One-Week Design Projects for Chemical Engineering Freshmen

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Abstract
Freshman chemical engineering students along with students from other engineering disciplines take a two credit Introduction to Engineering course in their first semester. The students are introduced to various topics including career options in various engineering fields, resume' workshop, communication skills, ethics, intellectual property, problem solving, critical thinking and time management. Approximately 30-35% of the grade is based on homework, quizzes and exams, while 50% is based on a design & build project, and 15-20% on interdisciplinary and discipline-specific mini design projects.

As the students have no formal training in engineering at this stage, the chemical engineering mini design projects are formulated to encourage students to relate the processes in their everyday life to unit operations and processes in chemical engineering. Areas in food processing such as meal preparation and fast food restaurant operation, and resource recovery and separation of mixtures have been used to introduce the concepts of flowsheet development, fluid mechanics, heat transfer, scale up, reactor operation and separation techniques. The students work in groups of three to four for about a week, and are required to make oral presentations and submit written reports for their projects.

In this paper, examples of chemical engineering mini design projects and sample student solutions will be discussed.

Background
Most universities have an introductory course for freshman engineering students that introduces them to the language of engineering, problem solving techniques, and basic concepts and fundamentals of the discipline. These techniques and the basic knowledge would then be required for more challenging and complex engineering problems during the next four to five years of engineering education. We have found that creating a shell of the whole curriculum with a one to two week introduction of each topic, with an emphasis on design thread through them, creates a more engaging and interesting learning style from the student's perspective. In the general engineering education part of this course, several mini design projects are assigned on a group basis. Since the students have no formal training in engineering at this stage and they certainly have not had any exposure to the theory and mathematical relationships involved, the mini design projects are formulated to encourage students to draw upon their everyday life experiences to develop simple flow sheets (block diagrams) involving unit operations and processes. The focus is to develop critical thinking skills in logical processing steps, coupled with simple mass and energy balances and economics.

Mini Design Examples

Two examples of chemical engineering mini design projects are described below. In the first example, a mythical fruit, *suntrango*, with multiple components of great value, is described and the students were asked to propose continuous processes for separation of the components and use them as raw material for consumer products. Basic description of the fruit and some potential uses were suggested in the problem setup. The students took this information and produced detailed design reports, which contained very sophisticated engineering analysis based on reasonable assumptions, and extended the uses to other plausible products.

In the second example, the students were asked to develop a continuous large-scale process for the production of their favorite food dish. Since the problem of preparing a food dish is very familiar, the students used the operations of cutting, mixing, heating, cooling, separating, etc., extensively in their processes. In the ensuing discussion, the concepts of fluid mechanics, heat and mass transfer, single phase and multiple phase systems, separation processes and reaction kinetics were easier to explain qualitatively, in simple terms. With reference to their flow sheets, they got a flavor (no pun intended) of what concepts would be used to size various units and the choices one can make in arriving at different designs for the same process.

MINI DESIGN PROJECT 1

Amazon Tribal Council
Suntrango-heavenlyfruit.com

To: **The Bison Chem-Es, Inc.**
Intro to Engineering Design
Howard University
Washington, DC 20059

From: **Sunny El Durango, Chief**
Amazon Tribal Council
Fruits & Nuts Grove
Amazon City, Brazil

Subject: **Design of a Continuous Process for the production of various products from *Suntrango.***

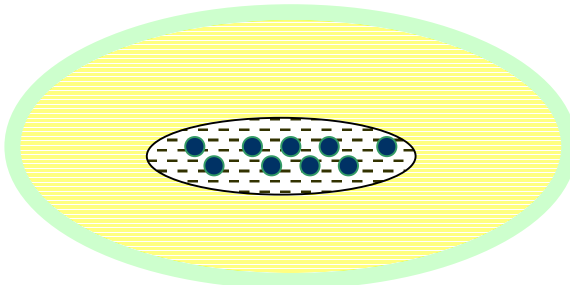
In the jungles of Amazons, we have been very fortunate to live in harmony with nature. *Suntrango* is a fruit that grows here in abundance, has quick growth-cycle, and has been used by our people for centuries. We have always known the nutritional and medicinal properties of *suntrango* and therefore use it in our daily food intake. Some people believe that *suntrango* and other fruits, nuts, berries and herbs from the Amazons keep us practically disease-free and contribute to our long lives (average age: 102 years).

Recently, a member of our tribe, Brother Gomez visited a chemist friend, Jose' Slickano in the industrial city of Sao Paulo. As is our custom, Brother Gomez brought some gifts from our village for his friend, including *suntrango.* Mr. Slickano liked the *suntrango* fruit a whole lot and decided to find out what chemicals gave it its unique properties.

After consulting with other experts, Mr. Slickano determined that *suntrango* can form a good raw material for a lot of very useful and profitable products. He suggested to us that he could set up a series of processes to produce various products from *suntrango*. However, he wants a major share of the profits and is not very environmentally conscious. The Council has decided that the best way to do things right is to keep overall control of the project in our hands. Therefore, we decided to pay Mr. Slickano a good compensation for his services and hire experts to design, build and operate the plant and market the products. Success of this venture would provide much-needed jobs to our community and economic benefits to our people.

A preliminary analysis of Mr. Slickano's research is attached for your review.

SUNTRANGO - THE HEAVENLY FRUIT



Suntrango is a hybrid fruit that looks like a coconut from the outside. The **outer shell** has **fuzzy fibers**. As you break the brittle outer shell, the **skin** covering the fruit is exposed, which looks like orange peel. The **fruit** is about an inch thick and looks like mango and tastes like a combination of mango and orange (sweet with a hint of tart). Inside the fruit is a mixture of **liquid** (consistency of water) and **seeds** (1/8" circular).

1. **Outer Shell:** It can be used for arts & crafts items, household products, reusable containers and other similar products.

2. **Fuzzy Fibers:** If fuzzy fibers can be separated from the outer shell, they form a very strong thread/rope and can be used in fish-line and other products where nylon fibers are used. Some of our tribesmen have even worn jackets made of these fibers, which are pretty rugged in the outdoor environment.

3. **Skin:** When the skin of the fruit is dried, it forms a high-energy nutritional snack, similar to the products used by astronauts and athletes.

4. **Fruit:** The fruit is delicious and once you taste it you are hooked. It can also be used in food dishes, sauces, pickles, jams and jellies.

5. **Liquid:** The liquid can be refined to a delicious table wine, *suntrangoria,* which is very popular in our tribe for all kinds of festive occasions.

6. **Seeds:** The seeds have medicinal properties and can be used in the formulation of various drugs. Preliminary studies have shown that these drugs can help in the treatment of arthritis, hypertension and some forms of cancer.

We are aware of your excellent reputation for technical competence and environmental consciousness. We know that as chemical engineers, you specialize in designing and operating facilities for large scale processing of chemicals, petroleum, food, pharmaceuticals and consumer goods. This project would utilize the same concepts: development and up-scaling from small-scale to large-scale continuous processes.

Your assignment is to design a series of continuous processes, and develop detailed flowsheets for each product line.

- On average, the *suntrango* weighs about 1 kg and contains 2% fuzzy fibers, 10% outer shell, 8% fruit skin, 50% fruit, 20% liquid and 10% seeds. We produce about 1 million *suntrangoes* on an annual basis and because it is a fast growing fruit, we can sustain an annual process feed rate of 75% of this production rate.

- Make appropriate assumptions regarding the food and product choices and quantities. You can make any reasonable assumptions (justify the outrageous ones). Explore various sources (Internet, restaurants, library, industries, etc.) of information on the data, procedures, techniques and processes.

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1. Your **group-report** must be organized according to the handout titled, "Mini-Design Report and Presentation Formats," and should include the following:

- Cover Page/TOC (1 point)
- Abstract (1 point)
- Problem Statement (2 points)
- Background, Constraints & Conditions (1 point)
- Continuous Process Flow Diagrams and Descriptions (Use extensively labeled block for each operation/function, including material input/output, unit operations/ processes) (6 points)
- Conclusions (1 point)
- References/Acknowledgements (1 point)
- **WRITTEN GRADE = (13 Points)**

2. **Your group should present your findings in one week** according to the handout titled, "Mini-Design Report and Presentation Formats." Oral presentation will be graded based on the following distribution:

- Appearance (1 point)
- Visual Aids (2 points)
- Content (4 points)
- Organization (1 point)
- Delivery (1 point)
- Teamwork/Group Dynamics (2 points)
- Questions/Answers (1 point)
- **ORAL GRADE (12 points)**

MINI DESIGN PROJECT 2

DESIGN OF A COMMERCIAL-SCALE CONTINUOUS PROCESS FOR A GOURMET-QUALITY FOOD DISH

- **BACKGROUND:**

Batch processes in batch reactors (such as pots & pans, ovens, etc.) are used for preparing most gourmet foods in a food laboratory (kitchen). The reaction steps are preceded or followed by material or feed preparation in other auxiliary pieces of equipment, such as blenders, food processors, separators and heaters/coolers. A delicate balance between ingredients and spices (raw materials), timing, and processing (cooking) time must be achieved to bring out subtle flavors.

At your community potluck dinner, coincidentally the President of "Gourmet Foods R Us", Pepper Quale, happens to be present and tastes your food dish. She showers praises and accolades, such as 'heavenly', 'better than my mom could ever make', I will make her/him a vice president with stock options and give perks-galore, if only she/he could make this dish for my company on a mass scale'. You are introduced to the President, Ms. Quale, and the following assignment is offered to you, which you accept.

- **PROBLEM STATEMENT:**

Develop a complete process flow diagram (with a continuous-flow reactor system at the heart of the process) of the entire operation that would produce 10 gal/h of your favorite gourmet food.

Presentation (13 Points) and Written Report (12 Points) Requirements:

In presenting (P) and reporting (R) your process design, you are asked to include the following:

1. **BACKGROUND** **P: 2 Points R: 1 Point**
   (a) Problem statement
   (b) Available data (batch system)
   (c) Name of the dish
   (d) Ingredients and quantities required for a given amount of the dish and the number of people it serves.
   (e) Step by step recipe

2. **MATERIAL REQUIREMENTS** **P: 1 Point R: 2 Points**
   (a) Scale-up of the ingredient amounts to produce 10 gal/hr of the dish

3. **CONSTRAINTS/ CONDITIONS** **P: 2 Points R: 2 Points**
   (a) Develop a set of constraints and conditions for each unit and stream.

4. **UNIT OPERATIONS/PROCESSES** **P: 4 Points R: 3 Points**
   (a) Draw a diagram of each unit operation and process, including all input/output streams, conditions of temperature, pressure, phase, size, etc.
   (b) Calculate/estimate the size of each unit and stream in the process.

5. **CONTINUOUS PROCESS FLOW DIAGRAM** **P: 4 Points R: 4 Points**
   (a) Develop a complete process flow diagram starting from the raw materials (from the grocery store) to the finished products. Also include any waste stream (onion peels, drained water, etc.), where appropriate.

   (b) Note that some operations would occur simultaneously in different units for different lengths of time. The output streams from various units may have to be combined or an output stream from a processing unit may have to be separated, drained, heated, cooled, etc. Make sure that the requirements for each processing step in the batch recipe are properly met in the continuous operation in an optimum manner.

Mini Design I: Partial Sample Solution (From Students' Report)

Some of the process block diagrams for a sample solution are given below. The flow diagrams presented here were accompanied by process description and detailed calculations in the students' report. Quantitative details and calculations are not included here in the interest of space limit of 2 MB capacity.

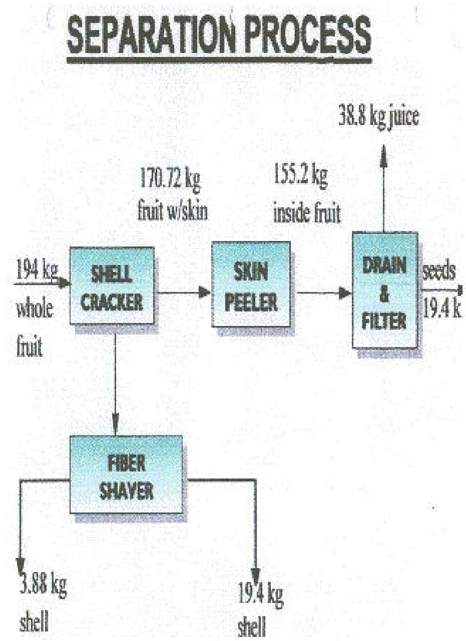
Assumptions & Justifications

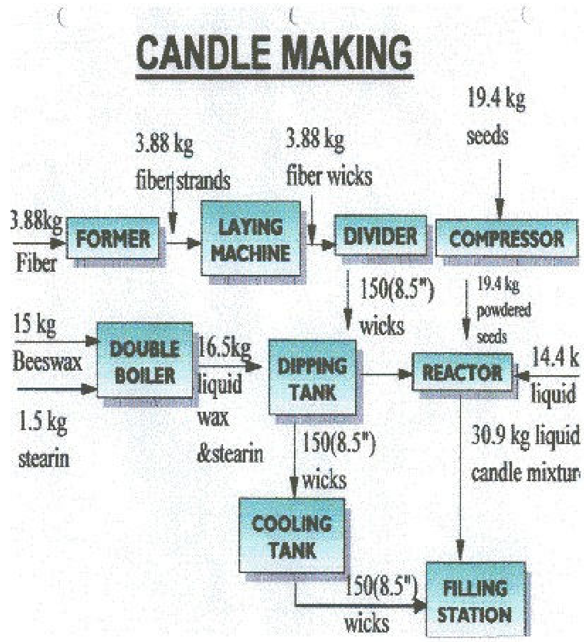
- The paper making process is implemented assuming that the fruit has a consistency of mango and orange combined. This would result in the flesh being stringy in nature hence capable of forming fibrous networks.

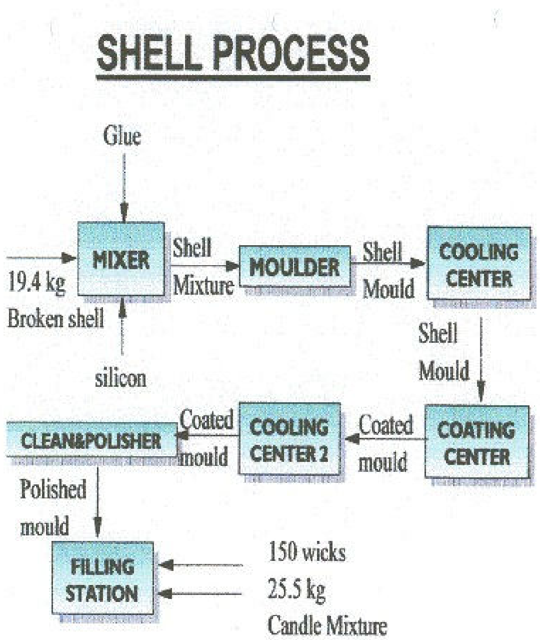
- Oil and fruit pulp from the *Suntrango* is used in soap manufacturing based on the assumption that the fragrance of the fruit is generally pleasant and it has cosmetic properties.

- Cold press oil extraction was used instead of steam extraction for several reasons
  1. Not all of the oil is to be extracted for use in soap (essence and potpourri requirements)
  2. The cold press has an extraction percentage of 65%

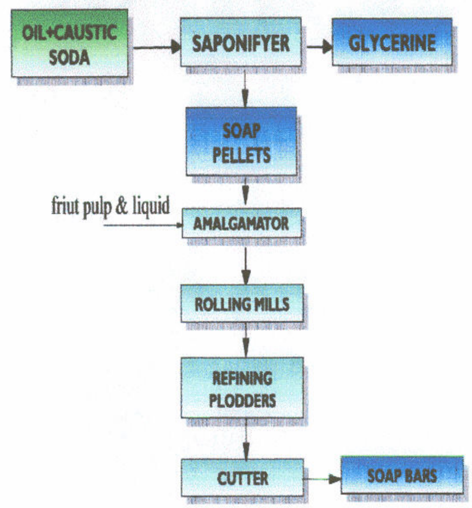
- Low chlorine bleaching is used in paper process. Elemental Chlorine Free (ECF) technology produces no dioxins and has no effect on the aquatic environment less pulp produces high yield than Totally Chlorine Free technology.


SEPARATION PROCESS
38.8 kg juice
170.72 kg
fruit w/skin
155.2 kg
inside fruit
194 kg
whole
fruit
SHELL
CRACKER
SKIN
PEELER
DRAIN
&
FILTER
seeds
19.4 k
FIBER
SHAVER
3.88 kg
shell
19.4 kg
shell

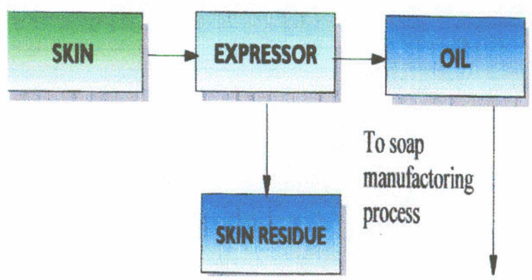

CANDLE MAKING
19.4 kg
seeds
3.88 kg
fiber strands
3.88 kg
fiber wicks
3.88kg
Fiber
FORMER
LAYING
MACHINE
DIVIDER
COMPRESSOR
150(8.5")
wicks
19.4 kg
powdered
seeds
15 kg
Beeswax
DOUBLE
BOILER
16.5kg
liquid
wax
&stearin
DIPPING
TANK
REACTOR
14.4 k
liquid
1.5 kg
stearin
150(8.5")
wicks
30.9 kg liquid
candle mixtur
COOLING
TANK
150(8.5")
wicks
FILLING
STATION


SHELL PROCESS
Glue
MIXER
Shell
Mixture
MOULDER
Shell
Mould
COOLING
CENTER
19.4 kg
Broken shell
silicon
Shell
Mould
CLEAN&POLISHER
Coated
mould
COOLING
CENTER 2
Coated
mould
COATING
CENTER
Polished
mould
FILLING
STATION
150 wicks
25.5 kg
Candle Mixture

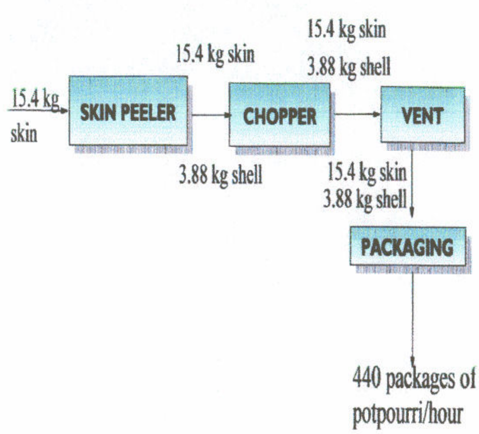
SOAP MANUFACTURING PROCESS



OIL EXTRACTION PROCESS



POTPOURRI MAKING PROCESS



DESIGN COMPARISON MATRIX

Design #1: Coal Powered Plant — Design #2: Hydroelectrical

Criteria	Weight	Rating	Score	Rating	Score
Environmentally Friendly	10	X 1	= 10	X 10	= 100
Rate of Energy Production	9	X 5	= 45	X 8	= 72
Availability	8	X 6	= 48	X 10	= 80
Cost of Raw Material	7	X 3	= 21	X 9	= 63
Safety	6	X 4	= 24	X 7	= 42
Labor Intensity	5	X 8	= 40	X 6	= 30
Convenience	4	X 6	= 24	X 8	= 32
Transportation	3	X 3	= 9	X 9	= 27
Storage	2	X 8	= 16	X 4	= 8
Waste Disposal	1	X 2	= 2	X 10	= 10
TOTAL			239		464

Mini Design II: Partial Sample Solution (From Students' Report)

Some of the process block diagrams for a sample solution are given below. The flow diagrams presented here were accompanied by process description and calculations in the students' report. Process description and detailed calculations are not included here in the interest of space.

Broccoli Chicken and Cheese Casserole
(Serving Size 8 - Produces I gal.)

1.5 lbs. of Chopped Chicken
2 cups of Rice
2 lbs. of Chopped Broccoli
2 cups of Chopped Cheddar Cheese
1 cup of Milk
1/2 cup of Butter
2/3 Tablespoon of Salt
1/3 Tablespoon of Pepper

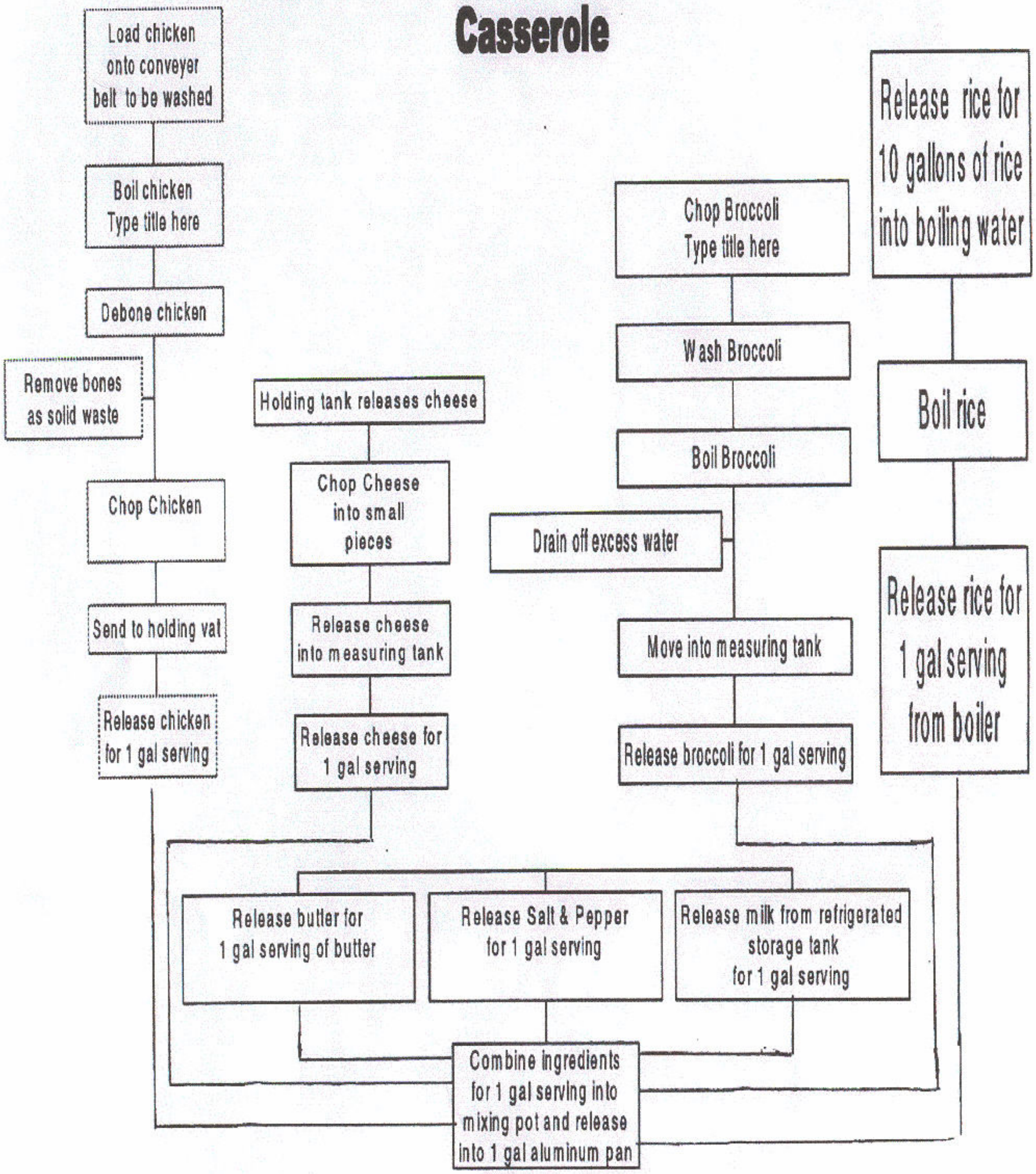
Broccoli Chicken and Cheese Casserole
(Serving Size 80 – Production Rate: 10gal/h.)

- **15 lbs. of Chopped Chicken**
- **20 cups of Rice**
- **20 lbs. of Chopped Broccoli**
- **20 cups of Chopped Cheddar Cheese**
- **10 cups of Milk**
- **5 cups of Butter**
- **6.67 Tablespoons of Salt**
- **3.33 Tablespoons of Pepper**

STEP-BY-STEP RECIPE

1. **Wash chicken and boil for 20-25 minutes at 100 F**
2. **De-bone chicken and dice into small pieces**
3. **Cut and wash broccoli, then boil for 8 minutes and drain water**
4. **Boil rice for 15 minutes**
5. **Combine broccoli, chopped cheese, rice, butter, milk and chicken in a mixing bowl and stir**
6. **Remove contents from mixing bowl and place into 1-gallon casserole dish.**
7. **Bake at 350 F in oven for 30 minutes**

Process Flow Diagram of Broccoli, Chicken, and Cheese Casserole



Summary

Through the use of mini design group projects extending over a one-week period, the students in a freshman introductory engineering course can be taught simple concepts of several unit operations and unit processes. If the projects are selected to solve problems emerging from everyday life experiences, the students show more interest in learning, feel more confident, and can relate to the problem and choices of potential solutions compared to traditional process design problems in chemical engineering.

BIOGRAPHICAL INFORMATION

Dr. RAMESH C. CHAWLA is a professor of chemical engineering at Howard University. He has over thirty years of experience in teaching, research and industrial consulting in the fields of chemical and environmental engineering. His research and teaching interests include reaction engineering, separation processes, environmental engineering, and physical, chemical and biological treatment of hazardous wastes.