Analysis on Availability of the Carbon Element in Alcohol Production

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Abstract: According to the concept of circular economy, the mass integration of alcohol production was investigated though the analysis of the carbon element contained in raw material cassava. Through the mass integration, the distillage wastewater turned into carbon resource and produced a great deal of by-product biogas while its chemical oxygen demand (COD) was reduced from 50000 mg/L to not more than 300 mg/L, the local secondary effluent standards, and other by-products such as CO_2 (liquidized) and fusel oil were recovered. In the way, the consumption of raw material was only 2.2 tons cassava to produce 1 ton alcohol (96%, φ) in the case study, much lower than the average level 2.92 t/t in China. The carbon element balance for production of alcohol was made through testing the concentrations of the carbon element of all mass flows. The results showed that the mass integration helped the availability of the carbon element increased from 44.74% to 64.75%.

Key words: alcohol production; cassava; carbon element; circular economy

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1 INTRODUCTION

Alcohol distillery is an industrial sector, which consumes great amount of raw material, water and energy. The average consumptions of one ton alcohol (96%, φ) are 2.7~3.1 tons of raw material, 102 tons of water and 217 kW·h of electricity, meanwhile 10~12 tons of the distillage with COD as high as 50000 mg/L are obtained[1,2].

The alcohol output reached 3 million tons in China in 2004. It meant more than 30 million tons of the distillages were resulted. It would be serious problem if they were discharged directly. Under the pressure of the laws of environmental protection, many small alcohol distilleries have been closed since 1990s because they could not solve the severe pollution.

2 CIRCULAR ECONOMY

The circular economy and many similar concepts practised in different countries are evolved from decades of worldwide efforts in searching for economic development that is in harmony with natural environment, its principles are 'reduction, reuse and recycle'[3].

Reduction is a method aiming at reducing the input material and energy flows into the production and consumption processes. Reuse is a method concerning processing. We should try to use natural resources and products in every possible way. Recycle is a method concerning output. Turning wastes to secondary resources reduces the wastes for final disposal in volume and decreases the consumption of natural resources. These will help to close the economy loop.

Contrary to circular economy, conventional industrial economy is a one-way linear economy, which is 'resource→ production→ consumption→ disposal'. Undoubtedly, this linear economic development is based on the cost of 'high exploitation, low utilization and severe pollution'.

According to the principle of circular economy, based on an intensive mass integration in Xintai Alcohol Distillery in Taicang (Xintai, as follows), the case study on the availability of the carbon element contained in raw material cassava was researched.

3 MASS INTEGRATION OF ALCOHOL PRODUCTION

3.1 Background of the Case Study

Before 1998 the wastewater distillage of Xintai was discharged directly into a river, sharing 70% total amount of COD discharged by all local industrial sectors. When the national project on renovating Taihu drainage area was launched in 1998, Xintai began to set up the distillage treatment system, consisting of digestion tank, upflow anaerobic sludge blanket (UASB) and sequential biological reactor (SBR) to reuse the carbohydrates contained in it and eliminate pollution. In 2003 it consumed 133000 tons of cassava to produce 45500 tons of alcohol, and obtained 20000 tons of liquidized CO_2 and 13 million cubic meters of biogas.

The basic processes of producing alcohol include 5 steps: milling, cooking, saccharification, fermentation and distillation. Xintai possesses two auxiliary

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installations, one is cogeneration power station, generating electricity and vapor for its alcohol production; another is the distillage treatment system, as showed in Fig.1.

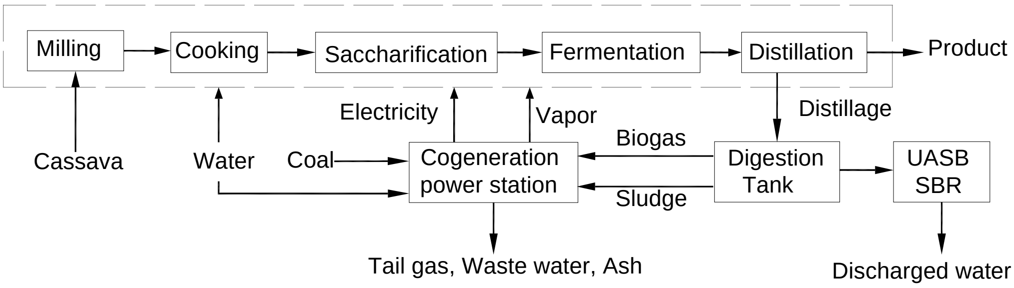

Fig.1 The flow chart of alcohol production in Xintai

3.2 Mass Integration

3.2.1 Input reduction of raw material cassava

The cassava is roughly made up of 65% starch, 20% vegetable fibre, and 15% other things, including water, protein and soil. It is usually considered that the starch with small part of fibre is fermented into alcohol, and the rest is decomposed into various kinds of other organic compounds, which are the main pollutants of the distillage. The reaction equations are shown as follows:

$$\text{Starch} \rightarrow C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2\uparrow. \quad (1)$$

Side-reaction:

$$\text{Some part of fibre} \rightarrow C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2\uparrow, \quad (2)$$

$$\text{Other carbohydrates of cassava} \xrightarrow{\text{Decomposition}} \text{distillage}. \quad (3)$$

Taking the advantage that some yeast could decompose more vegetable fibre into glucose, Xintai mixed the cassava residues, from which the starch was extracted but rich in fibre, with raw material cassava to produce alcohol.

Converting the cassava residues into cassava input, Xintai only consumed 2.22 tons cassava to produce 1 ton alcohol (96%, φ). In this way, natural resource of cassava was saved, and the waste of starch-production facility was reused as secondary resource.

3.2.2 Reuse and recycle of by-products

In the fermentation process, a great deal of CO_2 is generated according to Eq.(1). Such CO_2 is a safe auxiliary substance for drink and food production. Recycling CO_2 is not only profitable, but also helpful to reduce CO_2 emission, which results greenhouse effect. Xintai collected and liquidized 20000 tons of CO_2 in 2003.

During the distillation process, about 600 kg/d fusel oil is obtained. It is a kind of organic compounds and will result in photochemical effect. Collecting fusel oil brought about the benefits of economy and environment.

In milling process, usually alcohol distillery uses dry process with the apparatus of 1, 2 and 4 (see Fig.2) to separates cassava powder by pneumatic-conveyor gas. After separated by cyclone collector (1), the powder (S) at the bottom of collector (1) is mixed with spent cooling water (L) for cooking, and the gas coming out on the top of collector (1) drawn by exhaust fan (3) and discharged as G2.

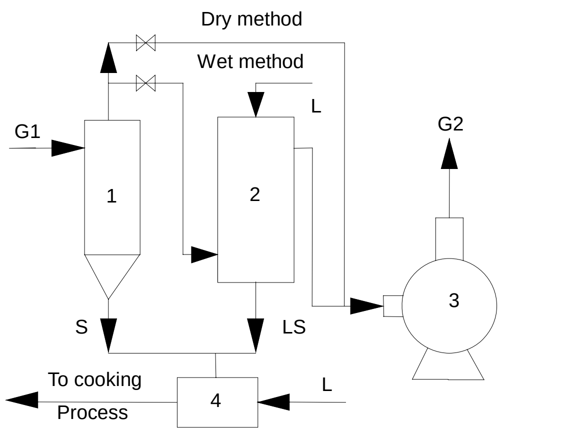

Fig.2 Dry/wet methods for separating cassava powder from gas

Equipped with advanced controlling technique, wet process (adding crashing tower) is applied to finish the same task (see Fig.2). After leaving cyclone collector (1), the gas flows into crashing tower (2) and is washed by spent cooling water (L), and discharged through exhaust fan (3); at the same time, the washing water containing cassava powder (LS) flows out at the bottom of crashing tower (2), and flows into the mixing tank (4).

Compared with dry process, the advantage of the wet process is taken to make exhaust gas cleaner and collect more cassava powder, and its disadvantage resulting secondary pollution of water is avoided, because the powder contained in exhaust gas is not useless and harmful pollutant but valuable raw material. The wet process helped Xintai reduce the input of cassava and eliminate the dust of exhaust gas.

3.2.3 Recycle at the pipe-ending

There are a lot of carbohydrates in the distillage. On one hand, they are pollutants; on the other hand, they would be resources if they were utilized.

With the help of the distillage treatment system (Fig.1), the carbohydrates are digested into biogas, then UASB and SBR continued to decompose carbohydrates in anaerobic and aerobic conditions to decrease COD to less than 300 mg/L, the local secondary effluent standards. Xintai yielded 37 m^3 biogas per ton of the distillage, much higher than the average level of 23 m^3/t in China[4]. It obtained 40000 m^3/d biogas and 100 t/d sludge, which were used as energy resources.

3.2.4 Integrated utilization of carbohydrates of cassava

All mass integrations carried out in Xintai are summarized in Fig.3.

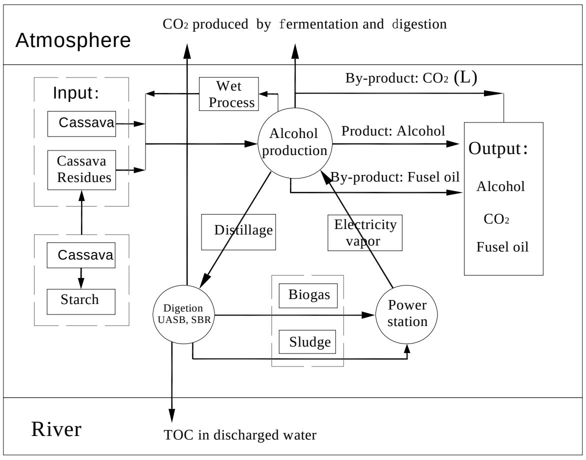

Fig.3 Integrated utilization of carbohydrates of cassava

Figure 3 shows that the raw material cassava is reduced, recycled and reused in alcohol production; only a small part of materials is discharged into water and atmosphere in the forms of total oxygen carbon (TOC) and CO_2.

4 ANALYSIS ON AVALIABILITY OF THE CARBON ELEMENT

In order to analyze the availability of cassava, the composition of the biogas and the concentrations of the carbon element in all mass flows were tested by the apparatus of SHIMADZU GC-14B and SHIMADZU TOC-VCPN. The experimental results are shown in Table 1 and Table 2.

Table 1 Composition of the biogas (%)

CH_4	CO_2	H_2	H_2O	Others
69	27	2.6	0.9	0.05

Table 2 Concentrations of the carbon element

Cassava mixture (%)	37.54
Dry sludge (%)	36.52
Fusel oil (mg/L)	6.45×10^5
Discharged water (mg/L)	285.7
Alcohol (%, φ)	96
CO_2 (L) (%, ω)	99.9

Making the element balance, the ratios of the carbon elements are calculated and the results are shown in Table 3.

Table 3 Ratios of carbon element in all mass flows

Substance	Mass flow rate (t/d)	TC (t/d)	TC (%)
Cassava mixture	450	168.9	100
Alcohol	154	75.6	44.74
CO_2 (liquid)	45	12.3	7.26
Fusel oil	0.6	0.5	0.27
CO_2 of biogas	450 (kmol/d)	5.4	3.19
Discharged water	1100	0.3	0.19
Biogas-sludge	100	7.3	4.32
CH_4 of biogas	1149 (kmol/d)	13.8	8.16

Note: TC means total carbon amount.

Table 3 shows that the sum of calculated amounts leaving the system was 68.13%. So it could be assumed that the rest (31.87%) exhaled from the fermentation and digestion diffuses into the atmosphere. Based on the assumption, the balance chart of carbon components is drawn in Fig.4.

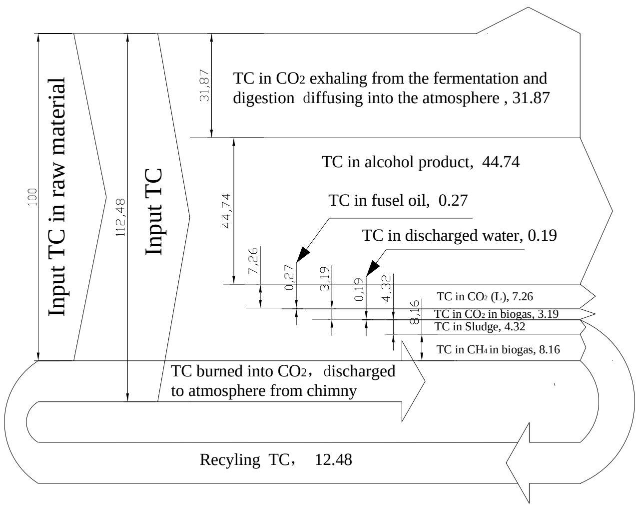

Fig.4 Carbon element balance of alcohol production

5 CONCLUDING REMARKS

(1) Achievements of circular economy on mass integration

By reducing, reusing and recycling raw material cassava in every possible way, the cassava consumption 2.22 t/t for production of alcohol in the case study was much less than the average level 2.92 t/t and the best level of 2.78 t/t. In addition, although the average concentration of starch in the feedstock was decreased due to addition of cassava residues, the total amount of carbohydrates was increased, that helped Xintai obtain more 14 m^3 biogas per ton of the distillage, and increased the availability of the carbon element by 3.19%.

(2) A ‘zero emission’ model for the alcohol distillery

With the help of the distillage treatment system, almost all organic wastes were recycled in forms of mass and energy. Only 0.19% carbon element was discharged into ambient water-body. If all alcohol distilleries in China implement the mass integration, our water environment would be improved immensely, because the total volumes of COD and biological oxygen demand (BOD) discharged by alcohol distilleries sharing respectively 18.0% and 12.5% volumes of all industrial sectors in China[5,6].

(3) Potential to improvement

Figure 4 shows that only 44.74% the carbon element was transformed into alcohol product, and recovering and reusing by-products increased its utilization rate by 20.01%. That means that the availability of raw materials in the process is 45% higher than those processes without reusing and recycling by-products.

In fermentation process 22.37% of carbon element was changed into CO_2 according to the reaction Eq.(1), and in the whole process 42.32% of carbon element became CO_2, but only 7.26% of CO_2 was recovered, 35.06% else emitted into the air. Limited by Eq.(1), it seems impossible to avoid a part of the carbon element becoming CO_2 unless a new reaction equation is found.

But there is a possibility to increase the conversion rate of fibre into alcohol, for instance, finding some new biologic enzyme from cows or sheep. If it could be done, the utility of carbon element would be improved significantly, because among the total carbon element, 44.74% changes into alcohol product, 22.37% becomes CO_2, the rest 32.89% is regarded as fibrous carbon element and goes into wastewater distillage. Now only 12.48% in the distillage is used in energy forms of biogas and sludge, and another part (20.31%) escapes into the air. That means that one fifths of cassava is wasted.

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