

ИНФОРМАТИКА, ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА И УПРАВЛЕНИЕ INFORMATION TECHNOLOGY, COMPUTER SCIENCE AND MANAGEMENT



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Научная статья



Математическая модель системы управления pH в *in vitro* модели желудочно-кишечного тракта домашней птицы

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Аннотация

Введение. Существенная нелинейность химических реакций кислот и оснований определяет алгоритмы управления в режиме подкисления или подщелачивания, то есть периодической дозации минимального объема кислоты или щелочи. Такое регулирование может быть малоэффективным, т. е. допускает недостаточную или избыточную концентрацию контролируемого вещества. Статья посвящена проблеме точного регулирования водородного показателя в мини-биореакторах. Предлагается использовать цифровую модель системы управления кислотностью для подбора концентраций дозируемых растворов, определения методов регулирования и повышения точности. Цель работы — обеспечение требуемой точности регулирования pH в *in vitro* мини-модели желудочно-кишечного тракта статического типа.

Материалы и методы. Исходная структурная схема модели включает накопители и потоки. Она представляет собой базу для основных дифференциальных уравнений, характеризующих изменение объема и кислотности. Для корректировки показаний кислотности результирующего раствора по температуре создана статическая модель, основанная на полиномиальной аппроксимации экспериментальных данных методом наименьших квадратов. В прикладном пакете Matlab Simulink исследованы структурные элементы математической модели. На реальной системе *in vitro* моделирования искусственного желудочно-кишечного тракта домашней птицы определены переходные характеристики для подтверждения адекватности математической модели.

Результаты исследования. В рамках данной работы авторы создали и проанализировали нелинейную математическую модель изменения pH в биореакторе с учетом внешних управляющих воздействий. Потоки раствора соляной кислоты, раствора щелочи и слива раствора из реактора представлены как элементы дифференциального уравнения, описывающего накопление жидкости в реакторе. Для повышения точности решение доработали с учетом температурной зависимости водородного показателя. Предложена математическая модель дозирования на основе регулятора с каналами щелочи и кислоты. Полученные данные позволили генерировать объединенную модель процесса регулирования pH в биореакторе. Адекватность решения подтверждена опытным путем. В виде структурных схем показаны модели: регулятора pH, регулирования объема содержимого в реакторе и химических реакций. Сравниваются переходные процессы математической модели и реальной системы управления. Установлено, что переходные характеристики математической модели и реальной системы идентичны по времени регулирования. Относительная погрешность регулирования реальной системой составила 0,35 %, а математической модели — 0,1 %, что соответствует требуемой точности регулирования $\pm 0,1$ pH. В виде графиков показано влияние исследованных потоков на реакцию нейтрализации.

Обсуждение и заключение. Предлагаемая математическая модель позволяет подобрать оптимальные методы и алгоритмы регулирования кислотности, что ускорит создание регулятора нелинейного процесса регулирования водородного показателя. В будущем эти наработки можно интегрировать в комплексную цифровую модель всего искусственного желудочно-кишечного тракта домашней птицы для оптимизации алгоритмов управления (дозации, перемешивания, периодичности и т. п.), а также аппроксимации к объектам *in vivo*.

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Table of Contents Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti

1. Understanding the eBook Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - The Rise of Digital Reading Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Advantages of eBooks Over Traditional Books
2. Identifying Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - User-Friendly Interface

4. Exploring eBook Recommendations from Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Personalized Recommendations
 - Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti User Reviews and Ratings
 - Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti and Bestseller Lists
5. Accessing Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti Free and Paid eBooks
 - Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti Public Domain eBooks
 - Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti eBook Subscription Services
 - Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti Budget-Friendly Options
6. Navigating Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti eBook Formats
 - ePub, PDF, MOBI, and More
 - Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti Compatibility with Devices
 - Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Highlighting and Note-Taking Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Interactive Elements Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
8. Staying Engaged with Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
9. Balancing eBooks and Physical Books Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Setting Reading Goals Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Fact-Checking eBook Content of Sistemy I Modeli Mabovogo Obsluzhivaniia V Kommercheskoi Deiatelnosti
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements
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