Introduction to Chemical and Biochemical Engineering (CBE)

Prof. Shishir P. S. Chundawat
Associate Professor of Chemical & Biochemical Engineering
Rutgers, The State University of New Jersey
The Wide World of Chemical Engineering

- Science and math applied together to solve problems and make the world better? That's engineering.
- And years ago, the National Academy of Engineers listed 14 grand challenges that engineers needed to work on in the 21st century.
- Of those, chemical engineers are directly involved in at least 10 of them!
- All that down there — all of that is chemical engineering.
- I just woke up here to look down and appreciate how broad (CHEM) actually is!

Make solar energy economical

Provide energy from fusion

Develop carbon sequestration methods

Manage the nitrogen cycle

Provide access to clean water

Restore and improve urban infrastructure

Advance health informatics

Engineer better medicines

Reverse-engineer the brain

Prevent nuclear terror

Secure cyberspace

Enhance virtual reality

Advance personalized learning

Engineer the tools of scientific discovery

https://www.engineeringchallenges.org
What is Chem-Bio Engineering?

• No universal definition...

• CBE’s apply basic sciences – math, chemistry, physics & biology – and engineering principles to understand, develop, design, operate & maintain processes that: convert raw materials to desired products, and improve quality of life in a sustainable manner!
CBE: Bridge Between The Laboratory & Real World

From Test Tube to Truckload

LABORATORY

Idea

Long-lasting lipstick
A new AIDS drug
Cleaner rivers
Faster bone repair
Delicious pizza at home
Cleaner air

REAL WORLD

End User

Chemical Engineering

12-hour lipstick at every drugstore
Enough AIDS drugs for Africa
Zero-effluent pulp mills
"Instant Grow Potion" for bones
Pizza factory with special freezing process
Scrubbers that remove chemicals from factory outputs
Historical Origins of Chemical Engineering

- **Scale-up** of chemical processes during industrial revolution

- Principles of operation of simple chemical reactions as batch processes (or **unit operations** like distillation)

- Initially, chemists & mechanical engineers worked together (18th century)

- Complicated chemistry demanded new concepts and innovations by 19th century
Petro-Agrochemical Revolution Made Possible by ChemE

- Chemical engineering developed as processes became more complex in 19th-20th century (e.g., Haber-Bosch Process)
- Continuous & multiple unit processes, control and safety designs
- Mass production of drugs, plastics, chemicals...& electronics/chips!
Evolution over last 60 yrs...

- 1960s – advanced mathematical methods
- 1970s – biochemical & biomedical applications
- 1980s – advanced computational methods
- Present day – highly interdisciplinary (e.g., nanotechnology, biotechnology, genetic engineering, materials engineering)
So, who is a chemical engineer?

One who applies principles of chemistry, math, physics, and biology to problems relevant to chemical, biological, biomedical, energy, environmental, food, and pharmaceutical systems.

Materials Sci & Eng

Product

Hard Materials

Microscopic

What’s the Difference?

Chemical Engineering

Process

Soft Materials

Micro and Macro

Large systems

~ Industrial-Process Eng + Chemistry (+ Biology)

ChE courses are ~ Mech Eng + Chemistry/Bio
CBE Student Societies & Clubs
American Institute of Chemical Engineers (AIChE)

AIChE is a student organization that helps foster a sense of community within the department through professional development and social events.

- Resume Critiquing
- Holiday Party
- Alumni Panels
- Coffee with Professors
- Industry Panels
- VBA Workshops
Omega Chi Epsilon (ΩXE): The Chemical Engineering Honor Society

Events focus on Professionalism, Academics, and Chapter Development:
Chem-E Car Club

Club members participate at AIChE competitions where teams design and construct a car that must:

- Be powered by chemical energy sources
- Carry a specified load
- Be able to stop after a certain distance

In 2018 and 2019 Rutgers placed in the Top Five in the regional competition.

In October of 2018, Rutgers placed Second in the national competition.

https://www.youtube.com/watch?v=rOuycSo-NQk (Rutgers Knight Wagon Video from 2018 AIChE National Competition)
Introducing Knight Wagon!

https://www.youtube.com/watch?v=rOyucSo-NQk (Rutgers Knight Wagon Video from 2018 AIChE National Competition)
ChemE’s earn highest salaries amongst all college graduates

Where it pays to attend college: https://www.kaggle.com/datasets/wsj/college-salaries/data
Data on the 2023 Senior Class

- **76%** of students in the senior year have completed **internships**
- **62%** of students in the senior year have **research** experience
- **93%** have had either **one or both** of those experiences
RU CBE students work at...

Barclays
Phillips 66
P&G
Colgate
GlaxoSmithKline
Monsanto
International
Messer Gases for Life
Air Products
Merck
PepsiCo
Nestlé
Johnson & Johnson
L'Oréal

...and many more companies in the US around the world
Chemical & Biochemical Engineering Faculty

Nanomedicine, Drug Delivery, & Systems Biology
- Translational Nanomedicine
- Biotech for Waste Upcycling
- Advanced Bio/Manufacturing
- Pharmaceuticals Engineering

Bioengineering, Bioimaging, & Industrial Biotechnology

Pharmaceutical Engineering
- Process Systems Engineering
- Industrial Catalysts
- Soft Matter Simulations
- Single-Molecule Biophysics

Sustainability, Catalysis, & Process Systems Engineering
- 24 Faculty (TT and Non-TT)
- 6 Women Faculty (#1 in SOE)
- 4 joint with Biomedical Engineering
- 1 joint with Chemistry-Chemical Biology

Molecular Simulations, Computing, & Data Sciences
- NJ Edison & Inventor of Year Award
- Biotech Training Program
- NSF Engineering Research Center
- NSF Early Career Awards

CBE Highlights
RU CBE Faculty Expertise

**Biomolecular Engineering**
Androulakis, Chundawat, Dignon, Dutt, Guo, Moghe, Roth, Schuster, Zhang

**Clean Energy and Sustainability**
Asefa, Celik, Chundawat, Dignon, Guo, Hildebrandt, Neimark, Shapley, Tsilomelekis, Zhang

**Computing and Data Sciences**
Androulakis, Celik, Dignon, Dutt, Glasser, Guo, Hildebrandt, Neimark, Ramachandran, Tomassone

**Pharmaceutical Engineering**
Chundawat, Dignon, Glasser, Muzzio, Ramachandran, Razavi, Roth, Schuster, Scicolone, Singh, Tomassone, Tsilomelekis, Zhang

**Soft Matter and Advanced Materials**
Asefa, Celik, Chundawat, Dignon, Dutt, Guo, Neimark, Schuster, Shapley, Tomassone, Tsilomelekis

**WE’RE HIRING!**
Aresty Research & Honors Program Opportunities

CBE Honors Academy & Aresty Research Options for Undergrads:
• 1 year as Aresty Research Assistant (e.g., end of freshman year)
  + 2 years of research
  + Professional and scientific skills development
RU CBE graduate’s study at...

...and many more MS/PhD granting graduate programs including Rutgers
CBE Students Research Symposium
CBE Undergrads At Work
How to ‘swim’ in a sandbox?

https://www.youtube.com/watch?v=My4RA5I0FKs
Rutgers has top-ranked program in Pharmaceutical Engineering

Rutgers Develops Continuous Drug Tablets and Advanced Biologics Manufacturing Processes to Enable Pharma Industry!

http://www.biopharminternational.com/fda-awards-five-grants-advanced-biomanufacturing-research-0

HOW TO DESIGN AND IMPLEMENT POWDER-TO-TABLET CONTINUOUS MANUFACTURING SYSTEMS

Edited by Fernando J. Muzzio and Sarang Oka
A medicinal product consists of active therapeutic substances (API) and inactive ingredients (Excipients) combined in a delivery system.

The **tablet** is the most common delivery system. Other e.g., Injectables, Patches

The active and inactive ingredients are combined in the form of **powders** consisting of many fine particles.

---

**Active Pharmaceutical Ingredient (API)**

**Excipients, Inert Fillers, & Lubricants**

**Coating**

---

Slide Courtesy: N. Shapley and F. Muzzio (CBE)
Mixing of fine powder particles is critical to tablet manufacture. Powders are made up of small, solid particles...

Sometimes powders act like a solid.

Sometimes powders flow like a fluid. We call such flows granular flows.

Why is mixing of solids or powders so difficult?

It is often observed that in a can of mixed nuts, the largest nuts (Brazil nuts) are usually at the top.

We often observe this ‘Brazil Nut Effect’ when opening a cereal box or package of granola: the largest pieces are at the top, especially if you shake it up first.

Why does this happen?

Now you will have a chance to experiment with some granular flows in class today!

Particle size separation is a big problem for pharmaceutical manufacturing, where a uniform powder mixture is required.
Why is mixing of solid powder particles so difficult?

Why do the large particles or objects move to the top?

As the large particle moves upward when you shake it up, small particles fall through the gaps that form. Then, the large particle is stuck at a higher position. Eventually, it reaches the top...

https://www.nature.com/articles/s41598-021-87280-1
Pharmaceutical Powder Blender Designs

V-blender

Conical Bin Blender

- Powder blending is a key step in tablet manufacturing.
- Need specialized equipment designs to minimize separation of powder particle types during blending.

Fig. 1. Blenders used for this work: (a) 7.5-L V-blender and; (b) 7.5-L conical bin-blender.

http://bectochemloedige.com/index.php/machines/blenders/v-blender
A fluidized bed is a system where the weight of powder particles is supported by flow of a gas or liquid and the particles are suspended in the flow.

- Drag force of fluid flow equals force of gravity on each particle.
- Applications: Catalysis, Pharma Manufacturing.
Granulation models can predict process attributes from particle-scale behavior.

- Sticky or hard to mix fine powder is clustered together with liquid to form freely flowing granules in wet granulation process, unlike dry granulation processes.
Chundawat Lab Research Themes at Rutgers CBE: Waste Upcycling, Accessible Healthcare, Biophysics of Life

Catalytic Domain
Polysaccharides

Carbohydrate-Active enZymes for waste biopolymers hydrolysis

Polyethylene Terephthalate (PET)

Protein engineering for waste plastic polymers upcycling

Designer Glycans Synthesis
Glycoengineering toolkit for designer prebiotics & antibiotics

Continuous manufacturing & process analytics for biologics

Visualizing cell wall polymers biosynthesis & hydrolysis

Force spectroscopy enabled enzyme & cellular engineering

Glycans
- α1-3
- α1-6
- β1-4
- β1-2
- Sialidase activity
- Fucosidase activity
- Galactosidase activity
- Hexoaminidase activity
- Glucose
- Galactose
- GlcNAc
- Fucose
- Sialic acid
- Mannose
- Galactosidase
- Hexosaminidase
- Fucosidase
- Sialidase

Recombinant Antibody
- Asn
- Asn
- Biosimilar?

FDA Approved
FDA Unapproved

Polyethylene glycol (PEG)

Culture Analyzer

Raman

Bioreactor

Flow Injection

LC/MS

Cell Cultivation

On-Line Sample Prep

Sample Analysis

TPA Concentration (mM)

Tf. Cutinase Concentration

PET polymer ester linkages (red arrows) can be hydrolyzed by enzymes like cutinase!

Protein bound to PET surface

Positively charged proteins show higher binding to PET!
Single-molecule bioengineering enabled by single-particle tracking

Download MATLAB App to simulate & visualize tethered single-particle motion under applied forces!

https://github.com/ChundawatLab/TPM-GUI
https://www.biorxiv.org/content/10.1101/2022.08.31.506066v1

Chundawat et al 2021 JBC, Markus et al. 2022 PNAS, Animations Courtesy NREL & LUMICKS
Thank you for your attention!

To get more information about CBE visit our website: http://cbe.rutgers.edu/

@ru_cheme
@rutgersaiche
@ruchemecar