Ways to Reduce Carbon-Dioxide Emissions at Brewery Enterprises

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Abstract. The world community is concerned about the global climate warming, among the reasons for which the increasing amount of carbon dioxide emitted is being considered, and carry out a systematic work to reduce greenhouse gas emissions into the atmosphere. Carbon dioxide (CO₂) is one of six types of gases (along with others), the content of which should be reduced, in accordance with the international obligation of Russia [1, 2, 3]. The content of chemical compounds of nitrogen, sulfur dioxide, carbon dioxide constantly increases in the atmosphere due to combustion of natural raw materials during production of energy and industrial goods, transport operation, etc. [4, 5, 6]. Carbon dioxide concentrates in the lower layers of the troposphere and absorbs infrared heat rays, which results in the growing planet temperature. According to rough estimates, the share of bacteria in the production of carbon dioxide in the biosphere does not exceed 50% [7, 8].

In this regard, the Russian enterprises producing carbon dioxide as a by-product must also understand the current environmental issues and try to reduce their emissions. In this paper, solutions are proposed for the correct emission of carbon dioxide in breweries.

1. Introduction

Carbon dioxide (CO₂) is one of six types of gases (along with others), the content of which should be reduced, in accordance with the international obligation of Russia [1, 2, 3]. The content of chemical compounds of nitrogen, sulfur dioxide, carbon dioxide constantly increases in the atmosphere due to combustion of natural raw materials during production of energy and industrial goods, transport operation, etc. [4, 5, 6]. Carbon dioxide concentrates in the lower layers of the troposphere and absorbs infrared heat rays, which results in the growing planet temperature. According to rough estimates, the share of bacteria in the production of carbon dioxide in the biosphere does not exceed 50% [7, 8].

The world community is concerned about the global climate warming, among the reasons for which the increasing amount of carbon dioxide emitted is being considered, and carry out a systematic work to reduce greenhouse gas emissions into the atmosphere. The main “greenhouse” gas is water vapor. The next one is carbon dioxide, which provided an increase in the greenhouse effect by 49% at the end of the 20th century compared with that of the beginning of the century. In 2017, the total mass of emissions was 9.9 gigatons of carbon. These data are presented in the report Global Carbon Budget, published on December 5 in Earth System Science Data [9, 10].

In this regard, the Russian enterprises producing carbon dioxide as a by-product must also understand the current environmental issues and try to reduce their emissions. Some companies, such as TETRA PAK, are currently offering a new service to reduce their environmental impact to
business. The company conducts an audit of the enterprise in the framework of which specific recommendations are being developed to reduce the level of carbon-containing compounds [11]. Pilot testing of the new service was carried out in Europe and the USA. For example, an inspection at Pacific Foods revealed the possibility of reducing carbon dioxide emissions by about 3.5 thousand tons.

2. Experimental part

The issues on recovery and recycling of brewing waste are discussed and, in principle, such opportunities are shown for thermal energy, wastewater [12, 13, 14]. The range of gaseous wastes in biotechnological processes is few. Carbon dioxide in breweries is released in the process of alcoholic fermentation of wort and is a by-product containing, in addition to carbon dioxide, traces of organic compounds and water vapor. About 75% of carbon dioxide produced during the main fermentation is used for technological needs of beer production, the rest can be used as commercial carbon dioxide for making soft drinks or for other purposes [15, 16]. According to the norms of technological design of breweries, the yield of recycled carbon dioxide of the main fermentation is 218 g per 1 dal of beer with an extract of the initial wort of 11%. In practice, a slightly smaller amount is obtained. The consumption of carbon dioxide in the production and bottling of beer according to domestic standards is 154 g per 1 dal of beer [16], and according to foreign standards it is 180-200 g per 1 dal of beer.

The practical consumption of carbon dioxide by an enterprise for its own needs may vary significantly, but the fact of its necessity is unconditional. The average CO₂ consumption rates for various technological needs are given in Table 1 [17].

| Technological operation                  | CO₂ consumption rate, kg/hl |
|-----------------------------------------|-----------------------------|
| Creation of back pressure and emptying the camp tank | 0.35-0.50 |
| Creation of back pressure and emptying the filter | 0.40-0.50 |
| Creation of back pressure in beer tanks | 0.3-0.5 |
| Creation of back pressure when bottling | 0.18-0.40 |
| Creation of back pressure when filling in kegs | 0.90-1.10 |
| Creation of back pressure when filling in cans | 0.60-0.80 |
| Partial carbonization                    | 0.10-0.20 |
| Total carbonization                      | 0.50-0.70 |

Often, breweries additionally produce non-alcoholic carbonated beverages. To saturate them with carbon dioxide and create backpressure during bottling, up to 1.2 kg of CO₂ can be consumed per a hl of liquid [18], which is a noticeable expense item for the manufacturer.

At large breweries (with a capacity of over 5 million dal of beer per year), the utilization of carbon dioxide from the fermentation tanks of the main fermentation reaches 98% [19].

At breweries of average capacity (from 1 million to 5 million dal of beer per year), carbon dioxide for fermentation is only partially utilized. This is explained by the fact that carbon dioxide compressors are used to compress fermentation carbon dioxide, the productivity of which is determined by the capacity of the brewery. Thus, for breweries with a capacity of up to 2 million dal of beer per year, the capacity of compressors is 50 kg/h, for plants with a capacity of 2-3.7 million dal per year, the compressor capacity is 100 kg/h. For small-scale breweries of 0.37 million dal and 0.92 million dal per year the capacity of compressors is 10 and 25 kg/h, respectively.

For small-capacity plants, the share of which in the balance of beer production is about 10%, carbon dioxide is not used as fermentation in them takes place in open fermentation tanks.

In the second half of the 20th century, the Russian industry produced only two types of units for carbon dioxide liquefying: the UVKS series with a capacity of 220 kg/h with a final pressure of 75 kg/cm² and the UKS series with a capacity of 270 kg/h with a final pressure of 15 kg/cm² [20].
Modern Russian industry offers more powerful units that allow obtaining a higher final gas pressure. In addition, there is the possibility for gas liquefying, which in this case becomes a commercially attractive product. Among the foreign models of equipment, the Union Engineering (Denmark), Wittemann (USA) and other units have proven themselves.

At the operating breweries of large and medium capacity, the production and storage of carbon dioxide is carried out according to a scheme, which includes the following steps:
1. Carbon dioxide from the fermentation compartment enters the skimmer for getting rid from beer and foam
2. The gas separated from the foam enters the gas holder.
3. Gas is supplied to the filter using a water ring compressor
4. Gas is filtered with a 0.5% KMnO4 solution to remove organic impurities
5. Gas is treated in a splash trap
6. Gas is treated using an activated carbon filter
7. The purified gas is directed to the compressor unit, where the 1st stage of compression is carried out.
8. The heated gas is cooled in a heat exchanger
9. Oil droplets are captured in a dehumidifier
10. The II compression stage takes place in the compressor
11. The second compression gas is cooled in a heat exchanger
12. Oil droplets of the second compression gas are captured in a dehumidifier
13. The III compression stage takes place in the compressor
14. Gas is cooled after the third compression in the heat exchanger
15. Oil droplets of the third compression gas are captured in a dehumidifier
16. Gas is filtered using the high pressure filter with activated carbon
17. Gas is filtered using the high pressure filter with silica gel
18. Carbon dioxide is liquefied in condensers (final pressure reaches 80 kg/cm²)
19. The liquefied carbon dioxide is stored in the pile batteries.
20. Carbon dioxide is pumped to carbon dioxide posts, where it fills cylinders or is transported for domestic needs (no-balloon transportation).

Carbon dioxide, filled into cylinders, can be used either for dispensing to consumer plants or for own technological needs (for transferring finished beer from beer carriers to the distribution network, etc.)

If the gas is not planned to be liquefied, then its processing is carried out according to a simpler scheme:
1. Carbon dioxide from the fermentation compartment enters the skimmer for release from beer
2. The gas separated from the foam enters the gas holder.
3. Gas enters a compression unit consisting of a compressor and a refrigerator, where it is compressed to 4-10 kg/cm².
4. After compression, the gas is cleaned from impurities using the filters.
5. The purified gas is stored in a gaseous state.

The carbon dioxide produced by the described method is used only for the technical needs of the brewing industry.

A membrane technology for the purification and accumulation of carbon dioxide seems to be promising. Membrane technologies are increasingly being introduced into technological processes. This is driven by the fact that modern membranes very well meet the technical requirements for separating ability, which makes it possible to separate gases (including carbon dioxide) from impurities and other gases. Such systems allow separating carbon dioxide from mediums where its content is relatively low (20% or less), which may allow their use in a wide range of industries.
The process of gas separation occurs at a pressure of less than 10 atm, which simplifies the technical requirements for equipment and therefore contributes to reducing the risks of destruction of tank equipment and environmental threats.

The performance of gas-separation membranes is based on different rates of gas passing from one medium to another through a partition with very fine pores. Gases of various nature (nitrogen, oxygen, carbon dioxide, etc.) behave differently. Some of them pass the membrane quickly (hydrogen, helium), some moderately quickly (carbon dioxide, hydrogen sulfide), some slowly (nitrogen, argon, methane). A difference in pressure is created on the surface and inside the membrane, which allows the “fast” and “slow” gases to separate.

The membrane consists of a fiber surrounded from the outside by a shell of a thin film about 0.1 microns thick, making the gases to pass it relatively easily. The selectivity of such membranes is the most important characteristic.

By appropriate selection of membranes and technology one can achieve the release of the targeted gas.

Production of carbon dioxide using membranes is carried out in the following technological sequence:
1. Cleaning the gas mixture with water
2. Primary compression of the gas mixture
3. Gas filtration at the first membrane module with waste separation
4. Secondary gas compression
5. Gas filtration at the second membrane module with separation of residual impurities
6. Storage and use of gas
7. Optional - liquefaction and gas storage

Nowadays application of carbon dioxide is not limited by the beverage industry. In the modern world, carbon dioxide is used in welding and foundry production, in metal cutting, industrial power engineering and other industries.

It is shown that electric welding in carbon dioxide environment increases labor productivity by 2.5–4 times as compared with manual welding and reduces the cost of the weld metal more than 2 times with high quality of welded joints [21, 22].

There is a possibility of workshops for filling with liquid carbon dioxide fermentation of metal ampoules intended for charging metal siphons with a capacity of 1 l. 6-8 g of liquid carbon dioxide is in each ampoule. With the capacity of the shop equal to 20 thousand ampoules per a turn, all the costs of organizing the use of carbon dioxide fermentation in brewing, including the purchase of a balloon park, pay off within 2-4 years, with net accumulation a year from 26 to 65% of the costs [21, 23].

The cost of carbon dioxide produced at biotechnological production is 1.5–2 times lower than that of CO₂ produced in industrial plants from flue gases. It is necessary to realize that carbon dioxide produced at brewing, wineries and distilleries is a waste of production, and its independent cost is conditional. In this regard, the economic benefit of CO₂ recovery is obvious.

Wholesale prices for carbon dioxide produced by biotechnological processes are similar to the prices for CO₂ produced in other industries, and fluctuate on average between 20,000 and 30,000 rubles/ton.

In other countries capture of carbon dioxide produced by the biotechnological method is practiced in many enterprises, which contributes to the reduction of CO₂ emissions into the atmosphere and contributes to the preservation of the ecological balance. Russian enterprises should also actively introduce and improve ecologically closed production cycles, since the industrial capacities of the biotechnology industry are growing all over the world, and, consequently, the load on the environment is also increasing.
3. Conclusion
Breweries, depending on productivity, it is recommended to do carbon dioxide emission in several modes.
1. Carbon dioxide is purified and stored in a compressed state at a pressure of up to 1 MPa
2. Carbon dioxide is purified and liquefied. Store at a pressure of 8 MPa
3. In mini-breweries, it is not advisable to clean and store carbon dioxide.
The cost of carbon dioxide obtained in biological production is 1.5–2 times lower than that of CO2 produced in industrial enterprises

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