Cooling System in Ethanol Plant with Starch Base Feedstock

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Abstract

In the production of bioethanol from starch base feedstock, fermentation process is one of the most important factors in making the efficient plant operation. When bioethanol is produced from molasses, it is possible to have the fermentation temperature at 36°C due to osmotic pressure and cooling heat generated by yeast can be rejected by normal cooling tower. However, for starch base feedstock, the fermentation temperature could not be that high due to the lack of osmotic pressure, the fermentation temperature is required to be controlled at 32°C, to prevent the growth of bacteria. In tropical countries, where wet bulk temperature of cooing tower is above 27°C, it is not possible to cool by cooling tower as it could cool water down to only 30°C. This means that the cooling water is only 2°C below the fermenting temperature which is not enough temperature difference for the heat exchanger to work. Also, The fermenting temperature can not be higher than 32°C, as it should allow bacteria to grow very fast which in turn would caused the adverse impact on fermentation efficiency, reduces ethanol and lower fermentation activity. Therefore, in using starch base feedstock as raw material, it is recommended to use chilled water system in cooling of fermenters and mash. Approximately 60-70% of total chilling water load is mostly used in fermentation.

Keywords: Cooling System, Ethanol Plant, Fermentation

1. Introduction

Bioethanol or ethanol is alcohol made from sugar fermentation by yeast. In general, the feedstocks that widely used in ethanol production are sugar base (cane juice, molasses) and starch base (cereal, corn and cassava). For sugar base feedstock, yeast can ferment sugar directly but in starch based feedstock, starch need to be hydrolyzed to sugar before it was fermented to ethanol by yeast. Starch hydrolysis has two steps, the first process is the liquefaction in which starch is hydrolyzed to smaller molecules called dextrin and resulted in the viscosity reduction. Then dextrin is hydrolyzed to monosaccharide sugar, this step is known as Saccharification. After that, sugar is fermented by yeast to produce ethanol. The distillation and dehydration process are used to increase purification of ethanol to the desired level as shown in Figure 1.

Fermentation is the process for yeast utilizes monosaccharide sugar and changes it to ethanol or Glycolysis in anaerobic condition as shown in Equation 1.[1]

$$C_6H_{12}O_6 + \text{Yeast} \rightarrow 2\text{CO}_2 + 2C_2H_5OH + 28.7\ \text{kcal} \quad (\approx 120.6\ \text{kJ}) \qquad (1)$$

The suitable temperature of fermentation for the yeast (Saccharomysis Ceravisiea) is in the range of 28-35°C [2-5]. Although at present yeast strain has developed temperature tolerance for fermentation at 35°C, the price of improved yeast strlain is too expensive for the industry and fermentation efficiency is better if fermentation temperature is controlled at 32°C or below.

Equation 1, shows that yeast always release heat during fermentation resulted in temperature increasing. Therefore, cooling system is necessary to remove heat from fermenting tank all the time to maintain the suitable condition for yeast metabolism. Every degree of increased temperature above 32°C, yeast will have lower metabolism, and bacteria starts to grow faster, competes with yeast to convert glucose. The end product of metabolism of bacteria is lactic acid and acetic acid which inhibit activity of yeast and the result is the reduction of ethanol yield of the plant. Furthermore, the higher fermentation temperature would increase stress to the yeast and reduce their activity as well.Most of heat generated during fermentation of ethanol takes place between the 10^{th} hrs and 30^{th} hour of fermentation. In average, the fermenter cooling system should be designed to cool 1023.4 kJ per kg of ethanol produced over a 20 hr period [4].

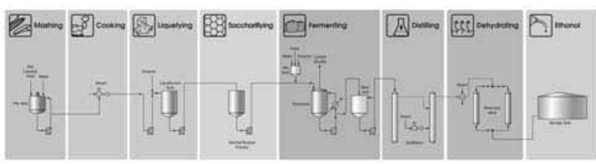

Figure 1. Main process block diagram of bioethanol production

2. Cooling system in ethanol plant in Asia

The estimated quantity of heat input, generation and rejection in each process is shown in Table 1. Cooling in each process is different depending on process requirement. In mash mixing, cooling system is not required. After cooking and liquefaction, cooling system is required to reduce liquefied mash temperature from 82°C to 32°C before pumping to fermenter. During fermentation, fermented mash temperature gradually raise due to energy releasing when sugar is fermented by yeast. Cooling system is used to control temperature not to exceed 32°C to maintain suitable condition for yeast activity. It also condense vapor and make vacuum system during distillation and dehydration. After ethanol reached desired concentration, the ethanol vapor is condensed and cooled down before sending to storage tank. The appropriate heat rejection system in continuous ethanol production plant is shown in Table 1.

Table1. Total heat balance in each process (kJ/hr/L of ethanol)

Section	Input	Generate	Reject
Cooking and liquefaction	77-79	N/A	63-65
Fermentation	0	49*	52-55
Distillation	250-280	N/A	167-195
Dehydration	7-10	N/A	85-89
Product handling	0	N/A	4-5

* heat generate in fermenter only

Table 2. Selected refrigeration system in each process for tropical countries

Section	Objective	Selected Cooling System
Cooking and Liquefaction	Reduce temperature (32°C)	Cooling water, Chilled water
Fermentation	Reduce temperature (32°C)	Chilled water
Distillation	Condense vapor and reduce temperature (19, 33°C)	Cooling water, Chilled water
Dehydration	Condense vapor and reduce temperature	Cooling water, Chilled water
Product Handling	Reduce temperature (38°C)	Cooling water

As shown in Table 2, chilled water is used in Cooking and Liquefaction, Fermentation, Distillation and Dehydration. In each process, the amount of chilled water is responsible to process condition as per following case study.

Case study

From studying chilled water system in bioethanol plant in Thailand, at required capacity of 200,000 litters per day of motor fuel grade ethanol, the generated heat can be roughly estimated, assuming that almost all glucose is changed to ethanol by yeast metabolism.

Ethanol 200,000 litters

The density is 781.69 kg/m3 , at 30°C

C_2H_5OH has molecular weight 46 g/mol

$$C_2H_5OH = 200\ m^3 \times 781.69\ \frac{kg}{m^3} = 156338\ kg.$$

$$C_2H_5OH = 156338000\ g. = \frac{156338000\ g}{46\ \frac{g}{mol}}$$

$$= 3398652\ mol$$

which is fermented from $C_6H_{12}O_6$

$$= \frac{3398652}{2}\ mol = 1699326\ mol$$

Generated heat from the required value are 1,699,326 mol x 120.6 kJ/mol= 204,938,762 kJ. Total fermentation time is 50 hours. Then, generated heat from yeast activity is 4,098,774.5 kJ/hr. When reserve for heat from environment and recirculation at 20%, the total heat exchange in fermenting tank equal to 4,918,529 kJ/hr. Due to the long fermentation period, four fermenting tanks were used to sequentially ferment mash and feed continuous beer to distillation, assuming that two of fermenting tanks were operated simultaneously. When sum with heat load from other equipment in fermentation section, total heat load in fermentation section is 13,504,400 kJ/hr. Chiller system was designed that Chilled water inlet and outlet temperature were 12°C and 18°C respectively. The amount of chilled water that is used in fermentation and each process is shown in Table 3. Most of chilled water load is in fermentation section (74%) which was included 496,258 kg/hr from temperature control in fermenter tank and 41,294 kg/hr from exchange heat in other equipment. Total chilled water load per litter of ethanol is 3.62 kg/hr. Considering total cooling water heat load in ethanol plant, the heat load from chilled water system is 20% of total heat load as shown in Table 4.

Table 3.Total chilled water load for rejected heat in each section of ethanol plant (200,000 litters per day)

Section	kg/hr	%
Cooking and Liquefaction	152,138	21
Fermentation	537,553	74
Distillation	18,111	2.5
Dehydration	16,663	2.5
Total	537,621	100

Table 4. Total heat reject by cooling tower water in each section of ethanol plant (200,000 litters per day)

Section	kJ/hr	%
Cooking and Liquefaction	9,922,000	11
Fermentation	-	-
Distillation	43,296,000	48
Dehydration	18,040,000	20
Product handling	902,000	1
Chilled water system	18,200,000	20

Total	90,200,000	100

3. Chilling system in ethanol plant

Generally, mechanical chiller, which uses the energy from electricity, is used in the plant. For ethanol plant that releases exceed steam or waste heat into the environment neither from boiler or turbine exhaust and require the chiller system in the production process or air conditioning, absorption chiller is a good choice to use energy as worth as possible. The plant that use absorption chiller can reduce the operating cost to almost zero for cooling system when comparing with electricity source chiller which has net cost of 2.03 bath per ton of refrigeration[6].

Conclusion

For bioethanol plant in tropical countries, Chiller system plays a crucial role for maintaining yield of the plant. Approximately 60-70% of total chilling water load is mostly used in fermentation in order to keep fermenter temperature suitable for yeast activity and prevent microorganism growth. Chiller system selection depends on process requirement. Absorption chiller is a good choice to recover energy and, in order to increase its efficiency, add heat exchanger or double-effect absorption chiller can be applied. In addition, biomass, by-product from ethanol production, is used to reduce or compensate boiler fuel by burning directly or making biogas.

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