The design of the device for the solid carbon dioxide production

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Abstract. We considered the method of carbon dioxide processing and recycling which is suitable for the use in food, refrigeration and other industries; moreover it provides a high level of carbon dioxide recycling and processing and its further use. The analysis of being in demand for this method was carried out in the field of processing liquid and solid carbon dioxide. A special feature of the method concept is the principle of solidification and the possibility of producing solid carbon dioxide with full use of raw materials without losses to the environment. A plant for producing solid carbon dioxide has been designed. The article presents the plant process flow diagram and describes its operation principle. We also mark the plant competitive advantages over analogues. Despite relatively small overall dimensions, the carbon dioxide return was anticipated by means of liquefaction back into the technological cycle. Feed connection can be carried out both from the cylinders with liquid carbon dioxide, and by connecting the liquid carbon dioxide pipeline from the liquefaction process flow at the enterprises.

1. Introduction
In recent years, Russian and foreign scientists have been actively involved in the development of technologies for the carbon dioxide processing and recycling, which corresponds to the agreement starting in 2022, which purpose is to limit the growth of the average temperature on the planet by 2 °C.

The Ministry of Natural Resources and the Ministry of Economic Development and Trade are developing a reporting methodology for greenhouse gas emissions for enterprises. The companies and the enterprises which emissions will exceed 150,000 tons of carbon dioxide equivalent per year will have to provide reporting about emissions to the Federal Service for Supervision of Natural Resource Usage by the end of 2019. By the beginning of 2020, all enterprises with annual emissions of more than 50,000 tons will provide such information. Afterwards a data verification and reporting system will be created and the financial impact tools will be input, i.e. that the tax fee will be set [1, 2].

Owing to the fact that in the near future the enterprises will have to pay for the carbon dioxide emission into the atmosphere, we can make a supposing that the enterprises will need the effective and economical ways of waste gases recycling and processing, including carbon dioxide. The technologies design and creation, which are provided the carbon dioxide recycling and processing, will be in demand for a very long time [1].

As promising areas of waste carbon dioxide application, we may suggest chemical and petrochemical industry, pharmaceutical and biotechnological, food industry and agriculture, medicine,
metallurgy and mechanical engineering, laboratory research, pulp and paper industry, electronics and ecology [11, 15, 16].

At the present time in order to get carbon dioxide in solid, usually the methods which are based on the process of throttling liquid carbon dioxide to atmospheric pressure, upon that liquid carbon dioxide is transformed into a gaseous and snow-like state are used. In such a case up to 70% of CO$_2$ gasifies, then enters the atmosphere, and is more rarely recovered [3, 11, 12, 14].

2. Materials and methods

To achieve this goal, a scheme of the plant for solid carbon dioxide production and its recycling in use at food, refrigeration and other industries is designed.

This technology is a definite innovation in the processing of liquid carbon dioxide and getting solid carbon dioxide. A conceptually new solidification principle and the possibility of producing solid carbon dioxide with full use of raw materials without losses to the environment is implemented in the carbon dioxide solidification plant.

3. The study of the structure of the modified lead-tin-base bronze

The designed plant consists of two closed cooling circuits with carbon dioxide which circulates through the first one, and a cooling agent circulates through the second one. The first circuit provides a regenerative cycle of carbon dioxide liquefaction which gasifies after throttling. The percentage of carbon dioxide which is transformed into the gaseous form, although not great, will still exist because of the physical and chemical properties of this substance. It is caused that CO$_2$ has a very specific behavior at relatively low temperatures. [3, 4, 8, 9, 10, 13]

In order to avoid the entrance of the "long-lived" greenhouse gas into the environment the liquefaction system that allows using absolutely entire carbon dioxide in the system is provided. The liquefaction cycle use is determined by the economic factors, because the fewer leakages, the greater the percentage of the raw materials will be transferred to a useful resource which will be realized in the future. The plant principle diagram is presented below in figure 1.

The liquid carbon dioxide flows from the cylinder (5) through the shut-off and control valves to the solidification device (10). The carbon dioxide which is appeared in the plant body is sucked out by the carbon dioxide compressor (2), after the carbon dioxide compression, it pumps it into the recuperative heat exchanger. The oil separator (3) which follows after the heat exchanger cleans the steam flow before the heat exchanger (evaporator-condenser) (4). The liquid that is condensed in the evaporator-condenser (4) passes through the air separator (7) and through the control valve (9) and then it is fed to the solidification device (10). The cooling device consists of a compound compressor (1) that sucks and compresses the superheated steam from the heat exchanger (4) at the first stage of the compressor and pumps it to the second stage of the compressor, where the flow is mixed with the cooling agent coming from the supercooler (12). The second stage of the compressor pumps steam into the air-cooled condenser (15), where it transforms into the liquid aggregate state. The cooling agent enters the linear receiver (14) after the condenser (15). After the linear receiver freon enters the supercooler in two flows, one of which is throttled by the thermostatic expansion valve (13) to an medium pressure and goes to the second stage of the compressor for mixing. The second flow is supercooled and throttled by the thermostatic expansion valve (11) to the evaporation pressure, which is used for feeding of the solidification device (evaporator) (8), in which it partially boils and enters the heat exchanger (evaporator-condenser) (4) for pre-boiling.

This plant works in the following way: the carbon dioxide liquefaction circuit includes a carbon dioxide solidification device (10) which is also the part of the second circuit (cooling). The supply of liquid CO$_2$ (raw materials) from the transport cylinders (5) through a pressure equalization reducer (8) which is equipped with a pressure control system (6) is connected to this device. The solid blocks of CO$_2$ extraction (final product) is also carried out in this device. In addition, the circuit includes a carbon dioxide compressor unit (2), which compresses the gas formed during the technological cycle and pumps it into the heat exchanger (evaporator-condenser) (4). In the heat exchanger the heated...
compressed gas is cooled and condensed due to the flow of vapor-liquid freon from the cooling cycle following after the solidification device (10). Remaining cooling agent that has not evaporated boils off in the heat exchanger and absorbs the carbon dioxide heat which transforms into the liquid state. This heat exchanger allows increasing the energy efficiency of both cycles, as well as it performs the role of a dryer before the suction into the freon circuit compressor. After the heat exchanger a throttle control valve (9) is installed to ensure optimal supply of liquid carbon dioxide to the solidification device (10). An oil separator (3), an air separator (7) and various cleaning filters are installed in the circuit in order to obtain a better and cleaner product.

Figure 1. The plant principle diagram for solid carbon dioxide recovery

The plant second circuit is a vapor compression refrigerating machine that operates on freon according to a two-stage compression cycle with a heat exchanger supercooler (12), provides the required temperatures in the solidification chamber (10) for the carbon dioxide crystallization and reducing the heat exchanger (4) temperature for its liquefaction. In this cycle the solidification device (10) performs the role of an evaporator, in which body the motion is carried out through the freon pipeline, that boils and absorbs heat from the liquid carbon dioxide, thereby CO₂ crystallizing in special forms is realized. After that the under-boiled freon enters the heat exchanger of the first circuit where the processes which are described above occur. The superheated vapor from the heat exchanger is sucked into the first stage of the piston compressor (1) and compressed to a medium pressure, and then it is pumped into the second stage of compression, where it is mixed with the cooling agent from the supercooler (12). The previously mentioned supercooler is a plate-type heat exchanger where the part of the liquid cooling agent instantly evaporates and captures the heat from the freon main mass (R410a). The evaporated cooling agent comes from the supercooler in the saturated wet steam form. After the mixing with the vaporous cooling agent from the low-stage compressor the
remaining cooling agent moisture evaporates simultaneously cooling the vapor from the first-stage compressor. This technology allows to reduce overheating and to get a lower vapor temperature at the compressor outlet and the increased cooling factor. There is a filtration system and the protection against the water hammer before the compressor. Further passing through the condenser (15) the gas performs a phase transition into a liquid which is merged into a linear receiver (14) by means of heat exchange with the environment. The linear receiver is designed for storing of the liquid cooling agent, which comes from the condenser and its uniform supply to the supercooler (12). After the linear receiver (14) the liquid cooling agent is divided into two flows, the first one then comes through the control valve (13) to the supercooler with a medium pressure where it performs the described above function. The second flow which is cooled due to the first flow boiling in the supercooler (12) enters the thermostatic expansion valve (11) which feeds the "evaporator" devise itself, where the cycle closes.

4. Conclusion
The scheme of the plant for the solid carbon dioxide production where the process of carbon dioxide returning via the liquefaction backwards to the technological cycle is designed. This scheme includes a device for converting liquid carbon dioxide into a solid aggregate state, which allows obtaining solid carbon dioxide without loss of CO$_2$ and without mechanical impact on the final product. The relatively small dimensions allow you to install the solidification device on the same frame both with a cooling circuit and with a liquefaction circuit. Feed connection can be carried out both from liquid carbon dioxide cylinders and by means of connecting the liquid carbon dioxide pipeline from the liquefaction technological scheme at the enterprises. The absence of mechanical elements in the device increases significantly the service life of this device. The sufficient construction simplicity is also an undeniable advantage that allows designing such devices in a short time with minimum expense. The possibility of obtaining a high-potential battery cooler in order to use it for various purposes, and reducing useless and harmful emissions to the environment makes this scheme not just relevant, but necessary for the carbon dioxide processing.

References
[1] Neverov E N and Korotkikh P S 2019 Investigation of the heat transfer process during cooling of trout using carbon dioxide Technique and technology of food production 49 (3) 383 -389
[2] 2015 Vedomosti, available at: https://www.vedomosti.ru/economics/articles/2015/11/17/617269-dengi-uglekislii-gaz
[3] Pimenova T F 1982 Production and use of dry ice, liquid and gaseous carbon dioxide (M.: Light and food industry) 8 58 - 208
[4] Neverov E N 2012 Production and use of carbon dioxide in industry: monograph (Kemerovo Technological Institute of Food Industry)
[5] Buyanov O N, Gorokhov A A and Neverov E N 2005 Investigation of the operation of a generator - dispenser of snowy carbon dioxide Bulletin of the International Academy of Refrigeration 4 20-21
[6] Porutchikov A F, Krysanov K S and Korolev I A 2014 New areas of application of regenerative refrigeration and gas machines News of MSTU MA-MI 3 58–62
[7] Danilov M M and Smirnov A S 2014 The main features of the formation of the solid phase of carbon dioxide Bulletin of the International Academy of Refrigeration 2 37–40
[8] Feliu J A, Manzulli M and Alós M A 2017 Determination of Dry-Ice Formation during the Depressurization of a CO$_2$ Re-Injection System CETCCUS 80 (1) 30-36
[9] Anurov S A 2017 Cryogenic gas separation technologies AR-Consult 2 (1) 2333
[10] Danilov M M and Nazarova A S 2016 Influence of the parameters of the gas mixture on the magnitude of the formed crystals of carbon dioxide Scientific journal NRU ITMO 4 (24) 1–5
[11] Khovalyg D M, Sinitsyna M, Baranenko A V, and Tsoi A P 2014 Energy efficiency and
environmental safety of low temperature technology. Scientific journal NRU ITMO 1-2-6

[12] Antonov A N, Arkharov A M and Arkharov I A 2015 Low-temperature technology machines. Cryogenic machines and tools (1) 536

[13] Altunin V V 2015 Thermophysical properties of carbon dioxide (Publishing house of standards) (1) 546

[14] Muhammad Sarfraz M Ba Shammakh 2018 ZIF-based water-stable mixed-matrix membranes for effective CO2 separation from humid flue gas. The Canadian Journal of Chemical Engineering 96 2475-2483. https://doi.org/10.1002/cjce.23170

[15] Neverov E N, Korotkiy I A, Korotkih P S and Lifenceva L V 2019 The Method of Carbon-Dioxide Recovery in Fish-Processing Industry. IOP Conference Series: Earth and Environmental Science 1 224

[16] Neverov E N, Grinyuk A N and Tretyakova N G 2015 The use of carbon dioxide for cooling rabbit carcasses. Current problems of science and education 2 317-321