MODELING AND SIMULATION OF THE BEER FERMENTATION PROCESS AND TEMPERATURE CONTROL

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Dedication

I dedicate this thesis for my parents and teachers, who have supported me all the way since the beginning of my studies.

Also, this thesis is dedicated to my fiancée who has been a great source of motivation and inspiration.

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Abstract

Beer is the most common alcoholic drink around the world. When talking about the beer quality, flavor of the beer is more concerned. Most of the brewers in Sri Lanka are using traditional methods to brewing beer. Most of brewers using pre identified recipe to produce mass production of beer. Therefore, beer quality i.e. flavor is varying brand by brand. It is important to study the variation of temperature, how will affect to the final alcohol production and the flavor compound formation. Beer manufacturing industry can be used this knowledge to increase the production efficiency and the product quality.

It is very important to know about dynamics of forming flavor compounds. In this work the fermentation process is concerned since all the flavor compounds are formed during the fermentation. The mechanistic model is developed by based on the knowledge of biochemical processes in the yeast cell and previously developed mathematical models which are available in the literature. There are many beer models can be found such as Engasser et al.,(1981);Growth kinetic model, Gee at al.,(1988), Phisalaphong et al.(2006);Growth kinetic model and effect on temperature, W.F. Ramirez and J. Maciejowski.,(2007);Optimal beer fermentation, etc. The beer fermentation process is modeled and simulated in MATLAB/Simulink environment.

Growth model, nutrient model, and the flavor model are considered and developed. Growth model consists of sugar consumption, biomass growth and ethanol formation models. Those models are developed with temperature dependent parameters to observe the effect of the temperature. Three amino acids which are valine, leucine and iso leucine are considered for the Nutrient model. Consumption of these three amino acids is considered during fermentation. Flavor model is developed based on the growth model and the nutrient model. Flavor compounds are categorized into three groups which are fusel alcohols, esters and vicinal diketones. Altogether nine parameters are considered as flavor compounds and the effects of temperature on those are simulated with MATLAB/Simulink and JModelica. Industrial temperature profile is obtained and applied for the developed model and simulated in MATLAB/Simulink and the results are analyzed.

PI controller is applied to get identified temperature profile to obtain flavor formation and the dynamic model is used for find suitable controller parameters for the best control. The controller is simulated in MATLAB/Simulink.

Keywords: Beer, Fermentation, Flavor, Modeling, Simulation, Temperature, Control

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Nomenclature

Symbol	Description
G	Glucose concentration (mol/m3)
M	Moltose concentration (mol/m3)
N	Moltotrise concentration (mol/m3)
X	Biomass concentration (mol/m3)
E	Ethanol concentration (mol/m3)
μ_1	Specific rate of glucose uptake (h^{-1})
μ_2	Specific rate of moltose uptake (h^{-1})
μ_3	Specific rate of moltotrise uptake (h^{-1})
μ_X	Specific rate of yeast growth (h^{-1})
Y_{XG}	Yield coefficiant, mole X per Mole G
Y_{XM}	Yield coefficiant, mole X per Mole M
Y_{XN}	Yield coefficiant, mole X per Mole N
X_0	Initial yeast concentration (mol/m3)
Y_{EG}	Yield coefficiant, mole E per Mole G
Y_{EM}	Yield coefficiant, mole E per Mole M
Y_{EN}	Yield coefficiant, mole E per Mole N
K_x	Empirical yeast growth inhibition constant $(mol/m3)^2$
μ_i	Maximum reaction velocity for i^{th} sugar (i = G, M or N, h^{-1})
K_i	Michaelis constant for i^{th} sugar (i = G, M or N, mol/m3)
$K^{/}_{i}$	Inhibition constant for i^{th} sugar (i = G or M, mol/m3)
μ_{io}	Arrhenius frequency factor for maximum velocity (h^{-1})
K_{i0}	Arrhenius frequency factor for michaelis constant (mol/m3)
$K^{/}_{i0}$	Arrhenius frequency factor for inhibition constant (mol/m3)
$E_{\mu i}$	Arrhenius activation energy for maximum velocity (cal/mol)
E_{Ki}	Arrhenius activation energy for michaelis constant (cal/mol)
$E_{\mu i}$	Arrhenius activation energy for inhibition constant (cal/mol)

R	Gas constant (cal/mol K)
T	Temparature (^{0}C)
ρ	Density of wort (kg/m3)
Cp	Specific heat capacity of wort (kg/mol ^{0}K)
ΔH_{FG}	Overall heat of formation for glucose (J/mol)
ΔH_{FM}	Overall heat of formation for moltose (J/mol)
ΔH_{FN}	Overall heat of formation for moltotrise (J/mol)
Y_{LX}	Yield coefficiant , moles leucine needs per mol biomass growth
Y_{IX}	Yield coefficiant , moles isoleucine needs per mol biomass growth
Y_{VX}	Yield coefficiant , moles valine needs per mol biomass growth
K_L	Michaelis constant for leucine (mol/m3)
K_I	Michaelis constant for isoleucine (mol/m3)
K_V	Michaelis constant for valine (mol/m3)
L	leucine concentration (mol/m3)
I	Isoleucine concentration (mol/m3)
V	Valine cincentration (mol/m3)
D	First order time delay (h)
τ_d	First order time constant for delay (h)
t	Time (h)
IB	Isobutyl alcohol concentration (mol/m3)
IA	Isoamyl alcohol concentration (mol/m3)
MB	2-methyl-1-butanol concentration (mol/m3)
P	n-propanol concentration (mol/m3)
Y_{IB}	Isobutyl alcohol yield
Y_{IA}	Isoamyl alcohol yield
Y_{MB}	2-methyl-1-butanol alcohol yield
Y_{PE}	n-propanol alcohol yield
μ_V	Specific rate of valine uptake (h^{-1})
μ_L	Specific rate of leucine uptake (h^{-1})
μ_I	Specific rate of isoleucine uptake (h^{-1})
EA	Ethyl acetate concentration (mol/m3)
EC	Ethyl caproate concentration (mol/m3)

IAc	Isoamyl acetate concentration (mol/m3)
Y_{EA}	Ethyl acetate yield per mole sugar fermented (mol/m3)
Y_{EC}	Yield coefficiant for ethyl caproate per mole bio mass growth (mol/m3)
Y_{IAc}	Yield coefficient for moles isoamyl acetate produced per mole isoamyl alcohol formed (mol/m3)
μ_{IA}	Specific rate of isoamyl alcohol formation (h^{-1})
VDK	Vicinal diketones concentration (mol/m3)
Y_{VDK}	Yield coefficient, mole VDK formed per mol biomass growth
K_{VDK}	Effective first order rate constant for uptake of VDK (m3/mol h)
AAl	Acetaldehyde concentration (mol/m3)
Y_{AAl}	Yield coefficient, moles AAl formed per mole sugar fermented
K_{AAl}	Effective first order rate constant for uptake of AAl (m3/mol h)
Kc	Controller gain
τ_i	Integral time (h)
SP	Set point
GS	Observed parameter for gain scheduling