Syllabus

Digital Food Physics and Engineering

(Short title: Digital Food Engineering)
BEE 4630/6630 (3 credits)
Cornell University, Ithaca, New York

Author

Ashim K. Datta, Professor, Dept. of Biological and Environmental Engineering
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Credits

3 hours (letter only)

Description

BEE 4630 and 6630: Mechanistic, model-based understanding and digital tools critically innovate in the design cycle for products and processes, food manufacturing is no exception. The course will introduce tools such as computational modeling, digital twins, and predictive knowledge bases, exploring deeper into the underlying universal physics-based frameworks describing transformations in food during processing. We will develop the framework that treats food as porous media with multiphase/multicomponent transport due to diffusion, capillary pressure, swelling pressure, and gas pressure, with shrinkage/expansion driven by moisture change and internal pressure. Mechanistic frameworks for food quality and food safety will complement the porous media approach. Case studies will include complex multiphysics applications such as meat cooking with shrinkage, case hardening during drying, puffing with a massive expansion, and microwave drying with shrinkage. Learning outcomes will include building the frameworks, understanding food processes using the frameworks, and creating a computational model through a learner-selected project.

BEE 6630: The graduate version of the course will require the project to be substantially more challenging computationally or in physical detail. In addition, in several places throughout the syllabus, graduate version of the course will have more advanced content (there will be separate web modules for undergraduates and graduates).

Prerequisites: Fluid mechanics, heat transfer, and mass transfer, or permission of instructor. The graduate version of the course (BEE 6630) will require prior coursework in at least fluid mechanics and heat transfer.

Corequisites:

None

Preparation Summary:

- Understand the basics of undergraduate fluid mechanics, heat transfer and mass transfer.
- Have interest in applying physical and engineering principles to food processes
- Comfortable with web-based self-learning modules for a user-friendly computational software
- Excited about building a food process model and its simulation
- Look forward to working in a group with members having varied background

Textbook(s) and/or Other Required Materials:

Datta, A.K. 2022. Digital Food Physics: Copies of PowerPoint notes provided by the instructor. Available at Campus Store.

Datta, A.K. 2022. Food Physics. Textbook under preparation. Available at Campus Store.

Class and Laboratory Schedule:

See details below under Topics Covered. This hybrid (online/in-person) course will have carefully recorded video lectures with active-learning enabled quizzes and online activities (such as concept mapping), a student-selected computational project, readings, and online discussion boards (all asynchronous). In-person meeting will be one in-class session every week devoted to the challenging concepts and helping with the computational project.

Instructional contact	Schedule	Which ones (see under Topics Covered below)	# Of class periods
Recorded video lectures on Canvas (25)	Mondays and Wednesdays, 50 min each day, on Canvas	All items with the first column in blue	27 [50 min]
In-person lectures and project discussions (17)	Fridays at 2:45-4:00 PM; Room to be announced	All items with the first column in red	15 [75 min]
Work outside video or in-person lectures above	6-9 hours each week, on your own schedule	1 semester-long project, 13 homework No exams	

Recitations: None

Labs: Computational, already included above

Assignments, Exams and Projects:

	Percent of total grade	Details
Computational project	50%	Each deadline carries weight of approximately 8% each.
Web lecture-embedded quiz and activities two days a week	15%	Quizzes follow the lecture topics on Canvas and are designed for instant feedback. Other online activities will include concept mapping and discussion board.
In-class quiz and activities once a week	15%	1) Every Friday, when we meet in-person, there will be a 10-minute quiz on the immediately preceding topic. 2) Individual student will upload on Canvas a picture of a portion of classwork done during each lecture
Homework once a week	15%	Homework (due every Friday) includes 1) web-based case studies for learning the computational software, 2) reading activities assigned, 3) short computational activity
Participation	5%	They are based on 1) response to questions asked in class and 2) attendance
Exams	None	
Graduate version of the course	Within the same percent of the total grade, BEE 6630 will require the project to be substantially more challenging in the physical complexity of the food process studied or in the computational complexity. In addition, sprinkled throughout the syllabus, BEE 6630 will substitute for more advanced content, typically using more rigorous engineering analysis (web modules at two levels of difficulty will be available for most of the topics, for undergraduates and graduates).	

Course learning outcomes

At the conclusion of the course, the learner will be able to

1. Explain a food physics framework in terms of its basic building blocks that can describe many food processes
2. Compare and contrast between simpler and more comprehensive physics frameworks for understanding food processes
3. Apply a food physics framework to complex food processes for their understanding and optimization
4. Create framework-based computational model of a food process that speeds up the design cycle

5. [BEE 6630] Analyze the transport phenomena, solid mechanics, and multiphysics (such as when microwave heating is added) at research level.
6. [BEE 6630] Build computational models for food processes with additional physical and/or computational complexity

CALS learning outcomes

At the conclusion of the course, the learner will be able to

1. Explain, evaluate, and effectively interpret factual claims, theories and assumptions in the physics of food processing.
2. Integrate quantitative and qualitative information to reach defensible and creative conclusions.
3. Communicate effectively through writing, speech, and visual information.
4. Demonstrate the capability to work both independently and in cooperation with others.

Topics covered

Abbreviations

P: Class time periods, 50-minute duration (Fridays are in-person; M and W are web-based), numbered consecutively 1-42 for a semester (project needs to move together, so it can be completed within the semester)

WL: Web-based asynchronous video lecture

IL: In-class lecture and discussion

IA: In-class activity such as groupwork as part of IL

OA: Out of class activity such as pre-class reading (PR), homework (HW), project meeting with professor, and project execution (PD)

P	TOPICS COVERED	WL	IL	IA	OA
1	☐ Course introduction (20 min)				
	FOOD PHYSICS AND DIGITAL FOOD				
	☐ Overview of digital tools and computer-aided food engineering (30 min) ☐ Computer-aided food engineering and its roadblocks ☐ Modeling and simulation: mechanistic approaches ☐ Digital twins ☐ Smart appliances		IL	IA	
2	☐ Databases: Example from properties prediction ☐ *How do topics relate to your interest? Class discussion* ☐ *Locate and study a digital twin or another digital tool from literature [web-based]* ☐ Basis of scientific understanding: Theory, Modeling, and Experimentation	WL			
	MODELING AND SIMULATION: PRINCIPLES, STEPS, AND APPLYING TO YOUR PROJECT [GOES CONCURRENTLY WITH THE FOLLOWING SECTIONS]				
3	☐ Why Model? ☐ ***PROJECT TOPIC SELECTION: GROUP DISCUSSION*** ☐ ***[PROJECT DEADLINE 1]*** *Preliminary project topic (student selected)*		IL	IA	PR PD1
6	☐ General Principles of Modeling [40 min] ☐ ***APPLYING TO YOUR PROJECT: GROUP DISCUSSION***		IL	IA	PR
9	☐ Steps in Developing a Model ☐ Step 1-Problem Formulation ☐ ***APPLYING TO YOUR PROJECT: GROUP DISCUSSION***		IL	IA	PR
12	☐ Step 1-Problem Formulation-continued ☐ ***APPLYING TO YOUR PROJECT: GROUP DISCUSSION***		IL	IA	PR

	☐ Concept mapping of your project ☐ ***[Project Deadline 2]*** *Detailed problem formulation for your project*				PD2
18	☐ Step 2-Model Implementation in a Software (web-based) ☐ *Peer-review of your problem formulation* ☐ ***Applying to your project: Group discussion*** ☐ ***[Project Deadline 3]*** *Working model with initial solution*		IL	IA	PR PD3
24	☐ Step 3-Model Validation and Sensitivity Analysis ☐ *Relating your project to building a digital tool* ☐ *Peer-review of the interim report* ☐ ***Applying to your project: Group discussion*** ☐ ***[Project Deadline 4]*** *Validated model with results for your project (Interim Report)*		IL	IA	PR PD4
30	☐ Step 4- Model Communication for your project ☐ ***[Project Deadline 5]*** *Oral Presentation*		IL	IA	PR PD5
36	☐ ***[Project Deadline 6] Written Report and in-person Feedback***		IL	IA	PR PD6
42	☐ ***[Project Deadline 7] Written Report with feedback incorporated***		IL		PD7
	PRINCIPLES: ENGINEERING FRAMEWORKS FOR FOOD PROCESSES				
4	☐ Overview of modeling frameworks for food processing [20 min] ☐ Applying to your project: Which framework will best suit your purpose? ☐ Lumped models [Review, pdf files] ☐ Single-phase models [Review, pdf files] ☐ Fluid flow (Navier-Stokes) for single phase ☐ Fluid flow in porous media: large and small pore-based approximations	WL			HW
5	☐ Heat equation for single phase ☐ Mass transfer equation for single phase ☐ Sharp boundary models	WL			
7	☐ Multiphase, porous media-based models ☐ *Reading Assignment: Find three hard questions not answered in the Datta paper* ☐ Qualitative introduction	WL			HW
8	☐ Transport of heat and mass	WL			
10	☐ Transport of heat and mass—continued ☐ Applied topics for undergraduates ☐ Advanced topics for graduate students	WL			HW
11	☐ Evaporation ☐ Applied topics for undergraduates ☐ Advanced topics for graduate students	WL			
13	☐ Boundary conditions	WL			HW
14	☐ Deformation ☐ Applied topics for undergraduates ☐ Advanced topics for graduate students	WL			
15	☐ Deformation--continued ☐ Applied topics for undergraduates ☐ Advanced topics for graduate students		IL	IA	
16	☐ Properties and coupling of physics through properties	WL			HW
17	☐ Simplifications	WL			
19	☐ Challenges and Limitations *Prepare a concept map for the porous media section of the framework that includes all of the topics in this section, showing clear connections.*	WL			HW
21	Unfinished/additional items		IL	IA	
22	Unfinished/additional items	WL			HW

	PRINCIPLES: ENGINEERING FRAMEWORKS FOR FOOD QUALITY AND SAFETY				
23	☐ Engineering framework for color, texture, flavor, and nutrient content	WL			
25	☐ Accounting for spatial and time variations	WL			HW
26	☐ Engineering framework for chemical safety, microbiological safety, and possibly risk	WL			
	PRINCIPLES: ENGINEERING FRAMEWORKS FOR MULTIPHYSICS				
27	☐ Microwave heating (electromagnetics) ☐ Microwaves as electromagnetic waves ☐ Simple heating: A slab in plane waves ☐ Microwave absorption and food dielectric properties	WL	IL	IA	
28	☐ Microwaves in an oven ☐ Food factors in microwave absorption ☐ Oven factors in microwave absorption	WL			HW
29	☐ Microwave heating (heat transfer) ☐ Simple volumetric heating, without and with diffusion ☐ Cycled and combination heating	WL			
31	☐ Simultaneous heating of multiple items ☐ Electromagnetics pattern as the dominant mode ☐ Coupling of electromagnetics and heat and mass transfer	WL			HW
	PRINCIPLES: ENGINEERING FRAMEWORKS FOR FOOD PROPERTY ESTIMATION				
32	☐ Material properties definitions and basics ☐ *Properties paper reviewed*	WL			
33	☐ Framework for prediction of material properties ☐ *Apply to a property of your choice*		IL	IA	
34	☐ Digital access to material properties: Introduction ☐ *Application to thermal properties: Module*	WL			HW
	APPLICATIONS				
35	☐ Sterilization ☐ Applied topic for undergraduates ☐ Fundamental physics of heat transfer, safety, and quality kinetics ☐ Optimization of sterilization: Effect of process and product parameters ☐ Advanced topics for graduate students ☐ Mathematical model description ☐ Thermal time distributions in microwave and conventional sterilization ☐ Optimization and extension to other heating modes	WL			
37	☐ Puffing ☐ Applied topic for undergraduates ☐ Fundamental physics of puffing ☐ Optimization of puffing ☐ Concept mapping ☐ Advanced topics for graduate students ☐ Mathematical model description ☐ Spatial and time variations in temperature, moisture, pressure, and deformation (porosity) ☐ Sensitivity analysis: Effect of puffing temperature, initial moisture, and gun puffing ☐ Concept mapping	WL			HW
38	☐ Microwave drying ☐ Applied topic for undergraduates	WL			

	☐ Fundamental physics of puffing ☐ Optimization of puffing ☐ Concept mapping ☐ Advanced topics for graduate students ☐ Mathematical model description ☐ Spatial and time variations in temperature, moisture, pressure, and deformation (porosity) ☐ Concept mapping Sensitivity analysis: Effect of puffing temperature, initial moisture, and gun puffing				
39	Unfinished/Additional items	WL	IL	IA	
40	Applying to a new process: Concept mapping	WL			HW
41	Project-related help		IL		
42	Course summary and concluding remarks		IL	IA	
42	**TOTAL TIME COMMITMENT for the SEMESTER** 25 web lectures plus 17 in-class lectures **15 in-class activities ##13 homework, 1 semester-long project No exams	25	17	**	##