Engineering Wine

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ChE 4273

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Overview

- Problem Definition
- Process Overview
- Consumer Satisfaction and Preference
- Application of Model
- Business Model
- Conclusions
- Recommendations

Problem Definition

History of Wine

- Predates recorded history
- Fables of medicinal uses
- Integral role in cultures
- Safe alternative to drinking water

Problem Definition

Wine of Today

- Unique product
- Evolved into an experience
  - Past: Quality defined by producer
  - Present: Consumer holds buying power
- Tasks of Producer
  - Identification of consumer wants
  - Adjustment of Product or Price

Problem Definition

Quality

- Outsourced for Evaluation
  1. Laboratories
  2. Competitions
- Problems
  - Increased Cost
  - Defined Post Bottling
  - Adjustment: Selling Price

Problem Definition

Solution

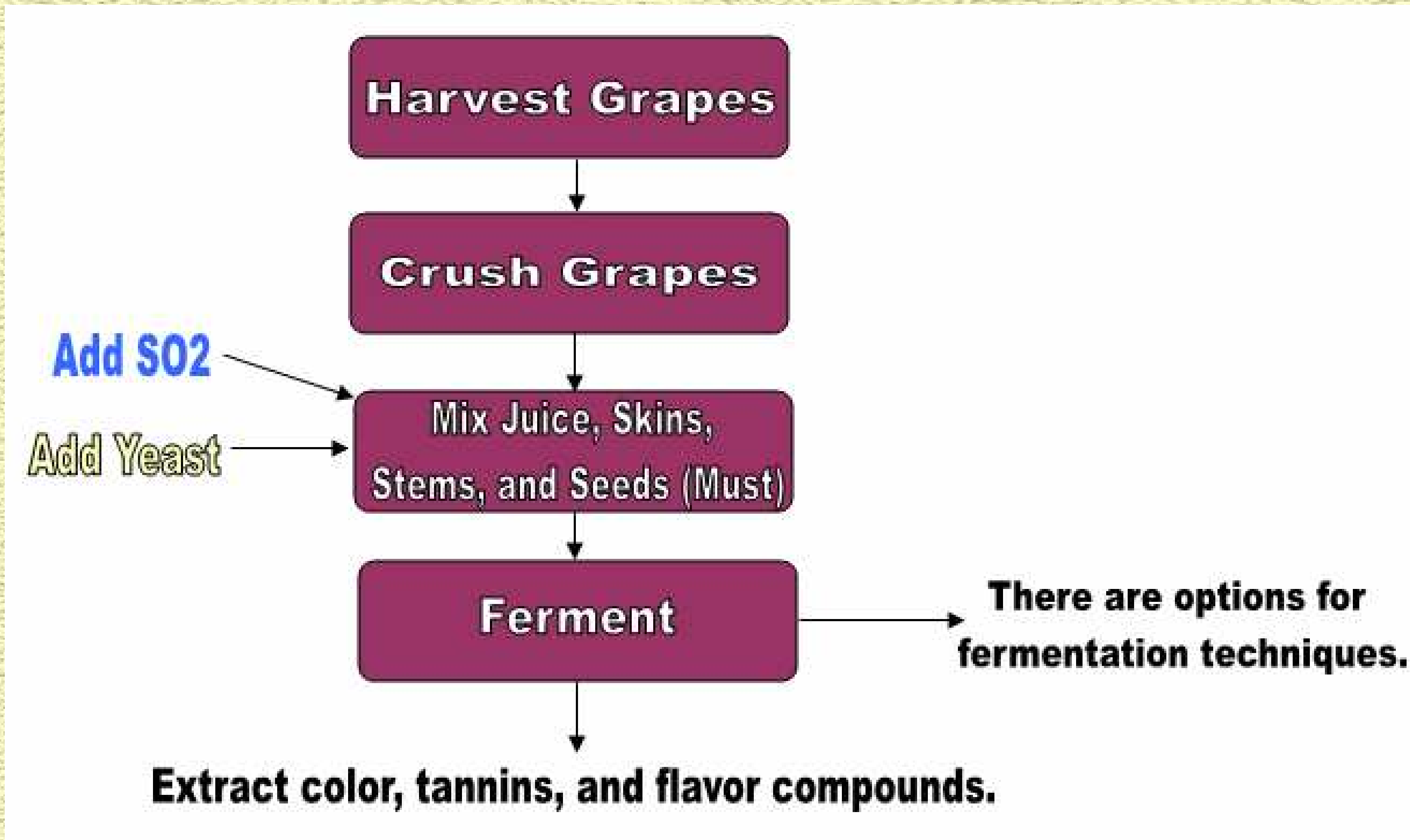
- Quality can be found before bottling
- Engineered to reach desired quality
- Profit can be maximized

Method

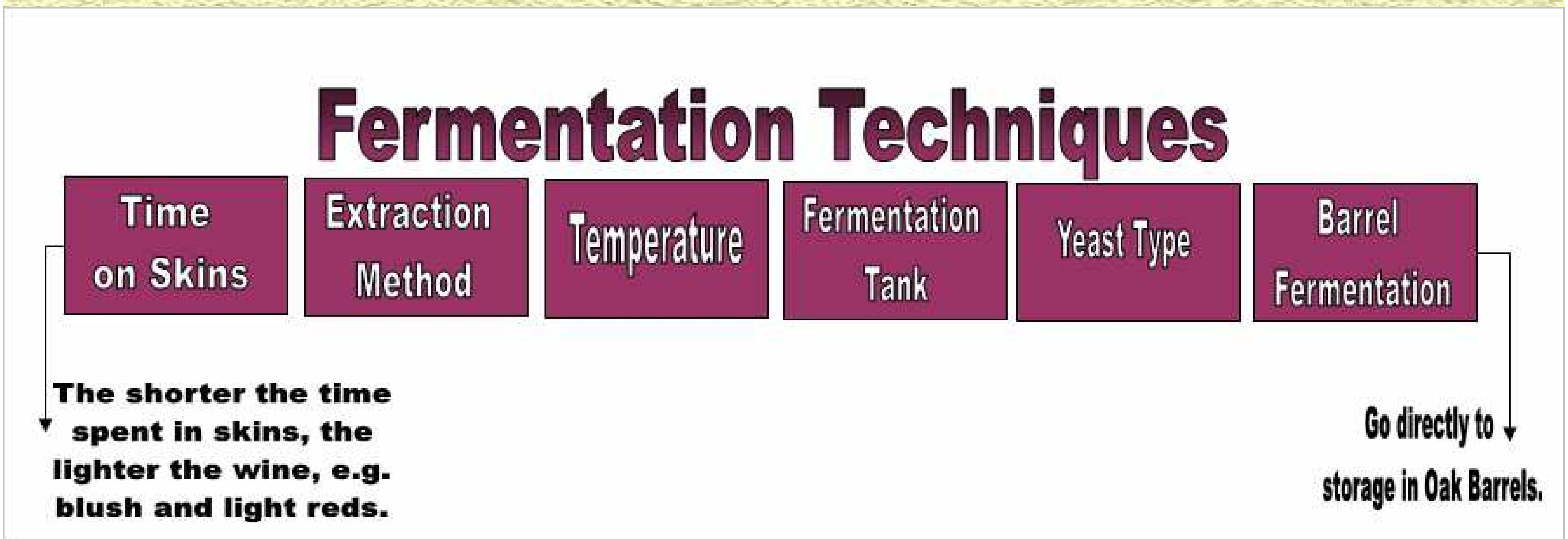
- Identification of Consumer Utility
- Adjustment to Process
- Competitor Comparison

Process Overview

Process Overview



Process Overview



Process Overview

Consumer Utility and Preference

Consumer Utility and Preference Theory

- **Quantification of Consumer Satisfaction**

$$S = d_1^{\alpha} + d_2^{\beta}$$

α = Inferiority Function
- Knowledge of product
- Function of Time

β=Superiority Function
- Consumer preference
- Comparison to competition

Consumer Utility and Preference Theory

- **By Maximizing Satisfaction (S)**

$$\beta d_1 p_1 = \alpha d_2 p_2 d_1^{\alpha} / d_2^{\beta}$$

- **Relation of Consumer Budget (Y)**

$$Y = d_1 p_1 + d_2 p_2$$

Consumer Utility and Preference

Theory

- β is ratio of consumer preference

$$\beta = H_2 / H_1$$

- Happiness Function

$$H_i = \sum w_i y_i$$

w_i = weight
- Based on consumer preference
- Fraction of 1

y_i = satisfaction score
- Based on consumer evaluation
- Manipulated by process

Consumer Utility and Preference

Formation and Integration

1. Identification of Characteristics
2. Quantification of Consumer Perceptions
3. Relation to Physical Properties
4. Assignment of Weight
5. Integration into Process

Limitations

*Estimations used to generate consumer expectations.

Consumer Utility and Preference

Characteristics

- Clarity
- Color
- Bouquet
- Acidity
- Sweetness
- Bitterness
- Body/Texture
- Finish/Aftertaste

Consumer Utility and Preference

Weights of Characteristics

Characteristic	w_i
Clarity	0.15
Color	
Hue	0.08
Brightness	0.08
Bouquet	0.30
Acidity	0.08
Sweetness	0.08
Bitterness	0.08
Body/Texture	0.15

Consumer Utility and Preference

Clarity	Turbidity (NTU)
Crystal Clear	0.10 - 0.5
Clear	0.50 - 1.0
Slightly Blurred	1.0 - 1.8
Blurred	1.8 - 3.0
Milky, Cloudy	3.0 - 4.0
Sediment Present	>4

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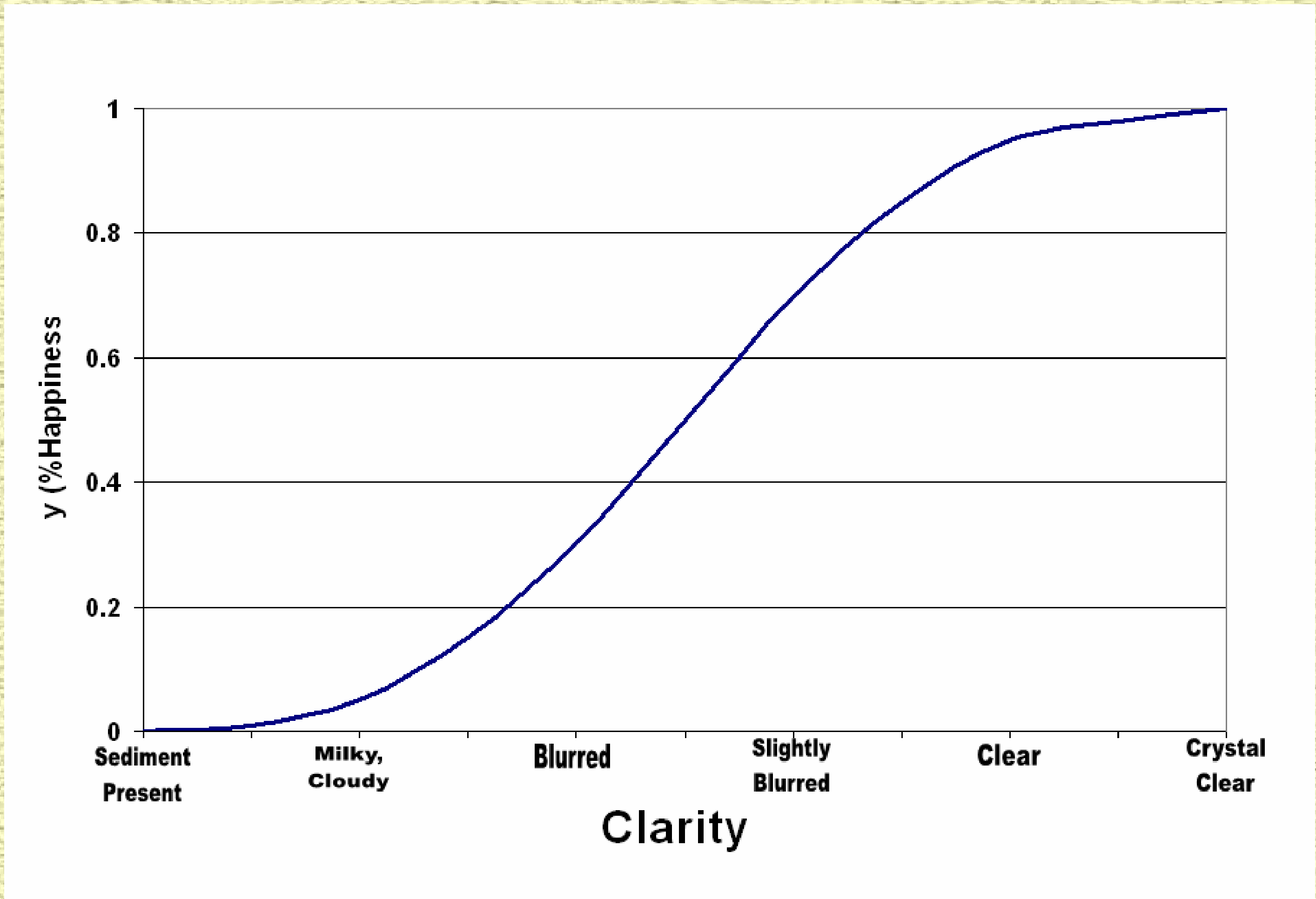
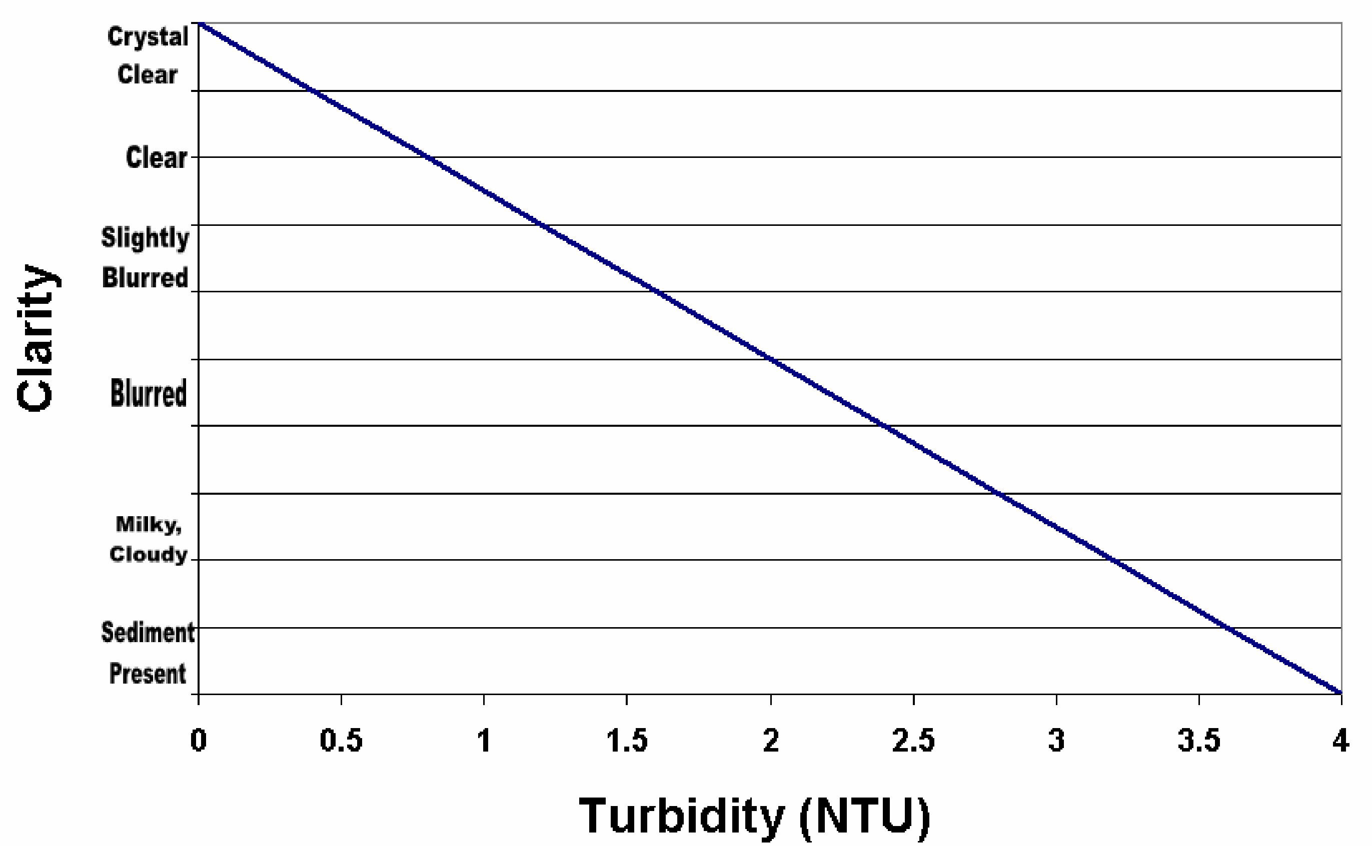
Consumer Utility and Preference



Consumer Utility and Preference



Consumer Utility and Preference

Clarity

- **Utility Function**

  $y_{clarity} = -.25x_{turbidity} + 1$

- **Manipulation**
  - **Bentonite**
    - **Binds to proteins**
    - **Cost: $7 / 8ounces**
    - **0.25-1.3 g/L of 5% Aqueous Solution**

Consumer Utility and Preference

Color

- Hue
  - Shade of color
  - Ranges from brown to red
- Brightness
  - Intensity of color
  - Ranges from dull to bright

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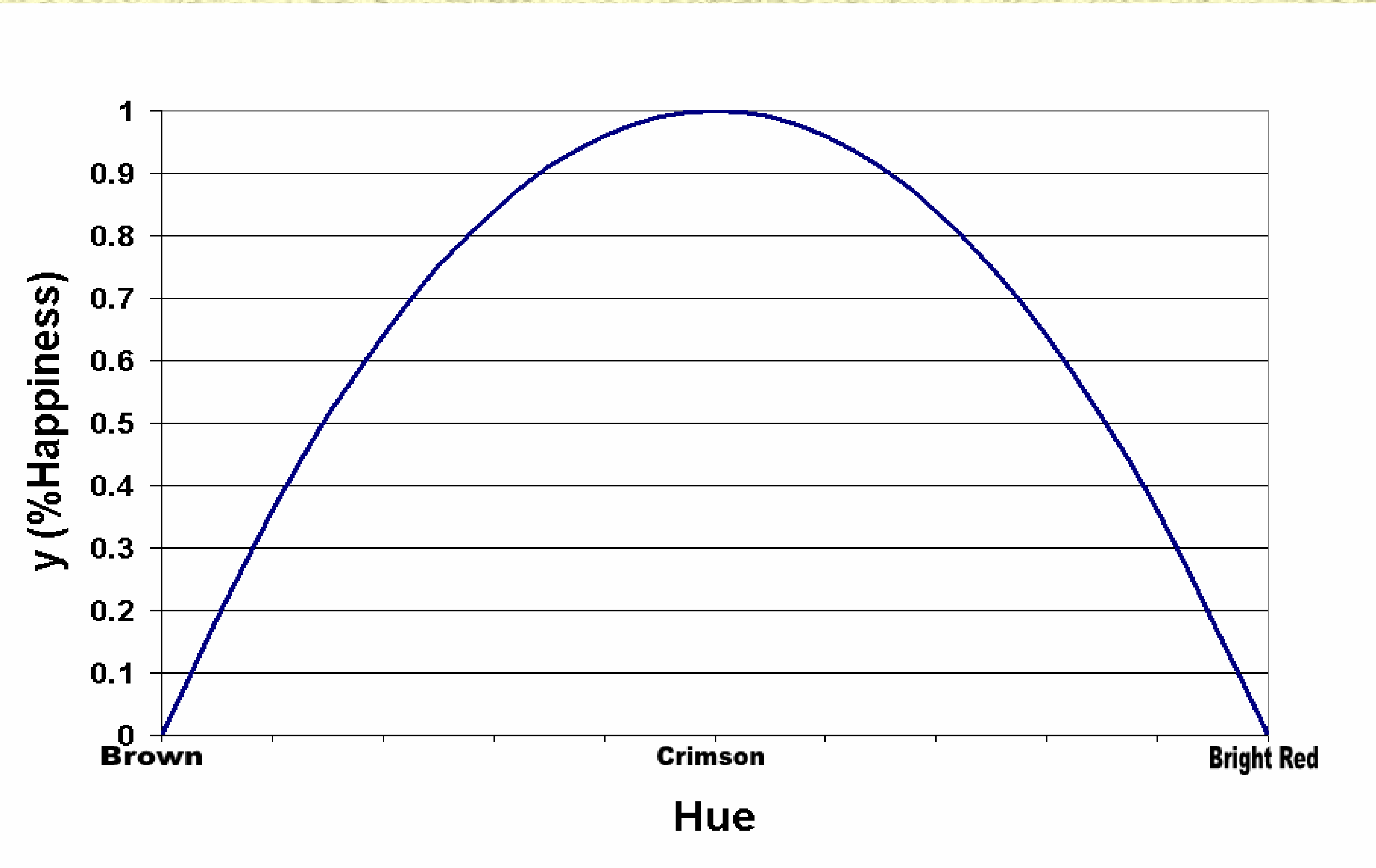
Consumer Utility and Preference



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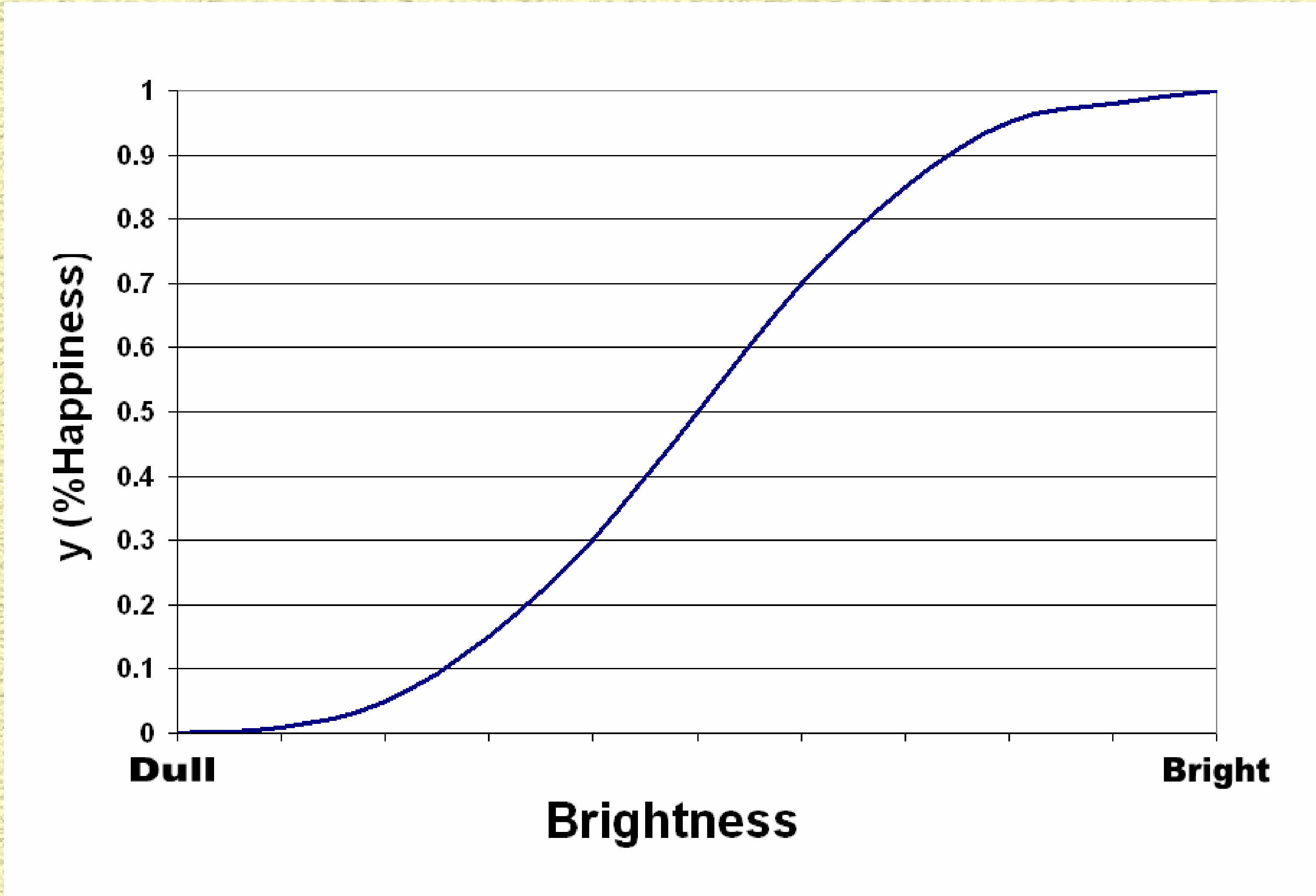
Consumer Utility and Preference



Consumer Utility and Preference

Color

- **Hue**
  - **Measurement**

    Absorbance Ratio = (D_{420}/D_{520})

    - **Red: <.44**
    - **Crimson: 0.44-1.0**
    - **Brown: >1.0**
- **Brightness**
  - **Measurement**

    $\% \ Brightness = D_{420} + D_{520}$

    - **0 (Dull)**
    - **1 (Bright)**

Consumer Utility and Preference

Color

- **Hue**

  Utility Function

  $y = -x_{D420/D520}^{2} + 2x_{D420/D520}$

- **Brightness**

  Utility Function

  $y = x_{Brightness\ Fraction}$

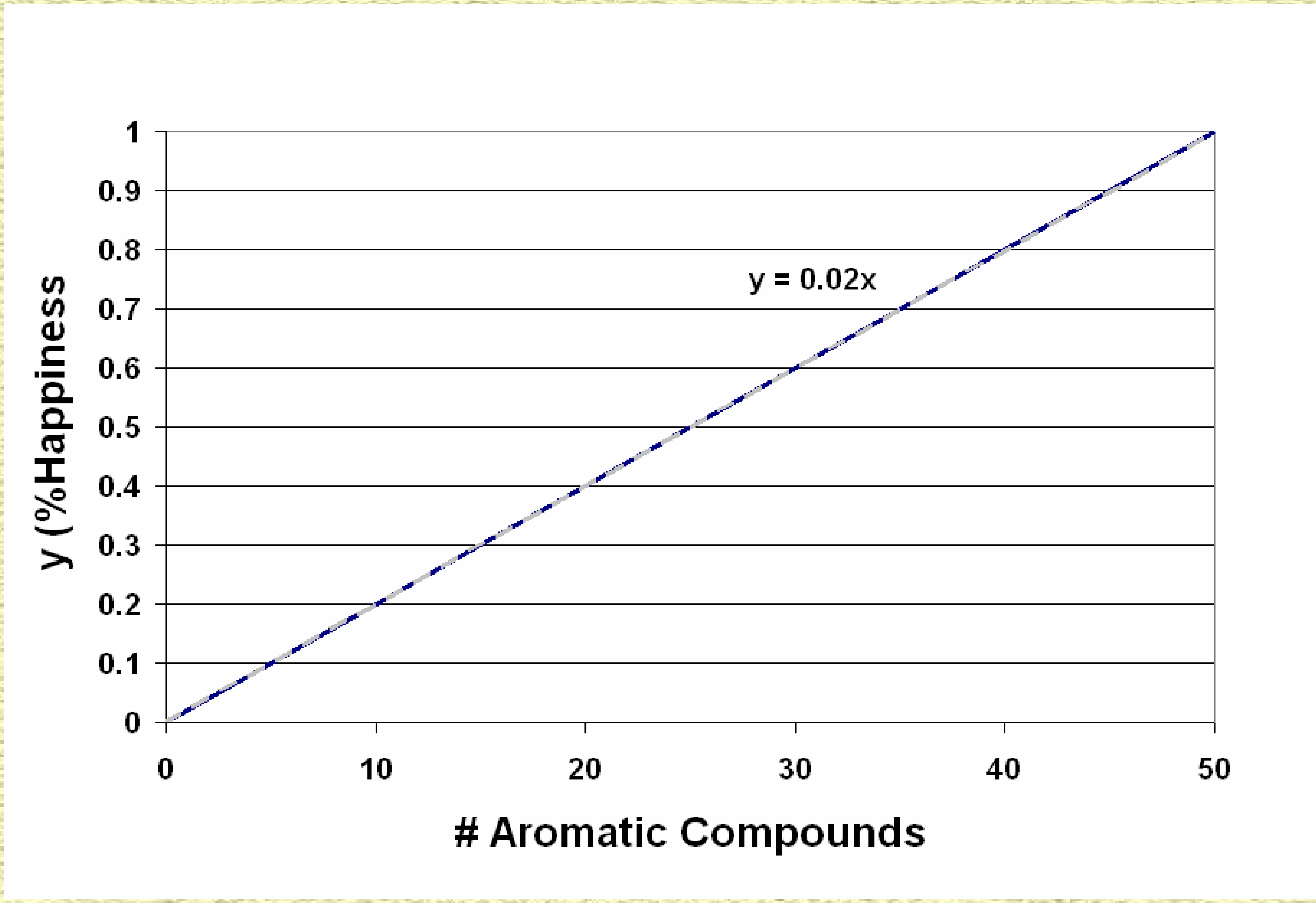
- **Manipulation**
  - Increase cold soak time
  - Alters flavor and aroma profiles

Consumer Utility and Preference

Bouquet

- Olfactory characteristics of wine due to processing
- Result of tannins, esters, and other compounds
- Measured by solid-phase micro-extraction
- Analyzed based on number of components
- Complexity in bouquet is desired

Consumer Utility and Preference



Consumer Utility and Preference

Body/Texture

- Feeling of wine in the mouth
- Depth and round feature
- Measured by % alcohol
  - Range: 8-16 %
  - Optimum: 12%

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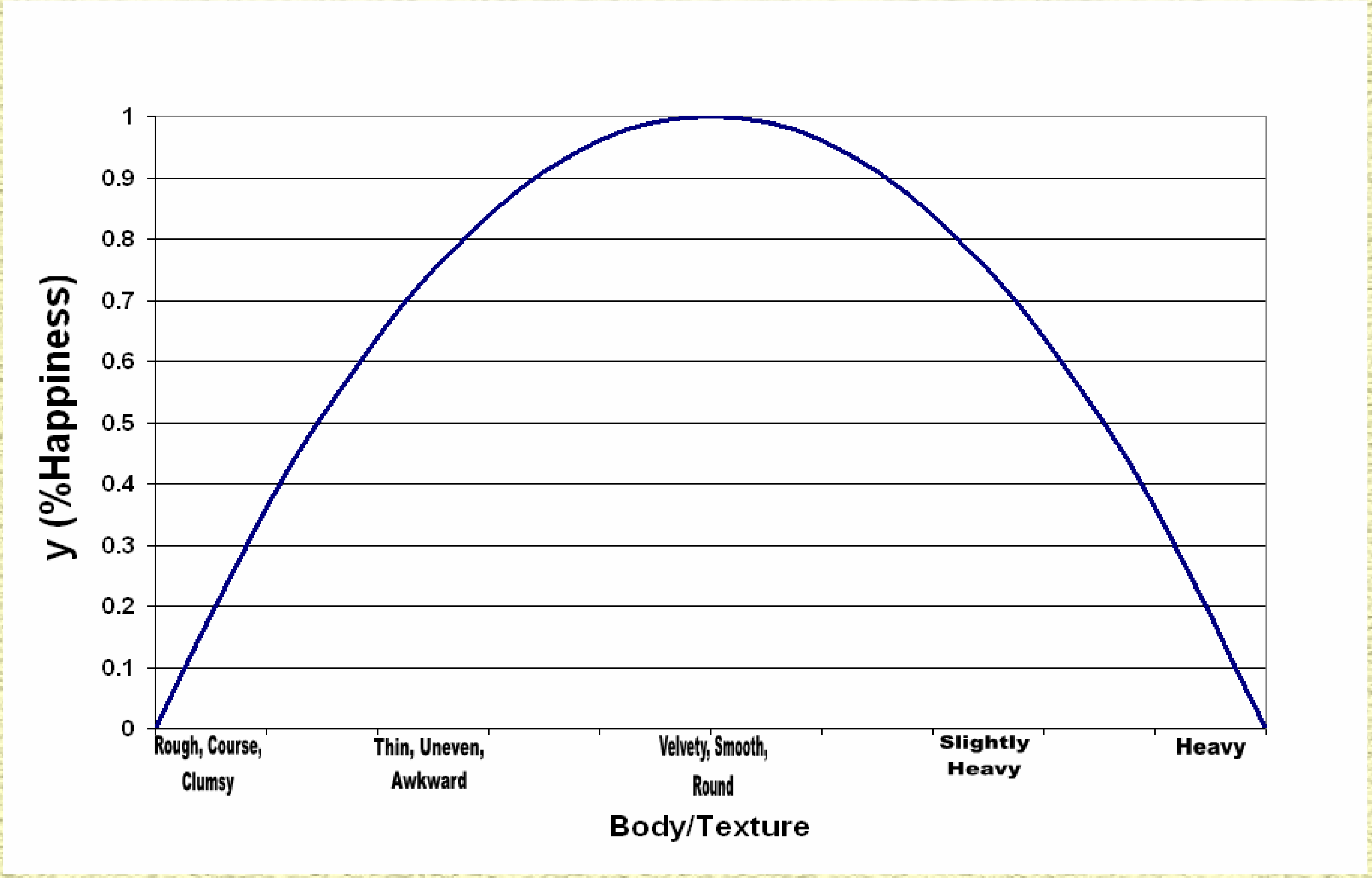
Consumer Utility and Preference



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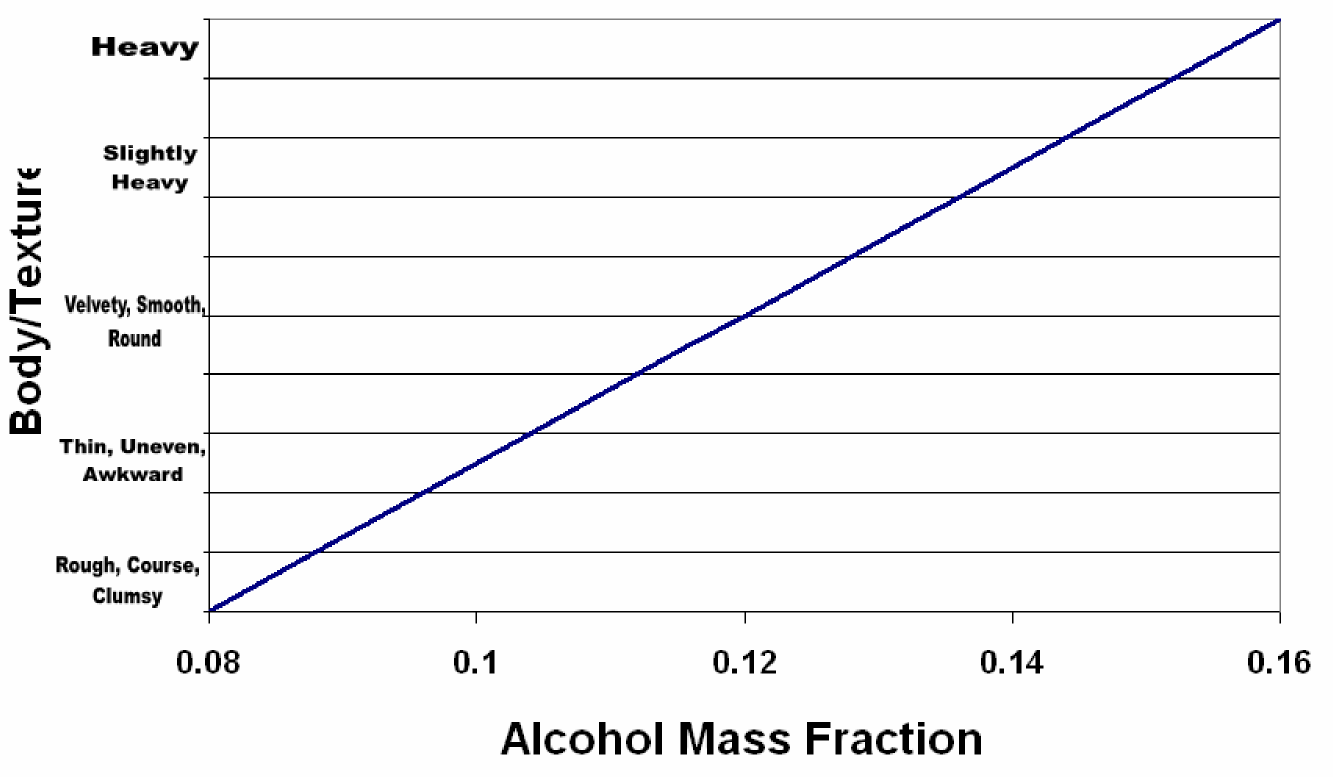
Consumer Utility and Preference



Consumer Utility and Preference

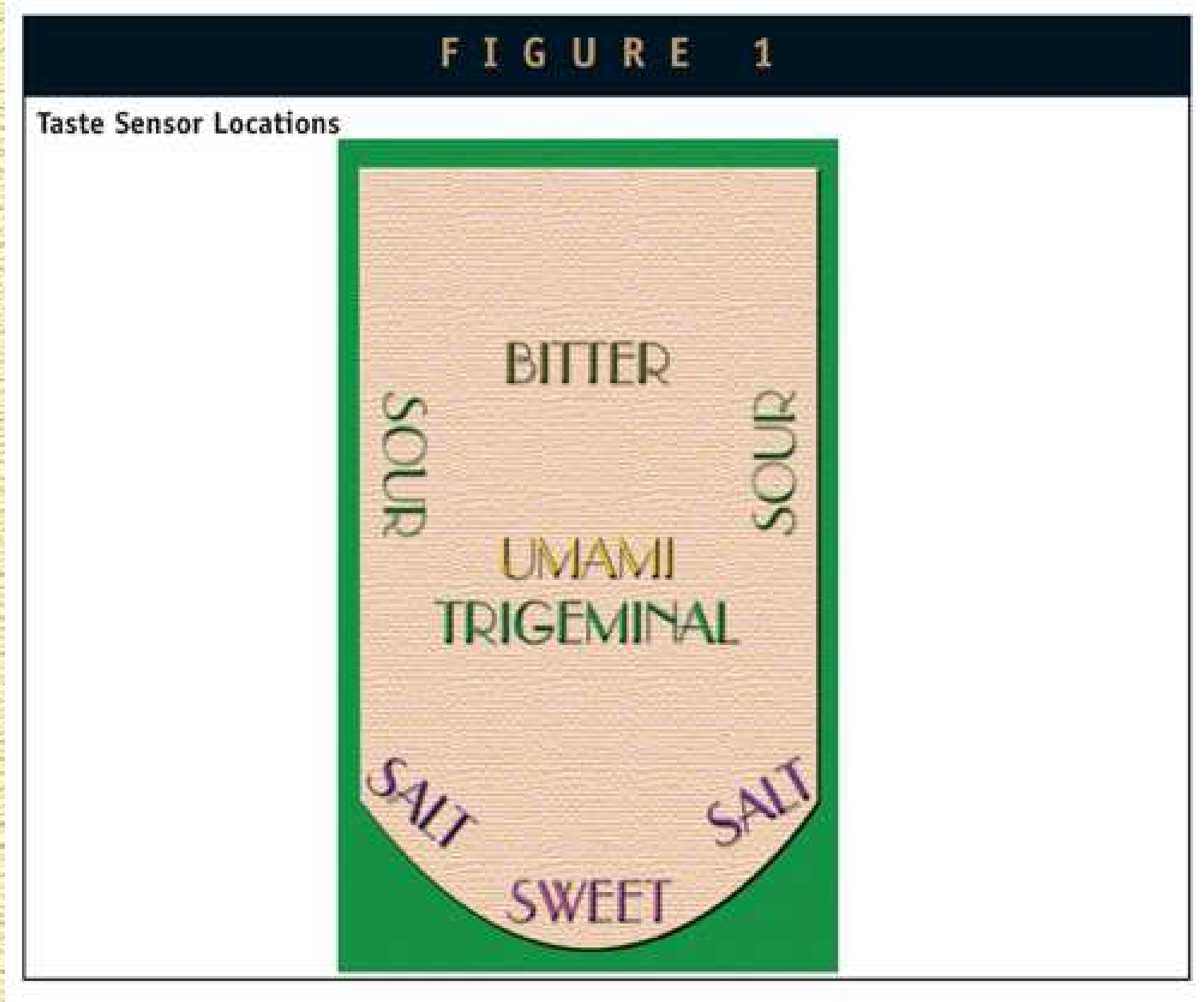
Body/Texture

- **Utility Function**

$$y_{Body/Texture} = -625\,x_{alcohol}^2 + 150x_{alcohol} - 8$$

- **Manipulation**
  - Fermentation Time
  - Increase time, increase alcohol

Consumer Utility and Preference



http://www.drugdeliverytech.com/cgi-bin/articles.cgi?idArticle=164

Consumer Utility and Preference

Flavor

- Analyzed based on three attributes
  - Sweetness
  - Acidity
  - Bitterness
- Balance is necessary

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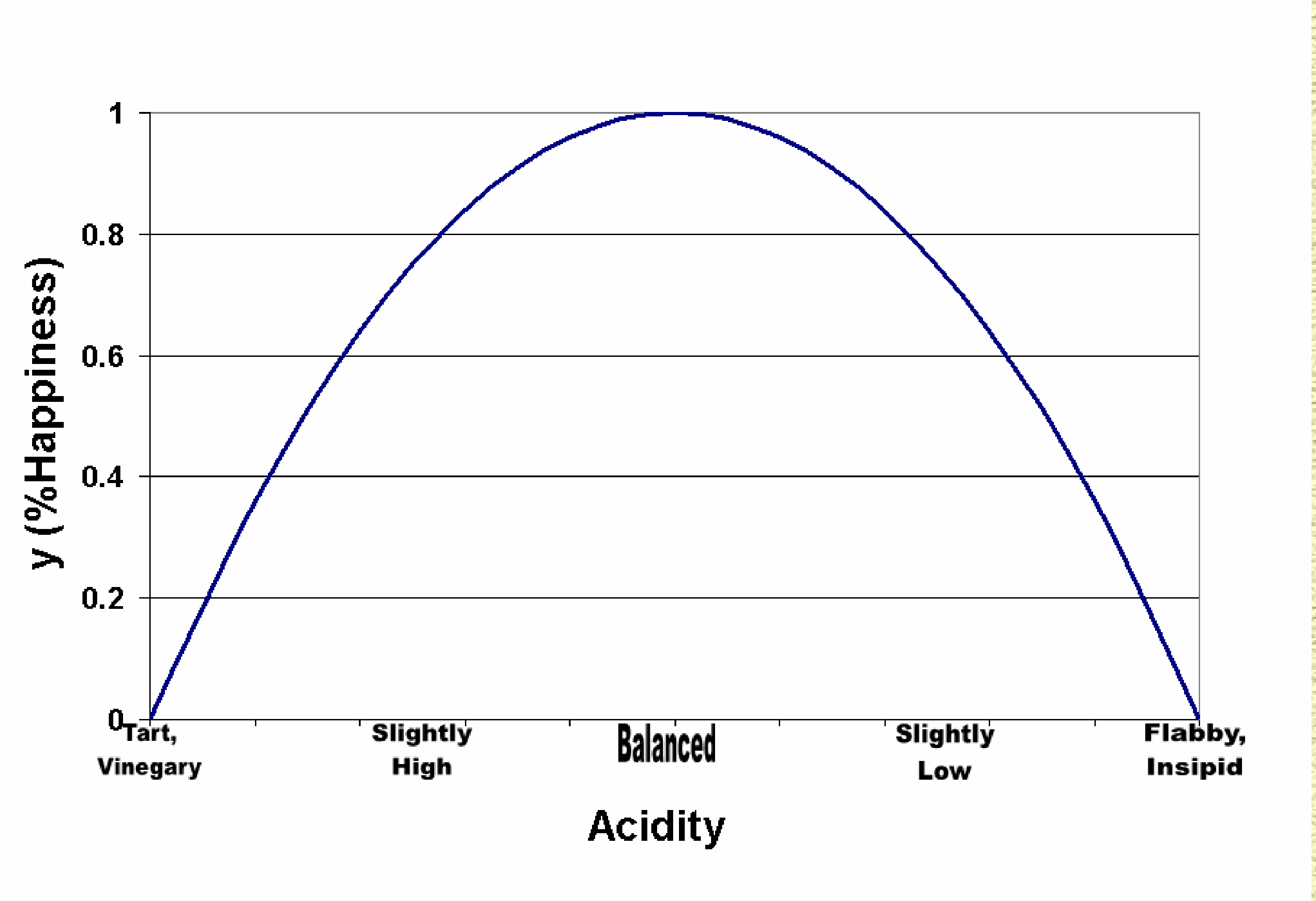
Consumer Utility and Preference



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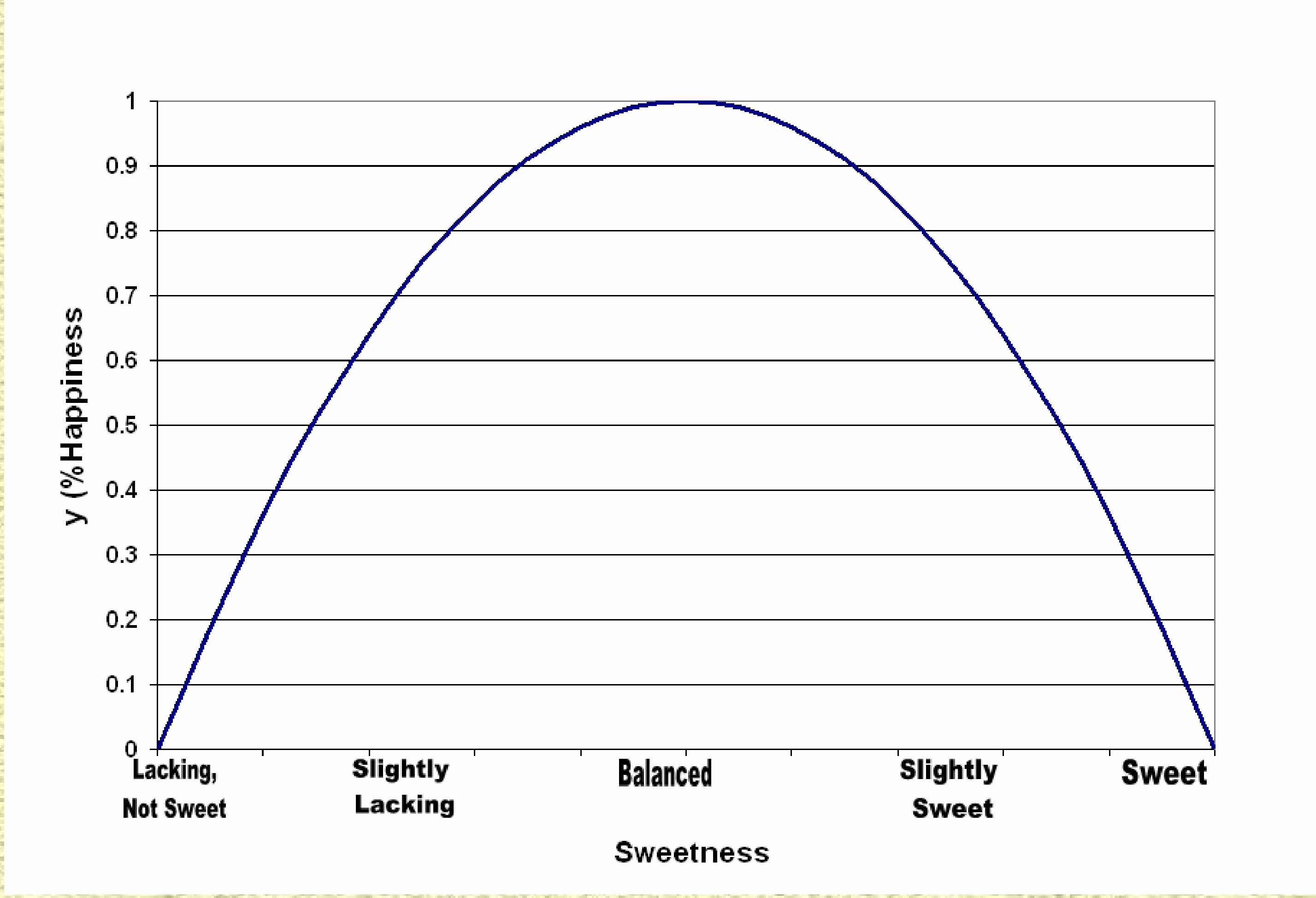
Consumer Utility and Preference



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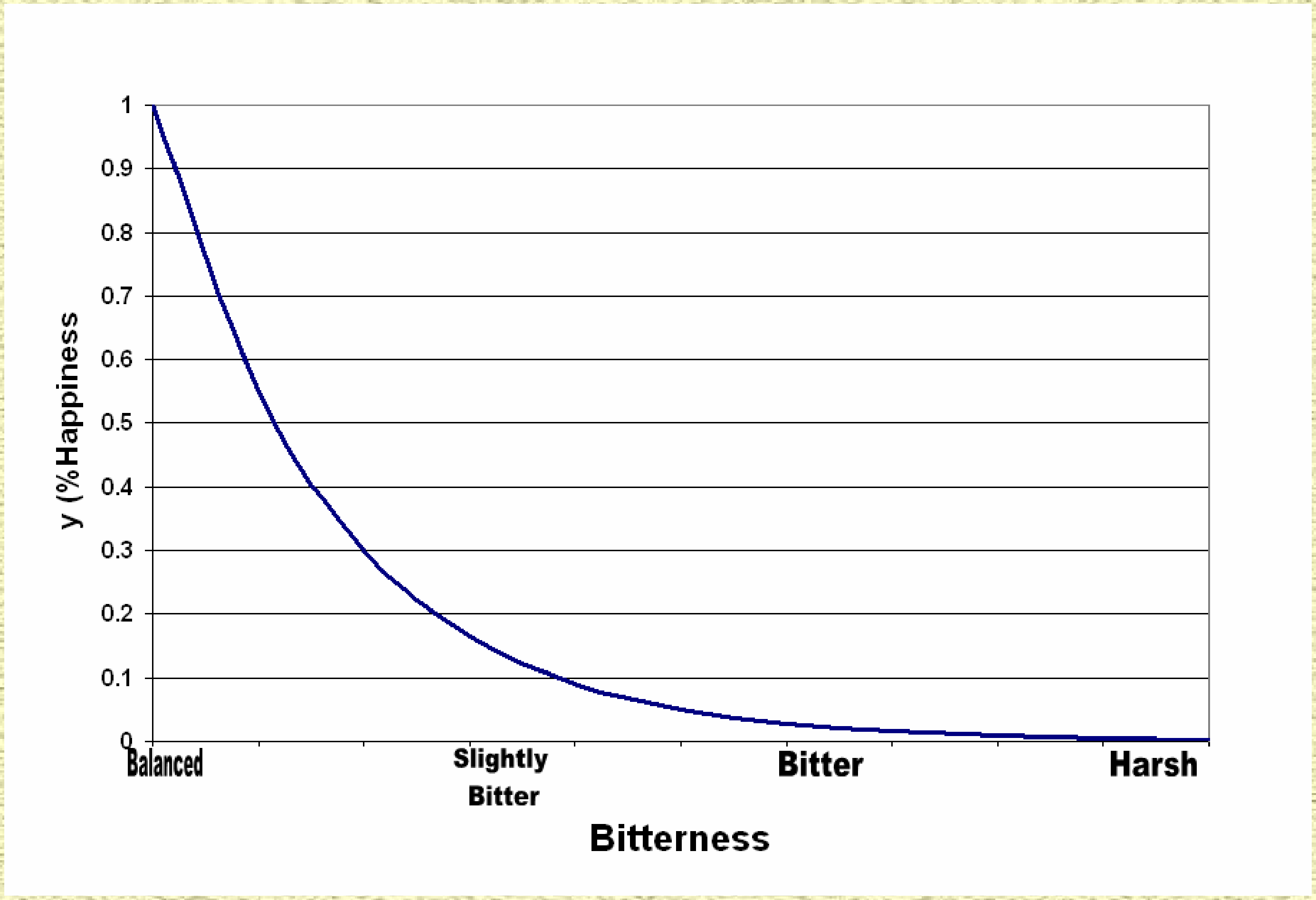
Consumer Utility and Preference



Consumer Utility and Preference

Acidity

- pH Level
  - Full Range: 2.9-4.9
  - Optimum: 3.0-3.4
- Manipulation
  - Malolactic Fermentation
  - Acid Blend ($5/6ounces)
  - 1 teaspoon/gallon

Consumer Utility and Preference

Sweetness

- Residual Sugar
  - Full Range: 0 – .2wt%
  - Optimum: .1 wt%
- Manipulation
  - Decrease fermentation time

Bitterness

- Tannin Content
  - Full Range: 0 – 3 g/L
  - Optimum: 0 g/L
- Manipulation
  - Increase aging
  - Polyclar

Consumer Utility and Preference

$$y_{acidity} = -x_{pH}^2 + 6.4x_{pH} - 9.24$$

$$y_{sweetness} = -100x_{\%Residual\ Sugar}^2 + 20x_{\%Residual\ Sugar}$$

$$y_{bitterness} = e^{-2x(tannin\ content)}$$

SUM OF SQUARES EMPLOYED FOR ERROR

$$y_{balance}=(y_{acidity} + y_{sweetness} + y_{bitterness}) - \{(y_{average}-y_{acidity})^2+(y_{average}-y_{sweetness})^2-(y_{average}-y_{bitterness})^2\}$$

ACCOUNTS FOR EFFECTS ON BALANCE

Consumer Utility and Preference

Finish/Aftertaste

- Final step of wine evaluation
- Based on length of time on palate
- Measured by residence time on palate
- Cannot manipulate process to alter
- Will not be used in overall function

Consumer Utility and Preference

Effects of Aging

- Largest influential factor of process
- Varies by type, time, and toasting effects
- Toasting method: pyrolysis of oak
- Ranges: Light – Dark

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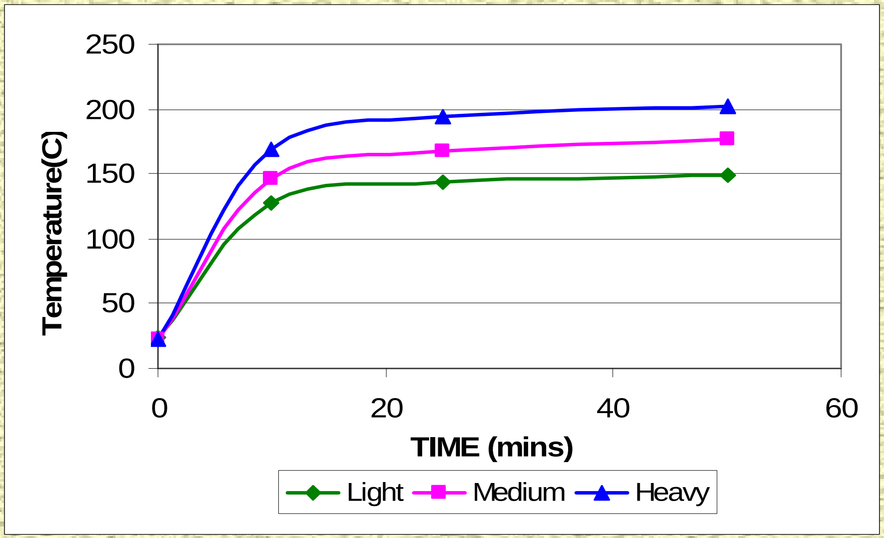
Consumer Utility and Preference

Toast Level	TIME (min)			
	0	10	25	50
Light	24	129	144	153
	24	127	145	148
	22	125	141	147
Medium	22	151	172	178
	23	147	172	181
	22	141	160	171
Heavy	23	168	197	205
	22	176	200	208
	21	162	185	194



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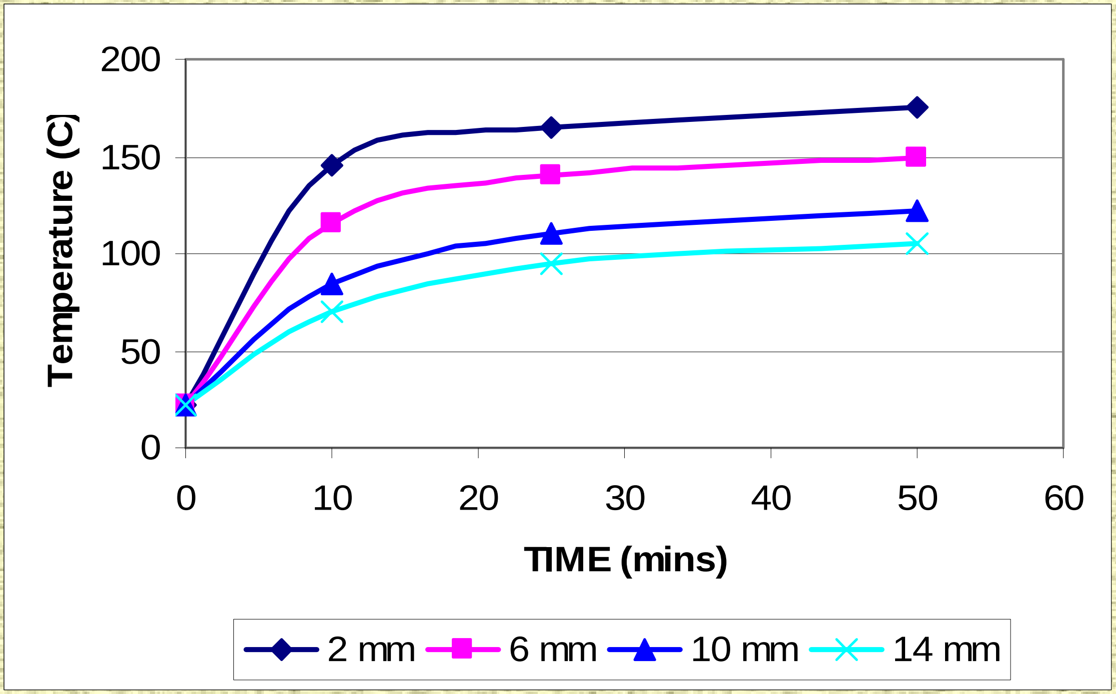
Consumer Utility and Preference

Temperature profile of medium toast.



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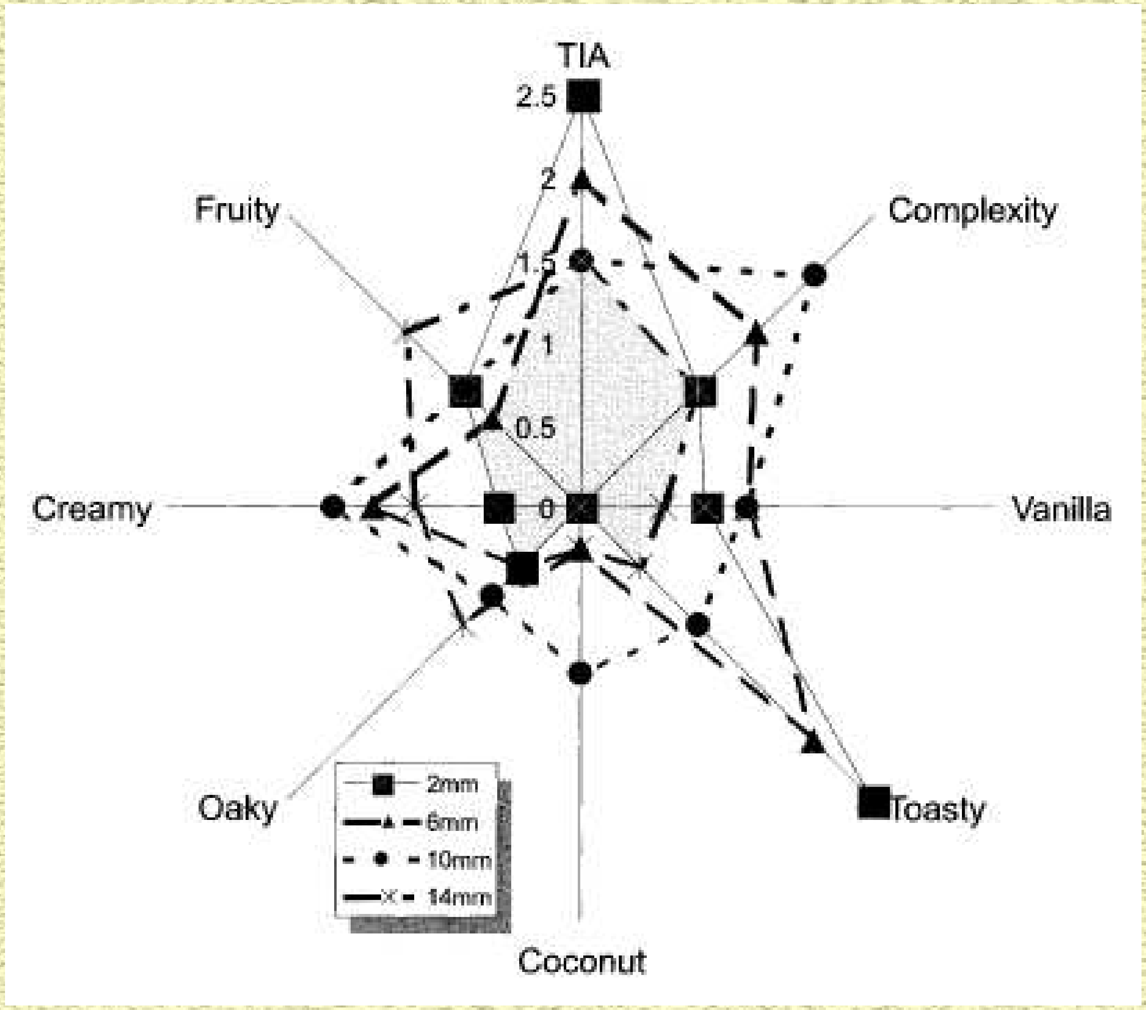
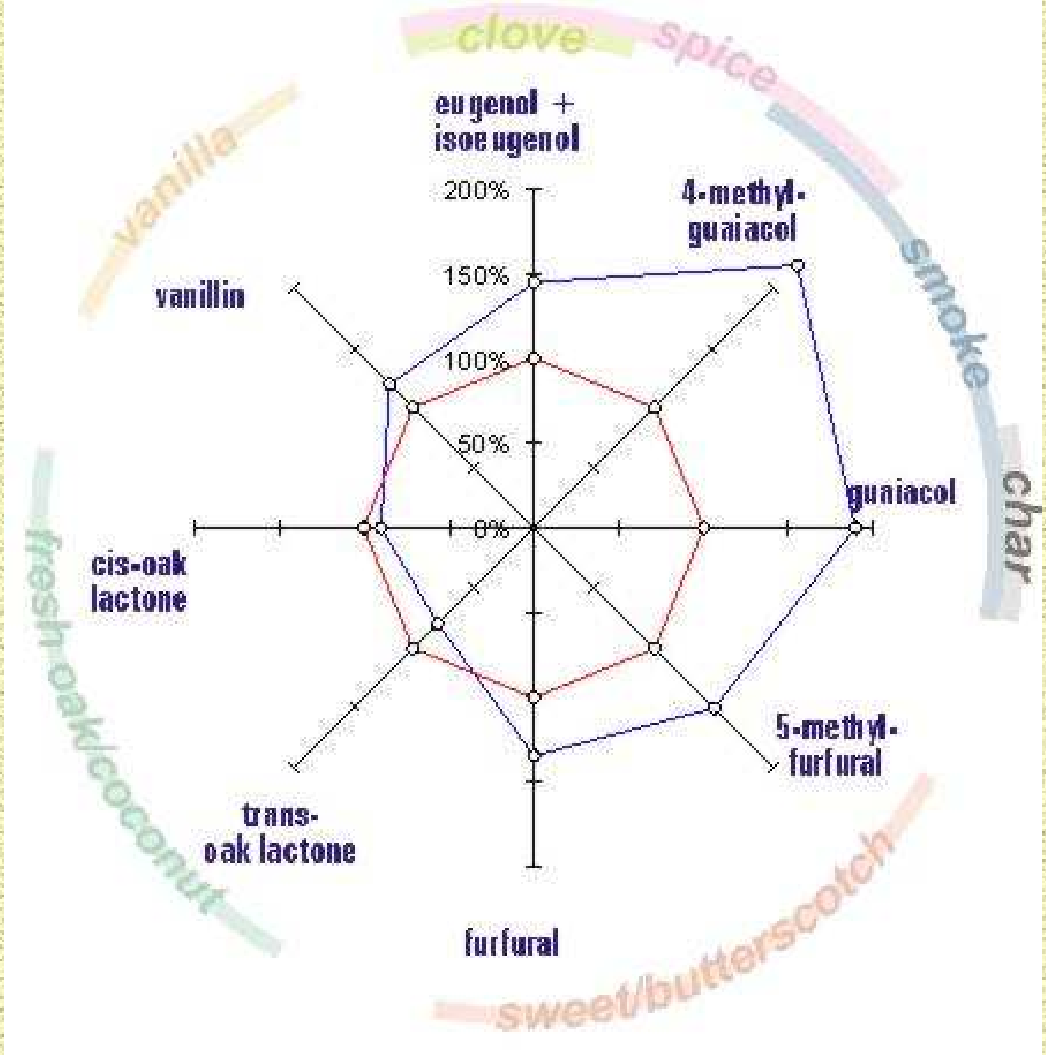
Consumer Utility and Preference



Consumer Utility and Preference



Consumer Utility and Preference

Complications

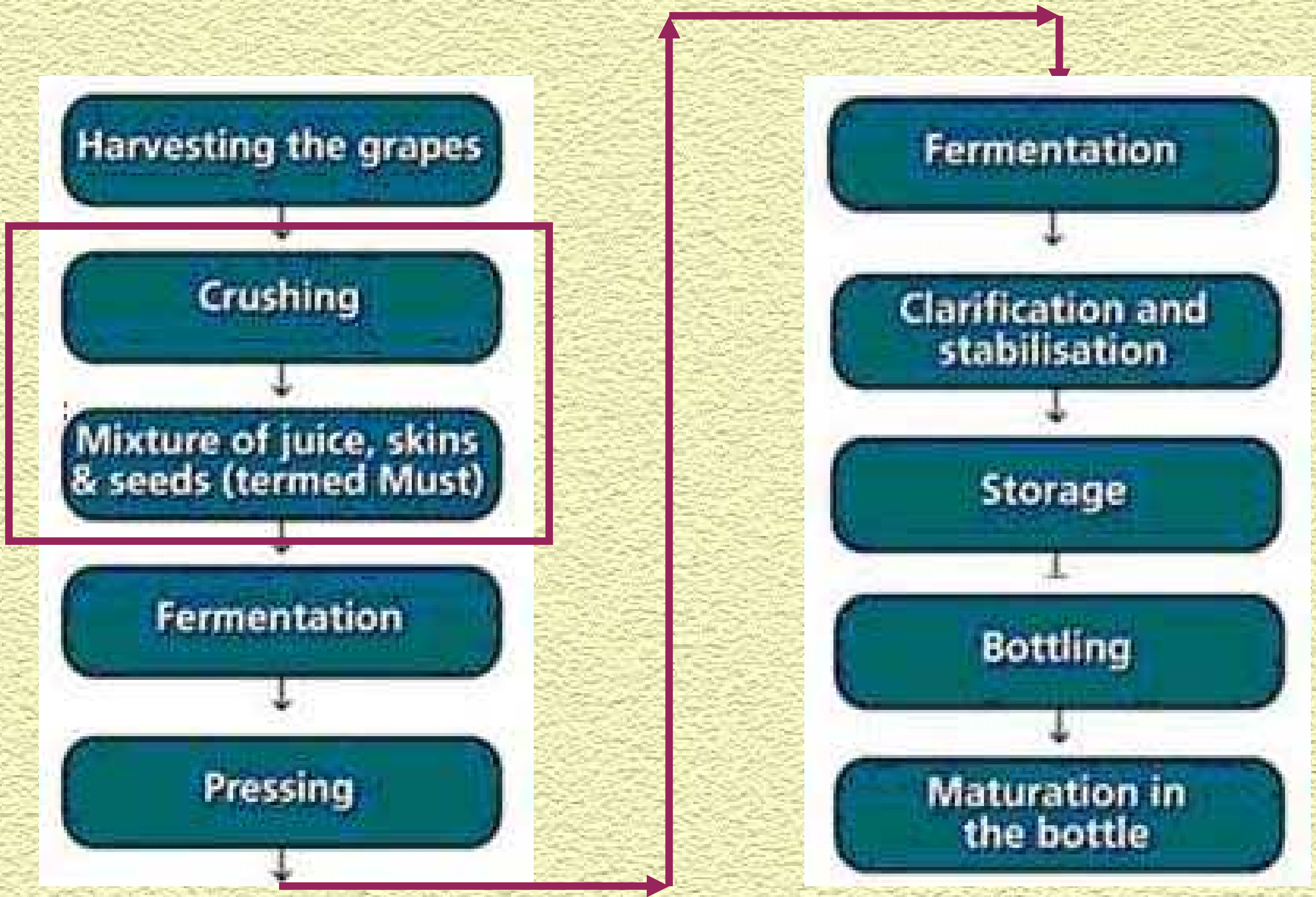
- Consequences of Manipulations
- More data is necessary
  - Diffusivity
  - Profile
  - Correlations of relationships

Consumer Utility and Preference

Perfect Bottle of Wine	
Characteristic	x_i
Clarity (NTU)	0
Color	
Hue (D_{420}/D_{520})	1
Brightness (%Brightness)	1
Bouquet (#Aromatic Compounds)	60.00
Acidity (pH)	3.2
Sweetness (wt% Residual Sugar)	0.2
Bitterness (g/L Tannins)	0
Body/Texture (%Alcohol)	0.12

Application of Model

Application of Model



Application of Model

Process - Crushing / Destemming & Cold Soaking		
Physical Properties of Must	Initial	Final
Clarity (NTU)	600	600
Color (absorbance fraction)	0	0.3
Color (brightness fraction)	0	0.5
Bouquet (# of aromatic compounds)	0	15
Acidity (pH)	3.6	3.2
Sweetness (wt% sugar)	22	22
Bitterness (g Tannin/L wine)	0	0.2
Body (wt% alcohol)	0	0
Calculated Happiness (H_1)	0.20	0.39

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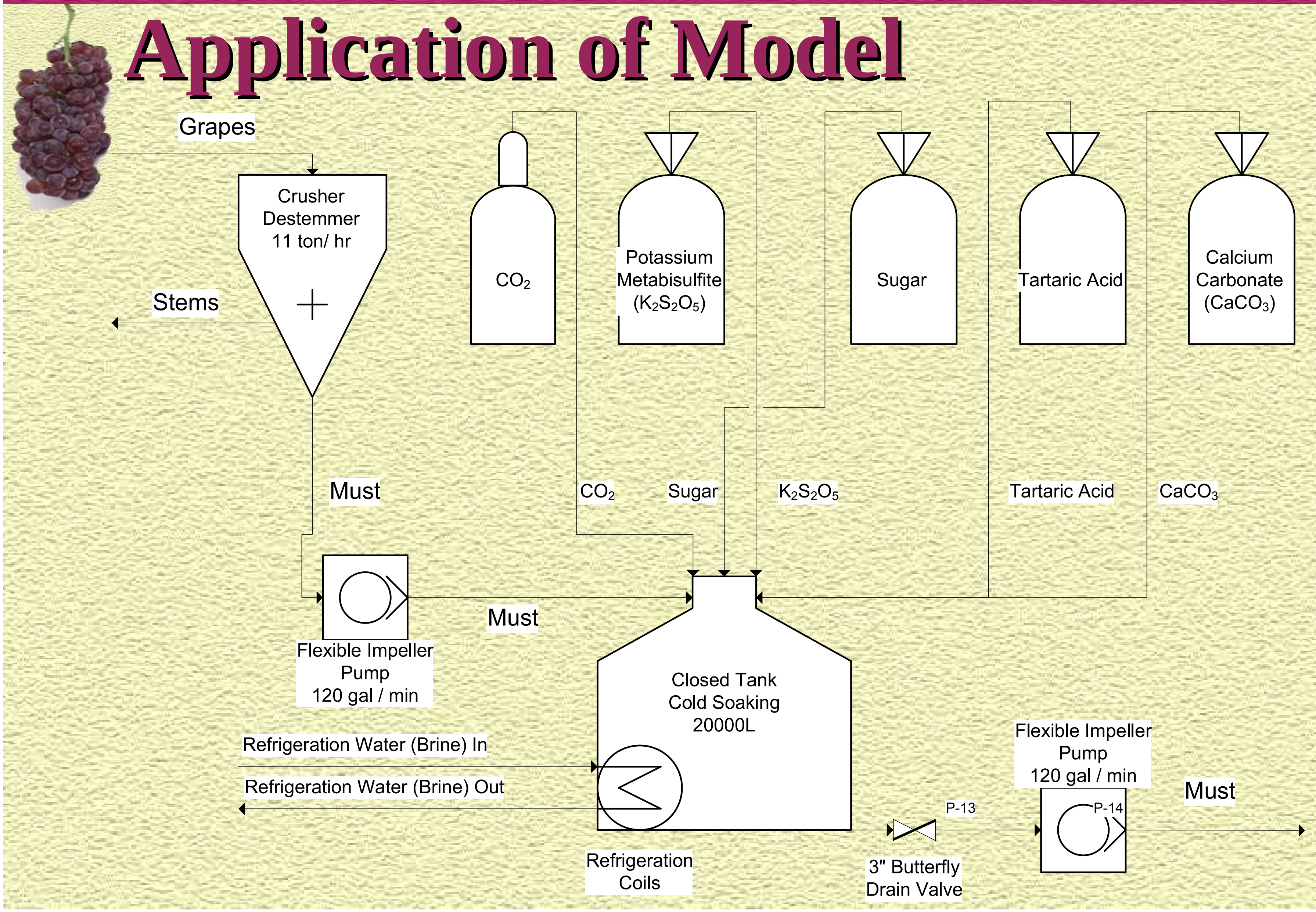
Application of Model



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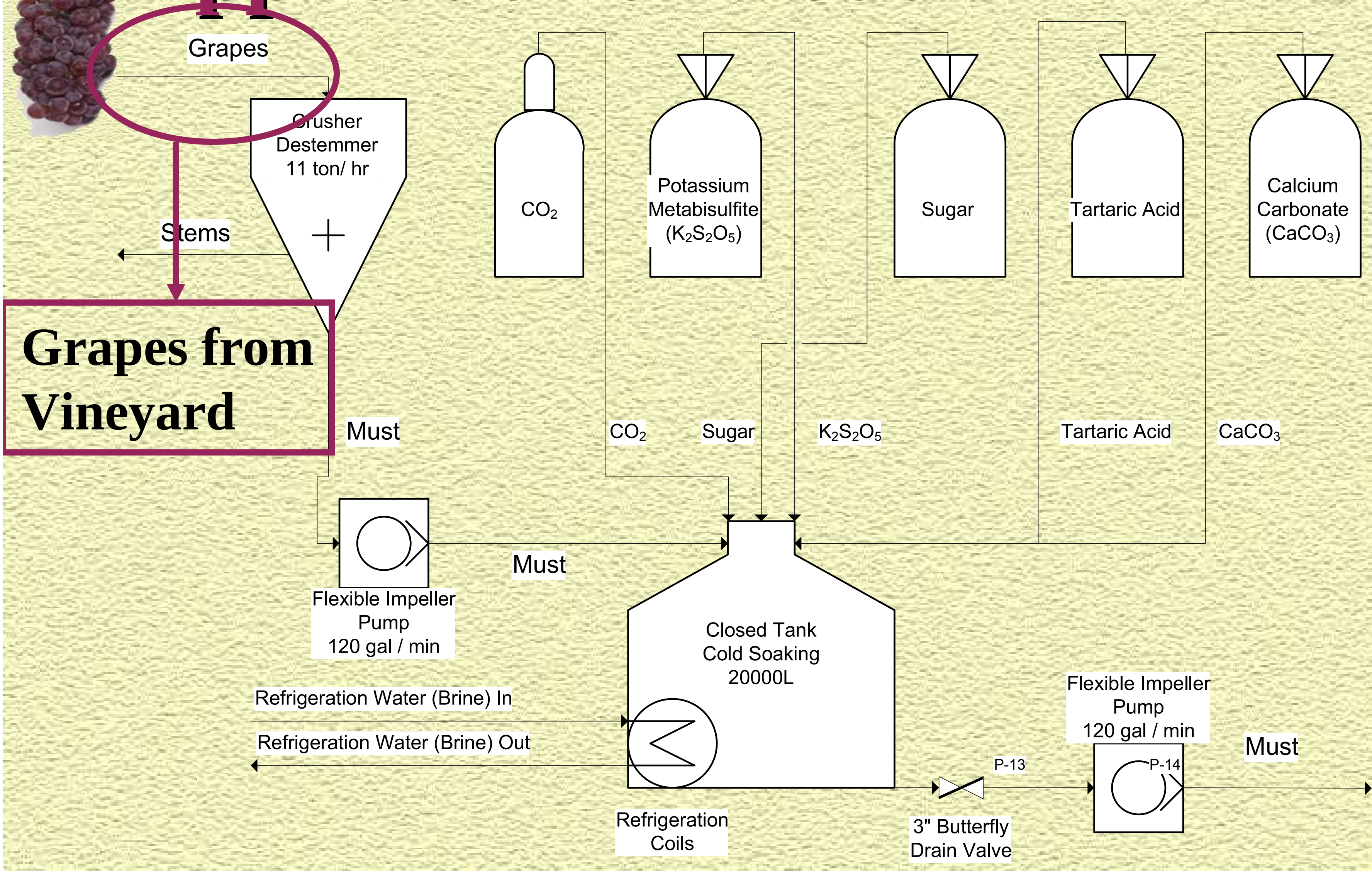

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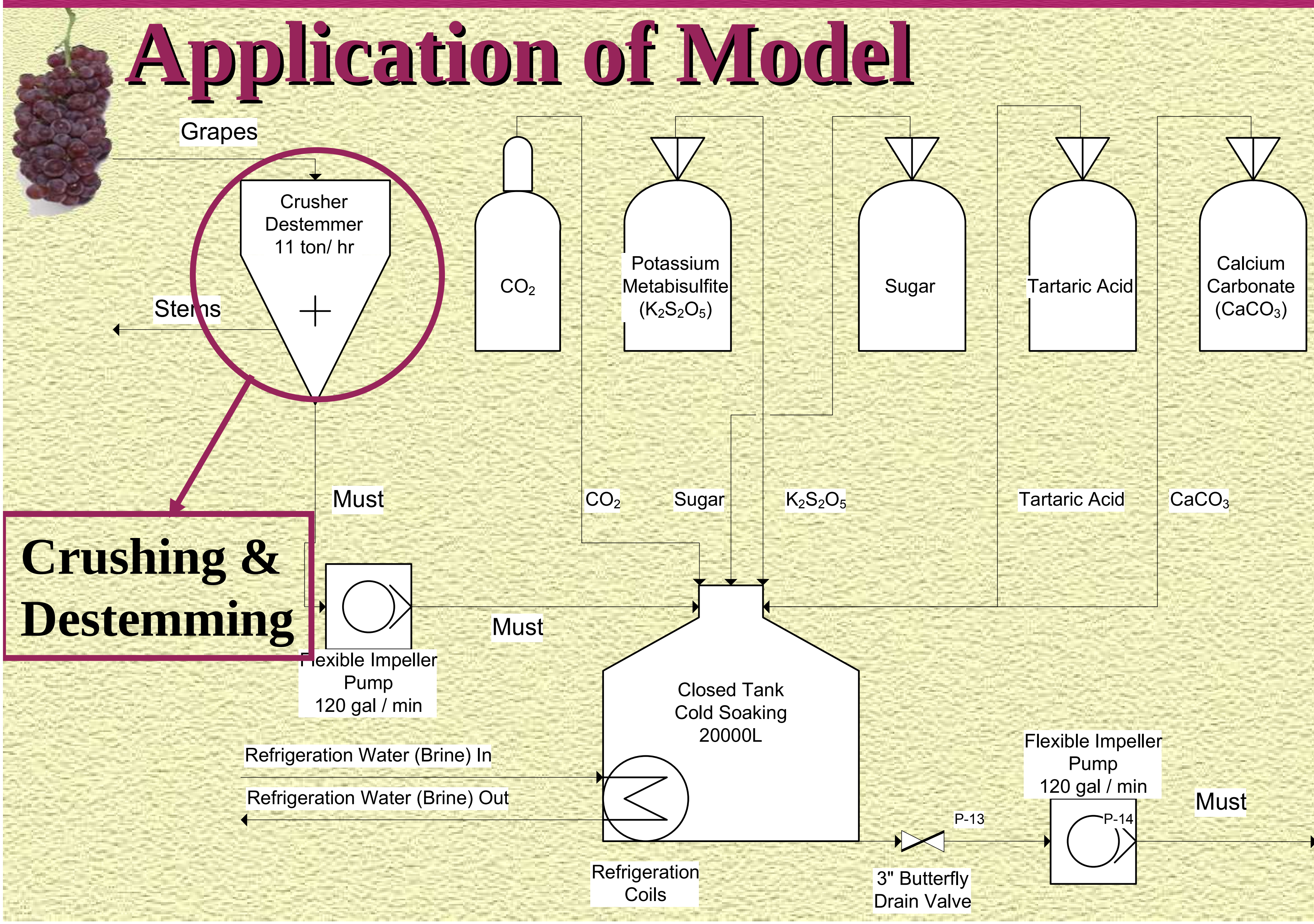

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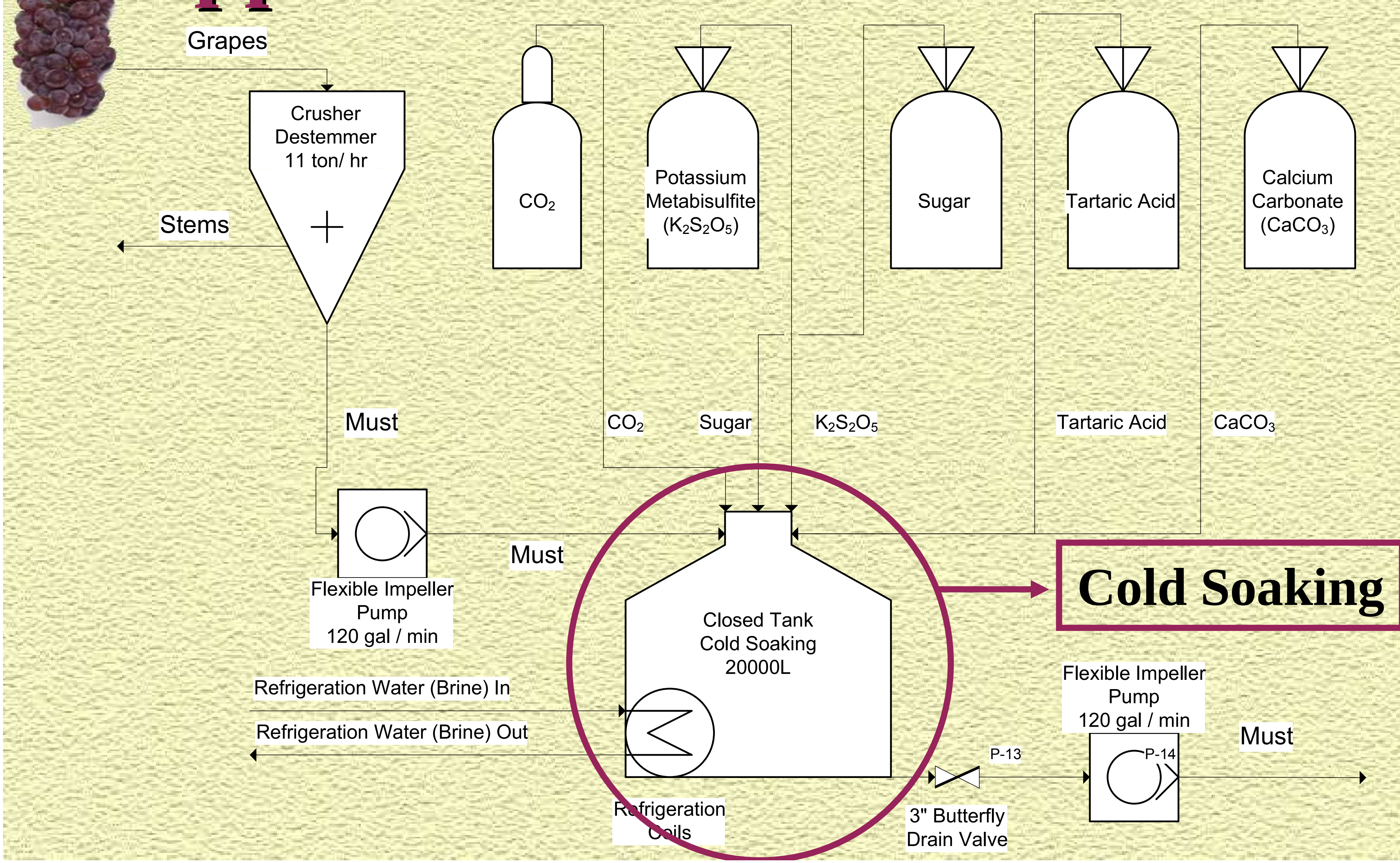

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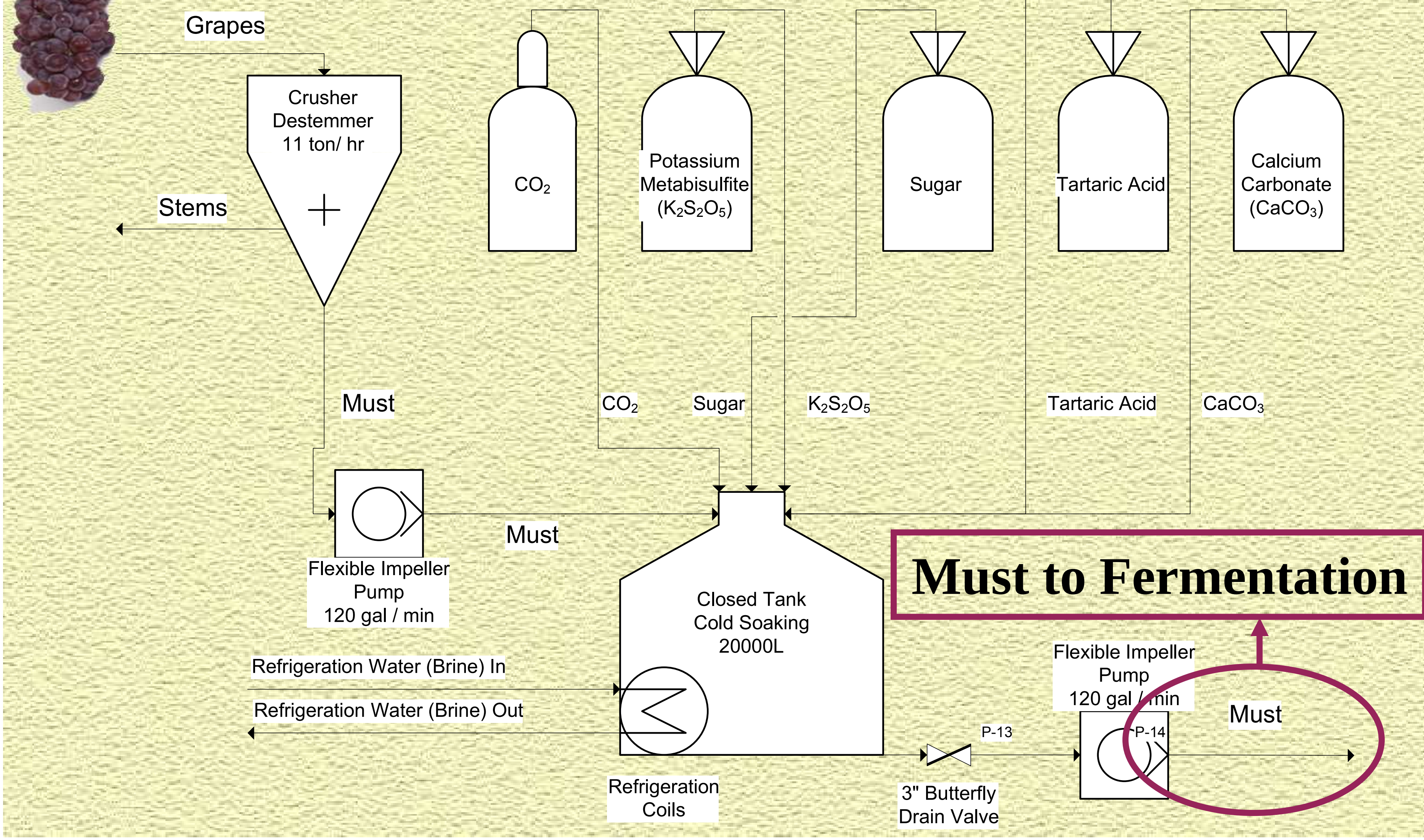

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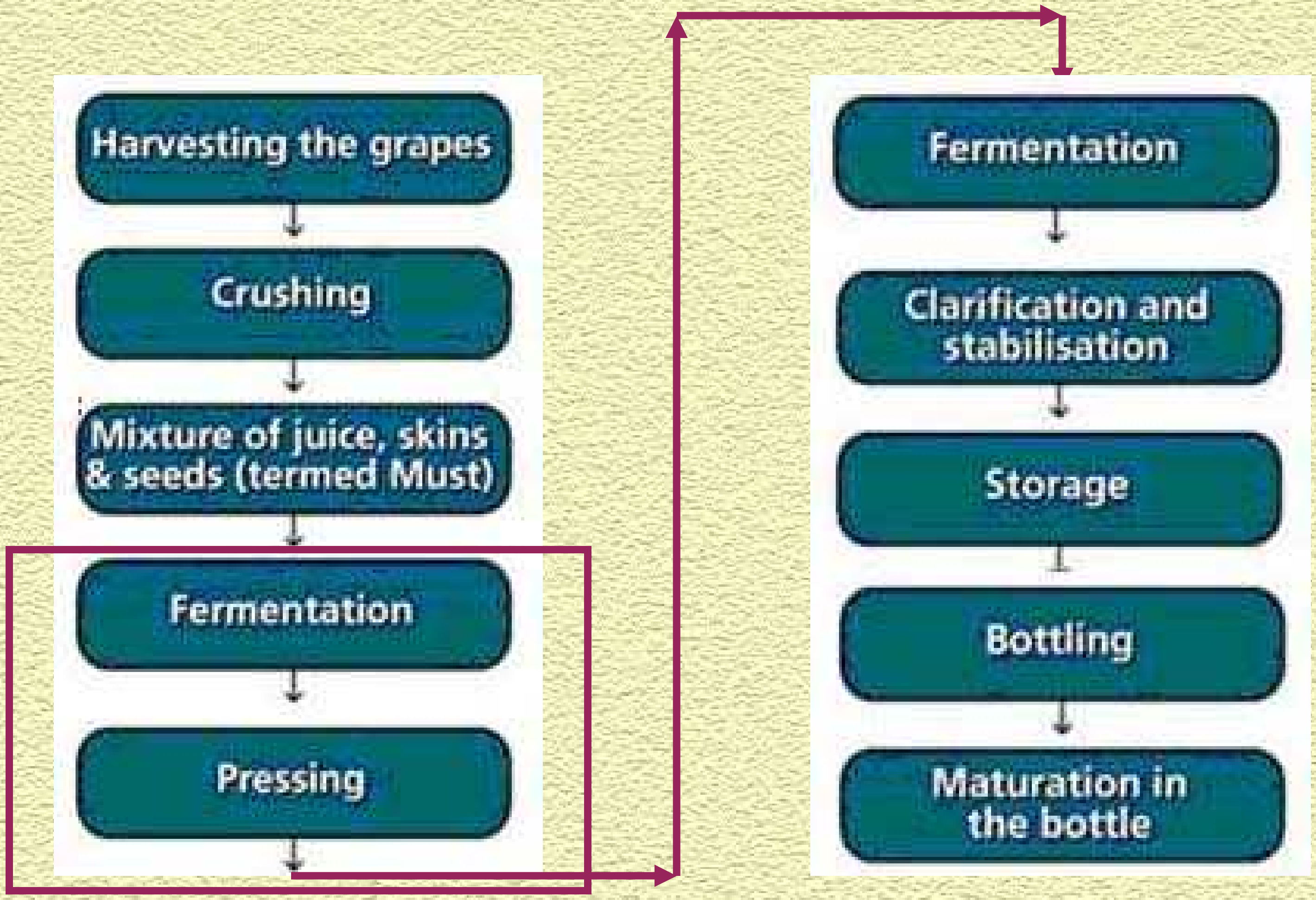

Application of Model

Process - Primary Fermentation & Pressing		
Physical Properties of Must	Initial	Final
Clarity (NTU)	600	600
Color (absorbance fraction)	0.3	1
Color (brightness fraction)	0.5	1
Bouquet (# of aromatic compounds)	15	18
Acidity (pH)	3.2	3.2
Sweetness (wt% sugar)	22	10
Bitterness (g Tannin/L wine)	0.2	2.6
Body (wt% alcohol)	0	0.07
Calculated Happiness (H_1)	0.39	0.40

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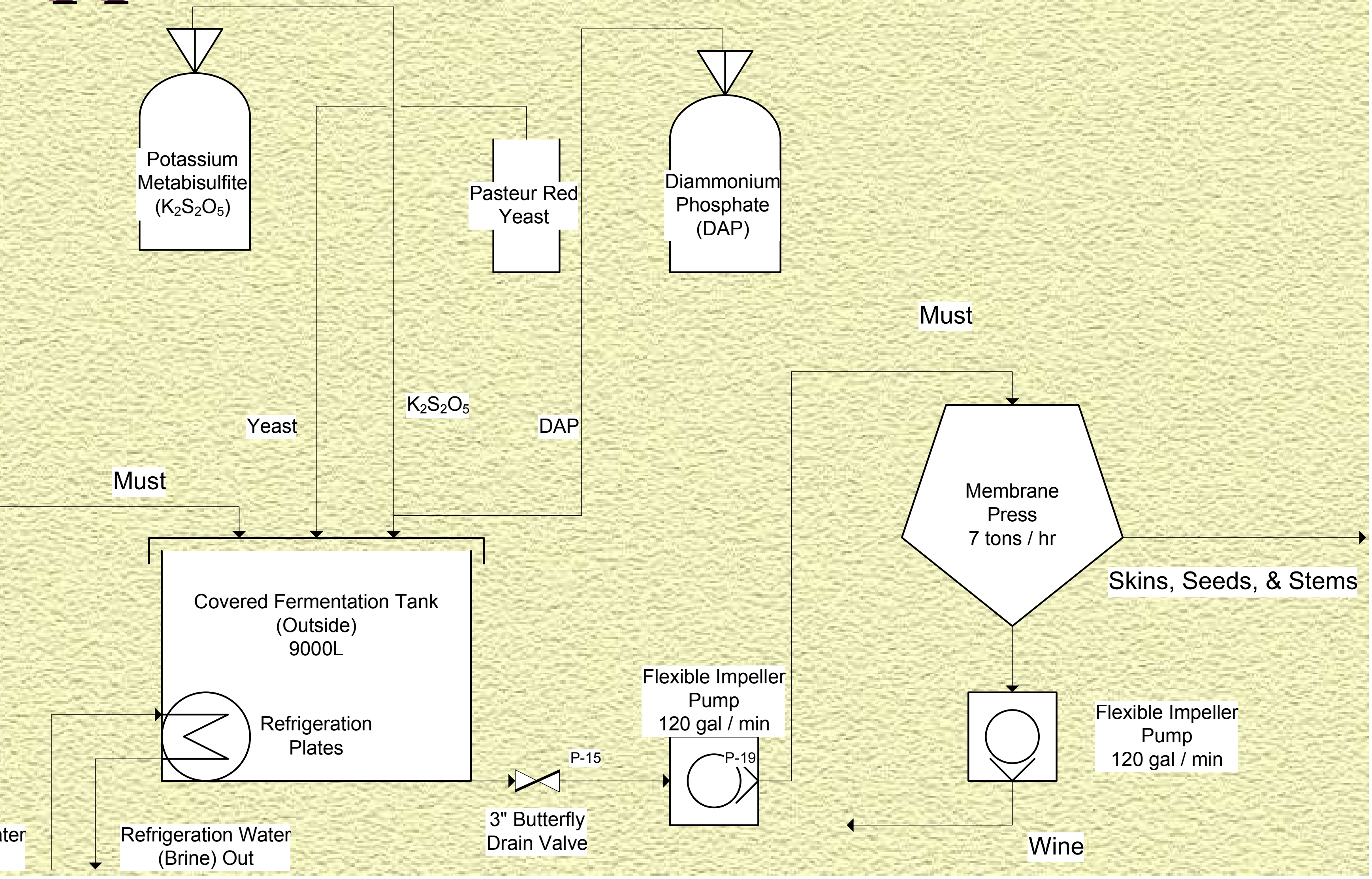
Application of Model



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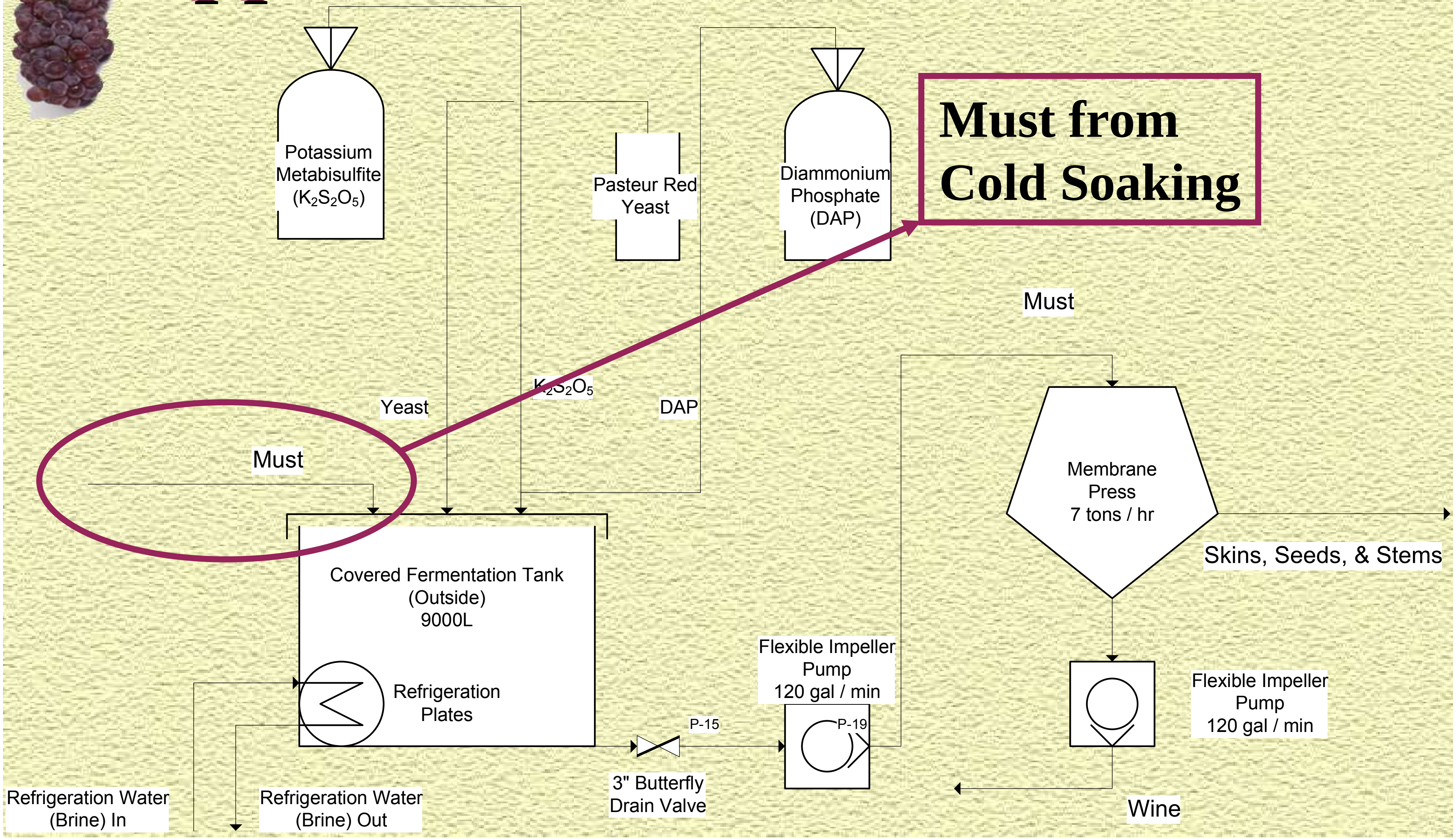

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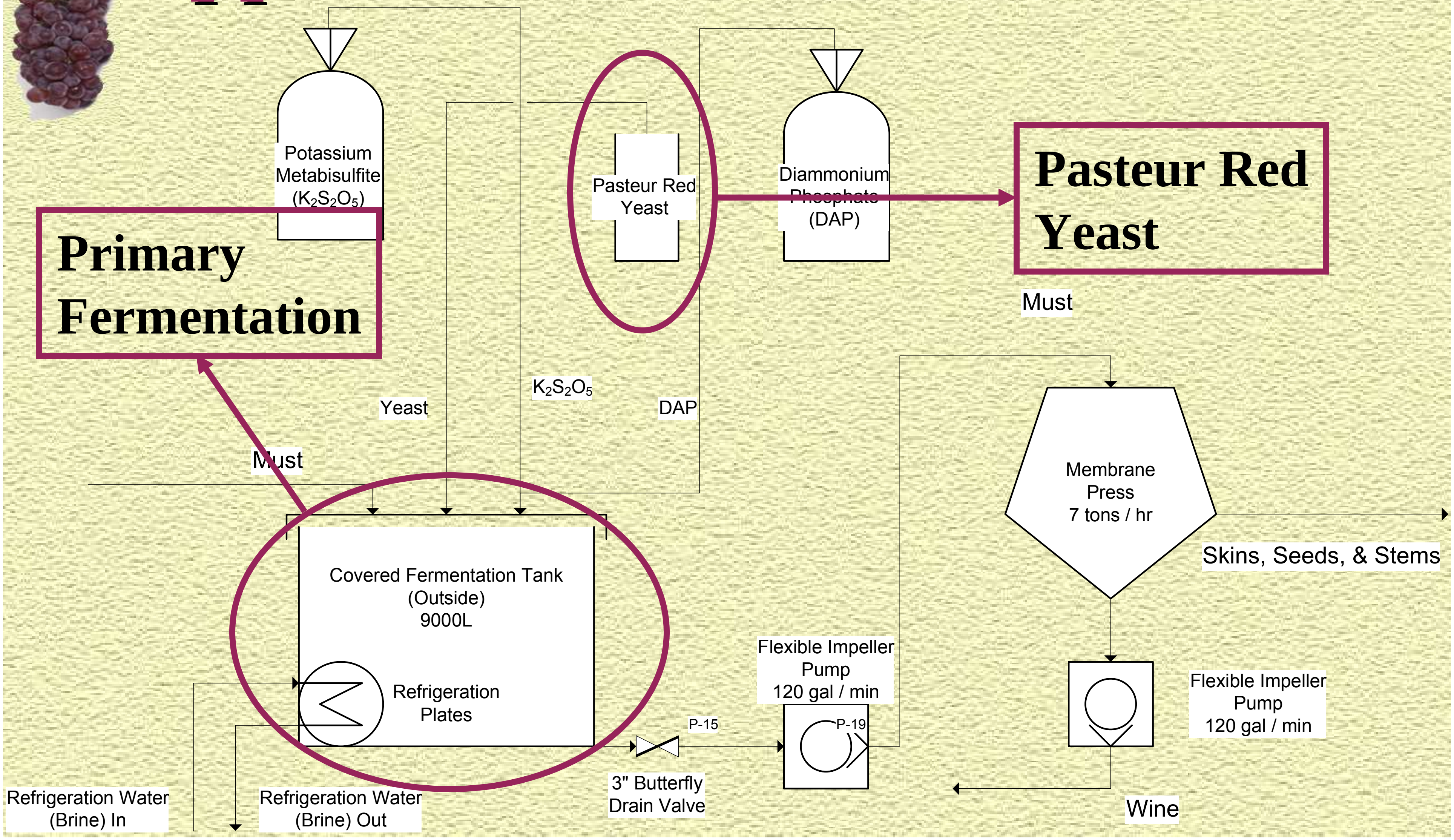

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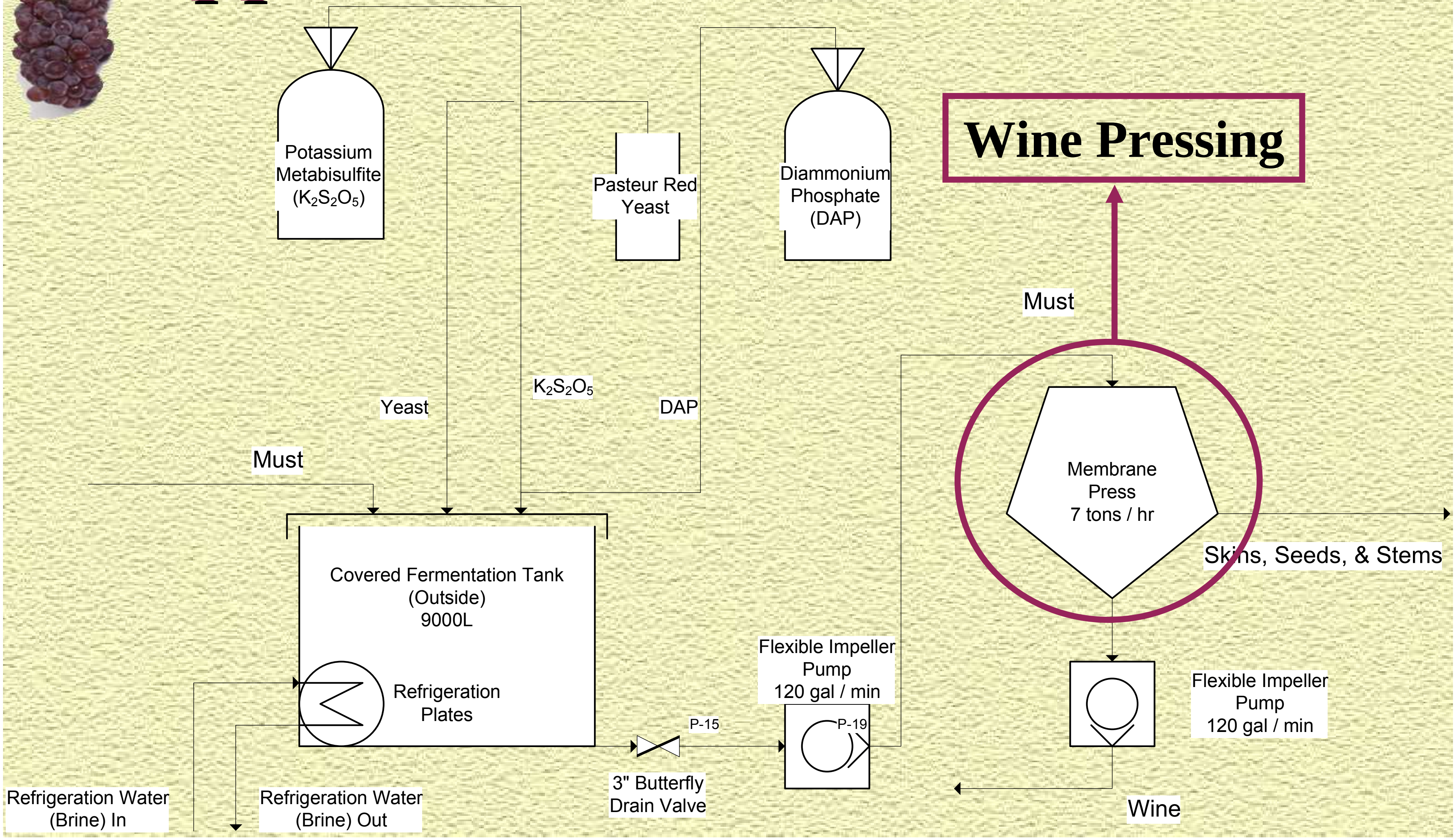
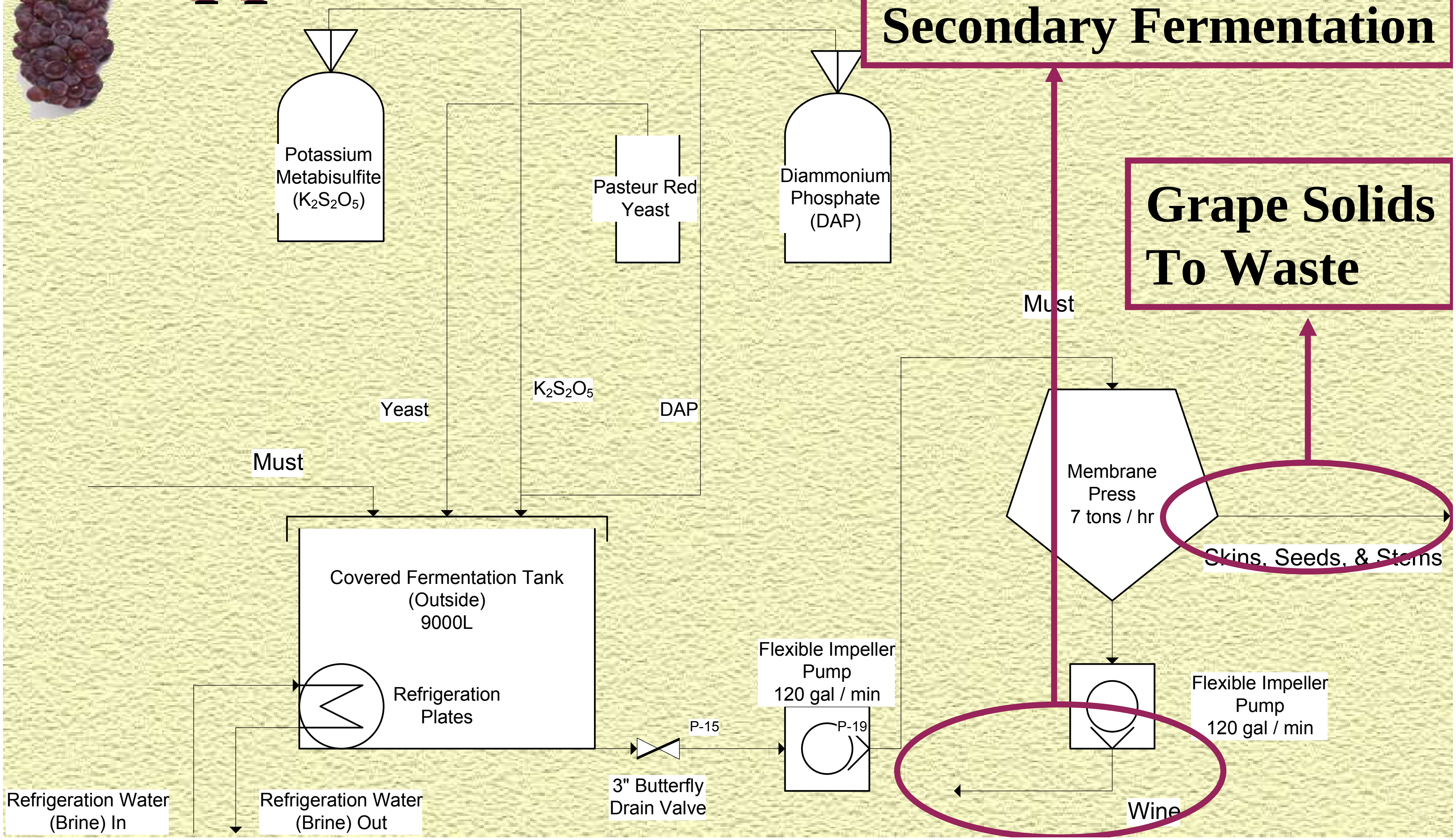


Application of Model

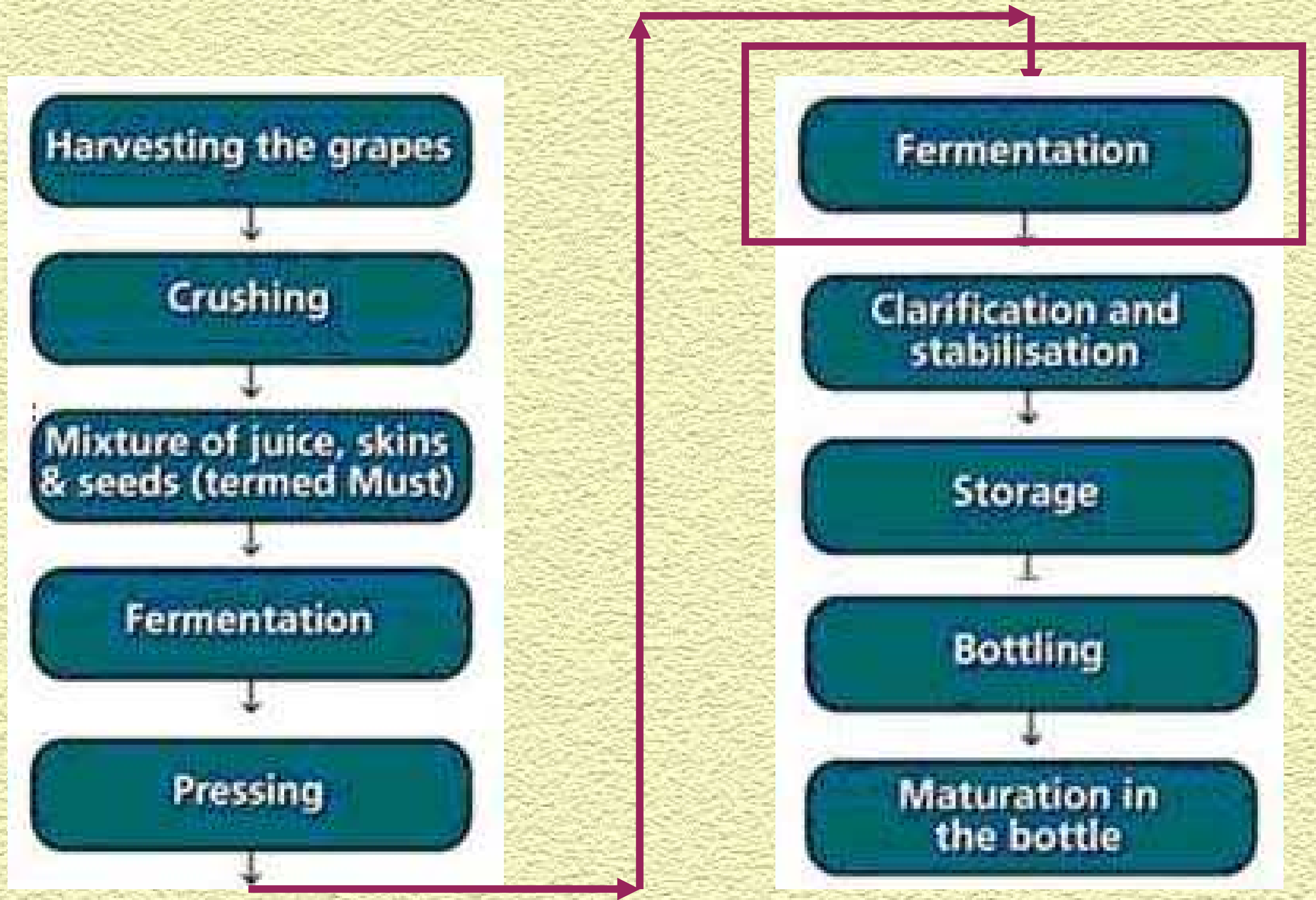
Pressed Wine to Secondary Fermentation

Grape Solids To Waste



Engineering Wine

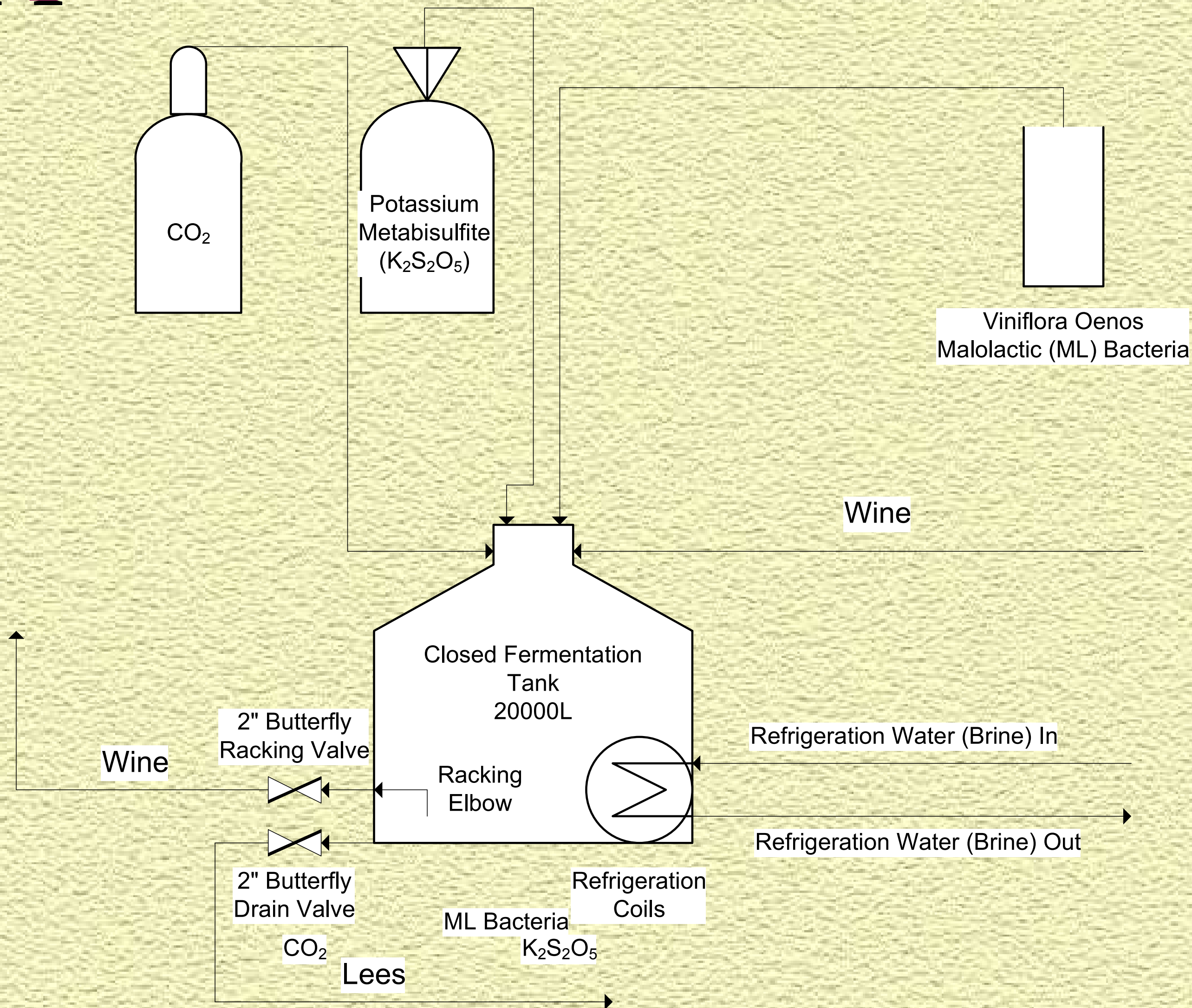
Application of Model



Application of Model

Process - Secondary Fermentation (Malolactic)		
Physical Properties of Must	Initial	Final
Clarity (NTU)	600	600
Color (absorbance fraction)	1	1
Color (brightness fraction)	1	1
Bouquet (# of aromatic compounds)	18	18
Acidity (pH)	3.2	3.8
Sweetness (wt% sugar)	10	0.2
Bitterness (g Tannin/L wine)	2.6	2.6
Body (wt% alcohol)	0.07	0.12
Calculated Happiness (H_1)	0.40	0.43

Application of Model



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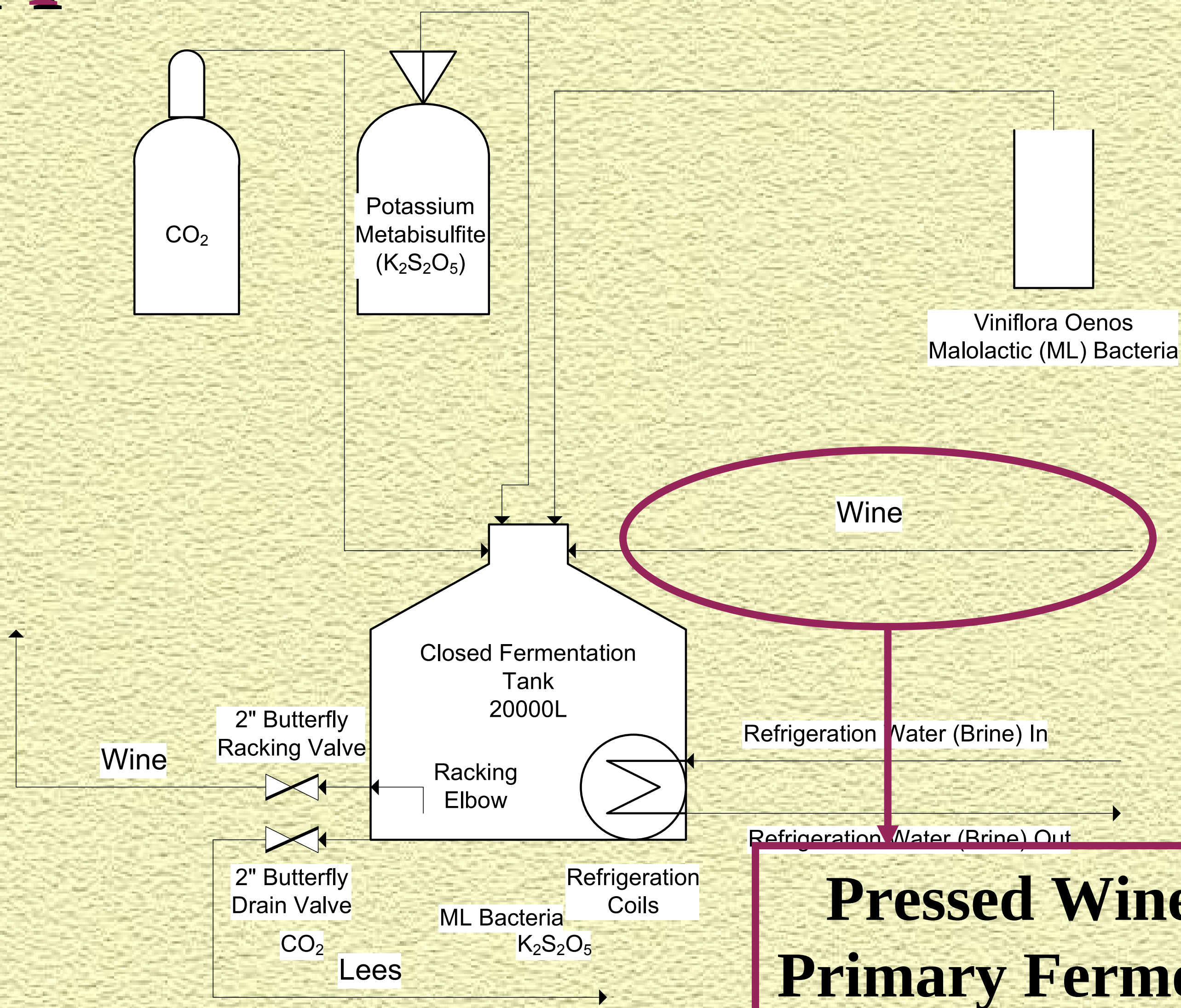
Application of Model



Pressed Wine from Primary Fermentation

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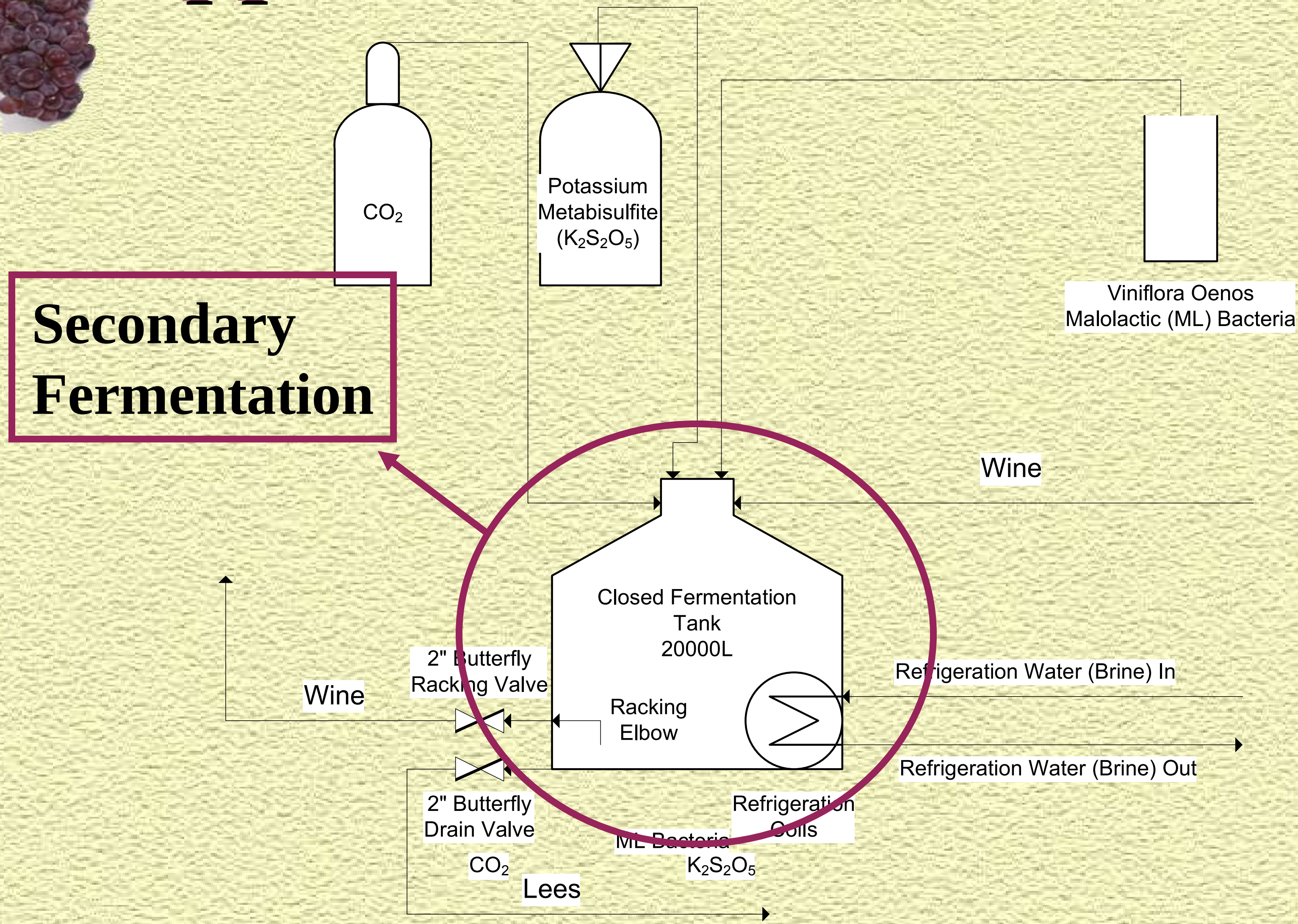
Application of Model



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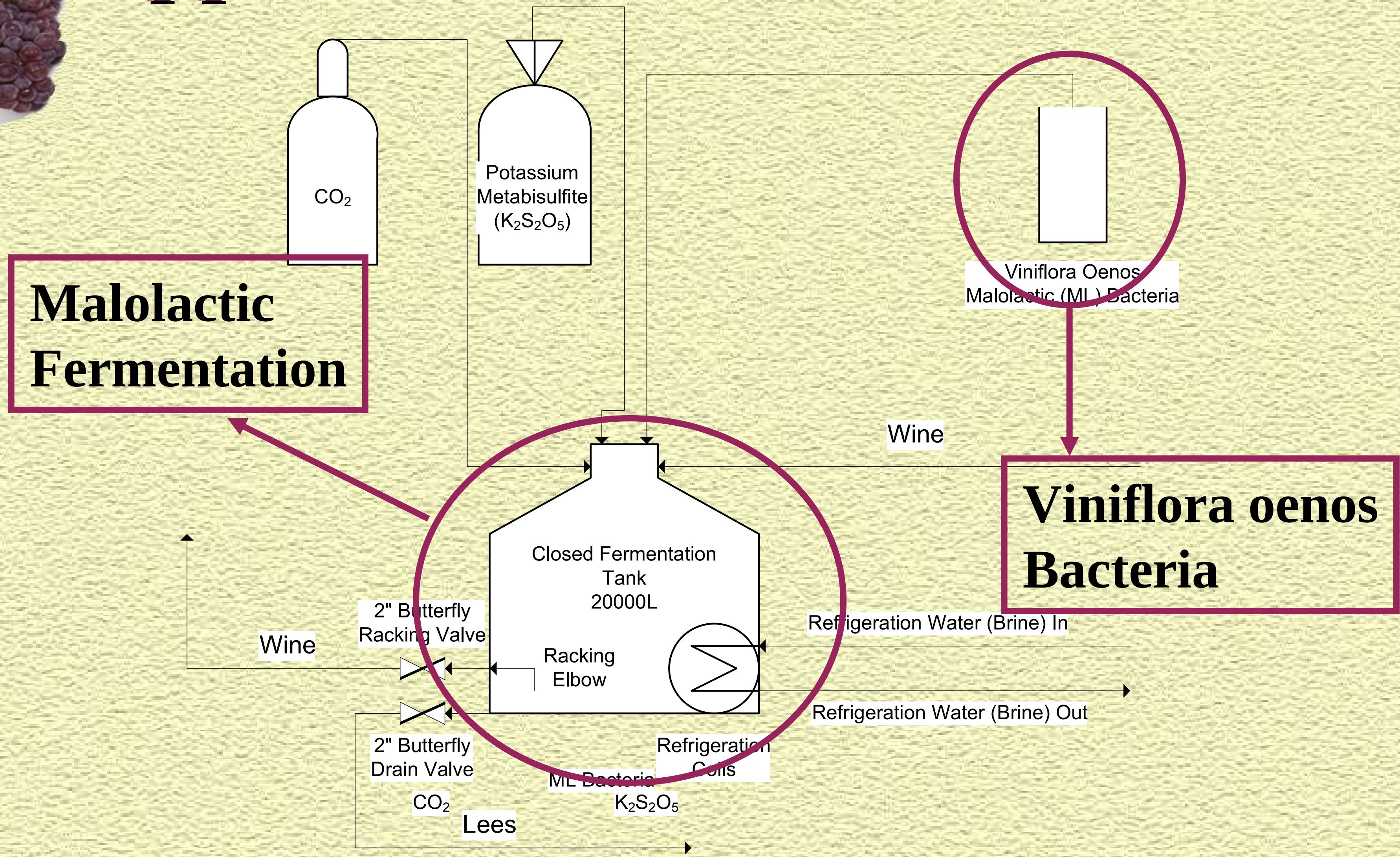
Application of Model



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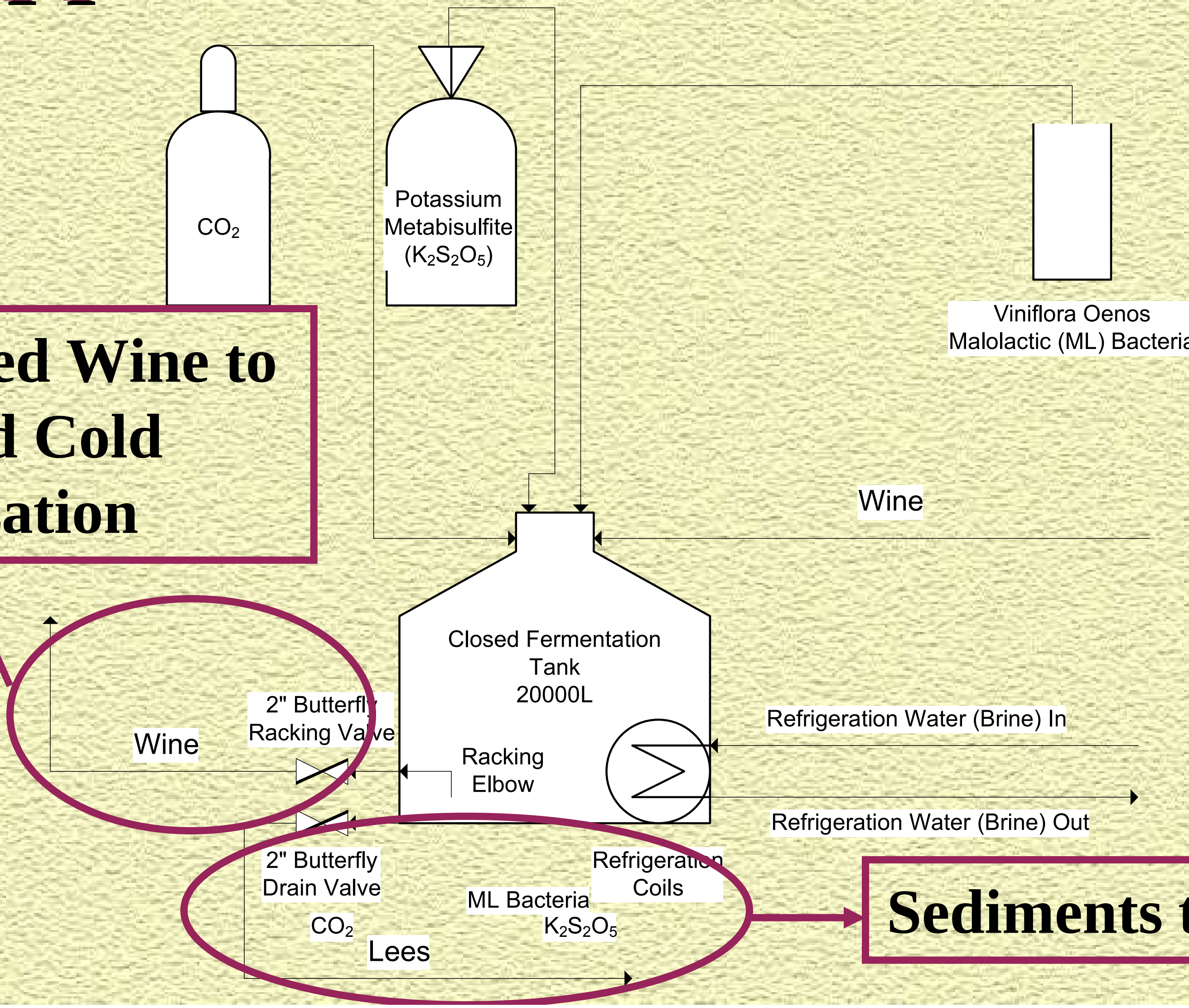
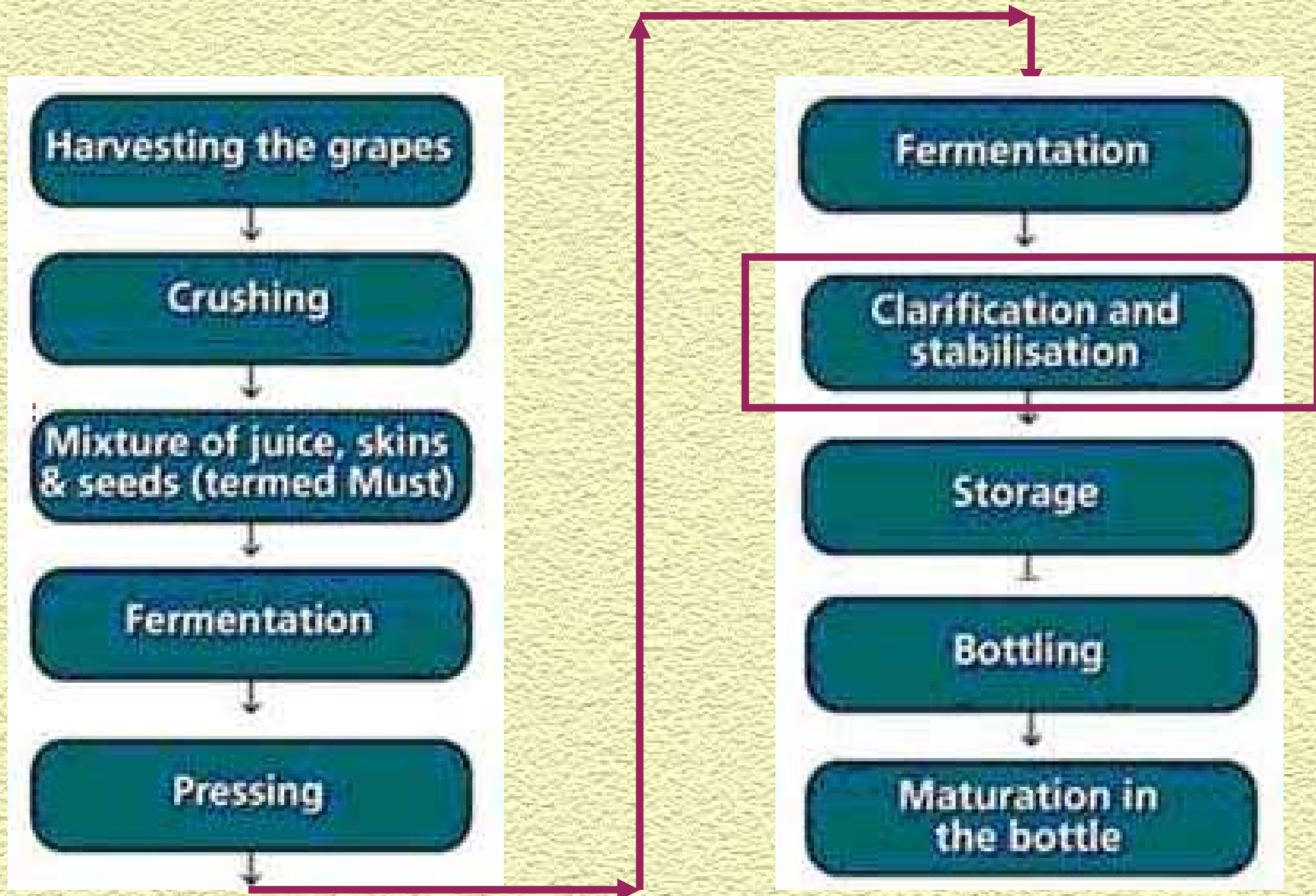


Decanted Wine to Hot and Cold Stabilization

Sediments to Waste

Application of Model



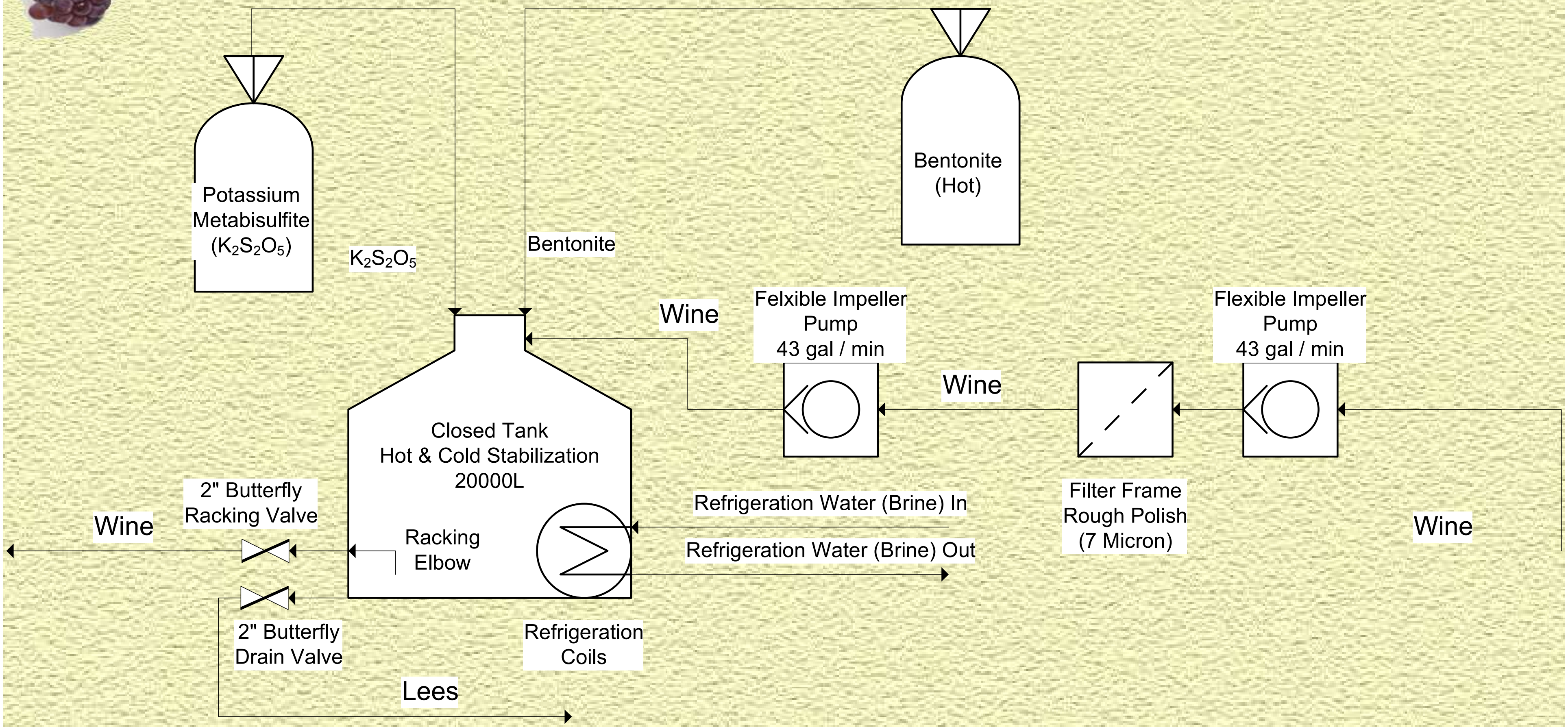
Engineering Wine

Application of Model

Process - Rough Filtering & Hot / Cold Stabilization		
Physical Properties of Must	Initial	Final
Clarity (NTU)	600	50
Color (absorbance fraction)	1	0.9
Color (brightness fraction)	1	0.97
Bouquet (# of aromatic compounds)	18	18
Acidity (pH)	3.8	3.2
Sweetness (wt% sugar)	0.2	0.2
Bitterness (g Tannin/L wine)	2.6	2.6
Body (wt% alcohol)	0.12	0.12
Calculated Happiness (H_1)	0.43	0.45

Engineering Wine

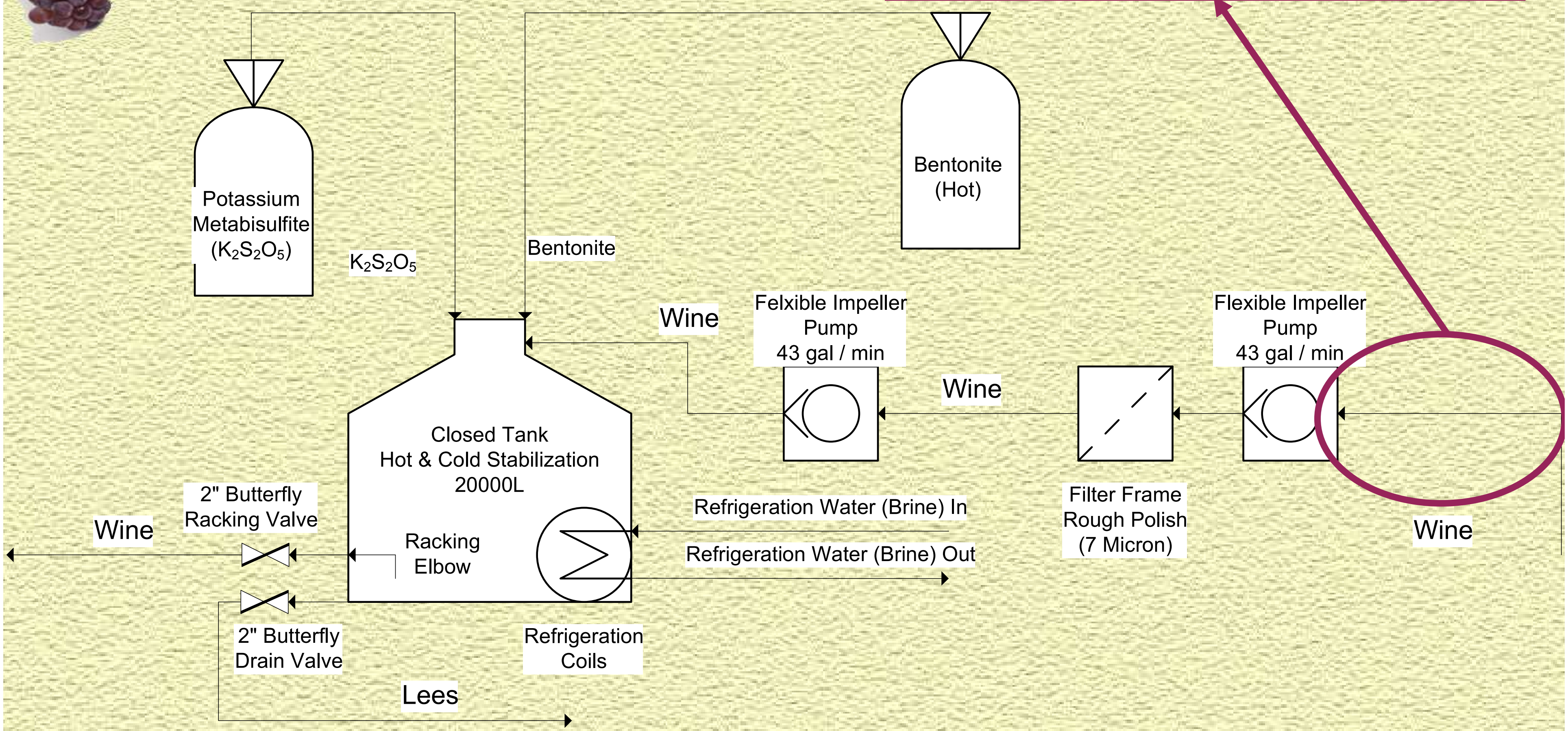
Application of Model



Engineering Wine

Application of Model

Decanted Wine from Secondary Fermentation



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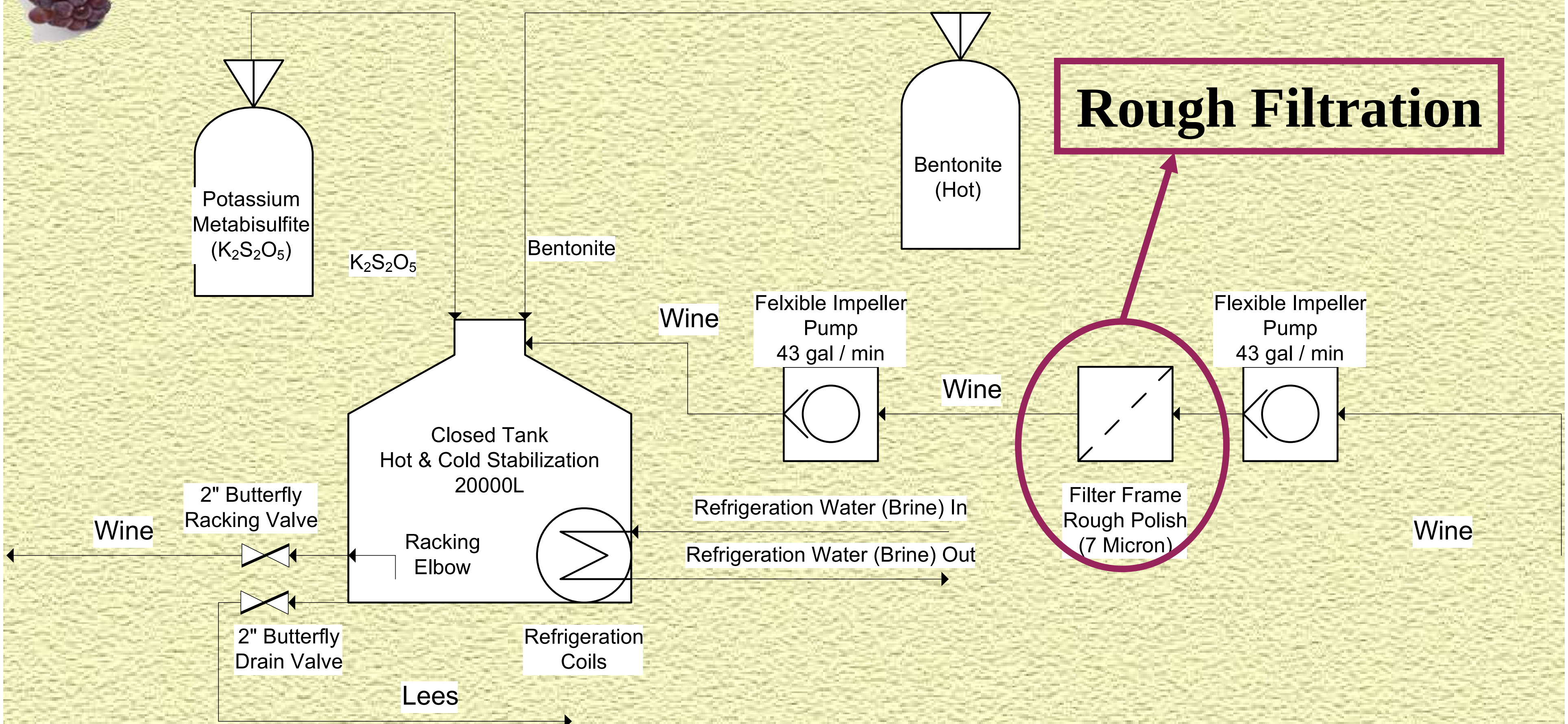
Application of Model



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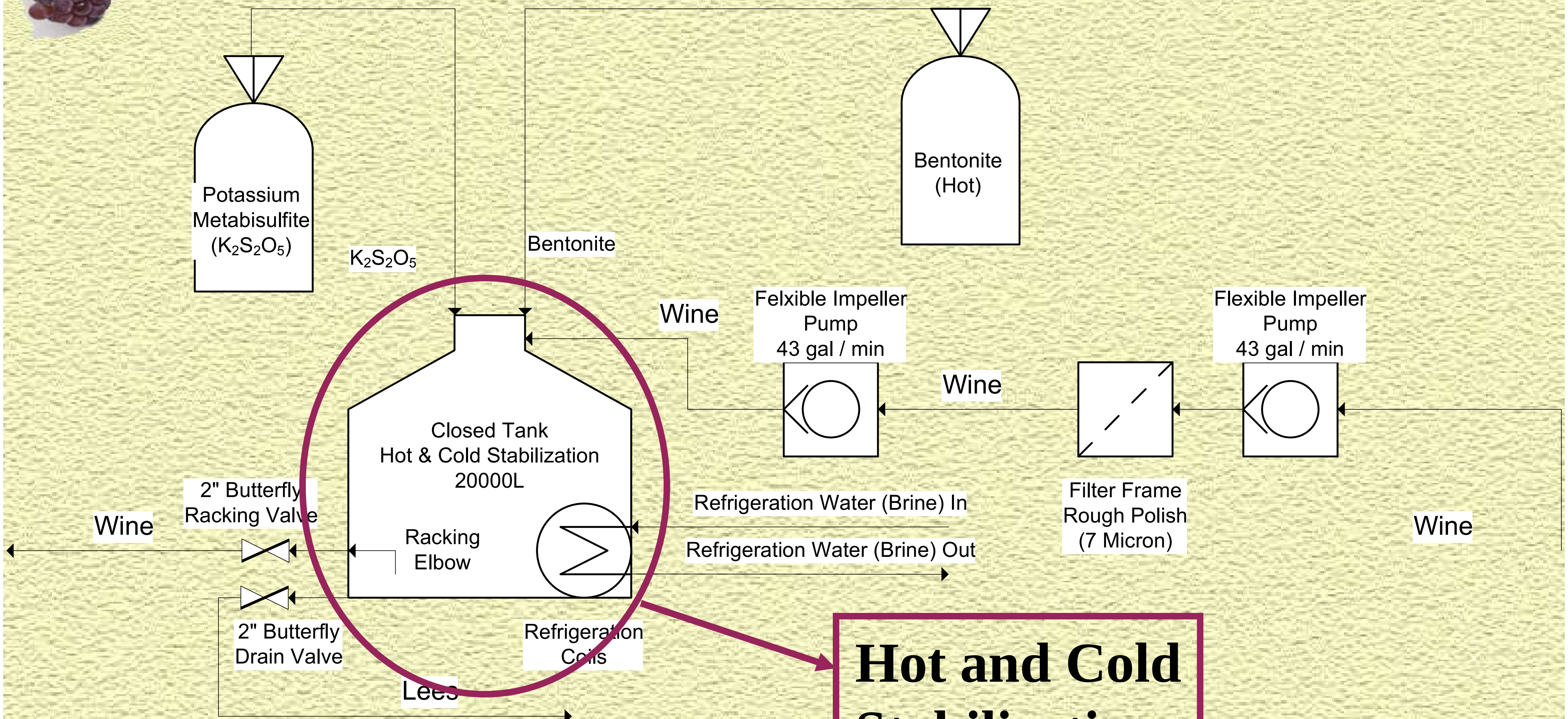
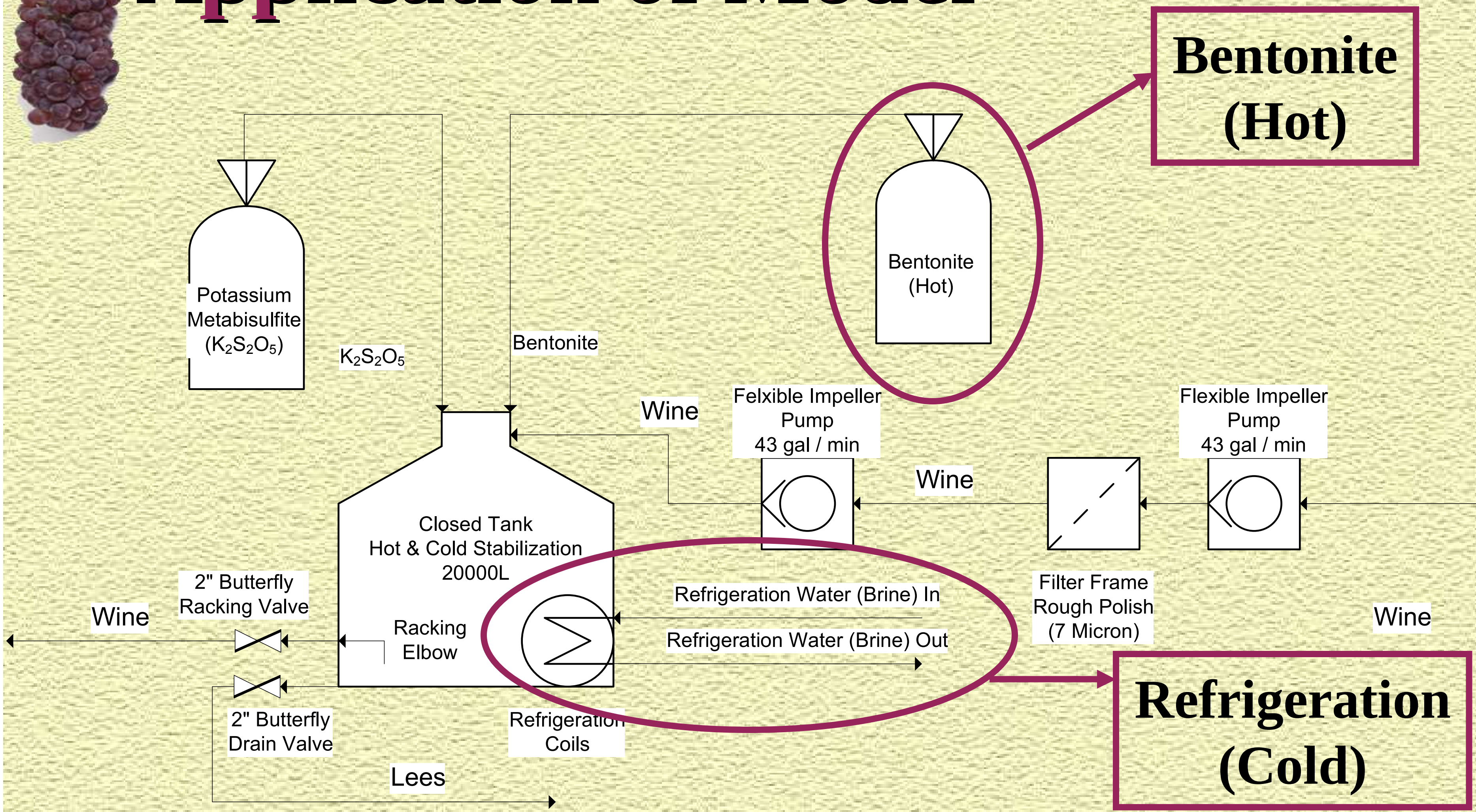
Application of Model



Hot and Cold Stabilization

Application of Model



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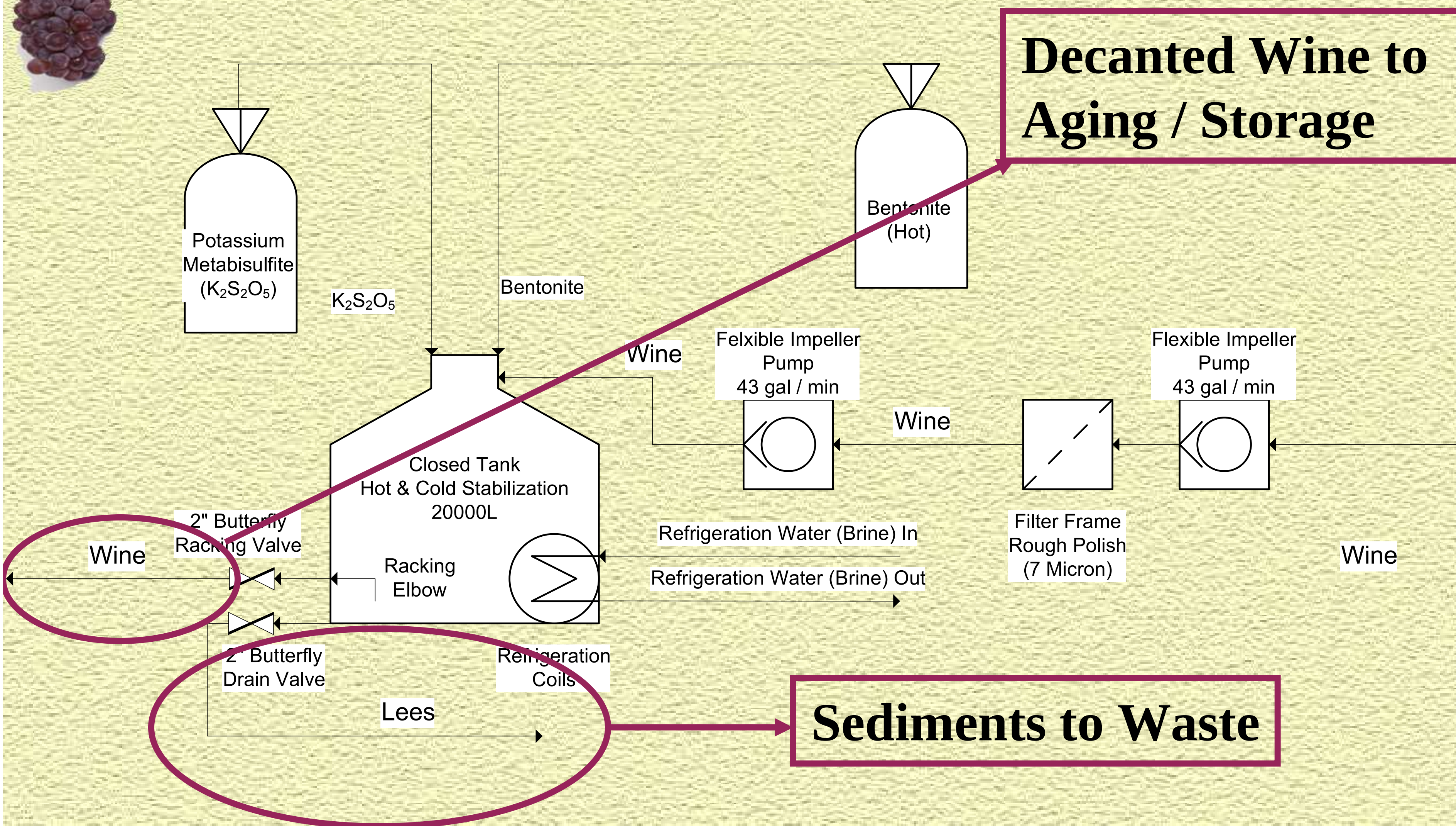

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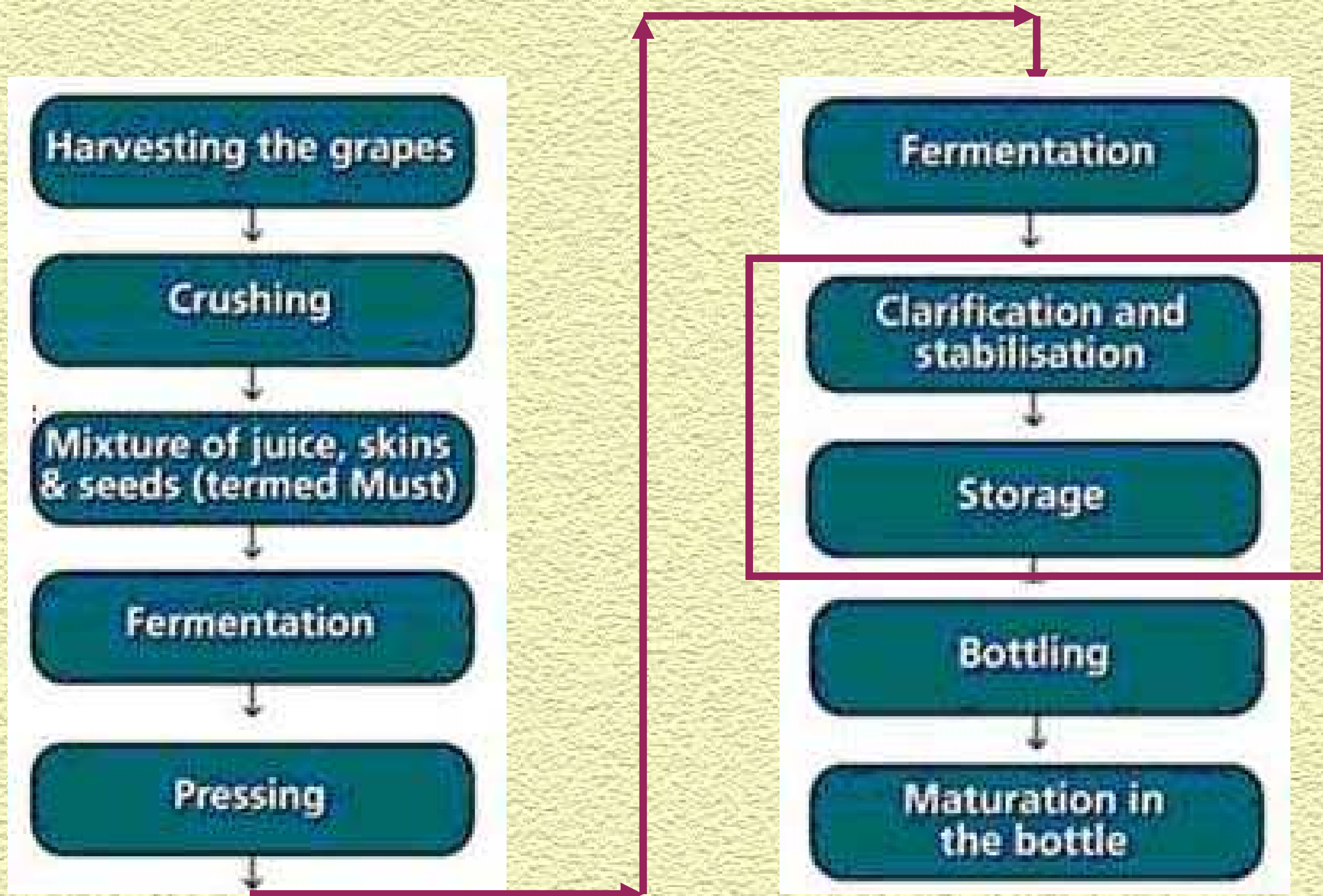
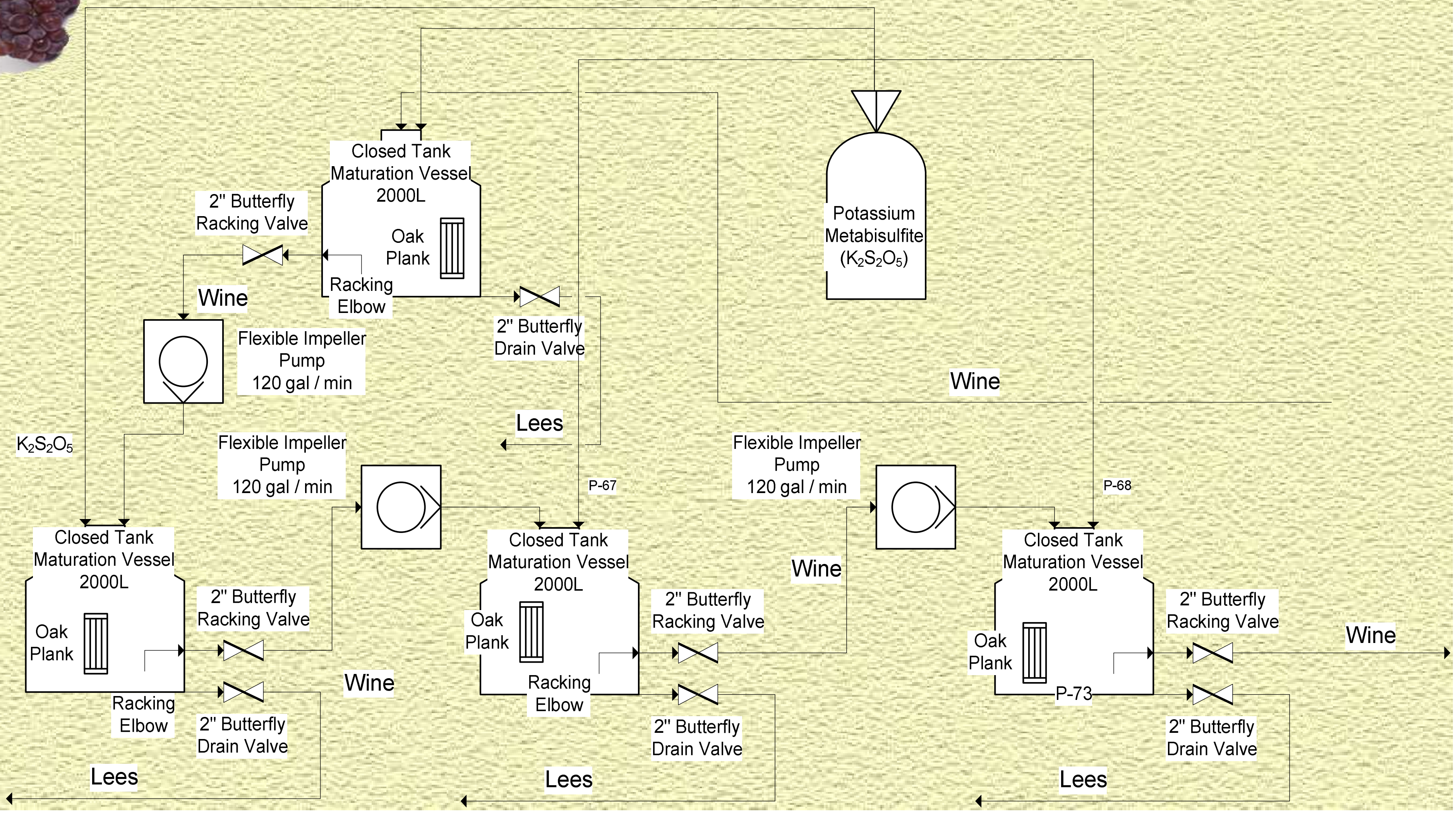


Application of Model

Process - Aging		
Physical Properties of Must	Initial	Final
Clarity (NTU)	50	30
Color (absorbance fraction)	0.9	0.7
Color (brightness fraction)	0.97	0.95
Bouquet (# of aromatic compounds)	18	30
Acidity (pH)	3.2	3.2
Sweetness (wt% sugar)	0.2	0.15
Bitterness (g Tannin/L wine)	2.6	0.2
Body (wt% alcohol)	0.12	0.12
Calculated Happiness (H_1)	0.45	0.63

Engineering Wine

Application of Model



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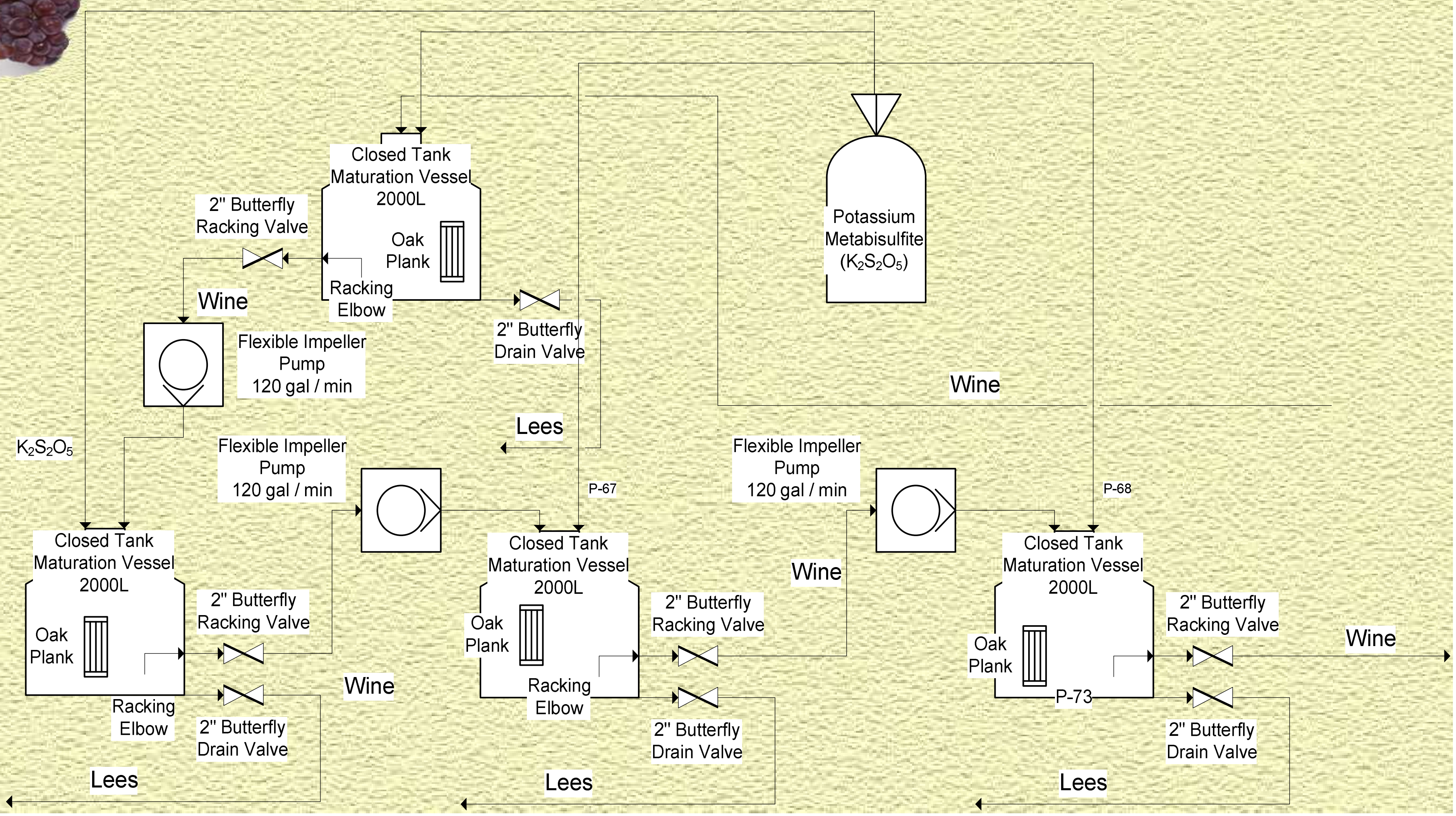
Application of Model



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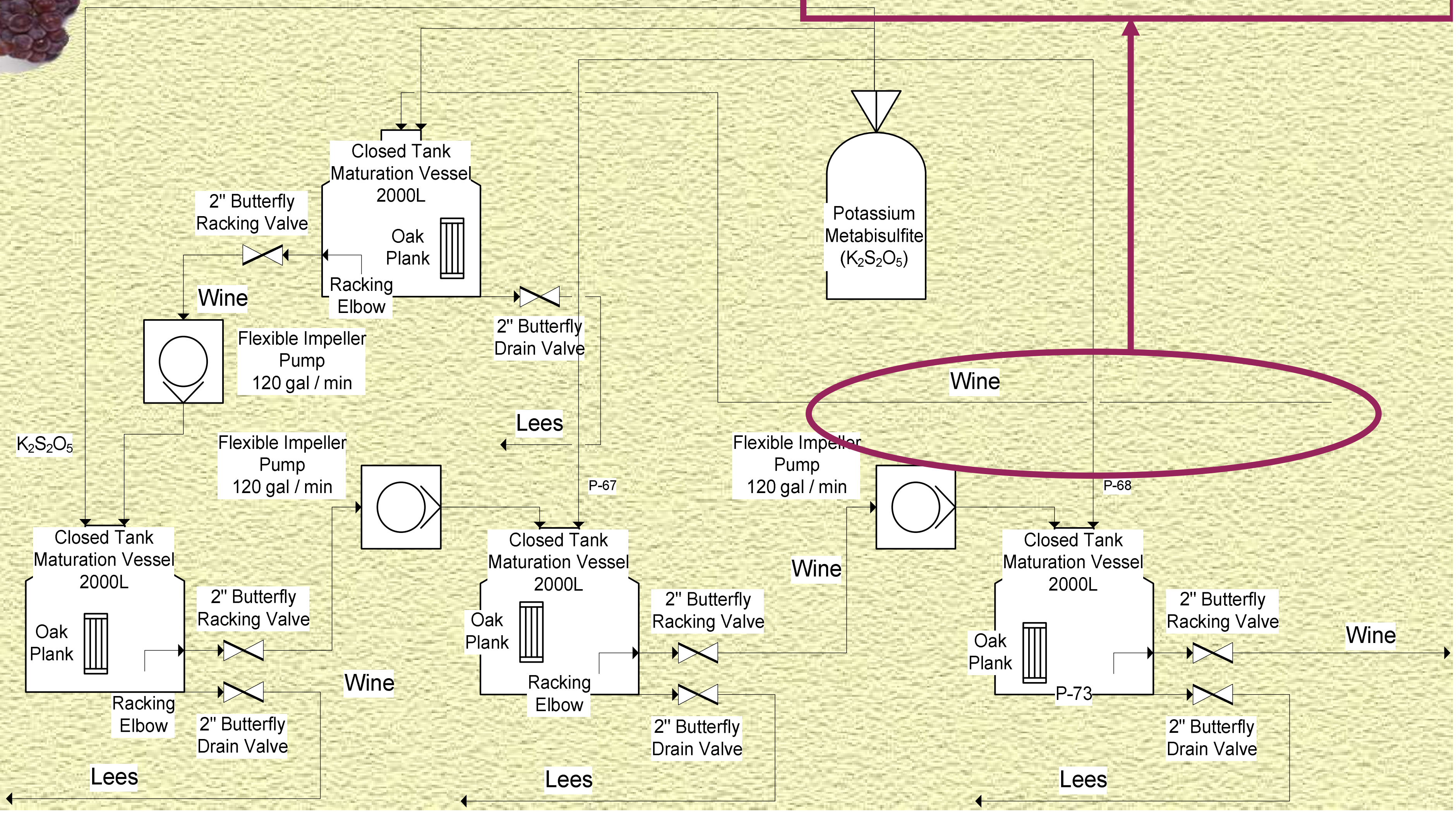
Application of Model

Decanted Wine from Hot and Cold Stabilization



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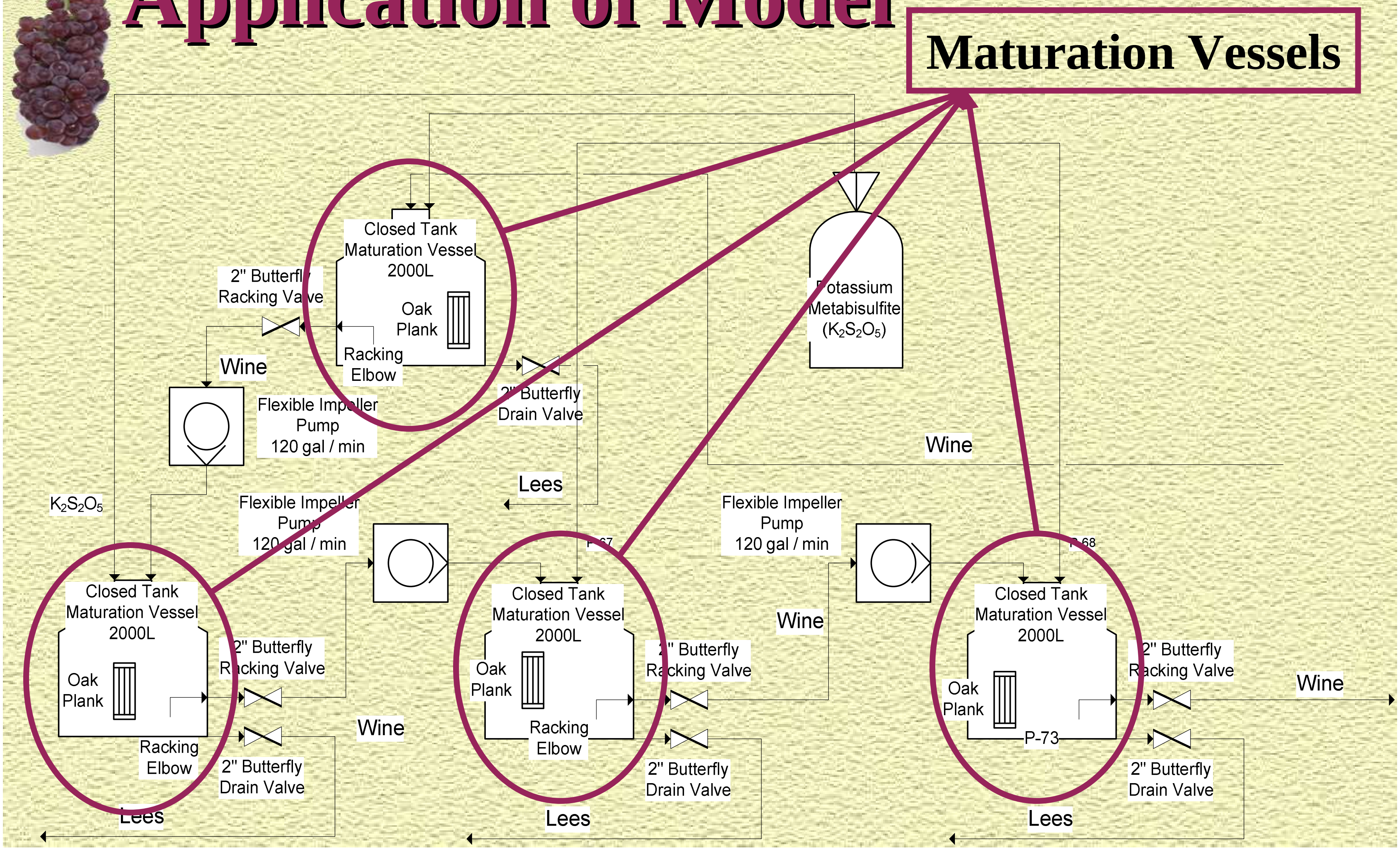
Application of Model



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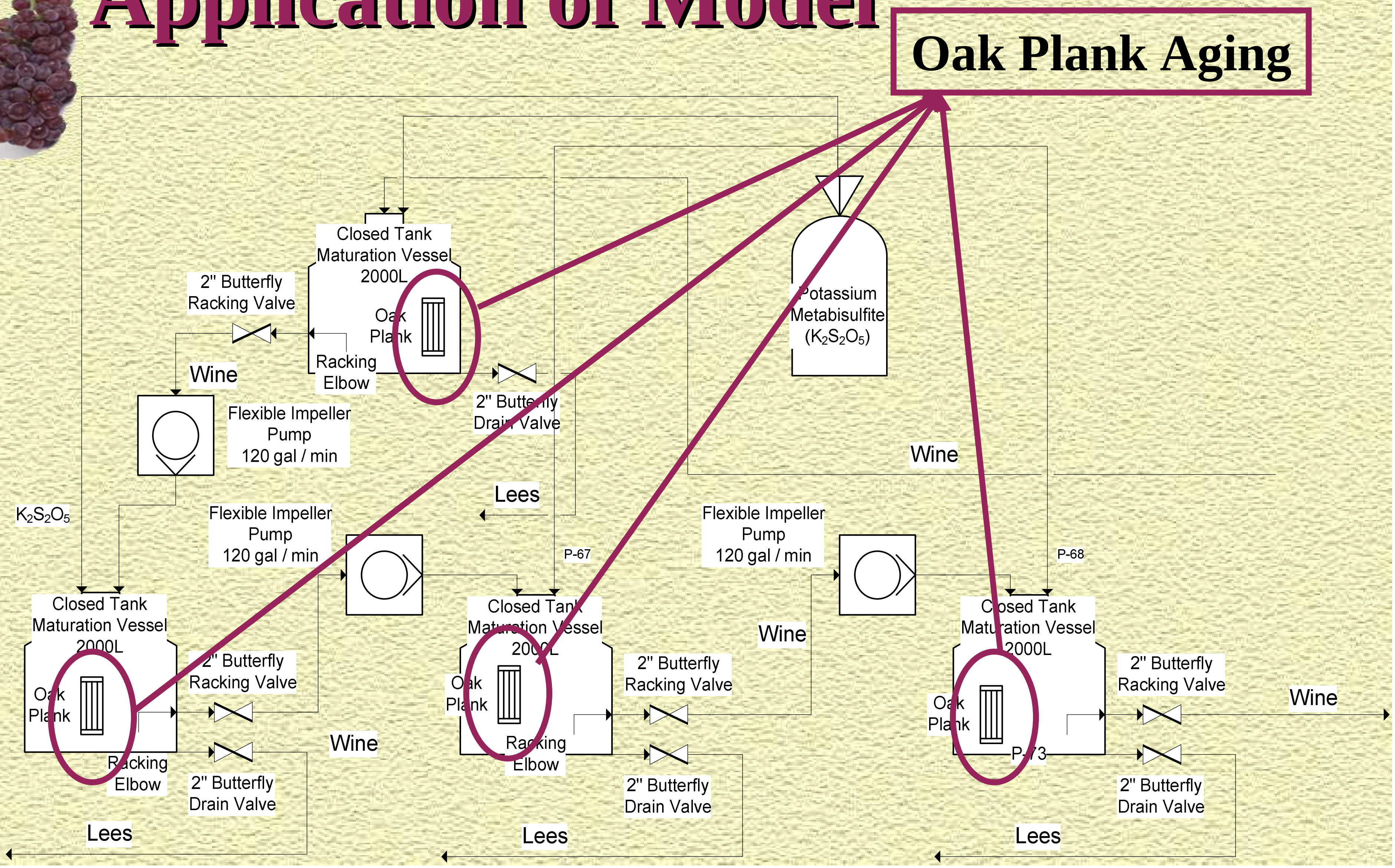
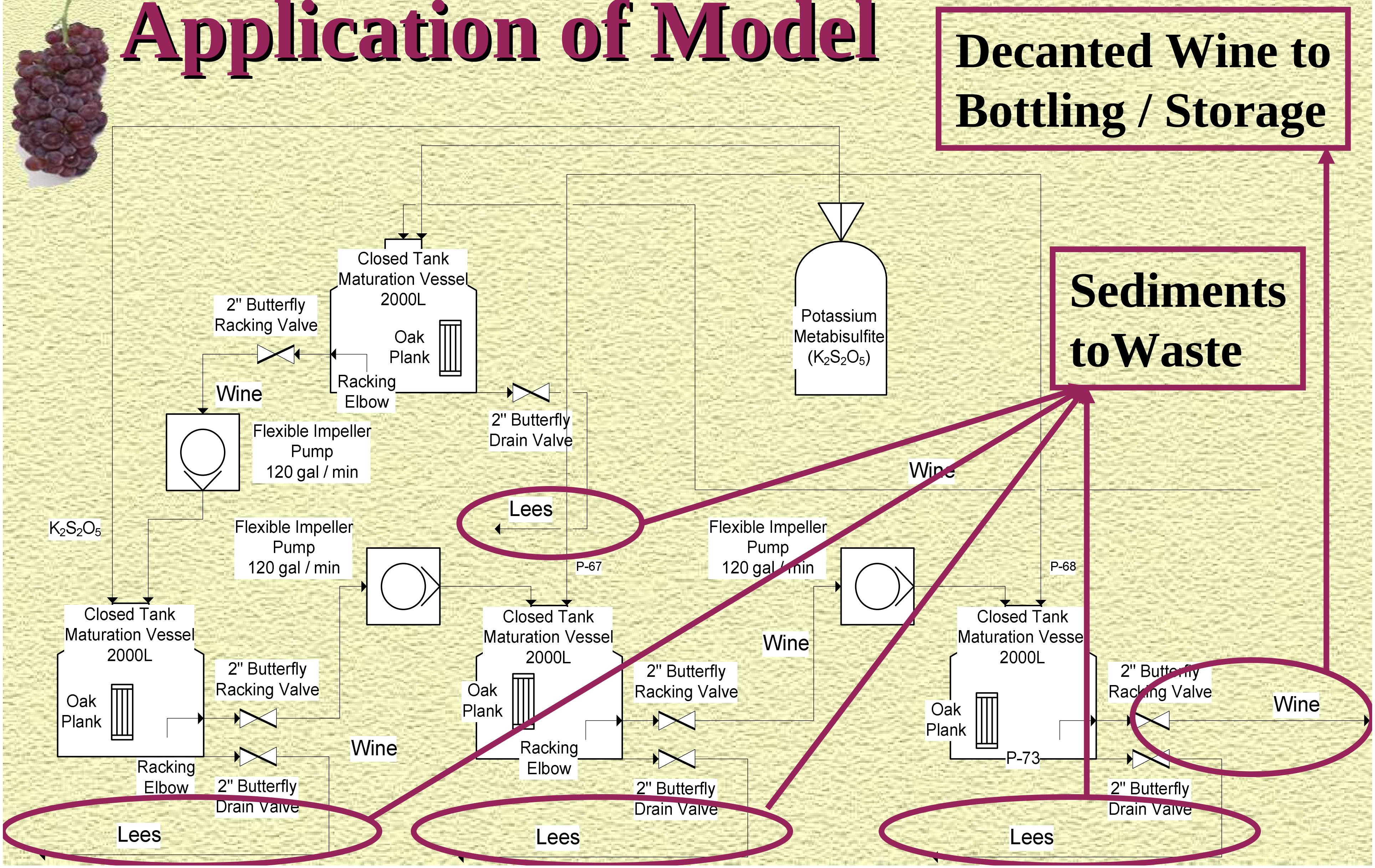
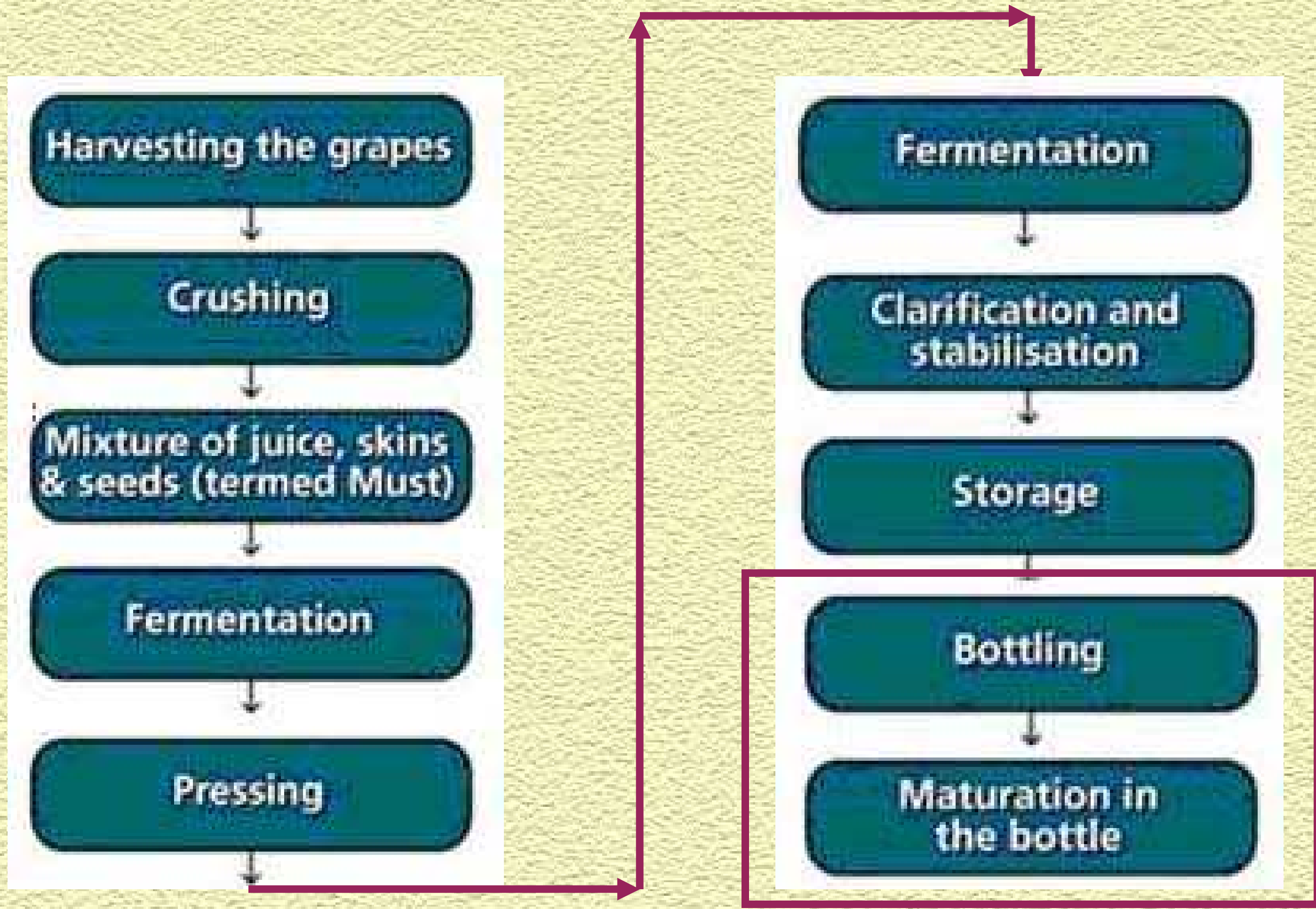
Application of Model



Application of Model



Application of Model



Application of Model

Process - Fine / Sterile Filtering & Bottling		
Physical Properties of Must	Initial	Final
Clarity (NTU)	30	0.02
Color (absorbance fraction)	0.7	0.6
Color (brightness fraction)	0.95	0.93
Bouquet (# of aromatic compounds)	30	30
Acidity (pH)	3.2	3.2
Sweetness (wt% sugar)	0.15	0.15
Bitterness (g Tannin/L wine)	0.2	0.1
Body (wt% alcohol)	0.12	0.12
Calculated Happiness (H_1)	0.63	0.77

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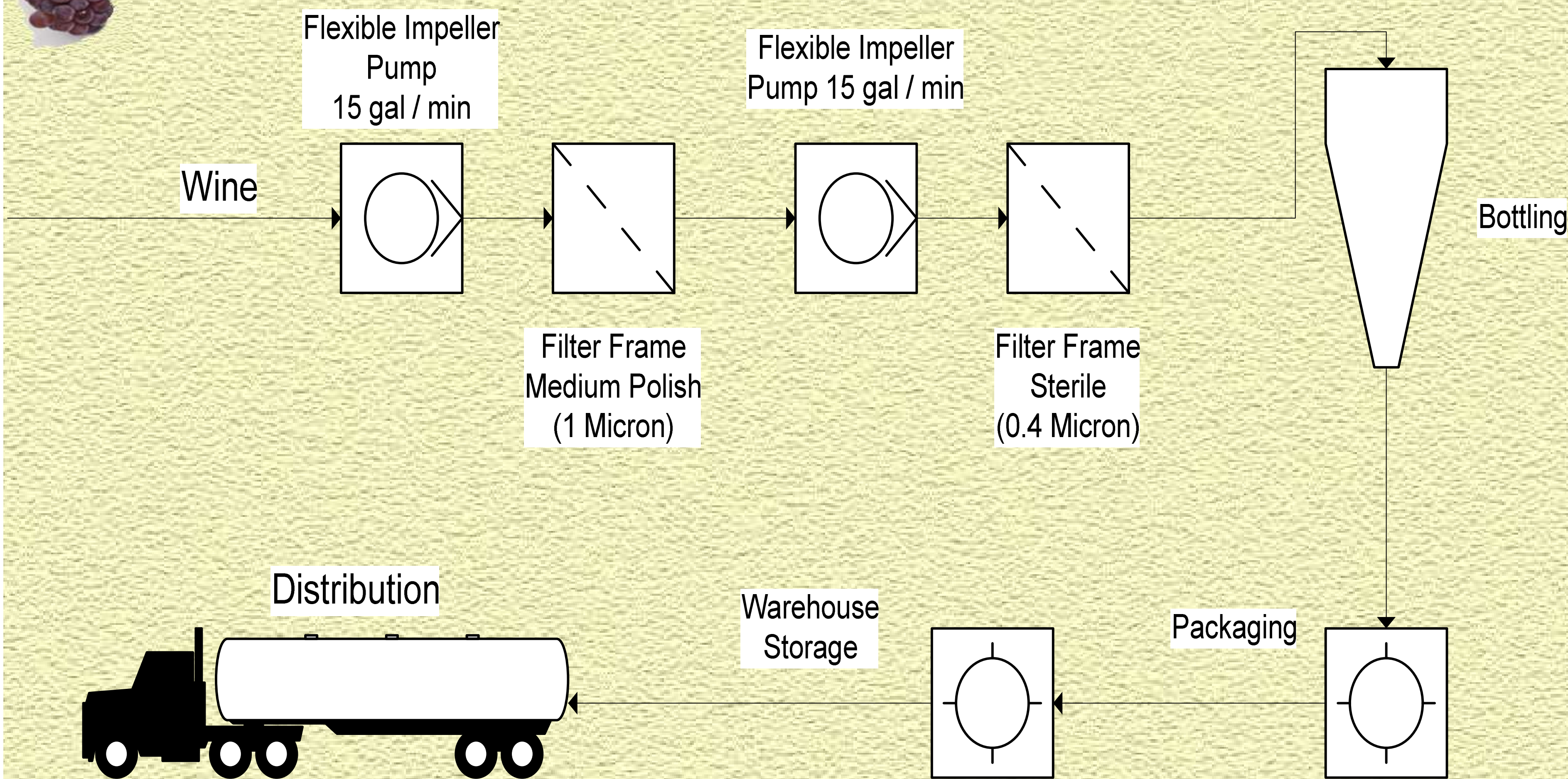
Application of Model



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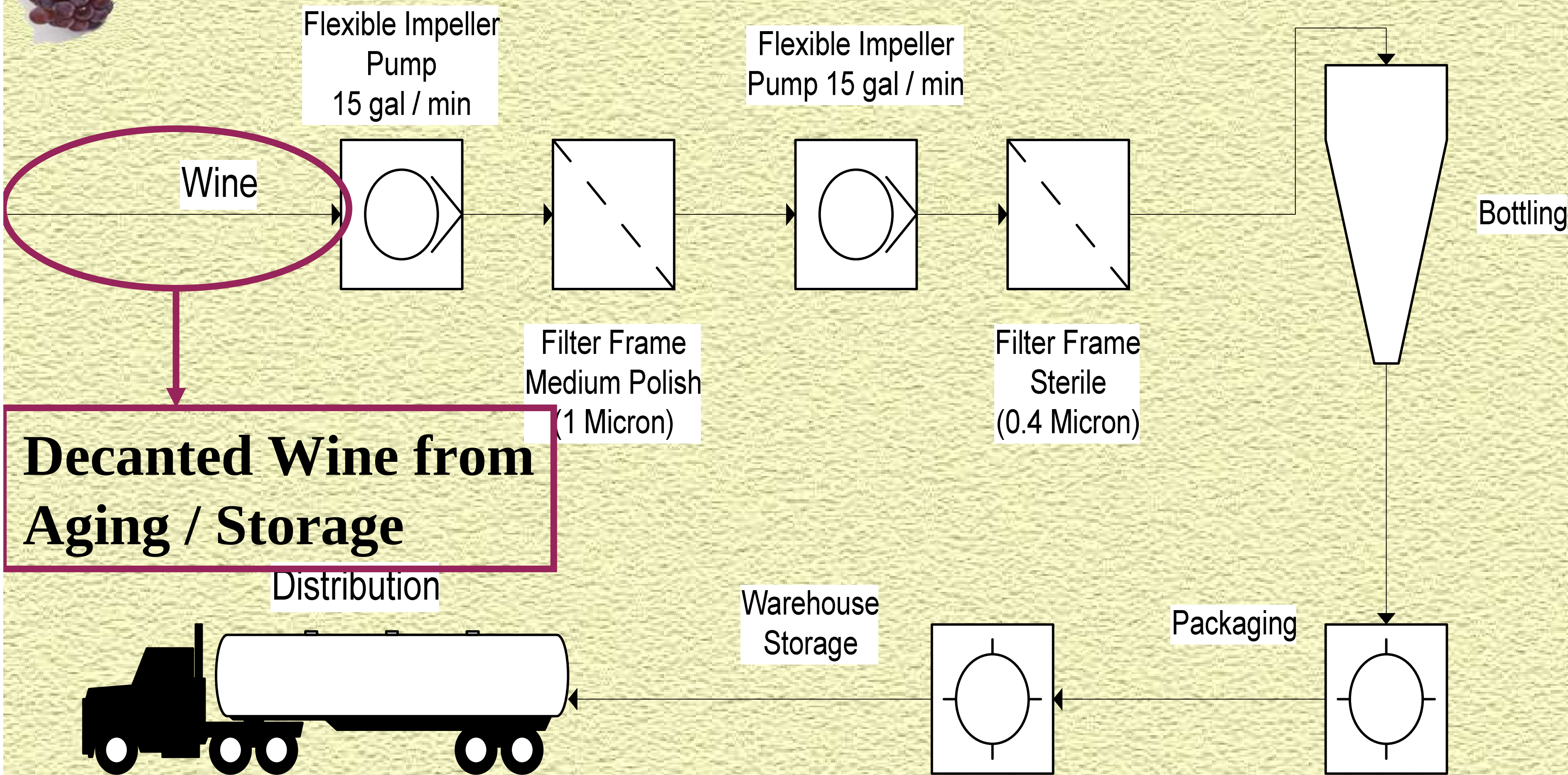
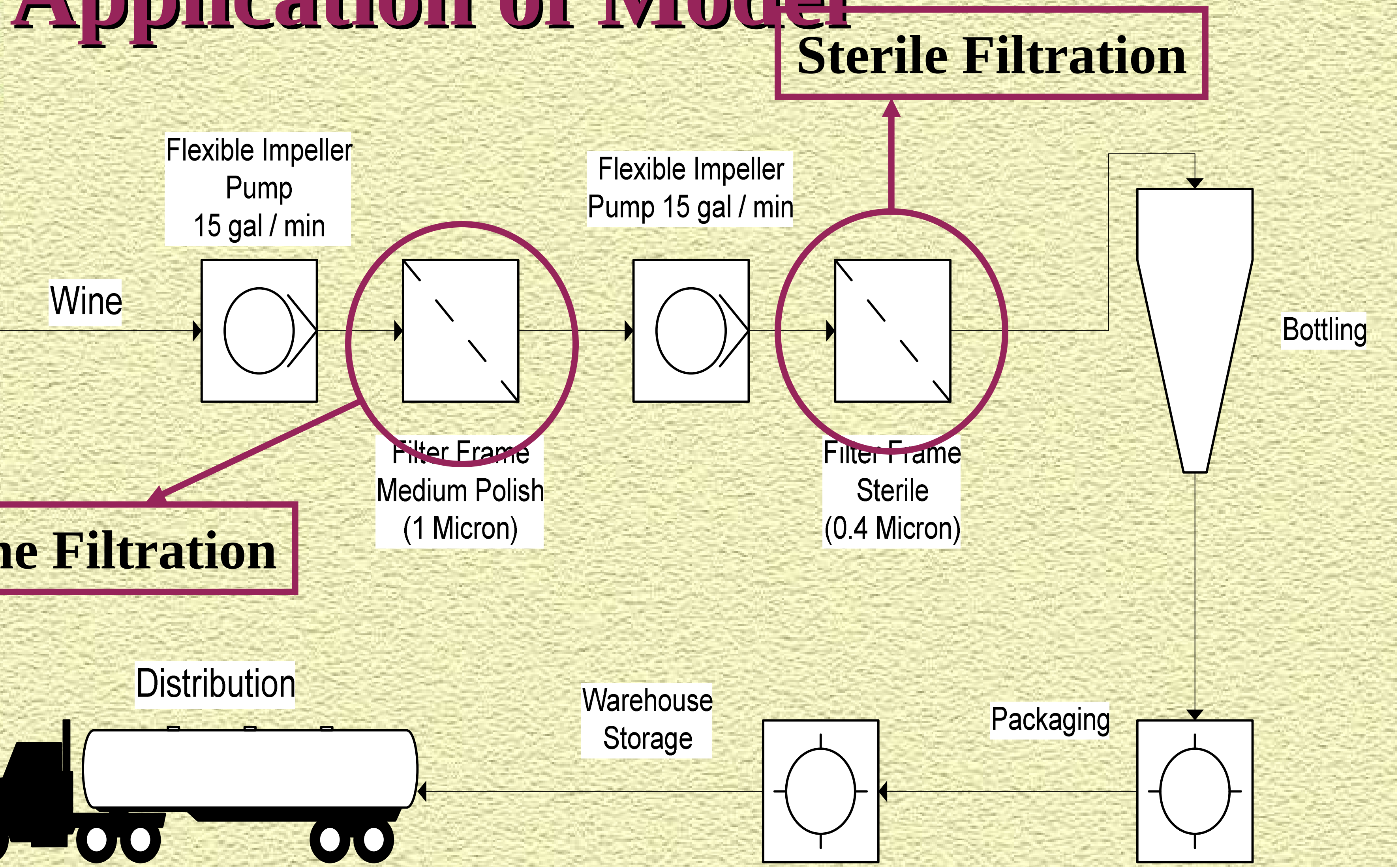
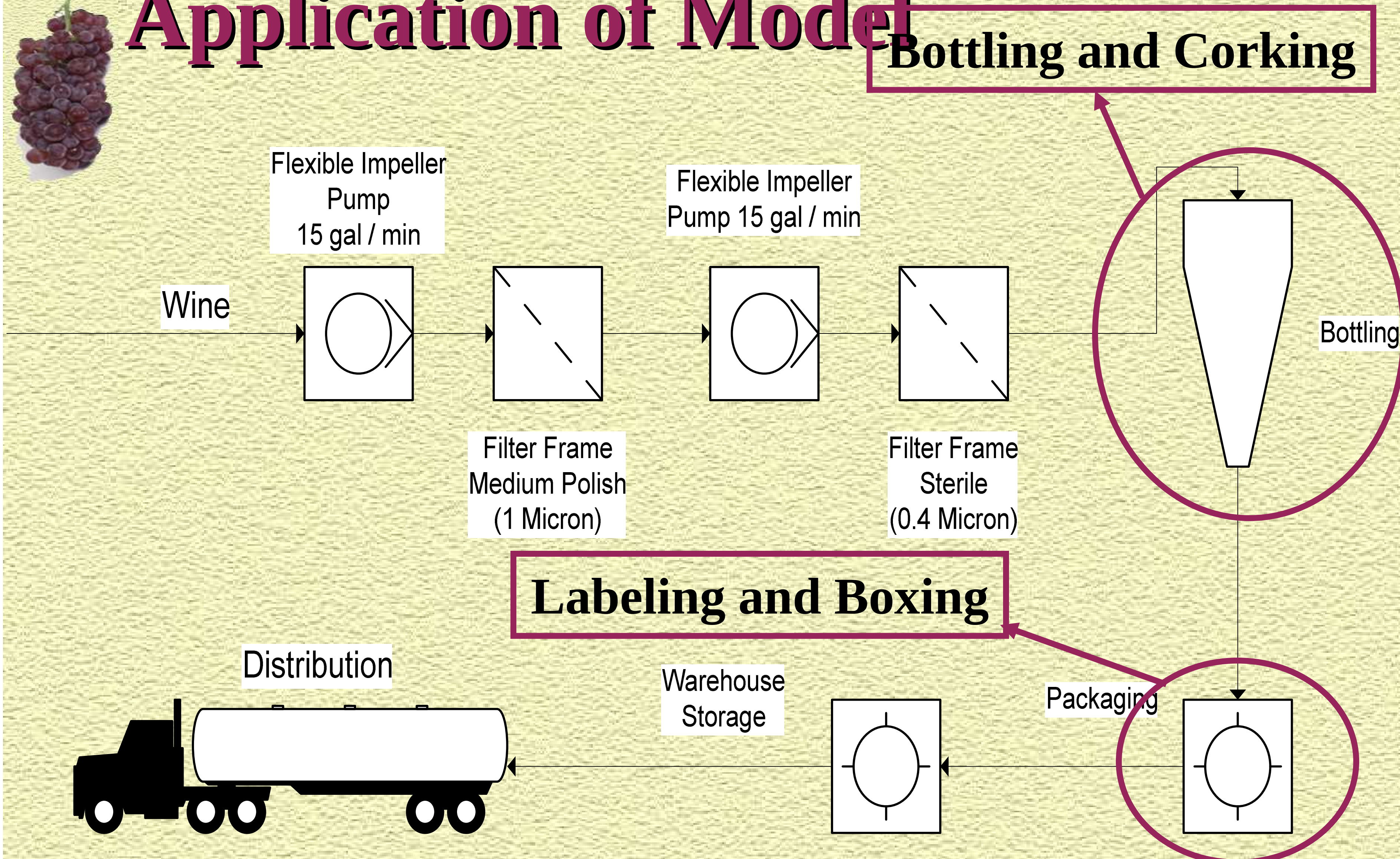
Application of Model



Application of Model



Application of Model



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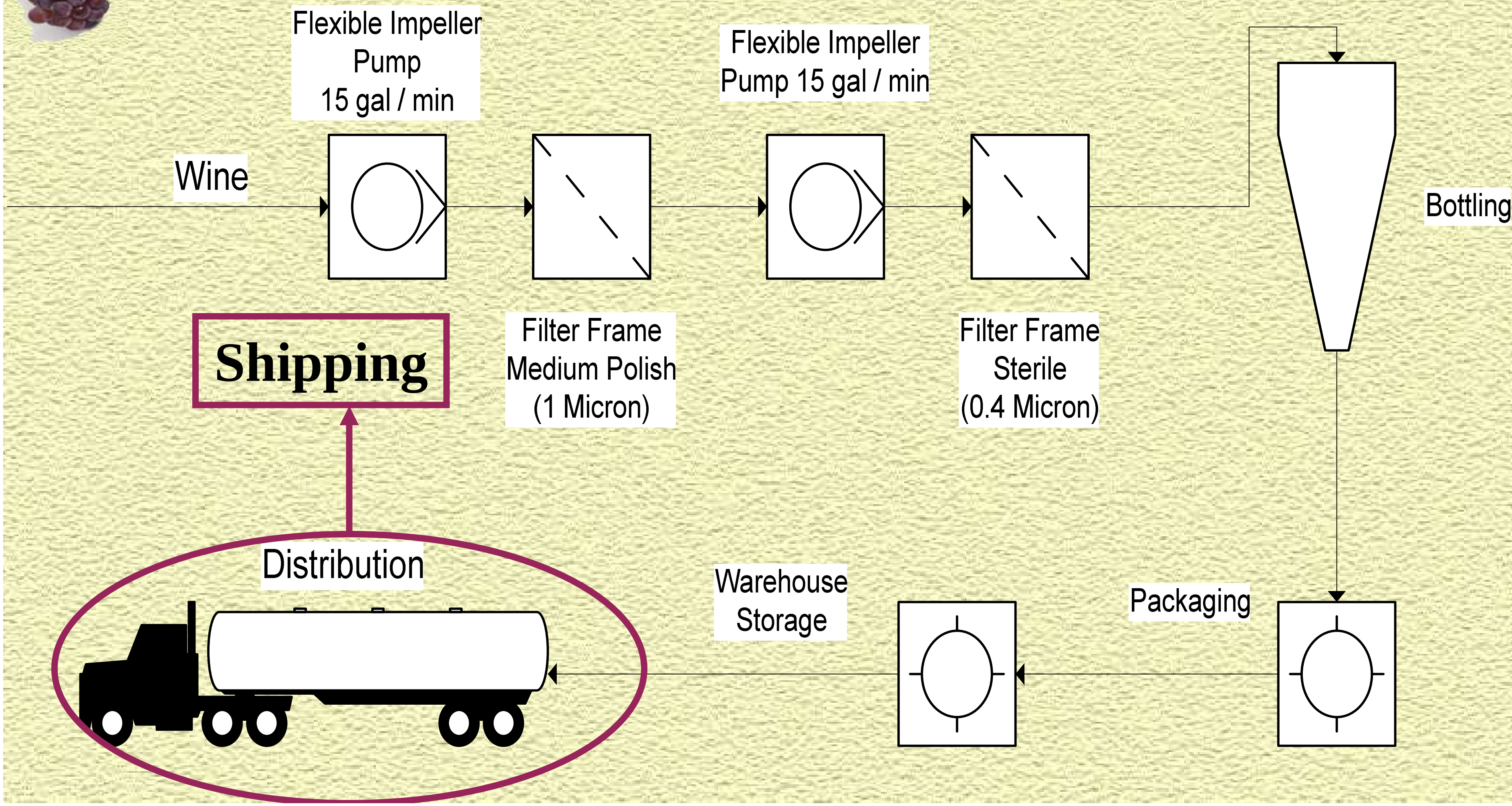


Business Model

Business Model

Goals

- Maximize return on investment (ROI)
  - Maximize net present worth (NPW)
  - Minimize total capital investment (TCI)

$$ROI = \frac{NPW}{TCI}$$

- Do not run out of working capital (WC)
- Minimize pay out time (POT)

Business Model

Assumptions

- Location – Oregon
- Grape Variety – Pinot Noir
  - Purchase grapes initially
  - Replace with vineyard production

Business Model

Assumptions

- Rate of Return (ROR) – 10%
- Product Selling Price (p_1) – \$30
- Competitor Selling (p_2) – \$30
- Superiority function (β) – 0.64
  - Happiness of Product (H_1) – 0.78
  - Happiness of Competitor Product (H_2) – 0.5
- Total pinot noir market (Y) - \$148 MM / year

Business Model

$$\beta = \frac{H_2}{H_1}$$

$$\beta d_1 p_1 = \alpha d_2 p_2 d_1^{\alpha} / d_2^{\beta}$$

$$Y = d_1 P_1 + d_2 P_2$$

Business Model

$$d_1 = \frac{\alpha}{\beta} * \frac{p_2}{p_1} * \left[\frac{Y - p_1 * d_1}{p_2} \right]^{1-\beta} * d_1^{\alpha}$$

Business Model

Variables

- Production – 0.1 to 2.0 MM Bottles / Year
- Advertising – 2.0, 1.0, or 0.2 MM $ / Year
- 99% > WC > 50% of TCI

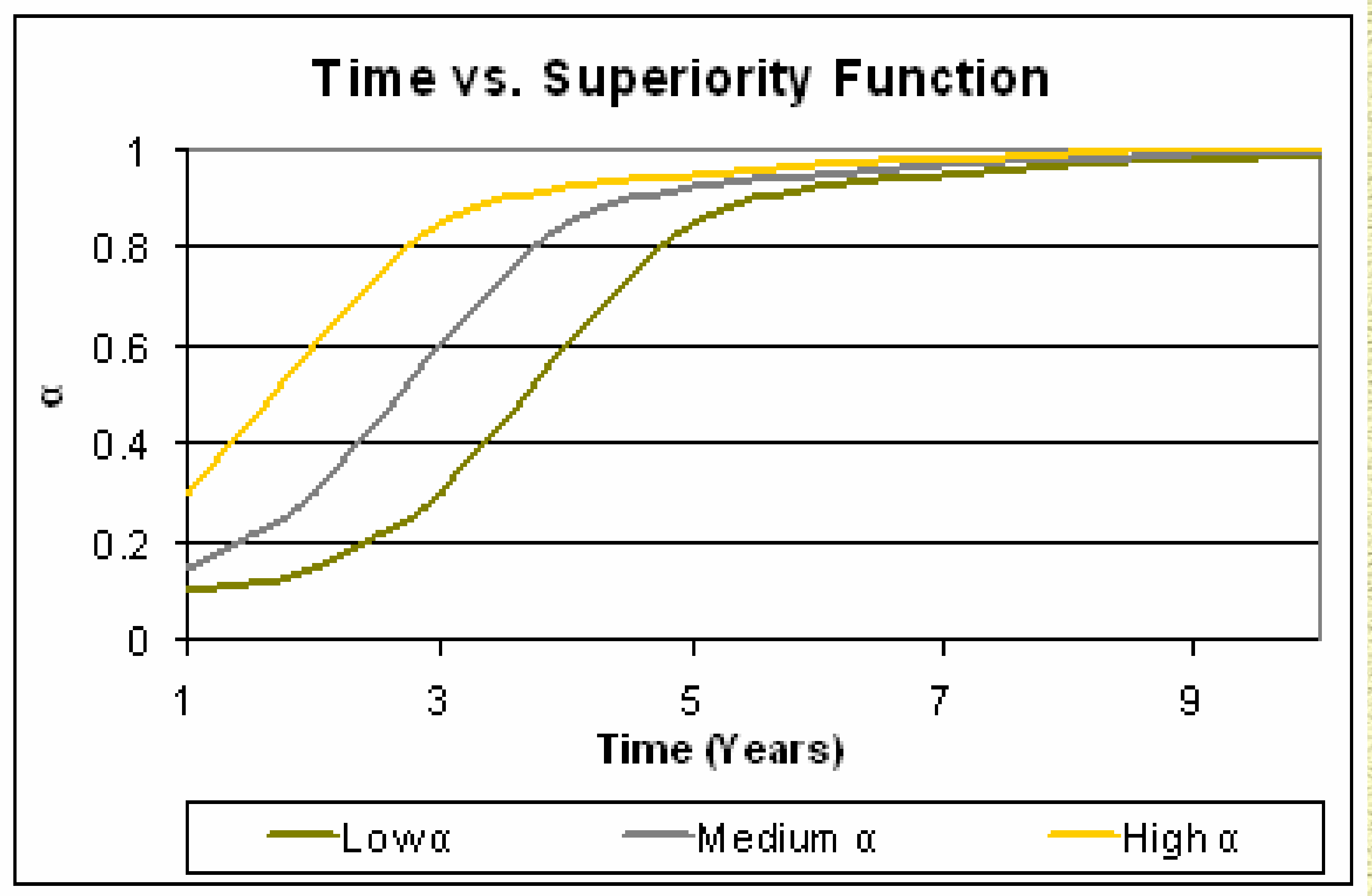
Business Model

Assumptions

- α is a function of time
- α values based on advertising costs
  - High - $2.0 MM / year
  - Medium - $1.0 MM / year
  - Low - $0.2 MM / year

Engineering Wine

Business Model

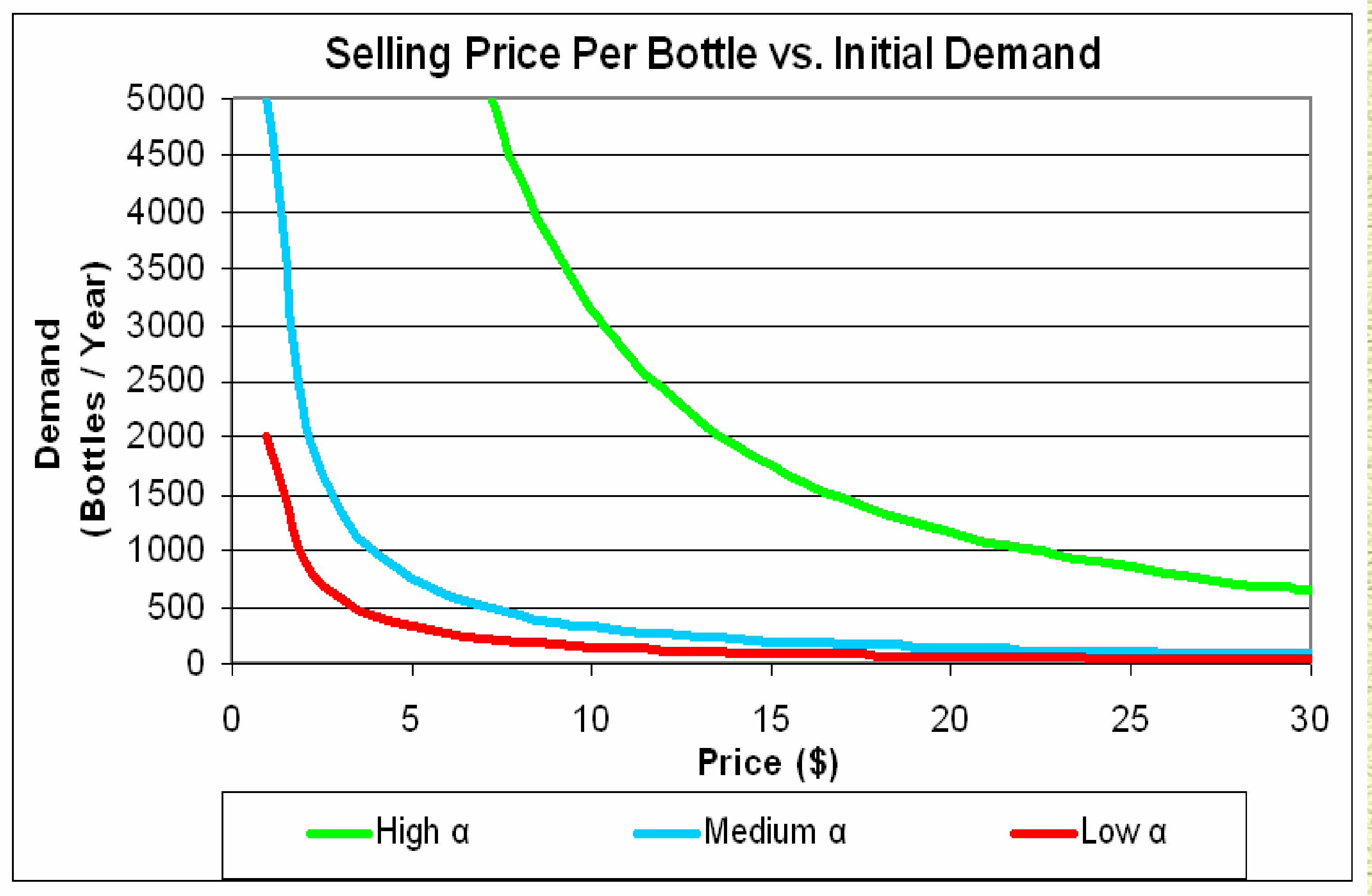


Business Model

Assumptions

- **Demand (d_1) varies with selling price (p_1)**
  - **Constant α values**
  - **Constant competition selling price (p_2)**

Business Model



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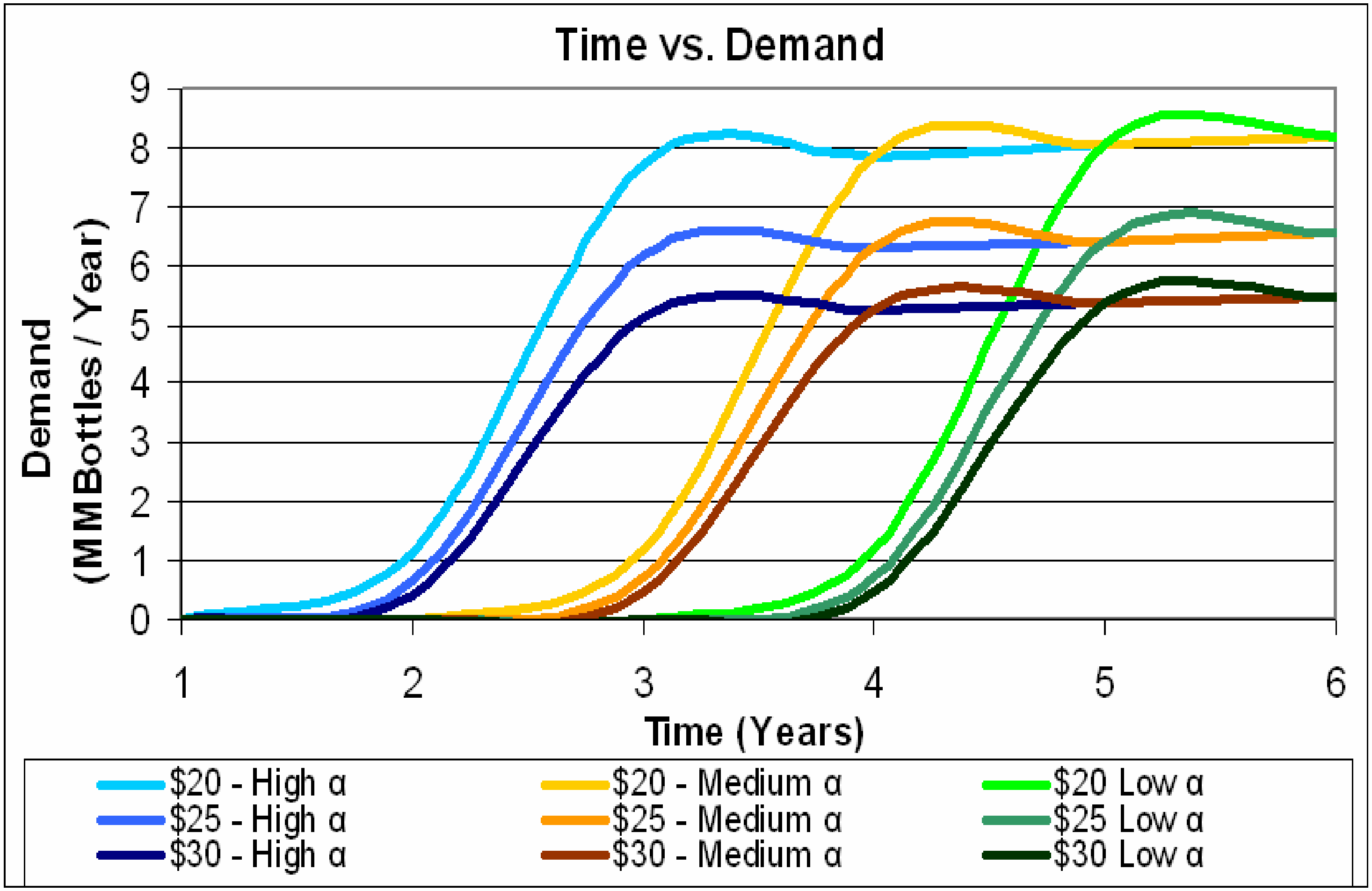
Business Model



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Business Model

Assumptions

- Constant production
  - Increase α
    - Decreases WC
    - Increases ROI
- Constant α
  - Increase production
    - Decreases WC
    - Increases ROI

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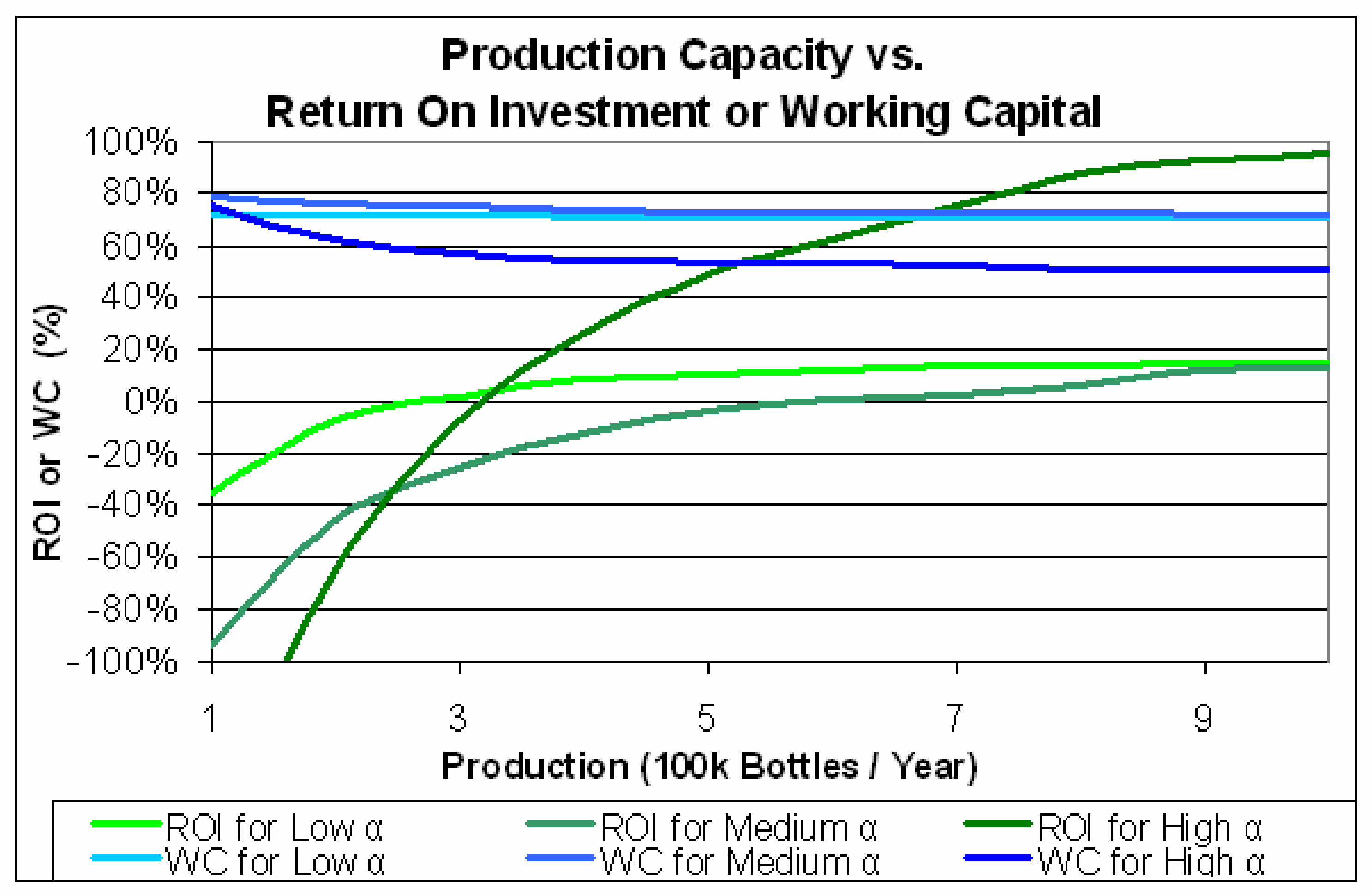
Business Model



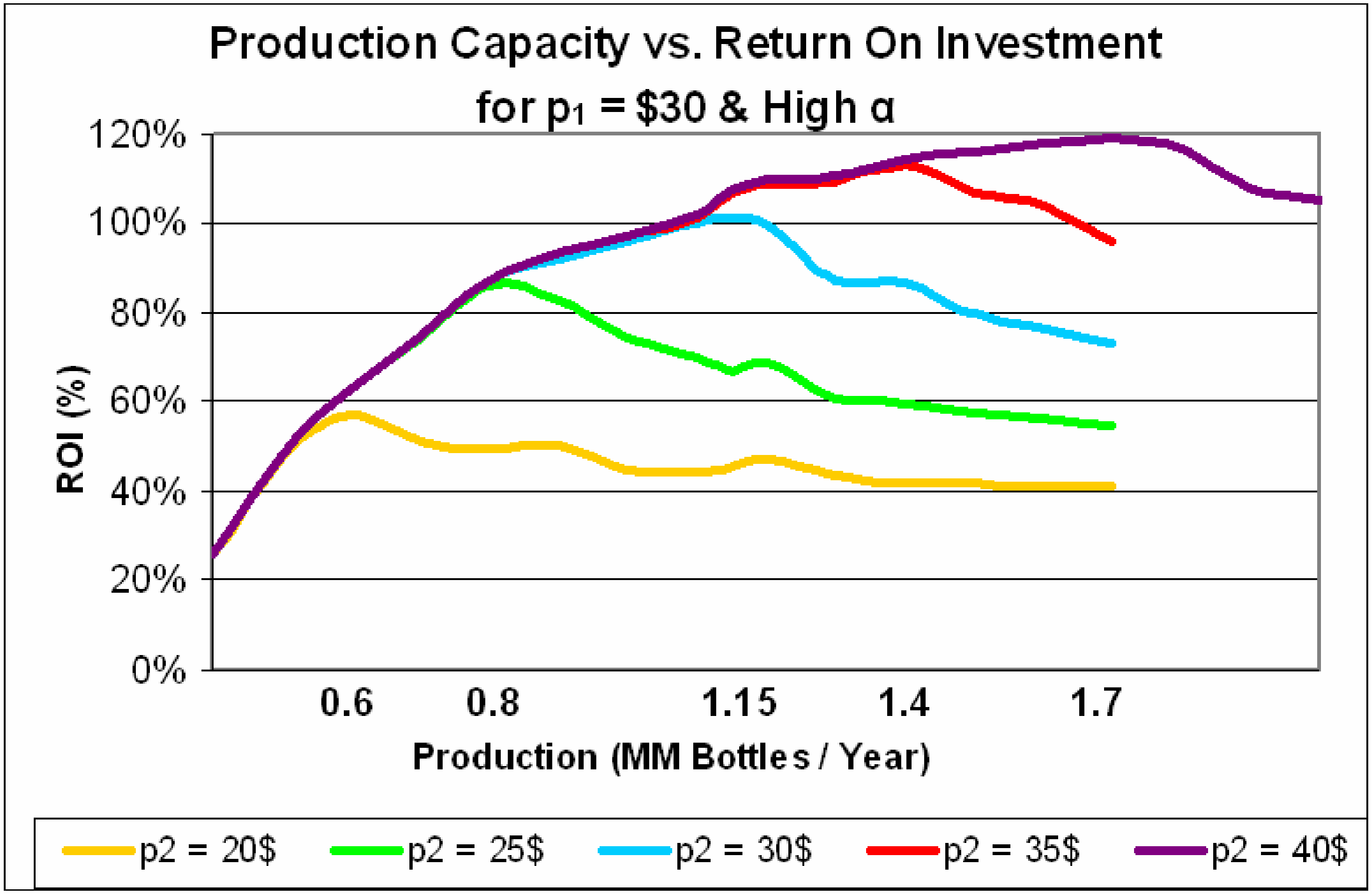
Business Model – Regret Analysis

Assumptions

- **Constant α, p_1, and production**
  - **Increase p_2**
    - **Increase ROI**
- **Constant α, p_1, and p_2**
  - **Increase production**
    - **ROI finds a maximum**

Engineering Wine

Business Model – Regret Analysis



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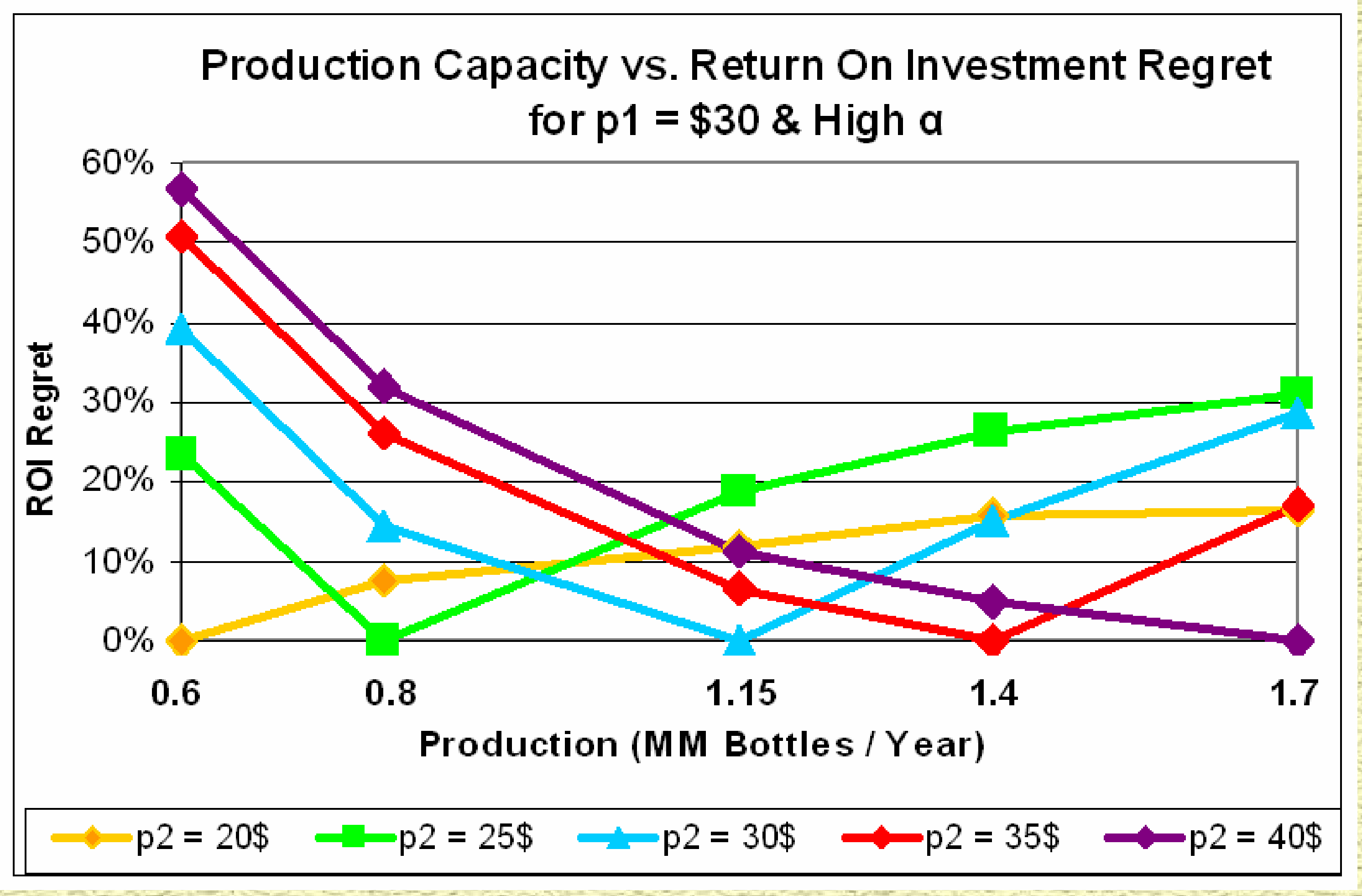
Business Model – Regret Analysis



Business Model – Risk Analysis

Optimum Scenario Comparison					
Production = 1.15 MM bottles / year & p_1 = $30					
p_2 ($)	ROI	NPW ($)	TCI ($)	POT (years)	WC %
20	33%	21000000	64000000	6	67%
25	46%	27000000	59000000	5	64%
30	67%	35000000	51000000	5	59%
35	93%	42000000	45000000	4	53%
40	107%	45000000	42000000	4	50%

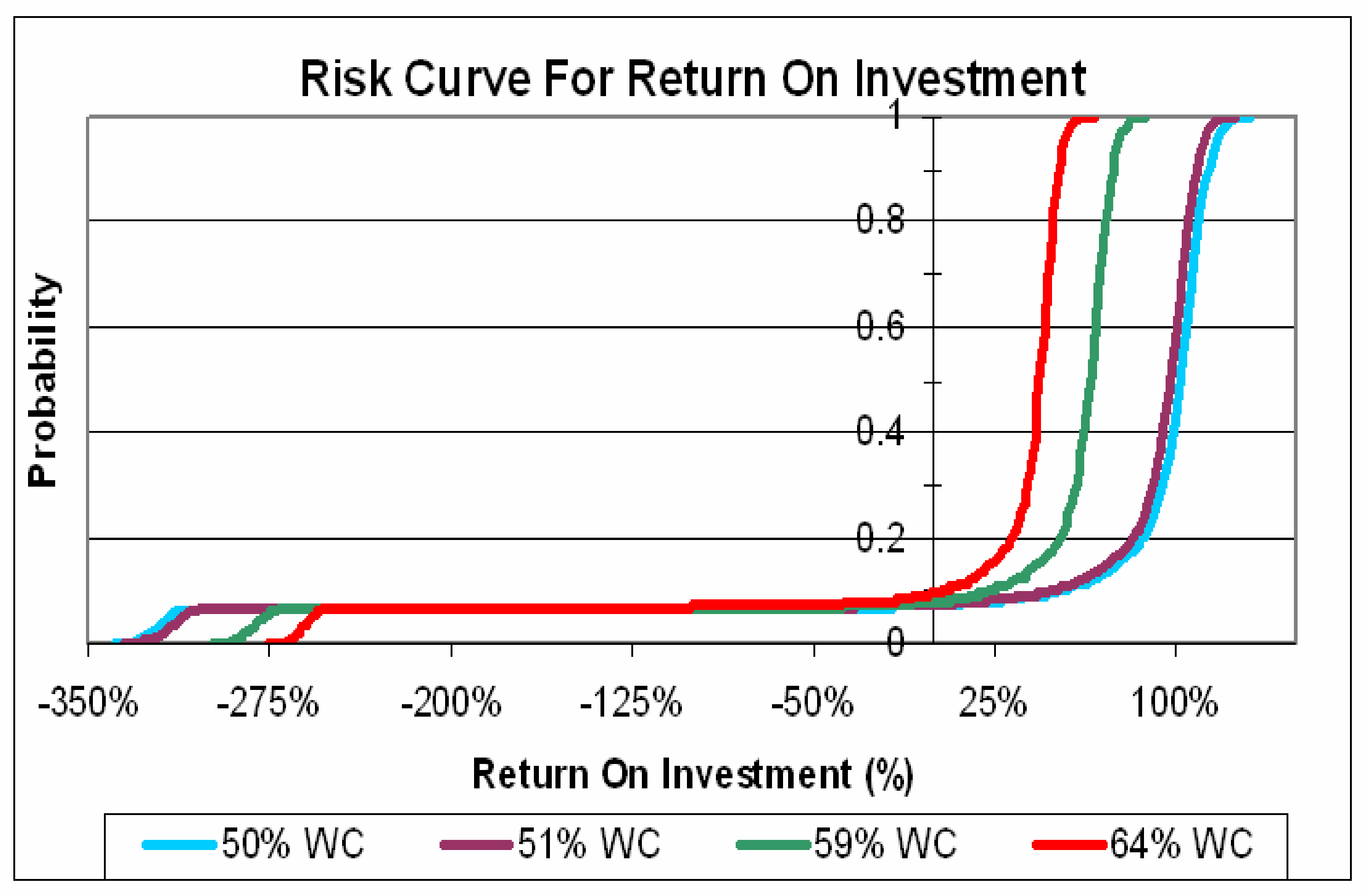
Business Model – Risk Analysis

Assumptions

- Production costs – 20% standard deviation
  - Raw materials, labor, utilities
- Superiority function - β
  - H_1 & H_2 – 20% standard deviation in each
- Inferiority function – α
  - 20% standard deviation for each year
- Selling price – p_2
  - $30 with a standard deviation of $10

Engineering Wine

Business Model – Risk Analysis



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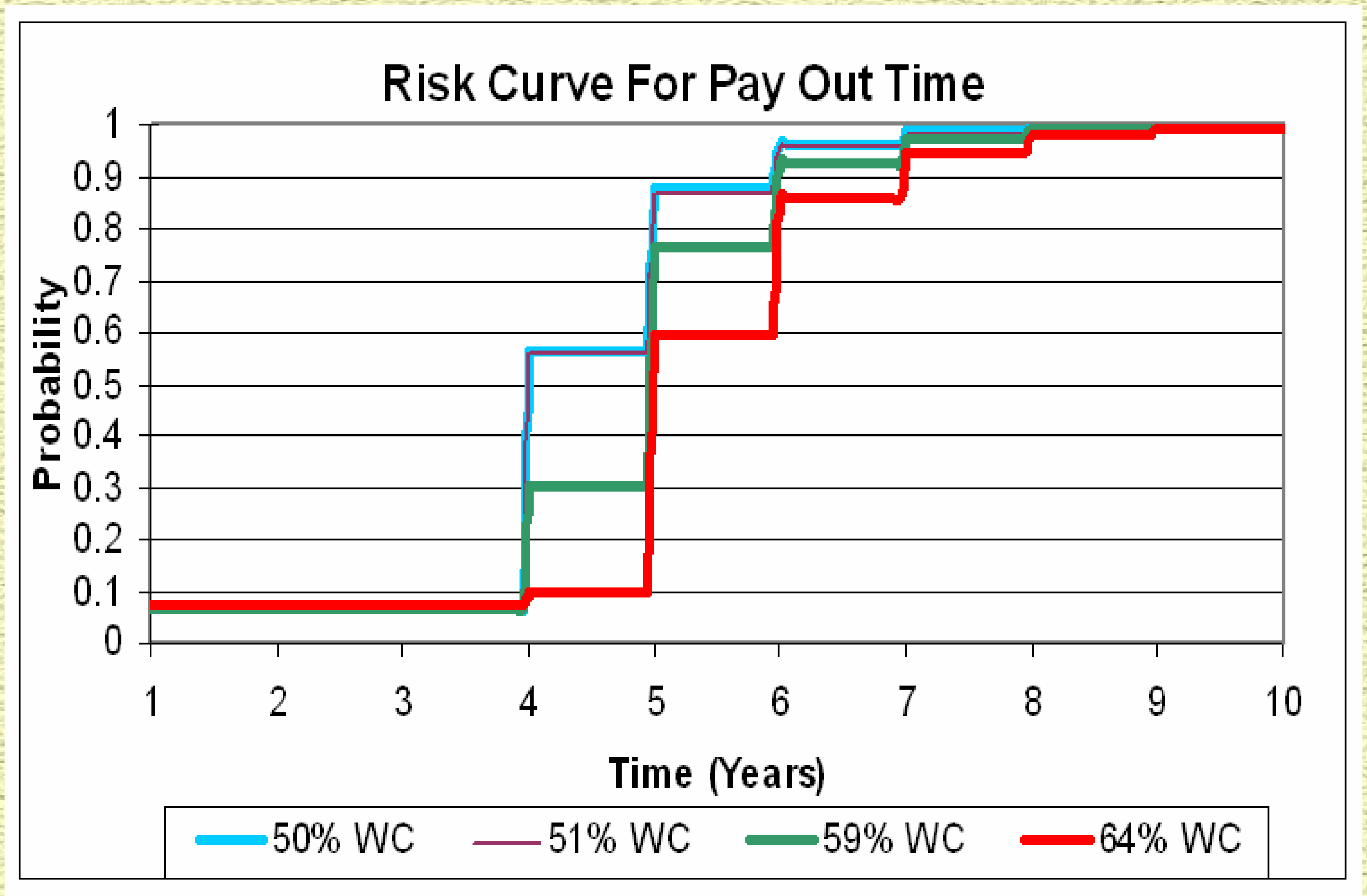
Business Model – Risk Analysis



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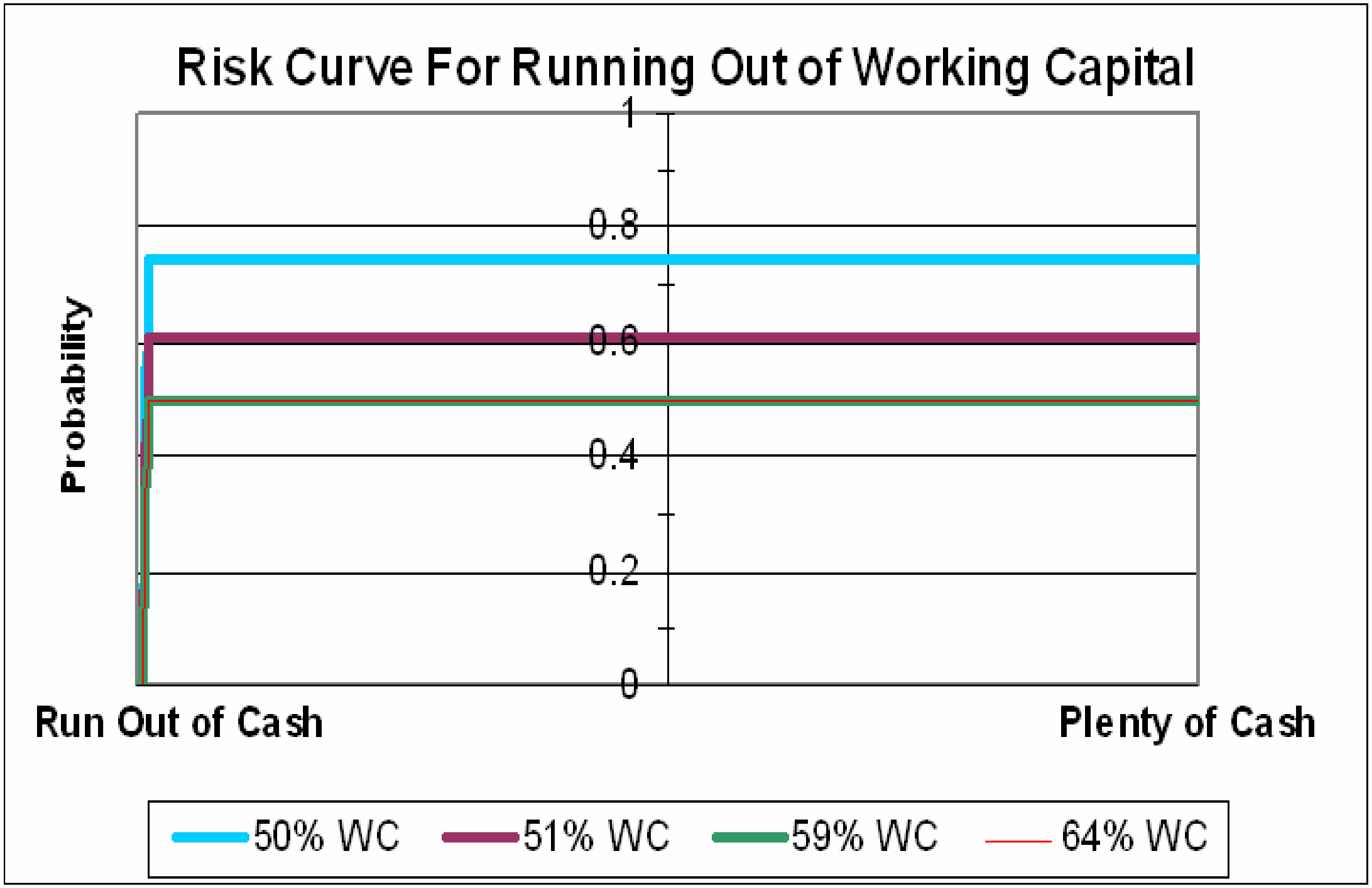
Business Model – Risk Analysis



Conclusions

- Quality of wine can be evaluated before bottling.
- Process can be adjusted at negligible cost.
- A business model can be formed to maximize ROI.

Conclusions

- For higher values of α and lower values of β, the less a competitor's price effects the producer's ROI.
- Based on the current business model, the optimum production capacity is 1.15 million bottles / year at a selling price of $30:
  - ROI – 102%
  - NPW – $44,000,000
  - Pay Out Time – 4 years

Future Work

- Incorporate more detailed economies of scale
- More detailed analysis of the physical properties and effects of process adjustments : modeling
- Study effect of bottle aging on happiness of wine

Acknowledgements

- Dr. Susan E. Ebeler, UC Davis
- Trung Hoang, T.A.
- Dr. Miguel Bagajewicz, Instructor
- OU CBME Department
- “Sideways”

Questions?