDA measurements of the flow in a tank stirred by a Rushton impeller Chemical Engineering Research & Design 76 A6 737- 747.

Pauline M. Doran, Bioprocess Engineering Principles, Second edition (2013). Elsivier. https://www.sciencedirect.com/book/9780122208515/bioprocess-engineering-principles.

Peker, S. M., Helvacı, Ş. Ş., Yener, H. B., İkizler, B., & Alparslan, A. (Eds.). 2008. 7 – Mixing in Solid–Liquid Systems. In Solid-Liquid Two Phase Flow (pp. 385–438). Elsevier. https://doi.org/https://doi.org/10.1016/B978-044452237-5.50009-6

Rose, A. H. 1985. Principles of fermentation technology. In Trends in Biotechnology (Vol. 3, Issue 9). https://doi.org/10.1016/0167-7799(85)90016-2

Rushton J.H, E.W. Costich E.W., and Everett H.J 1950. Power characteristics of mixing impellers. Parts I and II. Chem. Eng. Prog. 46, 395-404, 467-476.

Shuler M.L and Kargi F. (2002), Bioprocess Engineering Basic Concepts, Second Edition, Prentice Hall PTR.

Singh, J., Kaushik, N., & Biswas, S. 2014. Bioreactors – Technology & Design Analysis. April 2016, 27–36.

Spier, M. R., Vandenberghe, L. P. D. S., Medeiros, A. B. P., & Soccol, C. R. 2011. Application of different types of bioreactors in bioprocesses. In Bioreactors: Design, Properties, and Applications (Issue February 2016).

Uludag Y. Yapici K. Karasozen B. 2008. Numerical investigation of the effect of the Rushton type turbine design factors on agitated tank flow characteristics Chemical Engineering and Processing 47 (8), 1346-1355.

Viswalingam, K., & Solomon, F. E. 2013. A Comparative Study on Bio Reactors. Indian Journal of Economics and Development, May, 104–107.

Wang, S. J., & Zhong, J. J. 2007. Bioreactor Engineering. Bioprocessing for Value-Added Products from Renewable Resources, 131–161. https://doi.org/10.1016/B978-044452114-9/50007-4

Yapici K. Karasozen B. Schafer M. 2008. Numerical investigation of the effect of the Rushton type turbine design factors on agitated tank flow characteristics Chemical Engineering and Processing 47, 1340 -1349

Yianneskis M. Popiolek Z. Whitelaw J. H. 1987. An experimental study of the steady and unsteady flow characteristics of stirred reactors Journal of Fluid mechanics 175, 537- 555

Zlokarnik M. and Judat H, 1988. Stirring. In: W. Gerhartz, Ed., Ullmann's Encyclopedia of Industrial Chemistry, 5th ed., vol. B2, pp. 25-1, 25-33, VCH, Weinheim, Germany.

Zhong, J. J. 2010. Recent advances in bioreactor engineering. Korean Journal of Chemical Engineering, 27(4), 1035–1041. https://doi.org/10.1007/s11814-010-0277-5.

http://hejri.iauq.ac.ir/assets/subdomains/hejri/files/Books/mixing. Retrieved on March 22, 2024.

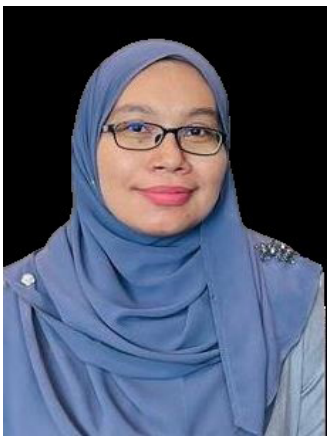
https://www.pctflow.com. Retrieved on March 20, 2024.

https://cdn.shopify.com – Baffles. Retrieved on January 15, 2024

https://cercell.com/bioreactor, Retrieved on January 10, 2024

http://www. hengko.com/bioreactor-sparger. Retrived on January 2, 2024

BIOGRAPHY



Dr. Noor Akhmazillah bt Mohd Fauzi is an Associate Professor at Universiti Tun Hussein Onn Malaysia (UTHM) with expertise in food technology, bioprocessing, and biotechnology. Holding a Doctor of Philosophy (Ph.D.) in Chemical and Materials Engineering from the University of Auckland, New Zealand, Dr. Noor Akhmazillah has improved her skills and knowledge in these fields through rigorous academic training and practical experience. With a Master of Engineering in Bioprocess from Universiti Teknologi Malaysia (UTM) and a Bachelor of Engineering in Biochemical-Biotechnology from the International Islamic University Malaysia (IIUM), Dr. Noor Akhmazillah has cultivated a strong foundation in both theoretical concepts and practical applications. Her diverse educational background, combined with hands-on experience in research and development, positions Dr. Noor Akhmazillah as a valuable asset in the field of engineering, particularly in the areas of bioprocessing and food engineering. Known for her innovative approach and problem-solving abilities, she is committed to advancing the frontiers of science and technology to address contemporary challenges in food production and bioprocessing.

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