A SUPERVISORY CONTROLLED SYSTEM FOR BEER RECOVERY FROM SURPLUS YEAST PROCESS

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ABSTRACT

In the manufacture of beer production, the quality of beer and economical operation play key roles. The yeast slurry which is the output product of fermentation process normally at the rate of 2-3% excess to the desired amount. However, such yeast contains 40-70% beer. This substantial proportion of beer must be recovered in economical managed process by applying centrifugal separation technology in beer recovery from surplus yeast process. This process will improve cost-effectiveness without changing the beer quality. The process outputs are approximately 60% beer and yeast. Currently, many breweries in Vietnam do not have such system. This fact motivates us to study and propose solution for beer recovery from surplus yeast process with the supervisory controlled system.

Keywords: *disc stack centrifuge; beer recovery; surplus yeast; supervisory controlled system; solid-liquid separation*

INTRODUCTION

In Beer production process, there is a need of economical and optimal operation in order to reduce wasting of resources. One of the effective solutions is using the beer recovering system from the surplus yeast process. From the fact that each beer production batch produces an excess of yeast (surplus yeast) volume amounts to ~2-3% of the production volume and about 50% of this volume can be recovered as in form of beer. This beer can be returned to beer production process meanwhile the yeast can be served as animal food. The recovering beer from the surplus yeast mixture has been studied and successfully applied in some breweries in the world such as Molson Coors, Heineken, ABInbev, Carlsberg etc., but non of breweries in Vietnam has such system yet. By integrating some sort of recovery system, the company has reduced significant duty-paid beer losses and increased the cost-effective without changing beer quality. With breweries becoming larger and waste disposal costs increasing, recovering high quality beer from yeast is again becoming a real topic for debate. Recovered beer quality is defined by flavour (yeast autolysis), remaining yeast cells, O2 pickup, filterability and microbiological stability [1]. Many different techniques are available to recover the valuable beer component from this yeast. Each provides different results in terms of beer quality, eases of handling and financial payback. The traditional techniques are belt and chamber filter presses [3] that are no longer commonly used due to the difficulty in cleaning the plant or the risk of including microbiological contamination. The usual techniques are centrifugation or filtration [4] which can overcome the disadvantages of the belt and chamber filter presses. In this paper, the techniques that we studied is centrifugation. It allows to recover high quality of beer (high yeast vitality, high clarification, low O_2 pickup) and increases yeast autolysis due to the gentle yeast treatment.

The whole process for beer recovering is described in *Fig. 1*. Surplus yeast with 66.3% volume fraction is taken from tank and mixed with degassed water. There is a linear pump on each pipe to ensure that the volume fraction of yeast before flows into centrifuge reaches 45.6%. Yeast flowrate and degassed water flowrate are measured and sent to PLC by sensors. The total inlet flowrate is 30.0 hl/h. The separator used in the system is BRUX 510, a continuous discharging disk stack nozzle centrifuge provided by Alfa Laval.

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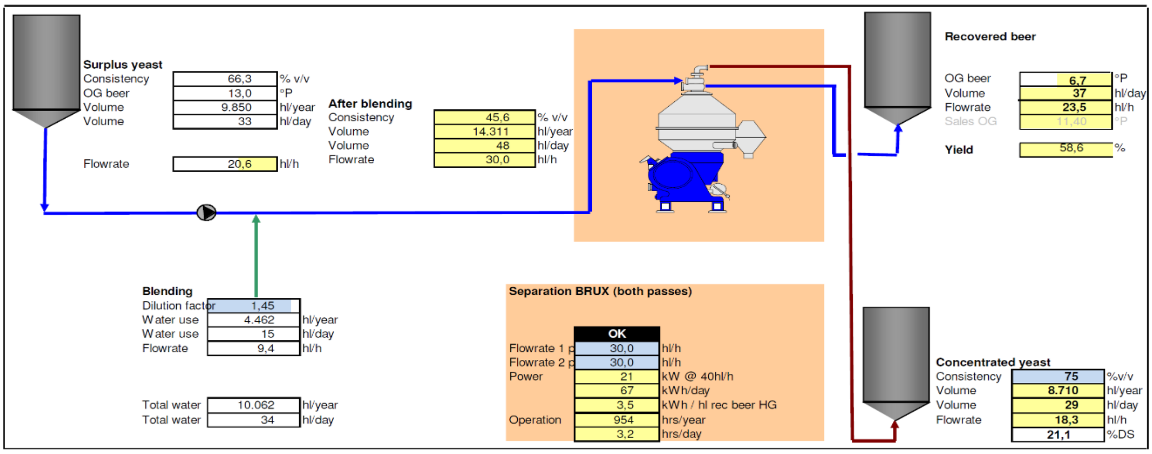

Figure 1. *Flow diagram of the beer recovering process*

The yeast is forced to the periphery of the BRUX 510 separator. From there, it is pushed through special concentrate tubes towards the center to vortex nozzles, from which it leaves the separator under pressure, via a built-in paring tube. Special vortex nozzles automatically regulates the flow of the concentrate. Thus, yeast is treated very gently. The beer is clarified on the disc stack and leaves the separator under pressure through paring disc and Oxy-Stop [2]. Outlet products of the centrifuge is separated into 2 pipes: concentrated yeast and recovered beer. After that, the concentrated yeast with 75% volume fraction flows through pipe to continuous hydrolysis system or for other uses.

DESIGN OF A CONTROL SYSTEM FOR BEER RECOVERY PROCESS FROM SURPLUS YEAST

Problem statements

Control objectives of the beer recovery from surplus yeast process are namely process sequential control, disc stack centrifuge control which determines angular speed of rotor of the disc stack centrifuge and maintain the density of concentrated yeast at the desire value.

The process sequential control problem focuses on manipulate the operation of the whole plant. This operation is separated into three stages. First, the controller will start up the process, open valves to let water flows in and cleans the centrifuge. Then, the controller will open valves to pump the mixture of surplus yeast and degassed water to centrifuge, maintain the plant at the operation point despite of the disturbance. The final stage of the operation is CIP, clean and make the plant ready for the next batch.

The disc stack centrifuge control only focuses on the separation process. Because the dynamic behavior of plant and the motor with the adjustment of angular speed is fast enough, the main purpose is to find the appropriate angular speed that manipulate the volume fraction of concentrated yeast in the outlet which need to be at rate of 75%, in other words, separation efficiency is 100%. The other control variable of the centrifuge controller is the density of concentrated yeast which is calculated through a quantity called dry fraction [5].

Determination angular speed of rotor of disc stack centrifuge

According to Ladislav Svarovsky in *Solid-Liquid Separation 4th edition 2000* [6], this type of centrifuge contains a stack of conical discs, as shown in *Fig. 2*. The surplus yeast mixture is fed through the center, passed underneath the disc stack and into the space between the stack and the wall of the bowl while both the stack and the bowl are rotating at a speed ω. The liquid then flows in thin layers between discs, radially inwards, towards the outlet, which is an annulus at the top center. Yeast particles settle on the lower surface of the upper of the two discs. The settling motion of the yeast particles is the first stage of the separation process. The second stage is the downward-outward sliding motion of the parrticles on the disc surface towards the disc periphery and their subsequent impingement on the wall of the bowl.

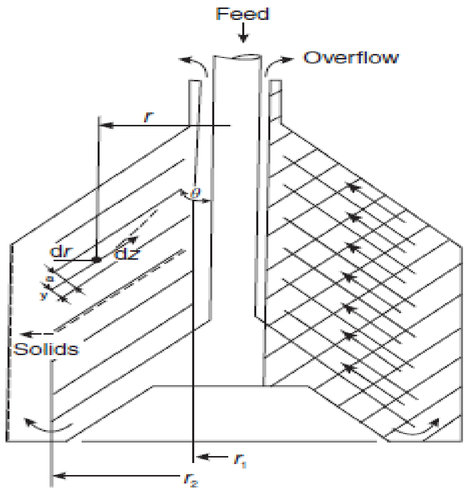

Figure 2. *Schematic diagram of a disc stack centrifuge. (r_1,r_2-outer and inner radius of disc; θ- half the included angle of the discs; a-clearance between discs; z-direction of flow axis; y-perpendicular axis to the z axis)*[6]

The flow of the continuous liquid-phase beer containing solid particles-yeast cells to be separated, is assumed to be evenly divided between the spaces formed by discs. The flow in each disc space is therefore *Q/n* where *Q* is the total flow through the entired disc stack and *n* is the number of discs. The flow of the liquid phase is also assumed to be in a radial plane and directed parallel to the surface of the rotating discs or, in other words, to have the same angular velocity as the disc stack. Under these conditions, the velocity of a yeast cell with diameter *x* at radius *r* from axis of rotation can be resolved into two components: the radial velocity *dr/dt*, which can be approximated by *Stokes' law*, and the velocity in the direction of flow *z: dz/dt*, which can be approximated by the velocity of the liquid at that point.

$$\frac{dz}{dt} = \frac{Q}{2\pi nra} = -\frac{dr}{dt\,sin\theta} \quad (1)$$

$$\frac{dy}{dt} = \frac{dr}{dt}cos\theta = Kx^2rcos\theta \quad (2)$$

Where *a* is the perpendicular clearance between the adjacent discs. θ is half the included angle of the discs and *y* axis is perpendicular to the *z* axis. *K* is a sedimentation constant defined by

$$K = \frac{\Delta\rho\omega^2}{18\mu} \quad (3)$$

Where Δρ is density difference between yeast and beer, *ω* is angular speed of rotor and *μ* is beer viscosity. From (1) and (2) we have

$$\frac{dy}{dr} = -Kx^2r^2\frac{2\pi na}{Q}cot\theta \quad (4)$$

Integrating Eq. (4) between the limit $y=y_1$ at $r=r_2$ and $y=a$ at $r=r_1$ determines the distance y_1 from bottom of plate at which yeast cells can just reach the top disc after covering full length of the space between the discs:

$$a - y_1 = Kx^2\frac{2\pi na}{3Q}cot\theta(r_2^3 - r_1^3) \quad (5)$$

For the separation efficiency is 100% which means all the yeast cells must reach the top disc before flow fully length of space, Eq. (5) must satisfy with $y_1=0$.

$$a = \frac{\Delta\rho\omega^2}{18\mu}x^2\frac{2\pi na}{3Q}cot\theta(r_2^3 - r_1^3) \quad (6)$$

Thus, we obtain the angular speed of rotor:

$$\omega = \sqrt{\frac{27\mu Q}{\Delta\rho x^2\pi ncot\theta(r_2^3 - r_1^3)}} \quad (7)$$

With the real parameters: Δρ=1459000 kg/m^3, *n*=12, *cot*θ=1, *x*=10 μm, *Q*=30 hl/h, *μ*=16000, r_2=2.1 m, r_1=0.15 m, we obtain

$\boldsymbol{\omega = 148.9 rad/s = 1421.7 rpm}$

as system desired operation parameters for the angular speed of rotor.

Eq. (7) allows us to determine the appropriate angular speed of rotor that makes the separation efficiency reaches 100%. Notice that, the higher angular speed is, the faster the plant performance will reach the desire efficiency. But there is a possibility that it will make the the liquid flow in centrifuge may not be stable and affect to yeast cells. Therefore, it is necessary to the set value for the angular speed of rotor to $\boldsymbol{\omega = 148.9 rad/s = 1421.7 rpm}$.

Design of the controller for the disc stack centrifuge

An important task while designing the controller for disc stack centrifuge is to maintain the density of concentrated yeast at the desire value. The density of concentrated yeast is related to the dry fraction according to equation (8), given in [7]

$$\rho_H = \frac{\rho_1 \rho_2}{x_H(\rho_L - \rho_1) + \rho_1} \qquad (8)$$

where ρ_1 is the density of 100% yeast when dried (approximately 1.460 kg/dm^3), ρ_2 is assumed to be 1kg/dm^3 (pure water), ρ_L=1.006 kg/dm^3 is the density of light phase outlet (recovery beer) and ρ_H=1.070 kg/dm^3 is the desire density of fluid (concentrated yeast). After caculation, the dry fraction of fluids x_H is the control variable that the controller have to maitain its value at 21.1%. Measuring the dry fraction of fluid, i.e. the percentage of the volume or weight of the fluid corresponding to completely dry yeast is a common way of quantifying how much yeast that fluid contains. Only the dry fraction which is greater or equal to 24% is considered.

The mass balance of the yeast can be written as following in Eq. (9)

$$\frac{d(x_H)}{dt} = \frac{1}{m}(x_I Q - x_H q_H) \qquad (9)$$

Where controlled variable, Q, q_H are the flowrate of the mixture inlet and outlet,x_I, x_H are the dry fraction of the mixture inlet and outlet, m is the mass of the volume containing yeast and beer. It is here assumed that there is perfect separation, i.e. $x_L q_L \approx 0$ with x_L, q_L are the dry fraction and flowrate of the light phase which means the recovery beer.

Use Laplace transform for equation Eq. (9) and obtain the transfer function

$$G(s) = \frac{X_H(s)}{Q(s)} = \frac{k_1}{k_2 s + 1} \qquad (10)$$

Where $k_1 = x_I/q_H = 1.16$; $k_2 = m/q_H = 54.64$. Eq. (10) has first-order form, the next step is to design the PI controller.

The transfer function of PI controller and the open-loop control system are $R(s) = k_p(1 + 1/(T_I s))$ and $G_h(s) = R(s)G(s) = k_p k_1(1 + T_I s)/(T_i s(1 + k_2 s))$ correspondently. Thus, the transfer function of closed – loop control system is

$$G_k(s) = \frac{G_h(s)}{1 + G_h(s)} = \frac{1 + T_I s}{\frac{T_I k_2}{k_p k_1} s^2 + T_I\left(1 + \frac{1}{k_p k_1}\right)s + 1} \qquad (11)$$

Assume that the transfer function of closed – loop control system is

$$G_k(s) = \frac{1}{1 + T's} \qquad (12)$$

We need to find the PI parameters that makes the closed-loop system stable at small frequency domain Ω. The smaller *T’* is, the wider Ω we receive.

$$\Omega = \{\omega \in R^+ | |G_k(j\omega)| \approx 1\} \qquad (13)$$

To get (12) from (11), the first step is to determine k_p, T_I of $G_k(s)$ in *Eq. (11)* and the zero point is $s=1/T_I$. That means $s=1/T_I$ satisfies denominator of *Eq.(11)*. Thus, we obtain $T_I=k_2$, replace and compare *Eq(11)* with *Eq(12)*, we receive $T' = k_2/(k_p k_1)$ and k_p has a big value. In this case, we chosse T_I= 54.64 and k_p=100. The step respose after simulation in MATLAB is shown in *Fig.3*.

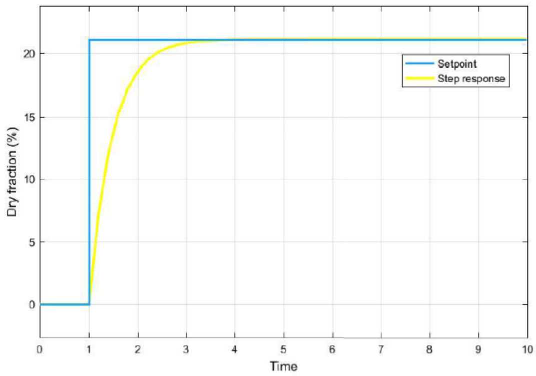

Figure 3. *Closed-loop response*

A supervisory controlled system for beer recovery process from surplus yeast

For operational and supervisory control functions of the system, Siemens solution with Programmable Logic Controller (PLC) S7 1200 and TIA Portal V13 is chosen . The configuration for the control system is listed as following: CPU 1214C [8] connected to

WinCC screen through Profinet Interface. There are 12 inputs of PLC which are pressure and flowrate of concentrated yeast, recovery beer, degassed water mixture yeast-water before and after diluted, dry fraction of yeast mixture flows in and discharged from centrifuge. The outputs of PLC are the state of actuators that are 2 linear pumps and 11 valves.

The integration system is depicted in the main screen of the HMI in *Fig. 5* with all process equipments and sequential operation follows the scheme denoted in *Fig.4*. The system requirements are summaried in *Table 1.*

The inputs of the process are surplus yeast, degassed water, CO2 and water. The outputs of the process are recovered beer and concentrated yeast return to the storage tank. On this supervisory screen, the operator can choose the proper mode to control the system and keep updated with the real time values of the process parameters. In addition, there are report and trending options as well as system diagnosis for management and maintainance planning.

Table 1. *System requirements*

	Input	
Surplus yeast	Concentration (%v/v)	66.3
	OG beer (oP)	13
	Flowrate (hl/h)	20.6
Degassed water	Flowrate (hl/h)	9.4
	Output	
Concentrated yeast	Concentration (%v/v)	75
	Flowrate (hl/h)	18.3
Recovery beer	OG beer (oP)	6.7
	Flowrate (hl/h)	23.5

The control algorithm of the three main stages of the beer recovery process are shown in (*Fig. 4*).

First, the operator presses START, the system jumps into Water Prerun mode. In which, only valve V5 is open to pump water through and clean the disc stack centrifuge. After a certain time interval elapsed, Running mode starts, Valve V2 and V3 are open and Pump P1, P2 pump yeast and degassed water for dilute surplus yeast to reach 45.6% volume fraction. Volume fraction of yeast before and after mixing with degassed water is measured by sensors and sent to PLC. PLC will calculate to have corresponding control signal for operating capacity of pumps. After that, the mixture flows down in centrifuge for separate yeast and beer. CO2 and water are fed to centrifuge separator by valve V4 and V5. As the output of centrifuge, recovered beer and concentrated yeast follow the pipes, discharged through valve V14 and V15. When the mode CIP (Clean In Place) is chosen, system state jumps into Clean Pipe mode. All valves for supplying water, CO2, degassed water, inlet yeast and outlet beer are closed. CIP mode works with Valve V1 opens and pump P1 on correspondingly. At the end of this mode, valve V12 and V13 is open for CIP returning process.

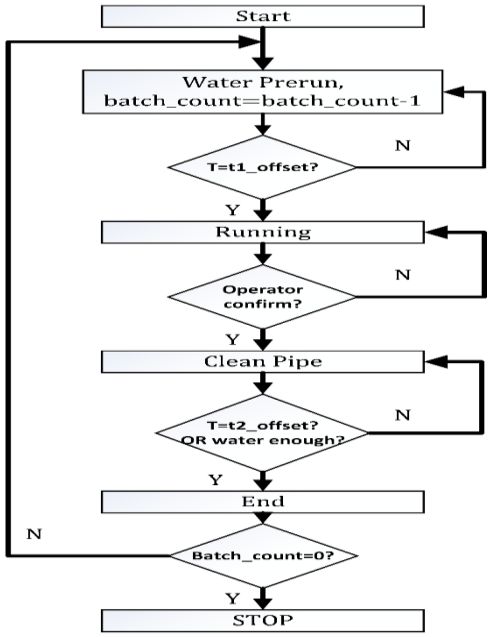

Figure 4. *Sequential operation of the Beer recovery process*

RESULTS AND DISCUSSIONS

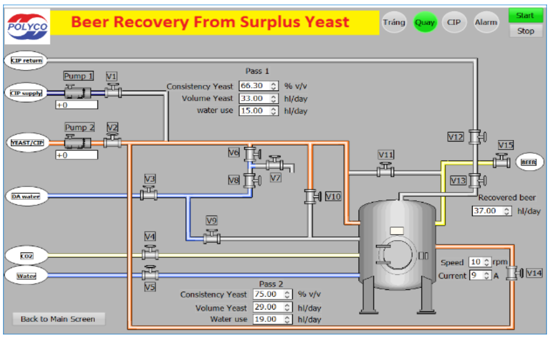

Figure 5. *The main HMI screen of the beer recovering system*

Obiviously, compare to the quality of the PI turning by modulus optimum method [9], the proposed PI controller is more flexible because the bigger k_p parameter we chosse, the wider Ω we receive. Moreover, the closed-loop control system is stable and without overshoot.

CONSCLUSIONS

Based on the high demand of effective and high proficiency of beer production process, the beer recovery from surplus yeast system is a good solution and can widely applied. The centrifugal separation technology with the continuous discharging disk stack nozzle centrifuge is carefull studied and the proposed controlled system are presented in this paper. From the working principle and mathematical model, the appropriate angular speed of rotor of the centrifuge is determined for efficiency operation. The simulation result showed the closed-loop system with proposed PI controller for the density of the dry fraction of concentrated yeast work properly. A supervisory controlled system for beer recovery process from surplus yeast is derived meets all system demands.

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TÓM TẮT

THIẾT KẾ HỆ THỐNG ĐIỀU KHIỂN GIÁM SÁT CHO QUÁ TRÌNH THU HỒI BIA TỪ BÃ MEN BIA DƯ THỪA

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Trong ngành công nghiệp sản xuất Bia, chất lượng sản phẩm, quá trình vận hành tối ưu và kinh tế là yếu tố rất quan trọng. Bã men thừa sau công đoạn lên men bia chiếm 2-3% dung tích. Tuy nhiên, bã men này lại chứa 40-70% dịch bia. Tỷ lệ bia từ bã men này có thể được thu hồi khi áp dụng công nghệ tách ly tâm. Phương pháp này được chứng minh mang lại hiệu quả kinh tế đáng kể mà vẫn ổn định chất lượng của Bia. Sản phẩm đầu ra sau quá trình tách là dịch bia có thể hồi lưu lại tank và bã men thải có thể được dùng làm thức ăn chăn nuôi. Tuy giải pháp này đã được áp dụng ở một số nhà máy Bia lớn trên thế giới nhưng lại chưa được tích hợp tại các nhà máy bia tại Việt nam. Thực tế này đã đặt ra bài toán nghiên cứu, thiết kế hệ thống điều khiển giám sát quá trình thu hồi bia từ bã men thải để ứng dụng cho các nhà máy bia tại Việt nam được trình bày trong bài báo này.

Từ khóa: *máy li tâm dạng đĩa; thu hồi bia; bã men dư thừa; hệ thống điều khiển giám sát; sự tách chất rắn-lỏng*

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