Design of Par-Baked Bread Facility

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Objectives

(1) Minimize energy utilization and optimize a formula closely resemble commercial bread quality
(2) Design processes to minimize energy utilization
(3) Use Plackett Burman Experimental Design process to determine optimal bread processing conditions
(4) Analyze the economics of the final plant design in terms of total product cost, annual profits and payback period.

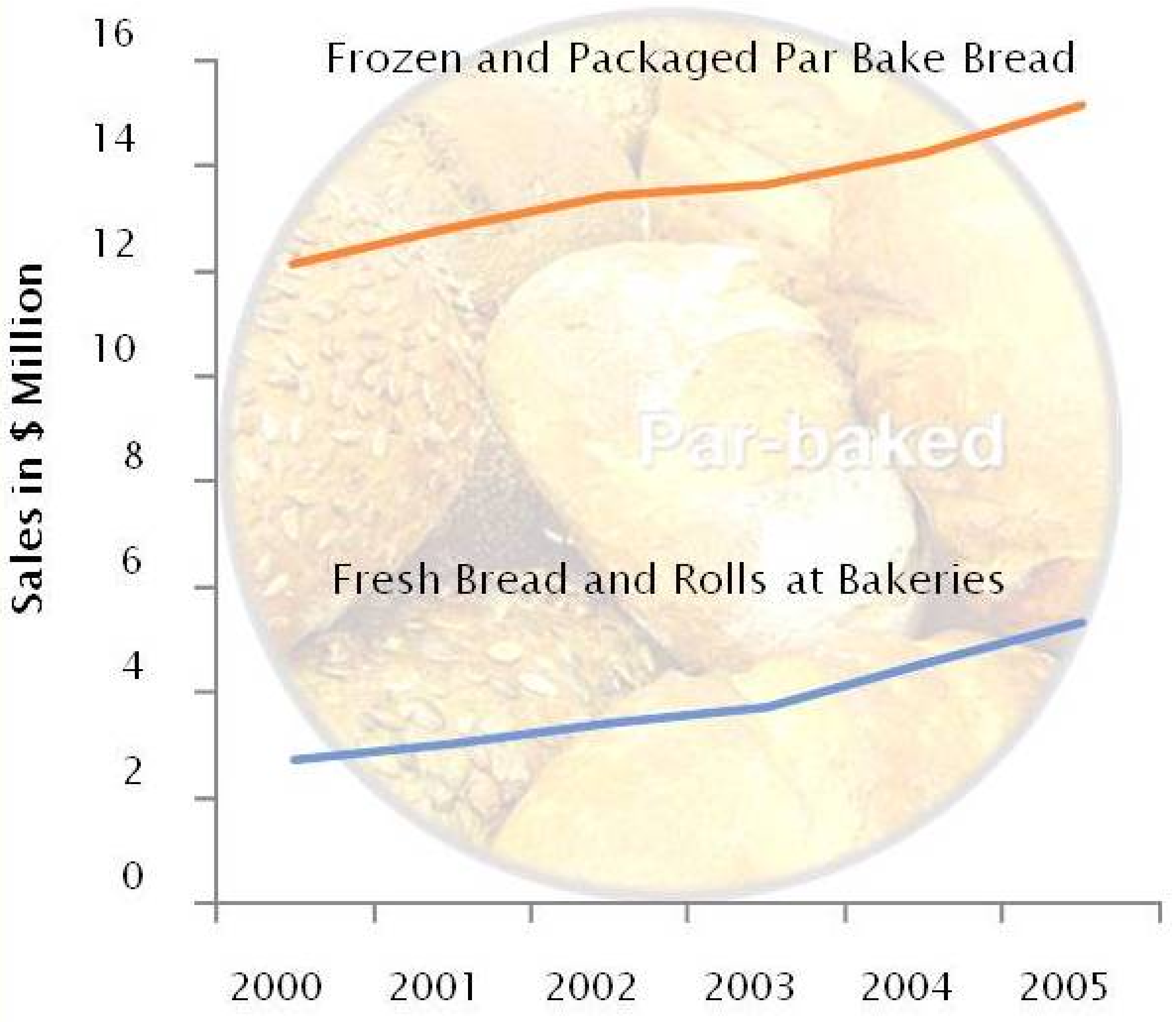


Figure 1 - Market Size and Opportunity for Par Bake Bread (Packaged Facts)

Background

Dating back in Egypt 2470 BC, bread-making has become a common practice to many societies around the globe. With a variety of ingredients, production and serving methods being introduced, par-bake bread is developed based on two-stage of baking process. Bread is partially baked and frozen to extend product shelf life while maintaining loaf quality. Its semi-finished process also allows consumers to bake the loaf to their desired serving quality based on the oven temperature and time.

The par baked bread industry started in the United States over 50 years ago. And its market began to expand tremendously over the past decade. Figure 1 shows a comparison between sales in conventional bakeries (fresh bread) and retail grocery stores (frozen par bake bread). The average $10 million sales difference shows the increasing popularity on frozen convenience food over fresh products. And this demand requires efficient production process in modern food industries.

Experimental Procedure

Our objective was to determine the optimal formula based on the original recipe of white bread. The Plackett-Burman experimental design is used to determine the ingredients that may be significant to our bread quality.

1. Ingredients were mixed for 30 minutes.
2. Dough is formed by compressing against the baking pan (20oz loaf).
3. The pan is proofed in a humidified oven with set proofing T = 105°F.
4. The dough is partially baked in oven to form the bread loaf.
5. Loafs are frozen under T = 18°F before analyzing objectively in texture, color, and moisture.

- Step 1, 3 and 4 are used for exp. design trials.
- Our exp. procedures are derived from a typical commercial bread process facility (fig. 2).

Final Recipe (20oz loaf)

3.5 g Yeast
14.2 g Butter
7.1 g Sugar
5.9 g Salt
354 g Water
229.9 g Flour

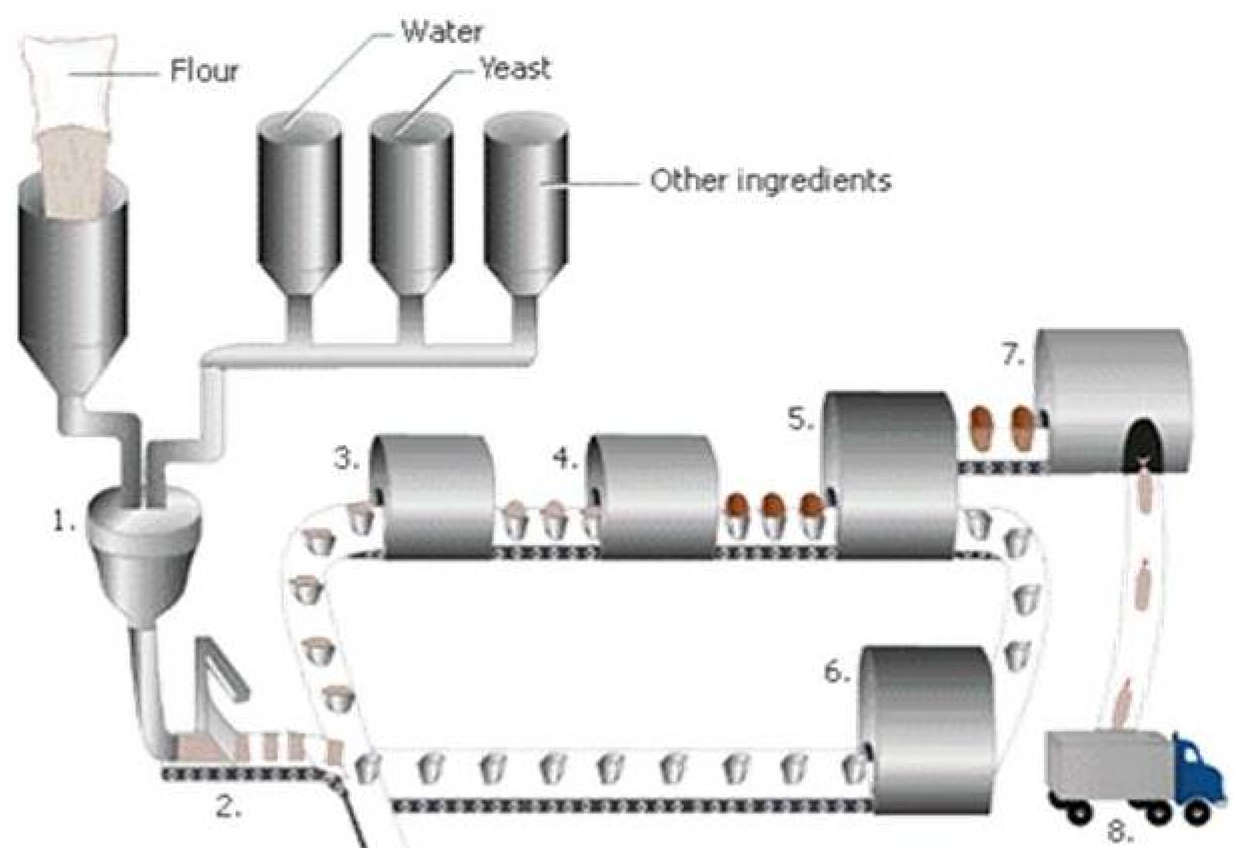


Figure 2 - Commercial Bread Process Facility (MSN Encarta)

Processing Steps

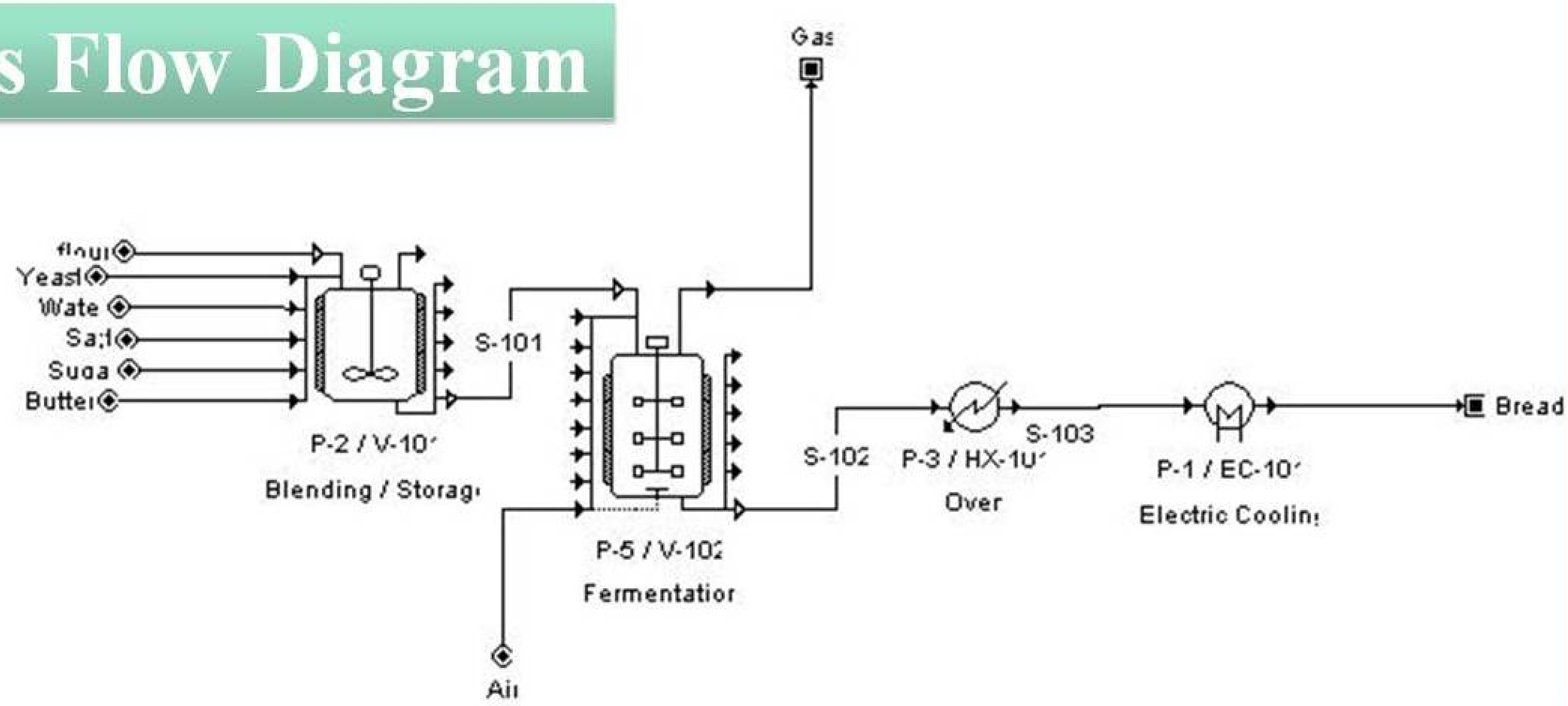
Industry	V.S.	Kitchen Lab
1. Mixer		1. Mixing Bowl
2. Cutter		2. Knife
3. Proofer		3. Humidifier
4. Oven		4. Oven
5. De-panner		5. N.A.
6. Pan Recycler		6. Dish washer
7. Packaging		7. N.A.
8. Transportation		8. N.A.

Plackett-Burman Design

TABLE 1 PLACKETT-BURMAN VARIABLES AND LEVELS			
Code	Variables	Levels	
		(+)	(-)
A	Pre-Prooofing Time	15	5
B	Proofing Time	60	40
C	Oven Time	40	20
D	Oven Temperature	375	300
E	Dummy		
F	Dummy		
G	Dummy		

TABLE 2 PLACKETT-BURMAN EXPERIMENTAL SETUP							
Run No.	A	B	C	D	E	F	G
1	+	+	+	-	+	-	-
2	-	+	+	+	-	+	-
3	-	-	+	+	+	-	+
4	+	-	-	+	+	+	-
5	-	+	-	-	+	+	+
6	+	-	+	-	-	+	+
7	+	+	-	+	-	-	+
8	-	-	-	-	-	-	-

Process Flow Diagram



Mixing

$flour_{in} = 59.5615\,kg$ $yeast_{in} = 1.0471\,kg$ $salt_{in} = 2.1814\,kg$

$sugar_{in} = 0.6199\,kg$ $H2O_{in} = 25.5503\,kg$ $butter_{in} = 1.2398\,kg$

Amount of raw materials in 100 kg of dough

$bread_{volume.i} = 0.0011\,m^3$ $Bread_{volume.i} = 2.1535\,L$ $Bread_{density.i} = 836.9635\,\frac{kg}{m^3}$

Initial Dough Volume and Density

Proofing

$$Bread_{density.m} := \frac{1}{\frac{\frac{X_{flour.i}}{1.11}}{\rho_{flour}} + \frac{\frac{X_{yeast.i}}{1.11}}{\rho_{yeast}} + \frac{\frac{X_{sugar.i}}{1.11}}{\rho_{sugar}} + \frac{\frac{X_{salt.i}}{1.11}}{\rho_{salt}} + \frac{\frac{X_{H2O.i}+.11}{1.11}}{\rho_{H2O}} + \frac{\frac{X_{butter.i}}{1.11}}{\rho_{butter}}} \cdot \frac{1}{coefficient_{expansion.m}}$$

$Bread_{density.m} = 283.5694\,\frac{kg}{m^3}$ ← This value shows the drop in density, due to expansion during fermentation → $volume_m = 0.0032\,m^3$

Baking- Calculating Energy Required

$$Cp_{bread.baked}(mc) := \left[4.19\cdot mc + \frac{.84\cdot(1-mc)}{100}\right]\cdot\frac{J}{gm\cdot K}$$

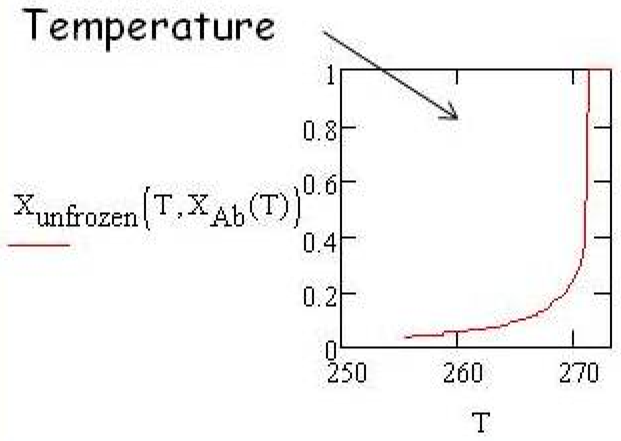
$\frac{Q_{oven.total}}{\eta} = 13.1156\,kW$ ← 131156 Joules of energy are needed to heat the bread every second

$volume_f = 0.1141\,ft^3$ Notice the further increases in bread size during baking

$Bread_{density.f} = 278.7393\,\frac{kg}{m^3}$

Freezing- Finding Water Frozen and Freezing Time

Model of % Water frozen vs. Temperature



$$X_{unfrozen}(T, X_{Ab}) := \begin{cases} 1 & \text{if } T > T_{freezing} + 273 \\ \left[\frac{X_{Ab}\cdot(1-X_{H2O.f})}{W_e}\right]\left(\frac{1}{\frac{1}{Mw_{H2O}} - \frac{X_{Ab}}{Mw_{H2O}}}\right) & \text{otherwise} \end{cases}$$

Tools such as integration calculate total energy for freezing

$$H_{freezer.loaf} := \int_{T_{ambient}}^{T_{initial}} Cp_{eff}(T)\,dT \qquad H_{freezer.loaf} = 721.1061\,\frac{J}{gm}$$

Planks equation for freezing time allowed us to model the complete freeze of one loaf

$$time_{freezing} := \frac{\lambda_{fusion}\cdot Bread_{density.f}}{(271 - T_{ambient})\cdot K}\left(\frac{p\cdot D}{h_{air.blast}} + \frac{r\cdot D^2}{k_{bread}(265)}\right)$$

$time_{freezing} = 62.569\,min$

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Economic Analysis

Production Rate: 5184000 loaves/year

Selling Price: $2.50 per 1 lb. loaf

Table 3: Economic Analysis	
Total Capital Investment	$ 7,746,200
Annual Product Cost	$ 6,890,487
Annual Revenue	$12,960,000
Annual Profit	$ 6,069,513
Payback Period	1.3 years

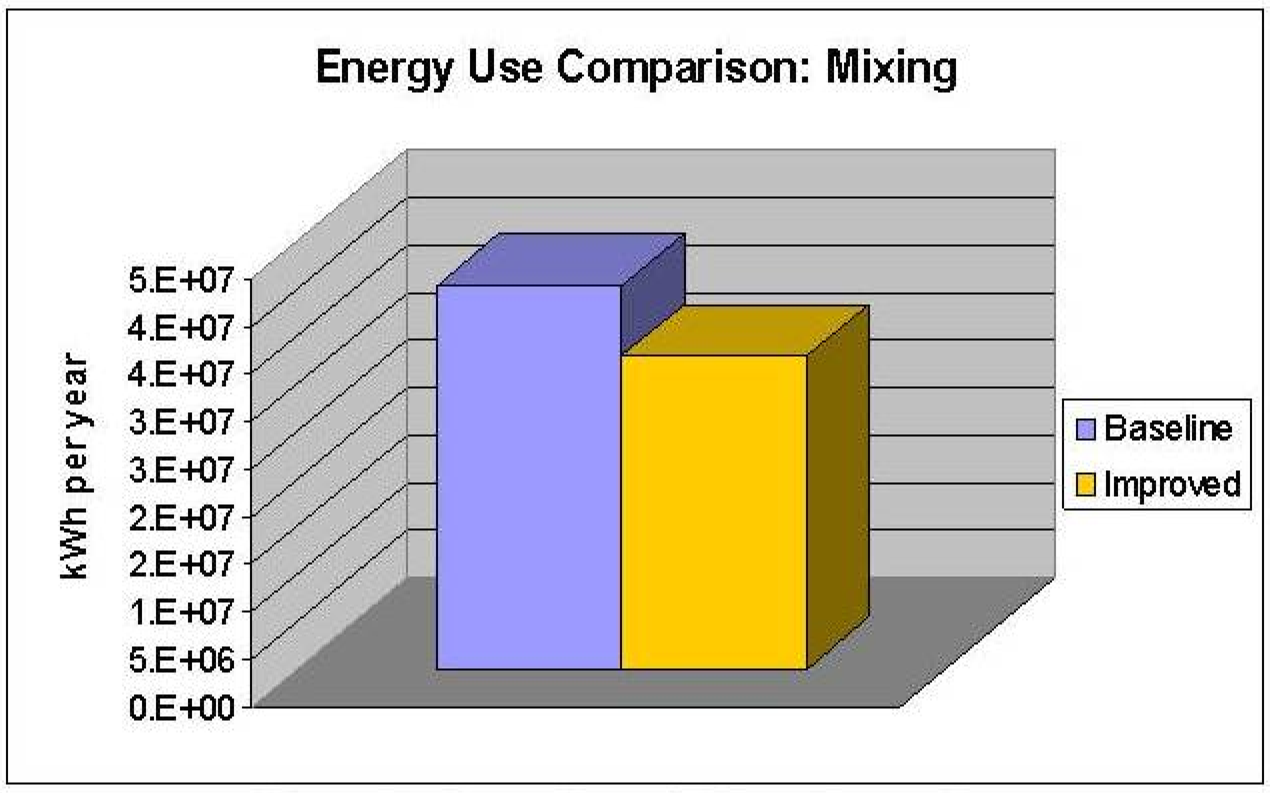

Figure 3 - Comparison of Mixer Energy Use Before and After Optimization

Optimization Results

Mixing Optimization:

- High efficiency batch mixer with 3 blade turbines
- Designed to reduce cleaning time after batches
- Allows for increased mixing time at lowered impeller speed
- Decreases overall energy use per batch

Figure 2 - High efficiency mixer

Energy Savings from Mixer:	7326000	kWh/year
Cost of Electricity:	0.12	$/kWh
Electricity Savings per Year:	$879,120	

Conclusions

A facility for the production of par-baked bread was designed. A Plackett-Burman experimental design was implemented to determine the optimal processing conditions for lab-scale par-baked bread production. These conditions were used to design a full scale facility which will produce about 5 million loaves of bread per year. According to financial projections, this facility will recoup the original capital investment over a period of 1.3 years. Annual profits will be $6 million.

Future Work

(1) Optimize remaining unit operations

(2) Use a Plackett-Burman experimental design to develop optimal par-baked bread recipe with improved sensory characteristics

(3) Pilot plant trials of optimized par-baked bread recipe

(4) More detailed economic analysis including quotes from equipment manufacturers

Acknowledgements

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