

Optimization of carbon dioxide compressing technology in the production of urea

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Abstract. In the article the questions of optimization of technological schemes of obtaining liquid carbon dioxide directed to the carbamide synthesis plant are considered. The main drawback of traditional technical solutions is high energy costs, mainly due to the need to compress CO₂ before it is fed to the synthesis reactor. Traditionally, technical solutions are proposed, based on the production of liquid low-temperature carbon dioxide, which increase the yield of nitrogen fertilizer. However, their significant disadvantage is high energy costs, which is largely due to the need to compress CO₂ before it is fed to the synthesis reactor. To solve the optimization of the technological stage of obtaining high-pressure carbon dioxide by combining the use of compression and pumping equipment, multifactor methods for modelling chemical-technological processes and software were used. With regard to urea aggregates of different power, several technological schemes are considered. The paper presents a variant of modernization of the turbocharger aggregate, due to which it is possible to achieve a significant increase in the yield of the final product of urea units in order to reduce CO₂ emissions into the atmosphere.

1. Introduction

Carbon dioxide formed in the production of ammonia is widely used in various industries. The most important of them are large-scale production of urea and plants that engaged in the production of high-viscosity oils [1].

This is due to the fact that residual oil can displace only those working agents that are mixed with oil and water or have an ultra-low interfacial tension. Such conditions occur when high-viscosity oil is displaced by carbon dioxide.

These methods are among the most high-potential, capable of reducing to 2-5 % residual oil saturation of the bottom-hole zone covered by the working agent. In the case of Russian oil-producing organizations, there fundamental importance, since the bulk of the residual oil in the known developed fields remains in the form of waterlogged reserves, which are more difficult to extract than from undeveloped reservoirs.

Carbon dioxide in water contributes to the tear and the washing the film of oil covering the grain of the breed, and reduces the possibility of a rupture of the water film. Because of this drop of oil with low interfacial tension are free to move in the pore channels.

According to available data, CO₂ dissolves in oil much better than methane and its gaseous homologues, and the solubility increases with the pressure and molecular weight of oil. In contact with oil, carbon dioxide is partially dissolved in it and simultaneously extracts hydrocarbons, enriching



them. As a result, the pressure required to displace oil with carbon dioxide is 3 times less than with hydrocarbon gas.

Another direction of industrial use of carbon dioxide is the synthesis of urea, carried out on large-capacity plants [2]. Solutions based on the production of low-temperature liquid carbon dioxide are proposed to increase the yield of nitrogen fertilizer [3]. Their significant drawback is the high energy costs for the production of commercial products, which is largely due to the need to compress CO₂ before it is fed into the synthesis reactor [4].

The purpose of our study was to optimize the technological stage of production of high-pressure carbon dioxide through the combined use of compressor and pumping equipment.

To solve this problem, we used multivariate methods for modeling chemical processes and special software. This made it possible to optimize the existing technological schemes and perform technological calculations that confirmed the correct layout of the equipment.

On the basis of experience in the operation of carbon dioxide plants were identified bottlenecks that prevent the increase in production volumes, as well as their high energy costs due to the imperfection of working schemes [5]. Taking into account all the above mentioned the essence of the proposed technical solution was the simultaneous use of a compressor-pump carbon dioxide installation, which effectively combines the process of obtaining liquid CO₂ at low pressure and supplying compressed gas with the required pressure (15 MPa) using a low-temperature pump to the urea synthesis unit.

In contrast to the traditional technology, we propose to compress gaseous CO₂ from 0.1 MPa to a relatively low pressure of 3.0 MPa, and then cool it due to the cold of gasification of the liquid carbon dioxide compressed to 15 MPa. For its condensation, an absorption water-ammonia refrigeration machine can be used, which uses the heat of CO₂ compression in a centrifugal compressor to produce cold [6]. With the modernization of the turbocharger unit can achieve a significant increase in the yields of the final product [7].

The proposed compressor-pump installation differs from others not only by the optimal construction of its technological scheme, but also by the use of internal sources of cold and heat in the form of a stream of cold carbon dioxide compressed to a pressure of 15 MPa, as well as a high-temperature part of the compressed gaseous CO₂ in a centrifugal compressor. With regard to urea units of different power level, several technological schemes are considered.

2. Research result

2.1 Technological scheme №1

Its operating principle is shown in figure 1. Carbon dioxide gas is fed at a temperature of 45 °C to the recuperative heat exchanger 1, in which it is cooled to 24 °C.

There, moisture is condensed from it, which is separated in the separator 2. After that, it is compressed in a centrifugal compressor 3 to a pressure of 3 MPa and enters with a temperature of 190-200 °C into a steam generator 4, in which it is cooled to 140-150 °C, expending heat for the production of steam with a temperature of 120-130 °C. The steam is fed into the heat-absorbing water-ammonia refrigeration machine 6, and the condensate formed in it is returned to the steam generator 4 by a water pump 5.

The gaseous CO₂ is then cooled in a recuperative heat exchanger 7 to 35 °C. The condensed moisture is separated in the separator 8, and the carbon dioxide gas is drained in the drying unit 9 and cooled in the recuperative heat exchanger 10. Then it is condensed and supercooled due to the cold of boiling ammonia in the evaporator condenser 11, into which ammonia is supplied from the absorption water-ammonia refrigeration machine 6 by the ammonia circulation pump 12. After that, CO₂ in the form of supercooled low-temperature liquid enters the storage tank 13. CO₂ steam and non-condensable gases from the tank 13 is used for regeneration and cooling of the switchable adsorbers of the drying unit 9. In this case, they are throttled to a pressure of 0.6 MPa through the valve 14 and successively pass the recuperative heat exchanger 9 and the electric heater 15, which is switched on in the regeneration mode of the adsorber of the drying unit, and in the cooling mode it is turned off. After drying unit 9, carbon dioxide vapours and non-condensing impurities are released into the atmosphere.

The liquid low-temperature carbon dioxide from the storage tank 13 is compressed by the pump 16 to a pressure of 15 MPa and, having passed three recuperative heat exchangers 10, 7 and 1 in last one CO₂ is gasified and fed into the urea synthesis column.

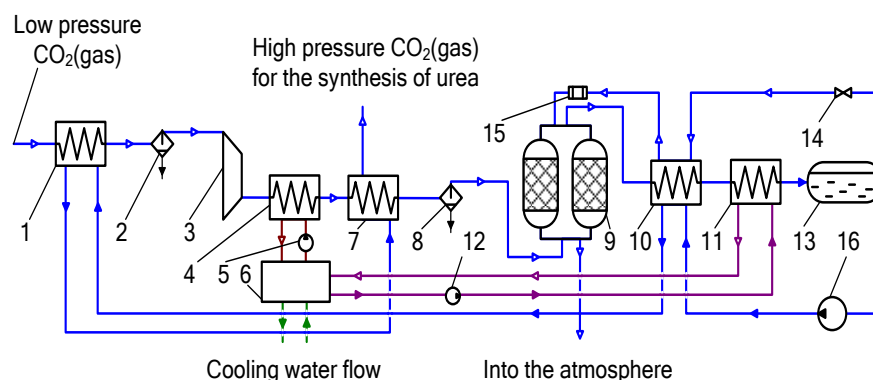


Figure 1. Principal scheme of the compressor-pump unit to provide high-pressure carbon dioxide urea production process: 1, 7, 10-recuperative heat exchangers; 2, 8-separators; 3-centrifugal compressor; 4-steam generator; 5, 12, 16 – pumps; 6 – cooling machine; 9 – drying unit; 11 – condenser-evaporator; 13 – tank; 14 – valve; 15 – electric heater.

As a result of technological calculations, it was found that the proposed scheme of compressor-pump carbon dioxide plant has lower specific energy costs for the production of high-pressure carbon dioxide compared to the existing compression system, and is also characterized by high reliability of operation.

For example, when carbon dioxide is compressed in an amount of 28,800 Nm³ / h in a centrifugal compressor up to 15 MPa (old scheme), electricity consumption is 7.2 MW, and unit costs reach 0.136 kWh/kg.

In the proposed compressor-pump carbon dioxide unit, the total electricity consumption for CO₂ compression in the amount of 28800 Nm³/h in the turbocharger to 3 MPa, its drying and condensation in the evaporator of the absorption water-ammonia refrigeration machine and its subsequent compression in the pump to 15 MPa, after which it is heated and gasified in recuperative heat exchangers and fed into the urea synthesis column, is 5.5 MW, of which 5.35 MW is accounted for the turbocharger and 0.15 MW.MW to drive the pump and ensure the operation of the absorption water-ammonia refrigeration machine. Specific energy consumption for the production of CO₂ with a pressure of 15 MPa will be equal to 0.104 kWh/kg.

Consequently, the energy savings for the production of the same amount of CO₂ with a pressure of 15 MPa will be about 24% or 1.7 MW. Up to 13.6 GWh of electricity per year can be saved during continuous operation.

2.2 Technological scheme №2

A similar reduction in energy consumption can be achieved by replacing the absorption water-ammonia refrigeration machine with a compressor ammonia refrigeration machine that produces cold due to boiling ammonia. In this case, the maximum pressure of carbon dioxide achieved in the compressor pump unit and required for liquefying CO₂ is 1.5 MPa.

The carbon dioxide thus liquefied is compressed further in the low-temperature pump to a pressure of 15 MPa and fed to the urea synthesis unit.

The principle of operation of the proposed compressor-pump unit is as follows (figure 2).

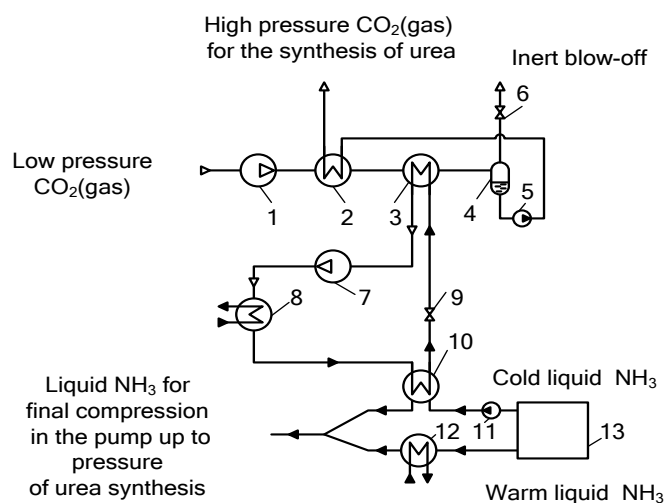


Figure 2. Principal scheme of the compressor-pump installation: 1-carbon dioxide compressor; 2-recuperative heat exchanger; 3-condenser-evaporator; 4-separator; 5, 11-pumps; 6-valve; 7-ammonia compressor; 8-ammonia condenser; 9-throttle valve; 10-liquid ammonia cooler; 12-heat exchanger; 13-ammonia synthesis unit.

The gaseous CO_2 is compressed in the compressor 1 to 1.5 MPa, cooled in the recuperative heat exchanger 2 due to the cold of high-pressure CO_2 gasification and liquefied in the plate-ribbed compact condenser-evaporator 3 using the cold of boiling liquid ammonia coming from the compressor ammonia refrigeration machine. The supercooling of liquid ammonia before the throttle in this machine is carried out due to the cold of liquid ammonia supplied by the pump 11 from the ammonia unit 13 with its pre-compression to 1.5 MPa before feeding to the production of urea. The amount of cold removed from the cold liquid ammonia is compensated by cooling the warm ammonia with recycled water in the water cooler 12 in order to ensure a constant mixing temperature of cold and warm ammonia going to the production of urea.

The sub-cooled liquid carbon dioxide after the condenser-evaporator 3 is supplied to the separator 4. From the separator, a small amount of CO_2 vapors and non-condensing gases are discharged into the atmosphere through the valve 6. The main flow of CO_2 is compressed by the pump 5 and gasified in the recuperative heat exchanger 2 due to the heat of compression of the gaseous CO_2 in the compressor 1. Further, in gaseous form, CO_2 at a pressure of 15 MPa is fed to the production of urea.

Compressor ammonia refrigeration machine operates on a simple cycle with supercooling of liquid ammonia before throttling into the condenser-evaporator 3. In it, ammonia gas at a temperature of -30°C enters the suction into the compressor 7, in which it is compressed to a pressure corresponding to the condensation temperature $+30^\circ\text{C}$. Condensation of ammonia is carried out in the condenser 8 using recycled water. After the ammonia condenser, liquid ammonia is supercooled in the supercooler 10 due to the cold supplied from the liquid cold ammonia going to the production of urea. As a result of such overcooling of liquid ammonia before throttling in the throttle 9, the cooling capacity of the compressor ammonia refrigeration machine is increased by 25%. This contributes to a greater yield of liquid CO_2 from the evaporator condenser 3.

The heated liquid cold ammonia after the supercooler 10 is mixed with liquid warm ammonia, which is pre-cooled by water in the water heat exchanger 12 to a temperature at which a constant temperature of mixing of these flows corresponding to $15\ldots 20^\circ\text{C}$ is provided. Further, liquid ammonia is sent to urea production for its subsequent compression in the pump to a pressure of 15 MPa.

When heating liquid cold ammonia from -30°C to $+10^\circ\text{C}$ in an amount of 19 t/h in the supercooler of the ammonia refrigeration machine, which in turn produces about 5 MW of cold at the boiling point

of ammonia-30 °C, it is possible to condense CO₂ in an amount of 60 t/h at a pressure of 1.5 MPa. After that, it can be compressed to a pressure of 15 MPa in the pump, while consuming a total of about 4 MW of electricity. The specific energy consumption will be 0.07 kWh / kg, which will reduce the energy consumption for liquefaction and compression of CO₂ in a low-temperature pump to a high pressure of 15 MPa by 40%.

3. Main results

In the course of the study, three variants of technological schemes for the production of liquid carbon dioxide directed to the urea synthesis plant are proposed. Their novelty is that the compression of CO₂ before it is fed into the urea synthesis reactor is carried out in two stages: first in the compressor to a pressure of not more than 3 MPa, and then in a low-temperature pump to 15 MPa. This makes it possible to achieve significant energy savings in the production of liquefied gas and improve the economic performance of production. Simultaneously, the optimized work of refrigeration equipment, which may facilitate the task of scaling up the units of urea with the aim of reducing CO₂ emissions into the atmosphere.

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