ENERGETIC BALANCE OF WHITE WINE PRODUCTION

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Abstract

It is widely known, that influence of temperature on winemaking is significant. Fermentation at higher temperatures causes losses of aromatic substances up to 75% (when fermentation is carried out at 30 °C). Hence, temperature of the fermentation must be controlled during entire fermentation. Therefore, first part deals closer with the material and energetic balance within the fermenter during fermentation, what is the most crucial part of winemaking. We assumed typical concentrations of nitrogen and sugar, adapted a model and simulated fermentation process. Our attention deals with duration of the fermentation, cooling requirements and in the case of refrigeration failure we investigated temperature increase and minimal cooling requirements to cool it back in a proper time. Second part deals with simple material and energetic balance at all. The measurement was made in industrial scale in one Slovak wine factory.

Keywords: *energetic balance, wine production, simulation*

INTRODUCTION

It is widely known, that influence of temperature on winemaking is significant[1]. Fermentation at higher temperatures result to a decrease of overall quality of wine. This effect is caused by faster fermentation, which is associated with release of carbon dioxide which occurs grater losses of aromas and bouquets. Fermentation processes in various temperature also affect the creating different compounds and it has influence on cooling requirements. Losses of aromas and bouquets at various temperatures are stated in Table 1.

Table 1. Losses of aromatic substances at various fermentation temperatures [4].

Fermentation temperature [°C]	Losses [%]
15 – 20°C	10 – 30
20 – 25°C	50
25 – 30°C	75

It is evident that the losses of aromatic substances are relatively high. Therefore, the temperature of fermentation must be controlled daily, especially in large production. The higher fermentation temperature causes the higher losses of ethanol as well. For example, if we have sugar content 217 g/l, we should obtain yield of ethanol about 12,4 % v/v theoretically, but this yield decreases as a temperature increase. It is 11,8 % v/v, 11,0 % v/v, 9,4% v/v and 4,8 % v/v for fermentation temperature 9°C, 18°C, 27°C and 36°C, respectively [2].

Factor influencing cooling requirements can be summarised into following:

a) generation of heat from the fermentation,

b) removal of heat by evaporation of water and ethanol and by leaving CO_2 (depends on temperature, rate of sugar consumption, surface area, that is in contact with gas phase),

c) heat transfer between surroundings and outer surface of the tank walls – convection, conduction, radiation (depends on tank geometry, materials of construction, and surroundings – velocity and temperature of ambient temperature),

d) removal of heat by refrigeration often by cooling jacket (often 40% of the total tank heat-transfer surface – unchilled top, bottom and 50% of the sidewalls [4].

Typical concentration of sugar in grape juice is in the range 160 g/l and 280 g/l and it consists of very similar amounts of D-glucose and D-fructose[3]. We assumed nitrogen levels from 140 mg/l (which is the smallest concentration of nitrogen to avoid sluggish fermentation) to 280 mg/l. We adapted a model of heat transfer in fermenter during wine fermentation and we simulated several possible situations in tanks. Simulations were performed for low, normal and high level of sugar and nitrogen in the scale described above. The outcome of this work shows necessary cooling requirements for maintaining the constant fermentation temperature. In the case, when the refrigeration failure will be in the worst time of fermentation, results show possible temperature rises in the fermenter. It has been demonstrated, that refrigeration failure only on 2 hours during the wine fermentation is insignificant on temperature rise. This work also presents influence of size of fermentation vessels on temperature rise, which is caused by ratio of outer surface area and bulk of fermenting must. Our results can be applied to wine industry for choice of enough cooling requirements.

MODEL DESCRIPTION

The following assumptions are used in the model:

a) The bubbles affect ideal stirring – the must is homogeneous during most of the fermentation.

b) Fermentation tank is situated in a closed room and heat transfer between surroundings (with a constant temperature during whole fermentation process and with no presence of air flux) and outside surface of the bioreactor involves a combination of both radiation and convection.

c) The average temperature of the outside surface is 0,5°C lower than average temperature of the must (resistance to heat flow from the must to the wall is negligible and effect of conduction through the wall is also insignificant).

d) Fermentation tank is filled up by must up to 88 % of his volume.

e) Effect of total acidity on the fermentation process is also negligible.

f) Nitrogen is the limiting substrate.

g) Grape must contain equal amounts of glucose and fructose.

h) Although fructose is used concomitantly with glucose, yeasts prefer glucose over fructose.

i) Ethanol inhibits sugar consumption.

j) CO_2accumulation in gas phase is negligible.

k) Biomass viability depends on a combined effect of ethanol and temperature.

l) Ratio height/diameter obtained from the real 10 m^3 (1,694) is the same in all cases

According to equations and estimations stated above, equation for energetic balance can be rewritten into following suitable form:

$$\frac{d(\rho \cdot H \cdot T)}{dt} = (1 - x_{evap}) \frac{\Delta H}{cp_m} \cdot \frac{d(S \cdot H)}{dt} - \frac{A_{ef} . U . (T - T_{amb}) + Q_{ref}}{cp_m A_F}$$

RESULTS AND DISCUSSION

Influence of upgraded and reduced biomass/nitrogen yield coefficient YX/N on ending time, maximal refrigeration cooling or maximal reached temperatures was described in table 2. This table represents deviations between our two borders, which had been chosen as a measure of possible deviation from real YX/N, calculated from equation as a dependency from initial nitrogen concentration. We chose deviation 20%, 10% and 5% from calculated value for nitrogen level of 140 mg/l, 180mg/l and 280 mg/l, respectively.

Results for fermentation without refrigeration cooling shows, that highest possible deviation between upgraded and reduced value of YX/N is only 2,4°C (sugar 280 g/l, nitrogen 140 mg/l) and decreases with increasing nitrogen concentration and decreasing sugar concentration to the smallest deviation 0,5°C (sugar 160 g/l, nitrogen 280 mg/l). Although effect of YX/N is not so serious in temperatures, his influence becomes greater comparing time, when temperature peaks were reached. Deviation in this time between upgraded and reduced value of YX/N decreases with increasing level of sugar and nitrogen. This effect is more visible at lower sugar concentrations. Deviation in ending time between upgraded and reduced value of YX/N is 4-5 times greater at high sugar concentration compared to the low sugar concentration. Slightly higher sensitivity can be found at nitrogen concentrations. Deviation in ending time between upgraded and reduced value of YX/N is approximately 6 times greater at low nitrogen (140 mg/l) than at high nitrogen (280 mg/l).

Results for fermentation carried out entirely at 16°C shows, that possible deviation in ending time between upgraded and reduced value YX/N decreases as nitrogen increases and sugar increases. Comparing only nitrogen it is approximately 6 times greater at low nitrogen than at high nitrogen. Comparing only sugar it is approximately 3,4 times greater at high sugar concentration than at low sugar concentration.

Last column in Table 2. where are stated values, that represent maximum reached refrigeration cooling during fermentation could be helpful for winemakers to ensure, if they have enough refrigeration cooling (it is reasonable to take into account worse case, to maintain desired temperature).

Table 2. Influence of upgraded and reduced biomass/nitrogen yield coefficient YX/N.

Sugar [g/l]	Nitrogen [mg/l]	Without refrigeration cooling						Refiigration cooling			
		YX/N reduced			YX/N upgrated			YX/N reduced		YX/N upgrated	
		T_{Max}	t (T_{Max})	t (end)	T_{Max}	t (T_{Max})	t (end)	t (end)	$P_{ref,max}$	t (end)	$P_{ref,max}$
		[°C]	[h]	[h]	[°C]	[h]	[h]	[h]	[kW]	[h]	[kW]
160	140	22.2	84,2	157,8	23,9	76,7	114,1	190,7	2,08	141,6	2,77
	180	23.2	79,2	128,5	24,1	75,5	110,3	158,3	2,52	137,3	2,90
	280	24.1	74,7	109,0	24,6	73,0	101,6	135,9	3,01	126,9	3,22
210	140	22.5	93,3	227,0	24,7	86,7	154,7	278,1	2,11	200,1	2,81
	180	23.8	89,3	178,8	24,9	85,3	148,8	226,9	2,56	193,4	2,95
	280	25.0	84,5	147,1	25,5	82,2	134,8	191,5	3,06	177,3	3,68
280	140	22,7	99,8	513,1	25,1	95,5	308,1	501,0	2,13	325,3	2,84
	180	24,1	98,3	372,0	25,4	94,0	293,9	382,2	2,59	312,3	2,98
	280	25,5	93,2	290,5	26,2	90,8	260,0	309,1	3,09	280,8	3,31

In order to show how YX/N andΔH affect temperature peak over changing fermenter volume, we upgraded only one of these values and kept all other constant. Increase in YX/N depends on initial available nitrogen concentration, whereas increase in ΔH is constant for all cases (20%). Influence of both separately is shown in Figure 1.When we look at Figure 1., we will conclude, that influence of upgraded YX/N is always the almost same, no matter if fermenter is larger or not. Compared to the original YX/N, results with upgraded value show an increase of 3,4 % (0,8 °C), 2,2 % (0,5 °C), 1,3% (0,5 °C) for high sugar/high nitrogen, normal sugar/normal nitrogen, low sugar/low nitrogen, respectively.

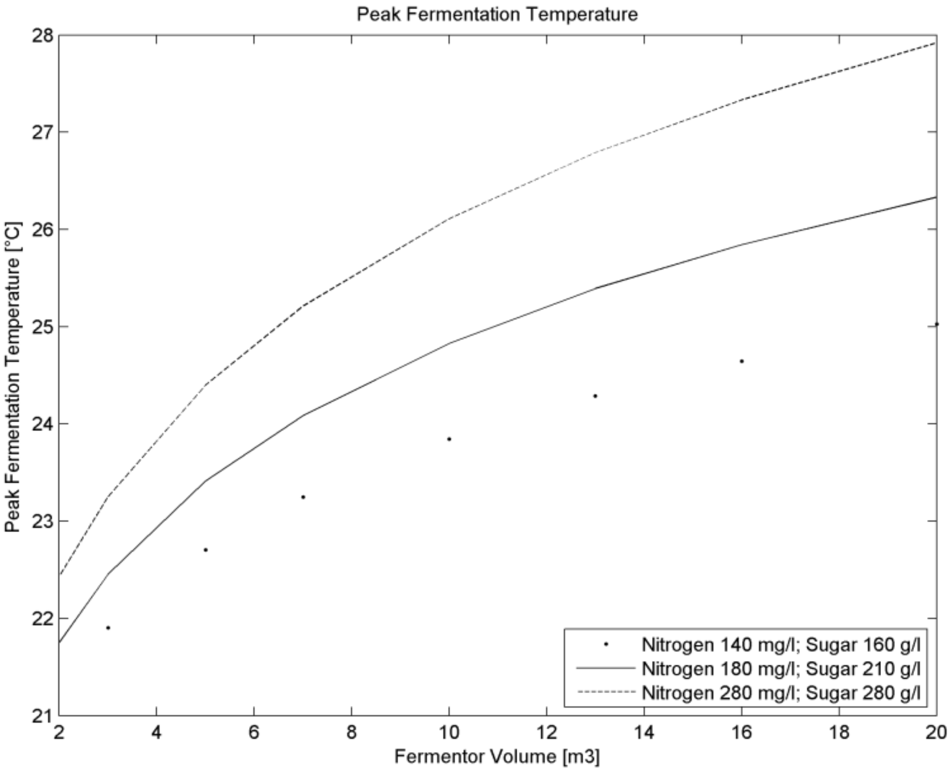

Figure 1. Maximum temperatures reached during fermentation (upgraded YX/N).

Figure 2 shows maximum refrigeration cooling capacity, that is needed to maintain temperature at 16 °C during entire fermentation when both constants (ΔH and YX/N) are upgraded in order to achieve results, that represents some border beyond which is unlikely to get, in real situations.

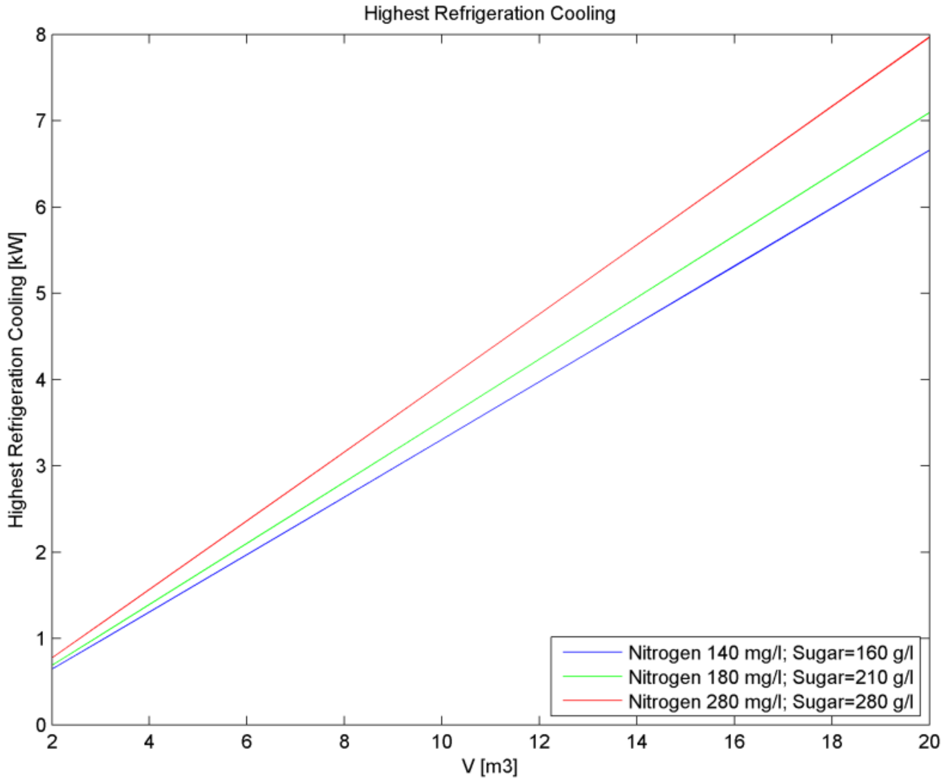

Figure 2. Maximum refrigeration cooling needed to maintain temperature at 16°C during entire fermentation (upgraded ΔH and upgraded YX/N).

Savings in energy consumption during fermentation process can be derived by properly managing of ambient temperature. We could let our cellar opened at night and closed during the day and thereby we could achieve slightly lower average in ambient temperature. Current situation is, that in the cellar is approximately 15°C. When we look at Table 3. we can see, that if we could maintain average temperature at approximately 12°C, we would obtain a saving about half of our current energy consumption[5].

Table 3. Influence of ambient temperature on energy requirements

t_{amb} [°C]	Δt [°C]	Q_{ferm} [kWh]	Q_{ref} [kWh]	Q_{wall} [kWh]	$Q_{heating-up}$ [kWh]	$Q_{ref} + Q_{heating-up}$ [kWh]
15	1	279,0	240,5	22,4	0,0	240,5
14	2	279,0	197,2	65,8	0,1	197,3
13	3	279,0	154,9	109,7	1/7	156,6
12	4	279,0	117,0	154,3	8,4	125,4
11	5	279,0	86,8	199,5	23,4	110,2
10	6	279,0	63,0	245,3	45,4	108,4

CONCLUSIONS

We evaluated processing organic white wine called "Pinot gris" in one Slovak winery. Our results show, that influence of sugar concentration almost does not play a role in reached temperatures, compared to the increasing nitrogen concentration, For normal concentration of nitrogen and sugar, maximum temperature observed from the simulation for 2 m^3 fermenter is 21,3°C (an increase by 33 % in comparison to the initial temperature) and this temperature peak increases with increasing fermenter volume up to 25,8 °C (an increase by 61% in comparison to the initial temperature), when 20 m^3 fermenter is used.

SYMBOLS

A_F	fermentation tank base area, m^2
A_{ef}	effective heat transfer area of the fermentation tank, m^2
c_{pm}	must specific heat, J/kg/K
H	height of the must in fermenter, m
ΔH	metabolic heat, J/kg
Q_{ferm}	total heat released by fermentation, J
$Q_{heating\ up}$	total heat added to maintain fermentation temperature, J
Q_{ref}	total heat removed by refrigeration, J
Q_{wall}	total heat removed through the wall, J
S	total sugar concentration, kg S/m^3
t	time, s
T	temperature, K
T_{amb}	ambient temperature, K
U	heat transfer coefficient between must and ambient, W/(m^2 K)
$Y_{X/N}$	biomass/nitrogen yield coefficient
ρ	must density, kg/m^3

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