https://dx.doi.org/10.22161/ijaers.6.6.62 ISSN: 2349-6495(P) | 2456-1908(O)

Calculation of the Yield of an Alcoholic Fermentation

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***Abstract*— *This study is associated with a result of an industrial process in the measurement of fermentative efficiency using physico-chemical data obtained routinely in the laboratory. In Brazil, besides sugar, final molasses, which is a by-product of sugar production, is also used in the production of ethanol. The alcohol is obtained after the fermentation of the broth or a mixture of molasses and broth, which consists of a biochemical process. Before being sent to fermentation the broth should be purified. The results obtained in the laboratory showed that the fermentation presented a yield of 91.55% (CTC Method) and 91.39% (Fermentec Method), close yields from 86.3 to 93.4% quantified in two harvests (2010 and 2011) operating in batch fed as in the current work.*

***Keywords*— alcohol, fermentation, sugar and ethanol industry, ethanol methodology, fermentative yield.**

I. INTRODUCTION

According to Lima et al., (2001), alcoholic fermentation has three main phases: preliminary phase, tumultuous and final or complementary phase. In the industrial operation, in the fermentation, yields from 86.3 to 93.4 were quantified in two harvests “2010 and 2011” Andrietta et al., (2012) operating in batch fed as in the current work. Silva et al., (2017) report that in the 2014/2015 harvest in industrial processing, fermentation efficiency of 89.99% was obtained; in the 2015/2016 crop, 92.04% were obtained. This shows that the fermentative efficiency varies between different harvests. The importance of this study is the use of experimental industrial results obtained in the sugarcane harvest of 2017, and uses them in the quantification of the fermentative yield, as carried out in the industry. The objective of this work is to show the results of the experiment performed in the laboratory of sugar and ethanol plant, in 24 hours of operation, comparing the methods of CTC (2005) and Fermentec, Silva et al., (2003) in the evaluation of the yield of alcoholic fermentation.

II. METHODOLOGY

The methodology used in this study consists of the use of experimental data of an industrial process in operation, using them to obtain the fermentative yield of the process described below. The must to ferment must have the concentration between 19 and 23° Brix; thus, the mixed broth is standardized with the addition of residual molasses from the manufacture of sugar or syrup from the evaporators. Yeasts produce a set of enzymes that catalyze the fermentation reaction with conversion of the sugars into ethanol. The formation of other compounds occurs during fermentation, such as glycerin, succinic acid, amyl, isoamyl, butyl and other alcohols. In the alcoholic fermentation in Brazil, the use of the discontinuous Melle-Boinot system is common. The yeasts are reused after separation by centrifugation of the fermented must in two fractions. Yeasts are sent to an acid treatment tank for reuse. The reuse of yeasts in subsequent fermentations minimizes cell multiplication. Thus, the sugar consumed converts to ethanol. The centrifuged wine is stored in a flywheel and is then distilled. The physico-chemical methods used in the industry where the present study ware carried out was described in (Silva et al., 2003). Industry software uses the equations described in the document. The efficiency of the alcoholic fermentation ware obtained under the determination of the ethanol produced as a function of the Mass of Total Reducer Sugar, fed daily in the fermentation process or Residual Reducing Sugar of the dorna, with the practical equations used in the industry: "CTC" and "Fermentec".

After carrying out the primary sieving treatment, calcium hydroxide is added to the broth, following heating and subsequent decantation, treatment similar to that used in the manufacture of sugar. The cooling of the broth is carried out in two stages: in a heat exchanger (regenerative) operating countercurrent with the cold mixed broth, the broth being cooled to about 60°C; final cooling to approximately 30°C, in plate changer with water flowing in countercurrent (COPERSUCAR, 2010). The fermentation, where the conversion of the sugars into

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ethanol takes place, was carried out, in most cases, in a discontinuous way in dornas. Yeasts produce a set of enzymes that catalyze the fermentation reaction. In spite of the complexity, for practical purposes one can represent the conversion according to the following steps:

• Saccharification: Consists of the hydrolysis of sucrose by the action of invertase.

$C_{12}H_{22}O_{11} + H_2O \rightarrow 2\ C_6H_{12}O_6$

• Alcoholic fermentation: Consists of the conversion of glucose and fructose into ethanol by the action of zymase.

$2\ C_6H_{12}O_6 \rightarrow 4\ CH_3CH_2OH + 4\ CO_2 + 47$ cal

Invertase and zymase are the enzymes produced by yeast. Formation of other compounds occurs during fermentation, such as glycerin, succinic acid, amyl, isoamyl, butyl, and other alcohols. In the alcoholic fermentation in Brazil, it is common to use the Melle-Boinot discontinuous system. Yeasts are reused after separation by centrifugation of the fermented must in two fractions: yeast milk and wine as shown in Figure 1.

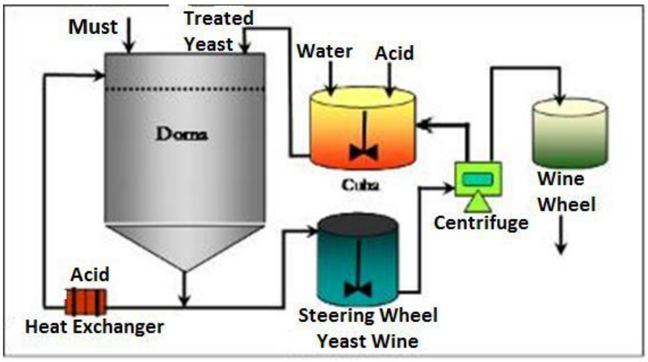

Fig. 1: Fluxograma da Fermentação Melle-Boinot (TANCREDO, 2010).

Using practical equations of CTC (2005), the experimental results allow to quantify fermentation yield and other parameters, such as yeast loss (kf); produced glycerol (kg); losses of total sugars (kart); acidity (kac), fermentative yield (RF).

Table 1. Results of analyzes

DESCRIPTION	UNIT	RESULT
Acidity in must (AM)	g/l	0.96
Yeast in the cuba (YC) (m/m)	%	40.15
Alcohol content in the cuba (ACC)	°GL	5.81
Acidity in the cuba (AC)	g/l	2.22
Yeast in the dorna (YD) (m/m)	%	11.99
Alcohol content in dorna (ACD)	°GL	9.85
Acidity in dorna (AD)	g/l	1.22
Glycerol in dorna (m/m)	%	0.37
Total Residual Reducing Sugar in Dorna (m/m)	%	0.21
Alcohol content in the steering wheel	°GL	9.74
Yeast content in the flywheel (m/m)	%	1.10
Conversion factor of yeast content in dry mass	-	0.33
Specific mass of alcohol at 100%	-	0.7893
Must volume	m³	7,749
Total Reducing Sugar in Must (TRSM) (m/m)	%	19.28
Volume of wine in the dorna	m³	10,808
Volume of yeast treated in the tank	m³	3,120
Volume of water in CO_2 washing (VW)	m³	432
Alcohol content in CO_2 washing water (ALC)	°GL	1.38
Volume produced of absolute alcohol (VPA)	m³	923

$$k_f = \frac{\text{Yeast content in the flywheel} \cdot 0.33}{\text{Alcohol content in the steering wheel} \cdot 0.7893} \quad (1)$$

$$k_f = \frac{1.10 \cdot 0.33}{9.74 \cdot 0.7893} = 0.0472 kg/kg$$

$$k_g = \frac{\text{Glycerol in dorna}}{\text{Alcohol content in the steering wheel} \cdot 0.7893} \quad (2)$$

$$k_g = \frac{0.37}{9.74 \cdot 0.7893} = 0.0481 kg/kg$$

$$k_{art} = \frac{\text{Total Residual Reducing Sugar in Dorna}}{\text{Alcohol content in the steering wheel} \cdot 0.7893} \quad (3)$$

$$k_{art} = \frac{0.21}{9.74 \cdot 0.7893} = 0.0273 kg/kg$$

$$k_{ac} = \frac{[AD - ((\frac{\%YD}{\%YC}) \cdot AC) - ((1 - \frac{\%YD}{\%YC}) \cdot AM)]}{[\frac{ACD}{100} - ((\frac{\%YD}{\%YC}) \cdot \frac{ACC}{100})] \cdot 789.3} \cdot 1.837 \quad (4)$$

being: YD = yeast in the dorna; YC = yeast in the cuba; AD = Acidity in Dorna; AC = Acidity in the Cuba; ACD = Alcohol Content in Dorna; ACC = Alcohol Content in the Cuba; AM = Acidity in Must.

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$$k_{ac} = \frac{[1.22 - ((\frac{11.99}{40.15}) \cdot 2.22) - ((1 - \frac{11.99}{40.15}) \cdot 0.96)]}{[\frac{9.85}{100} - ((\frac{11.99}{40.15}) \cdot \frac{5.81}{100})] \cdot 789.3} \cdot 1.837 = -0.0033 Kg/Kg$$

$$RF = \frac{100}{(1 + 1.19 \cdot K_f + 0.50 \cdot K_g + 0.51 \cdot K_{ac} + 0.51 \cdot K_{art})} \quad (5)$$

$$RF = \frac{100}{1 + 1.19 \cdot 0.0472 + 0.50 \cdot 0.0481 + 0.51 \cdot (-0.0033) + 0.51 \cdot 0.0273}$$
$$= 91.55\%$$

The system of calculation of yield using the Fermentec method, Silva et al., (2003) uses the equations:

$$\text{Liters of recovered alcohol } CO_2 = \frac{VW \cdot ALC \cdot 100}{VPA} \quad (6)$$

being: VW = volume of water in CO_2 washing; ALC = alcohol content in CO_2 washing water; VPA = Volume produced of absolute alcohol.

$$\text{Liters of recovered alcohol } CO_2 = \frac{(432 \cdot 1.38) \cdot 100}{923}$$
$$= 74.42 m^3$$

$$APF = ([1] \cdot [2]) - ([3] \cdot [4]) + [5] \quad (7)$$

being: APF = Alcohol Produced in Fermentation; [1] Volume of wine in the dorna; [2] Alcohol content in dorna; [3] Volume of yeast treated in the tank; [4] Alcohol content in the cuba; [5] Liters of recovered alcohol CO_2.

$$APF = (10,808 \cdot 9.85) - (3,120 \cdot 5.81) + 74.42 = 88,406.02 m^3$$

$$RF = \frac{APF}{(Must\ volume \cdot TRSM \cdot 0.006475)} \quad (8)$$

being: TRSM = Total Reducing Sugar in Must.

$$RF = \frac{88,406.02}{(7,749 \cdot 19.28 \cdot 0.006475)} = 91.39\%$$

III. RESULTS AND DISCUSSIONS

With the physicochemical analyzes performed in the laboratory to monitor the entire industrial process, the industrial results shown in Table 1 are reached.

The two calculation methods "CTC and FERMENTEC" presented similar results. Therefore, both methods are suitable for quantifying the fermentative yield. In addition, the results were close to the upper limit of the range reported in the literature: 86.3 to 93.4% (Andrietta et al., 2012).

The final fermentative yield of the CTC and Fermentec Methods were 91.55% and 91.39%, respectively. These results are used in the manufacture of ethanol, in process control, when fermentative efficiency is reduced.

IV. CONCLUSION

With the results of the analyzes presented in Table 1, used in the previous equations, the fermentation presented a yield of 91.55% (CTC Method) and 91.39% (Fermentec Method), close to the higher values obtained in ethanol plant in Brazil, which is 86,3 to 93,4%. The result shows the importance of obtaining data from the units with the physicochemical analyzes to obtain the efficiency of the process.

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