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FUNDAMENTAL BASIS OF INNOVATIVE TECHNOLOGIES IN GAS INDUSTRY

The global gas industry achieved impressive results in its development. Cumulative gas production is close to 150.0 Tcm. Technologies making possible to support efficient development of giant shale gas and tight gas resources were brought into being during the last decade only. We have all grounds to talk of material successes in studies of gas hydrates.

The next step forward in the global gas industry largely depends on the development of new innovative technologies. State-of-the-art research-and-engineering and process solutions are needed to support growing efficiency of hydrocarbon field discovery, exploration and development, gas transportation and gas chemistry development. Newly developed technologies shall at the same time meet stringent requirements of environmental friendliness and energy efficiency.

It is impossible to resolve the assigned tasks without advance integrated fundamental and exploratory studies of key challenges in the gas science and practice.

Firstly, there is a need to find new opportunities for the expansion of the raw material base of the gas industry and improve the performance of discovering, exploring and developing gas resources. Research work in this case shall be based on modern methods of scientific studies, the latest achievements in information and computer technologies, findings of the latest research in allied sciences, and current achievements of geosciences.

Oil and Gas Field Exploration

Further progress in oil exploration largely depends on the success of fundamental research related to the investigation of impact of global geological processes on oil and gas generation and oil and gas accumulation. These predominantly are dynamics of geosphere shells, global and local fluid dynamics, and impacts of the in-depth energy flow on processes taking place in the asthenosphere and rock sphere.

Dynamic processes taking place in geosphere shells are implemented in the form of the ongoing energy and substance flow from the entrails of the Earth. The energy flow is a function of Earth in-depth conditions in broad terms and is notable for a wide variety from the standpoint of spatial implementation, time intervals and intensity of energy impact.

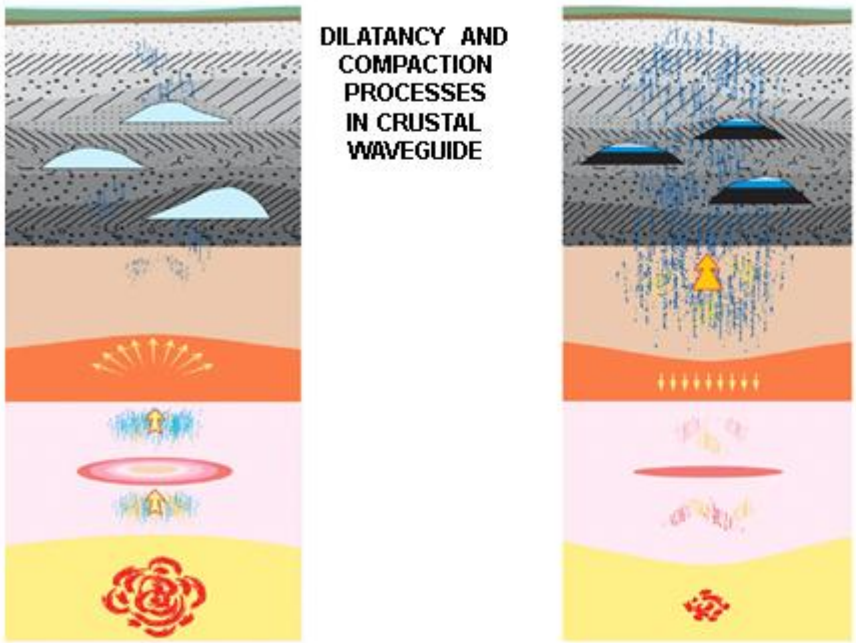
Geophysical studies at depths of 10-25 km identified abnormalities characterized by inversions of seismic velocities, changes in rock conductivity, etc. It was proposed to designate such abnormal zones representing fractured rock filled with fluids as crustal waveguides (CW).

Energy impact converts CW into a quasicoherent state embodied in abnormal properties of crustal waveguides. Change in energy impact affects the degree of fracture openness and specificities of CW filling with fluids. The study presents a description of dilatancy and compaction mechanisms operating in crustal waveguides. The dilatancy effect is associated with the opening of fractures and CW filling with in-depth fluids. Fluids to a greater or lesser degree are squeezed out of crustal waveguide in compaction conditions and move towards lower pressures in upper horizons, proactively ‘flushing’ the sedimentation mass. This provides efficient gathering of hydrocarbon accumulations in a pool. Such conditions determine the polygenic nature of many gas fields (Fig. 1).

The formation and development of a giant Astrakhan Field is associated with the movement of fluids over fractures tracing thrusts of the Karpinsky Ridge. The pattern of fluid processes in deep fractures depends on processes of dilatancy and compaction in crustal waveguides that are successively taking turns. Calculations revealed that negative pressures occurring in fracture upon fault in dilatancy conditions generate a mighty effect of fluid pressurization. Fluids press forward the surrounding rock mass as a result of self-excited processes in fracture zones and crustal waveguides (Fig. 2).

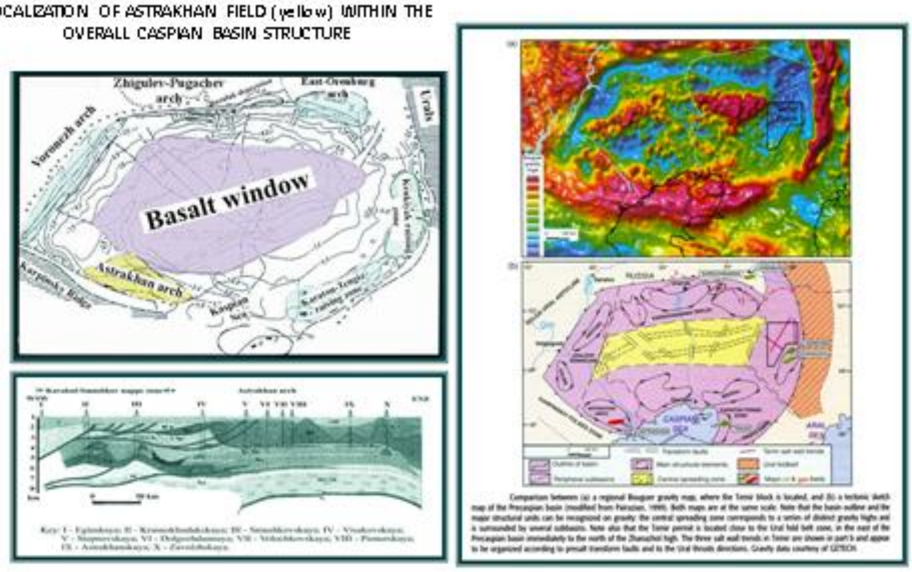
Exploration drilling in deep levels was started within the Astrakhan carbonate massif in 1997. Five deep wells were commissioned for drilling to this end. One of these wells on the right bank of Volga pioneered the discovery of a gas condensate field in Carbonic deposits (Middle Carbon). In 2001 commercial inflows of hydrocarbons were produced in Devonian-2 well in the Middle Devonian carbonate-terrigenous complex at a 6,850 m depth. This discovery makes possible to consider the Astrakhan carbonate massif a single giant field with unique resources of hydrocarbons. The problem of field formation at big depths and with a high density of resources becomes topical in this regard.

High-molecular components (HMC) consisting of ozokerite and ceresin alike components, paraffin wax and petroleum series hydrocarbon components were identified during a study of core samples in the Orenburg gas and condensate field at the turn of the 1980s. The detailed investigation of HMC resulted in the discovery of a new kind of hydrocarbon feed that we called “matrix oil”. Such oil is associated with the most dense varieties of a natural carbonate reservoir.



IMPACT OF FRACTURE ZONES ON DEFORMATION OF ASTRAKHAN CARBONATE MASSIF AND FORMATION OF A MAMMOTH HYDROCARBON FIELD

LOCALIZATION OF ASTRAKHAN FIELD (yellow) WITHIN THE OVERALL CASPIAN BASIN STRUCTURE



Matrix oil is a new variety of hydrocarbon feed identified within limits of carbonate reservoirs of gas and condensate fields. Matrix oil resources were discovered for the first time and therefore had not been accounted in the traditional estimation of reserves. According to the conclusion of the State Reserves Commission’s expert examination board of the Russian Ministry of Natural Resources dd. June 3, 2005, matrix oil resources in the Orenburg gas and condensate field total 2.56 bn tons of oil equivalent.

Studies revealed that the carbonate rock constituent substance forming the matrix of productive deposits of certain gas condensate and oil condensate fields is a natural polymeric carbonate-organic buildup of complex structure.

Matrix oil is a carbonate analog of shale oil, a natural buildup with unique properties, characterized by a variable degree of maturity of oils containing extremely complex high-molecular components.

Sample tests of high-molecular components of matrix oil ascertained a high content of nonferrous and precious metals along with rare and rare-earth metals therein (Fig. 3). The concentration of certain metals is so high that it is comparable with the concentration of these elements in deposits of mineral resources.

Oil and Gas Field Development

Current successes in the development of geology, geophysics, oil and gas research and practice, new gas industry technologies and technical deep drilling capabilities unveiled new prospects for developing fields of gaseous hydrocarbons bedded in deep depths, with complicated geological factors, with pressure, volume and temperature properties not encountered before and in rocks, whose physical and geological parameters materially differ from those known before.

The bulk of gas production in Russia has stemmed for more than 30 years from the basic giant fields in Western Siberia – Urengoy, Yamburg and Medvezhye – that reached a declining production phase and are characterized by an ongoing reservoir pressure reduction. Gas production from the Cenomanian reservoirs of these fields annually declines by 20-25 bcm. At the same time, residual resources of the so-called low pressure gas are over 5.0 tcm.

Gas production is characterized by:

- reservoir pressure drop;
- produced water flooding;
- failure of bottomhole formation zone with sand packs forming in the perforation interval and in eductors; and
- low energy parameters of bed and a number of other factors.

A package of technologies intended for meeting challenges complicating the operation of wells has been developed. The main task of a developed package is to support the lengthy and efficient workability of gas wells and increase the final factor of gas recovery from the Cenomanian deposits at the closing development stage.

Developed technologies comprise:

- sand ingress and water show control technology;
- technology of waterproofing implemented without well killing with the use of coil tubing equipment; and
- Behind-the-casing water inflow elimination technology.

The sand sloughing reduction and water ingress control technology is implemented through the polymer/solvent system injection into the bed with further special treatment. The selection of polymeric system parameters for specific conditions of the Cenomanian gas pool creates conditions for the implementation of self-organization processes in the wellbore zone. This results in the buildup of a polymeric-sand filter that reinforces the well bottomhole zone, prevents sand sloughing and provides for a free flow of gas (Fig. 4).

The technology demonstrated a high field and cost efficiency. 49 jobs have been completed in the Urengoy, Yamburg, and Medvezhye gas fields starting from 2010.

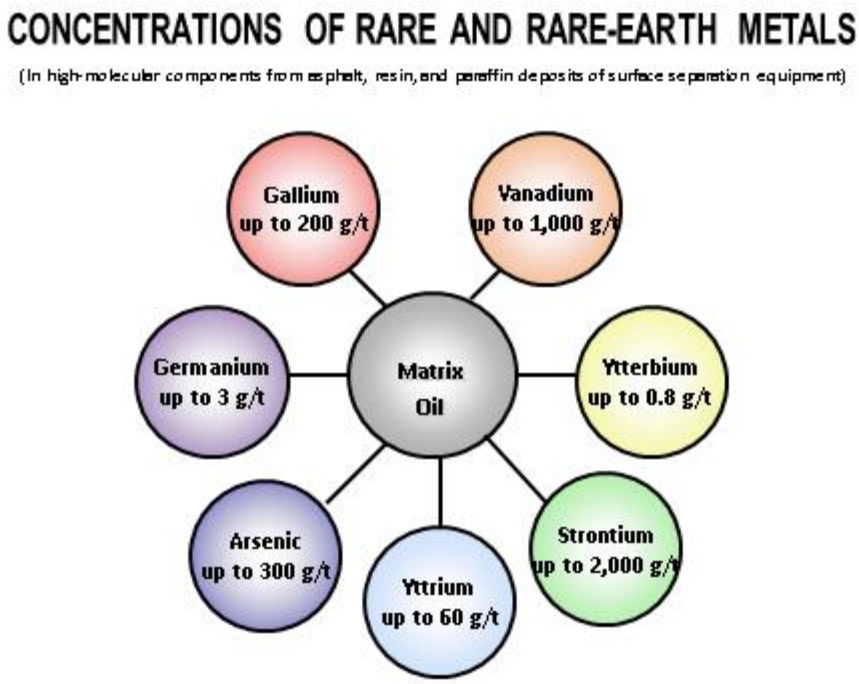
Production of gases containing hydrogen sulfide is no less critical challenge. The proven gas reserves in the Astrakhan gas and condensate field are over 3.2 bcm. Higher content of hydrogen sulfide is a primary feature of the field. H_2S accounts for more than 25%. A natural gas chemical facility with a production capacity of 12 bcm was built to separate hydrogen sulfide from methane. These volumes also determine gas production rates.

The discovery of three new fields within the limits of the Astrakhan carbonate massif makes it possible to increase gas resources to 5.0 tcm. However, production growth is restrained by a lack of efficient technologies for hydrogen sulfide separation from methane as a primary product. The investigation of the gas mixture behavior under low temperatures enabled the creation of cryogenic technologies supporting efficient methane separation from hydrogen sulfide (Fig. 5). The solution of the problem of hydrogen sulfide separation directly at wellhead and low cost of the unit (it is several dozen times lower than the plant cost) will make it possible to considerably increase gas production within the limits of the Astrakhan carbonate massif.

The generalized thermohydrodynamic theory of multiphase filtration of hydrocarbon mixtures has been developed as a basis for input of new knowledge into hydrodynamic models of hydrocarbon field development and new software products.

Unique capabilities of computer technologies make it possible to support material advance in the development of 3D hydrodynamic modeling methods and appropriate simulation of the gas and gas condensate field development lifecycle.

A theory of unstable conditions of gas condensate and gas-oil mixture flows is a new area in physicochemical hydrodynamics. It has been theoretically proved that areas where final decision-making is difficult occur during the filtration of gas-fluid mixtures with phase transition within the framework of classical models. These areas are associated in practice with near-wellbore zones of gas and condensate fields. Various unconventional flow conditions of oscillating nature emerge in instability regions. Effects of nonequilibrium, phase transitions, capillary relaxation and others, which are usually negligibly small, start playing a dominating role in instability regions. The developed theory makes it possible to describe oscillatory operating conditions of wells observed in practice and develop new methods of studying gas and condensate wells.



Dynamics of chaos to order transitions in the course of field operation is investigated using various chaotization criteria. This makes it possible to create methods of control over status of system connections and develop technologies to manage field energy performance.

The combination of such studies with modern methods for analysis of noise term of process parameter time series provides an opportunity to develop an efficient package for diagnostics of natural reservoirs in the course of gas field operation for optimal management of development process. Evolution is determined in this case in time specifically for those parameters of formation and hydrocarbon system that are responsible for multiphase filtration dynamics.

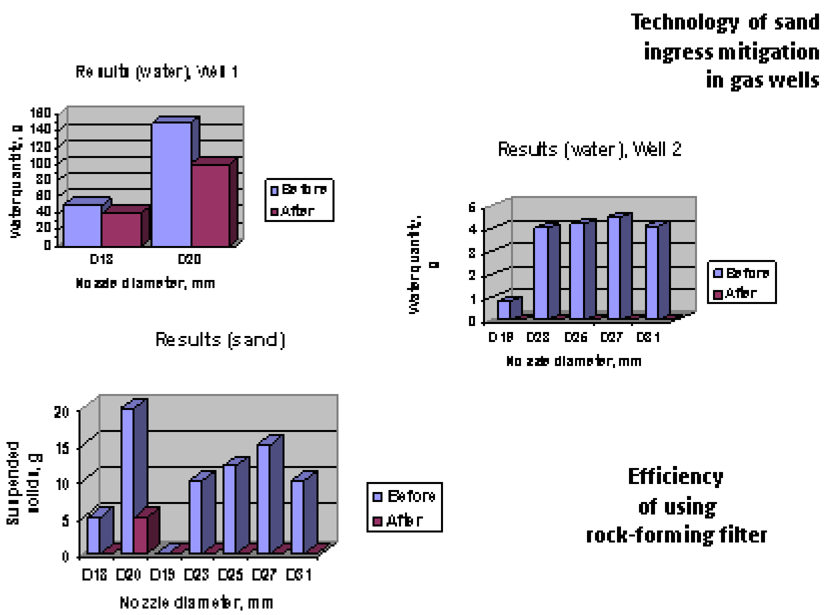
Fundamental studies demonstrate the possibility of performing transition from conventional technologies of oil and gas field development to the development of field energy management technologies, mechanisms and methods of managing the hydrocarbon system. It is necessary in this case to preserve initial conditions of unstable equilibrium of the system formed for millions of years and enabling to maximally use the system's proper energy, monitor and possibly manage the phase state of the hydrocarbon system.

Gas Transportation

The bulk of gas volumes are currently supplied to consumers over the gas pipeline system. The originating gas transportation infrastructure is tightly linked within the "producer – consumer" system and is costly. The liquefied natural gas industry has been proactively developed in recent decades, affording greater flexibility in the relationship between the seller and the buyer.

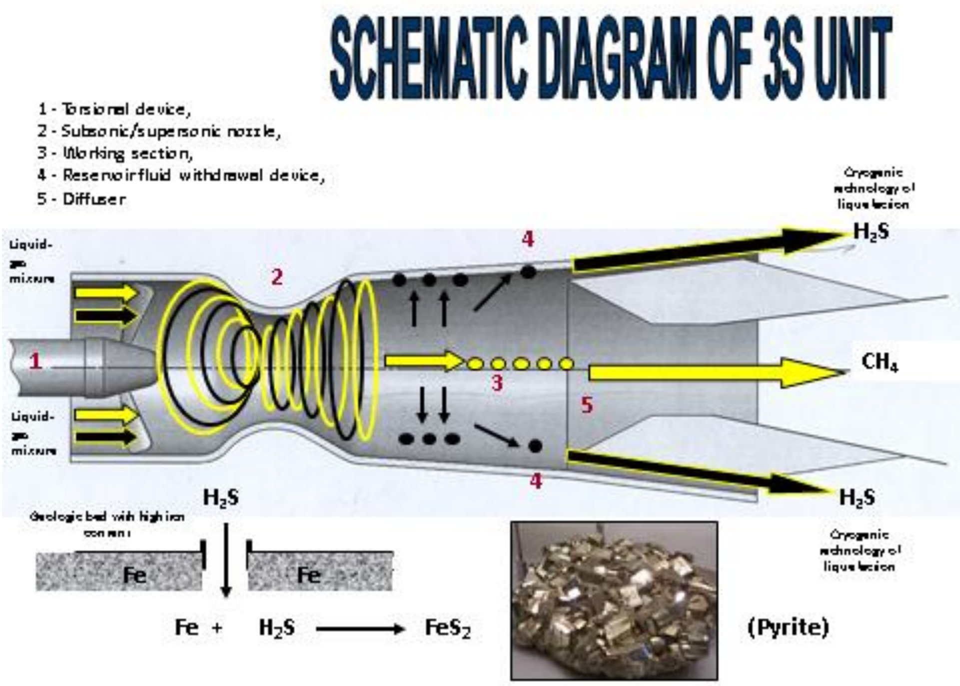
The creation and use of the new generation of relatively cheap sorbents in combination with the latest achievements in the development of transportation means for pressurized methane carriage opens a new epoch in natural gas transportation.

A new material has been developed as a result of multi-year studies: carbon fiber based on available cheep feedstock. It enables to improve methods of pressurized gas transportation and storage, either through an increase of transported gas volumes in existing tanks or by a 1.5-2 time reduction of storage and carrier volume vs. the existing one. Hydrated cellulose, a milling product, was selected as the initial feed for production of such hydrocarbon fiber. Activation parameters for hydrocarbon fibers were identified, differing by production technology and final treatment temperature. It was ascertained that the sorption capacity of hydrated cellulose hydrocarbon fiber becomes much higher after special extra treatment and activation. The hydrated cellulose hydrocarbon fiber carbonized up to 1,000°C after its treatment in carbon dioxide flow at 900°C temperature boasts the best sorption characteristics. Developed activation conditions make it possible to increase specific surface of hydrocarbon fiber up to 2,000 m^2/g and methane sorption capacity up to 620 cm^3/g. Three times more methane is accommodated under such sorbent characteristics in 60 l tank (for motor vehicles) filled with 1 kg of activated hydrocarbon fiber under the same pressure than without fiber.



The new method of transportation comes to a simple gas pressurization technology while the use of development sorbents makes pressurized gas competitive by many indicators. Firstly, this is an opportunity to use land motor and rail transport for gas supply to consumers in the most diverse and often remote regions of the country. Secondly, river and ocean vessels can be used for gas transportation. Thirdly, this is the cheapest and the safest and simple kind of methane transportation in terms of technology.

The transportation distance is the only limitation for the time being. Depending on transportation means, the cost-efficient gas supply distance is within 2,000 km. However, such distance is quite sufficient to make natural gas available for the majority of new consumers that do not receive gas at present exactly because of unresolved transportation problems. We named this kind of transport “virtual gas pipeline”.



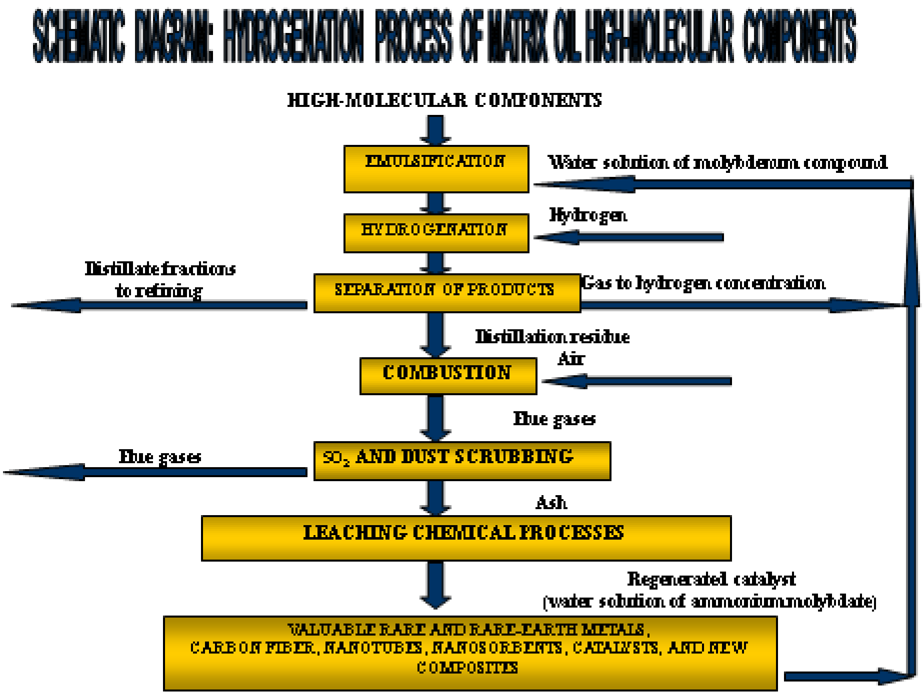
New energy transportation opportunities emerged in connection with the discovery of the superconductivity phenomenon. The superconductivity phenomenon is known to appear when a conductor having relevant properties is placed into environment with temperature of -98°C and lower. Such conditions are achieved when a bar made of special ceramics or another material providing for superconductivity is placed into the liquefied methane environment. Electric power and liquefied gas are supplied nearly without losses in a single pipeline with the bar type superconducting material. Such technology makes it possible to replace a considerable number of large diameter gas lines and power transmission lines by small diameter pipeline, dramatically reduce energy losses, improve energy flows manageability and naturally save a huge quantity of metal. A material for bar type segment of the pipeline needs to be selected and a problem of its efficient insulation should be resolved in order to implement this project.

Gas Chemistry

Russia boasts the largest resources of conventional natural gas. The tasks of developing the richest gas resources in Eastern Siberia are currently at the foreground. In addition to methane, they contain ethane, propane, and butane along with helium and other valuable components. The scientists of the Russian Academy of Sciences achieved substantial progress in the creation of new technologies for the gas chemical industry.

Matrix oil resources in the Orenburg gas and condensate field are especially important for new gas and petrochemical production.

Fig. 6 shows a schematic diagram of the hydrogenation process for high-molecular components of matrix oil, which supports production of rare and rare-earth metals, new catalysts for the hydrocarbon fiber of composites, as well as nanotubes and nanosorbents.



Conclusion

An innovative program of the gas industry development shall be based on the maximized use of fundamental and applied science achievements. Scientific research should be aimed at developing the feedstock base, creating new technologies that increase the degree of hydrocarbon recovery form subsurface, and developing new research-and-engineering and process solutions improving the efficiency of gas chemical production and the reliability of gas transportation system operation.