New low temperature technologies of natural gas processing

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Abstract

Over the past 10 years a number of companies have been working at improvement of supersonic technologies of natural and associated gas processing. During this period, technologies have evolved from a theoretical research and laboratory experiments to a large industrial plants. Main principle, which lies at the basis of these technologies is target components separation due to the deep gas cooling, achieved in a supersonic swirling gas flows. In such cooling process, heavy fractions, contained in natural gas, are condensed, and condensate droplets are separated from the gas due to the flow swirling.

In the world there are only 4 supersonic gas separation units, which are in currently operating.

The majority of currently operated industrial units of supersonic separation are designed for the gas treatment and for LPG extraction. Heavy fractions, heavier than propane and water, are separated from the gas in these devices.

As compared to the existing low temperature processes of gas processing, in which the gas cooling is usually effected by gas expansion in a Joule-Thomson valve or in turbo-expander, either by the use of chillers, supersonic separation technology has the following advantages:

- high reliability, caused by the absence of revolving mechanical parts,
- high efficiency, associated with the capability of providing very low gas temperatures inside the supersonic device,
- low operating expenses,
- the ability of devices to operate without constant manned supervision.

High flow speeds in supersonic separation devices enables devices to be small in size. Thus, at a gas flowrate of 100 MMSFD and a gas pressure of 100 bar, the supersonic separation device has a length of about 2 meters. This makes the supersonic separation technology especially interesting for using on offshore platforms. A high reliability of these devices, caused by the absence of rotating mechanical elements, will likely lead to a wide-scale application of these technologies in a subsea production complex.

A significant progress was recently being made in the development of supersonic technology for the separation of acid components (such as CO_2 and H_2S) from natural gases. In this case, acid components separation is carried out under the conditions, corresponding to the formation of CO_2 crystals. However, due to the fact that the period, when droplets are in a supersonic nozzle, lasts for 0.0001 - 0.001 seconds, crystallization processes have no time to develop, and as it was shown by the tests it is possible to ensure acid gas removal. Herewith, the concentration of acid components in gas can be reduced to 2 - 3% mol. at any concentration in the inlet gas.

Introduction

During recent years a new direction of natural gas separation has been expanding at a very rapid rate - it is a technology of supersonic separation, called 3S-technology (SuperSonic Separation) $[1-2]$.

The technology is based on cooling of natural gas in a supersonic swirling gas flow. Separators, manufactured in accordance with this technology, allow not only to separate the liquid from the gas, but also to extract some target hydrocarbons fractions. This technology will apparently make it possible to realize subsea gas processing, consisting in providing the required hydrocarbon and water dew points in gas, piped from subsea gas fields.

In supersonic separation technology a supersonic gas flow is implemented by means of convergent-divergent Laval nozzle. In this nozzle, gas accelerates to speeds faster than the sound of speed in gas. At that, due to the conversion of potential energy of the flow into kinetic energy, gas is cooled.

The expansion of natural gas , even to a small Mach numbers (M ~ 1.5-2.0), makes it possible to cool the gas down to temperatures, sufficient for condensation not only of components, heavier than propane, but even heavier than ethane. Cryogenic temperatures of natural gas can be achieved without any additional sources of cold, such as chillers, turbo expanders, etc. In 3S-technology the selection of condensate drops, condensed in a supersonic nozzle, and containing target components, is implemented under the influence of centrifugal forces. The centrifugal force field is created by flow swirling in the chamber of supersonic nozzle.

The basic scheme of 3S-technology device (3S-separator) is shown in Fig. 1.

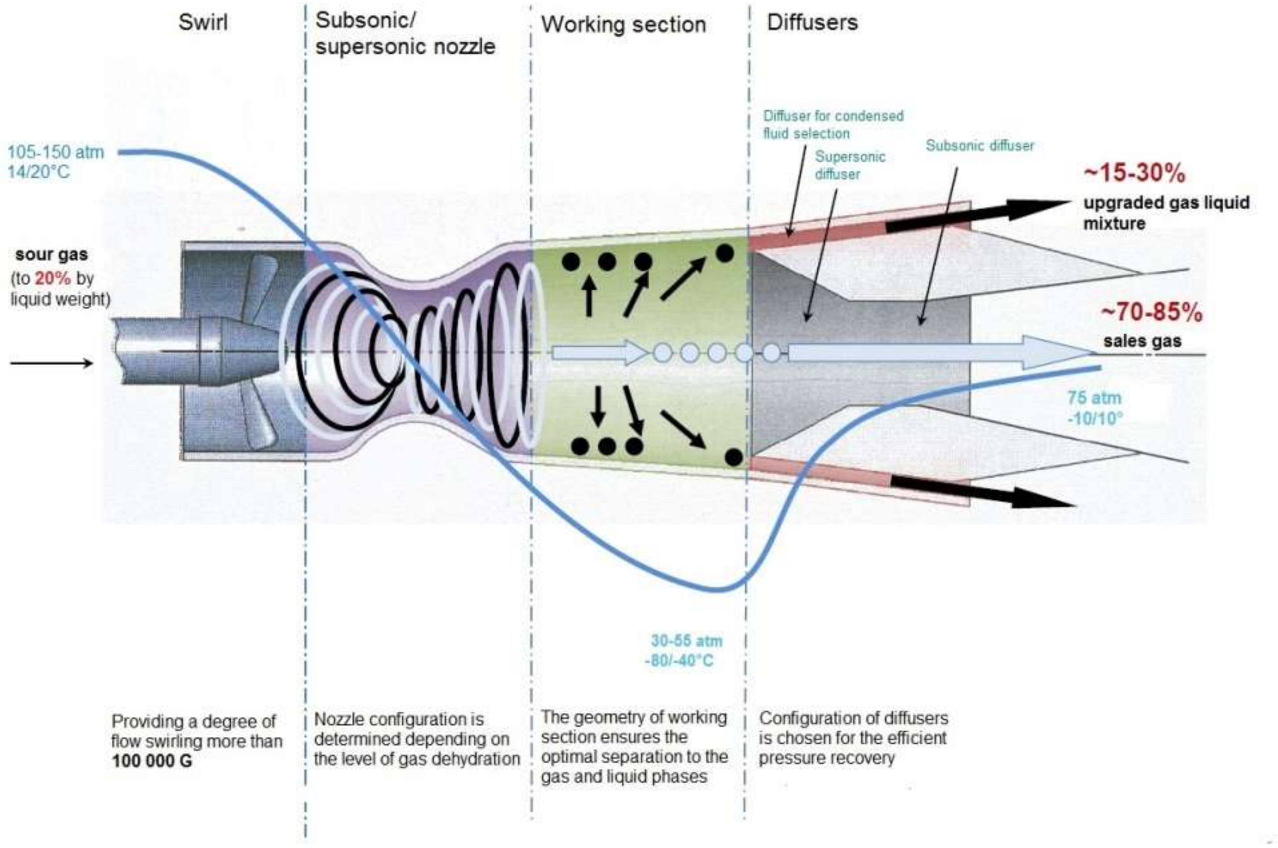

Fig.1 Basic scheme of 3S-separator

3S-separator comprises a swirling device, subsonic and supersonic nozzle, working section, a device for condensed fluid selection and diffusers.

The use of diffuser at the outlet of 3S-separator's working section, due to the diffusion, makes it possible to converse a flow potential energy into kinetic energy, which causes the gas pressure at the outlet of diffuser higher than the static pressure of gas in a supersonic nozzle, in which the condensation of the target component takes place.

3S-technology as a method and devices, based on this method, are patented in Russia and CIS countries, as well as in USA, Canada, Australia, UK, France, Netherlands, Spain, Italy and other countries.

At present two supersonic separation devices are in commercial service. These devices had been mounted at gas processing facilities of "Rosneft", JSC and at the gas field of Chinese public company "Petrochina".

3S-Separator, mounted in 2007 in JSC "Rosneft" (Gubkinskoe complex gas treatment plant (CGTP)) allowed to decrease the hydrocarbon and water dew points by 20°C, compared with the standard scheme with Joule-Thomson valve, used previously on the site.

This Separator is still in successful operation and provides a treatment of about 80 000 nm^3/h of natural gas at an inlet gas pressure of 70-80 atm.

Fig.2 3S-separator at Gubkinskoe CGTP, JSC "Rosneft"

In 2011, 3S-separation unit was successfully launched by Petrochina Company at YAHA field in China. This separation unit, consisting of two 3S-Separators, allowed decreasing the hydrocarbon and water dew points in sales gas more than by 20°C, compared with the standard scheme with Joule-Thomson valve, used previously on the site. The gas pressure at the inlet of the unit was 108 atm., the gas flow rate was 160 000 Nm^3/hr.

Fig.3 3S-separation unit at YAHA field («Petrochina»)

In 2009, exploratory tests of 3S-separator have been successfully carried out at Zapolyarnoye field of Gazprom. According to results of these tests it was recommended to use 3S-separators at other fields of "Gazprom".

Fig.4 3S-separation unit at Zapolyarnoye field of Gazprom

Currently, 5 units of 3S-separators are being installed on different gas processing facilities in Russia and abroad.

The main advantages of 3S-technology are the following: small dimensions of the unit, the absence of moving parts, the absence of necessity of service, the possibility of using the reservoir energy, and, as a result, reducing of capital and operating costs.

The main features of 3S-technology application for the gas treatment

At present, the main configuration of natural gas treatment at fields with medium and high gas formation pressure is a scheme of low-temperature gas separation (LTS).

In this case, the purpose of this treatment can be both a need to receive hydrocarbon and water dew point, and, in some special cases, a need to provide the necessary level of Heat Value (HV) of treated gas.

At the initial period of field exploitation, the Joule-Thomson effect, realized in JT-valve by Gas Pressure Reduction, is mainly used for the gas cooling in schemes of LTS. When the formation pressure of gas falls dawn, turbo-expanding assemblies, in which the gas cooling is achieved due to the both Joule-Thomson effect, and to the additional work, made by gas, are usually used in schemes.

Basic schemes of low temperature separation (LTS) with the application of JT-valve and turbo-expander unit are shown in Fig. 5 and 6.

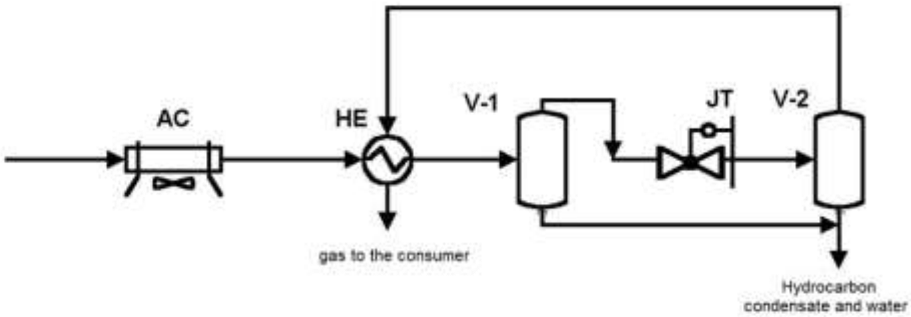

Fig.5 LTS scheme with gas throttling

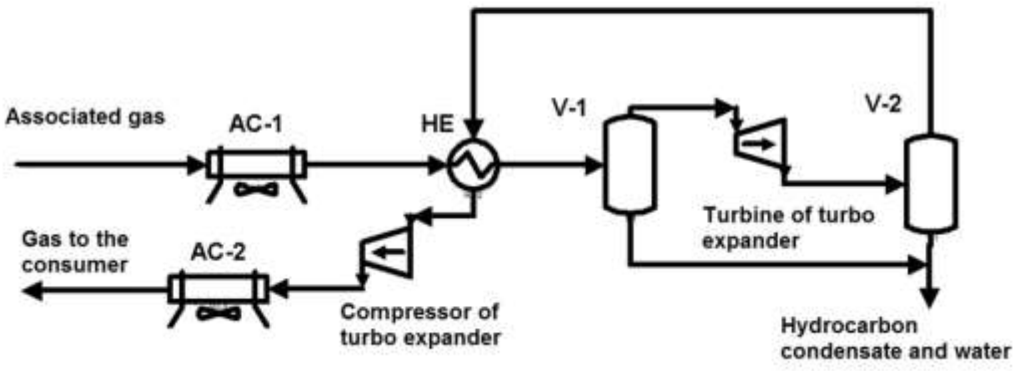

Fig.6 LTS scheme with turbo expanding assembly

First, the reservoir gas is cooled in a heat exchanger by means of sea water or in the air-cooling unit AC and in recuperative heat exchanger HE and then the gas is fed to primary separator V-1, where the liquid fraction (water and heavy hydrocarbons) is separated from the gas. Then the gas phase from separator V-1 is fed to the JT-valve or to the turbo-expander unit TE. After JT-valve or turbo expander unit the cooled gas comes to the low-temperature Gas boot V-2, where the condensed components are separated, and then the gas is going to a heat exchanger HE. After the heat exchanger (in Fig. 5) the gas is supplied to the main gas pipeline, it is compressed in the compressor of turbine expansion unit (Fig. 6), cooled in air-cooling unit and also fed to the main pipeline.

Using of 3S-separators makes the performance of these gas treatment schemes more efficient. The last tested units of 3S-separators can be used both: without any additional devices (Fig.7) and, if it is necessary, in combination with a recuperative heat exchangers and the secondary separators (Fig.8).

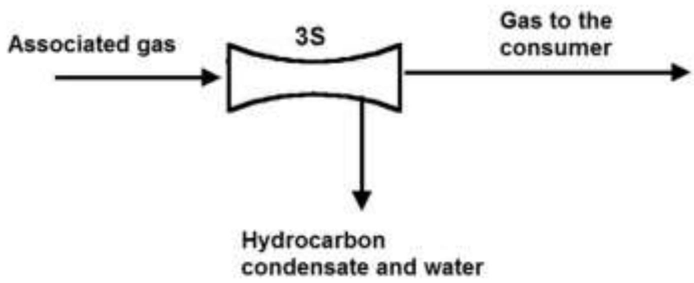

Fig.7 3S-separator

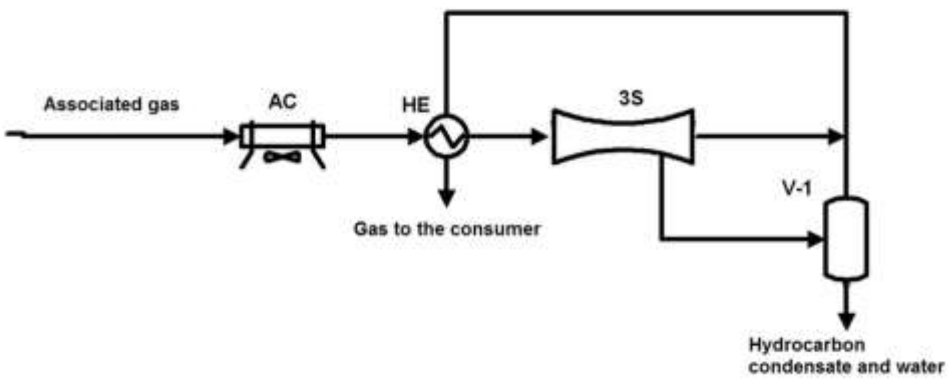

Fig.8 Combined scheme of using of 3S-separator

The most interesting variant is using 3S-technology at deposits, where the pressure of treated gas at the outlet of gas treatment unit must be maintained at ~ 100 atm. The high pressure of gas at the outlet of the unit may be caused by the need to transport the gas at long distances. This is especially important in cases, when the treated gas must be transported via a subsea pipeline. This variant is particularly of current interest when developing fields, located far away from shore (Shtokman field, etc.).

In such conditions, it is impossible to ensure the natural gas treatment, using JT-valve or turbo expander. It can be explained by the fact that in standard schemes it is impossible to condense target components at the pressure close to 100 atm. Fig. 9 shows the phase diagram of the natural gas on the temperature-pressure plane. In such a phase diagram, the natural gas is a two-phase mixture of gas and liquid. To ensure a natural gas separation during the low temperature technological process it is required that a natural gas was in two-phase state at any point of the process. At the same time, for any gases there exists a critical value of pressure (CCB) and a critical temperature (CCT), above which the formation of the liquid phase is not possible. For natural gases the critical pressure often does not exceed 100 atm. That is why at pressures greater than 100 atm. it is almost impossible to conduct a condensation and separation of natural gas components in conventional low-temperature processes.

In Fig. 9 there is a diagram, that shows changes of thermodynamic state with depending on sequential passage of natural gas through the different parts of unit, which schemes are given in Fig. 5-7.

P-T diagram A-D-F-E corresponds to the scheme of the unit with JT-valve, shown in Fig. 5, A-D'-F'-E'-E -corresponds to the scheme with turbo expander (Fig. 6), A-B-C- to the scheme of 3S-separator (Fig. 7). Parts A-D, A-D' and F-E, F'-E' show the passage of gas through the cooling and heating channels of recuperative heat exchanger HE, D-F part shows gas throttling in JT - valve, D'-F' part shows the gas flow through the turbine of turbo expander TE, E'-E part shows a gas compression in turbine expander TE.

A-B-C Chart corresponds to the gas passage through the 3S-separator (Fig. 9). At that the part A-B - corresponds to the natural gas expansion in the nozzle of 3S-separator, accompanied by the gas cooling process, condensation of target components and by the separation of condensed drops of condensate, part B-C - shows the compression of gas inside the diffuser of 3S-separator.

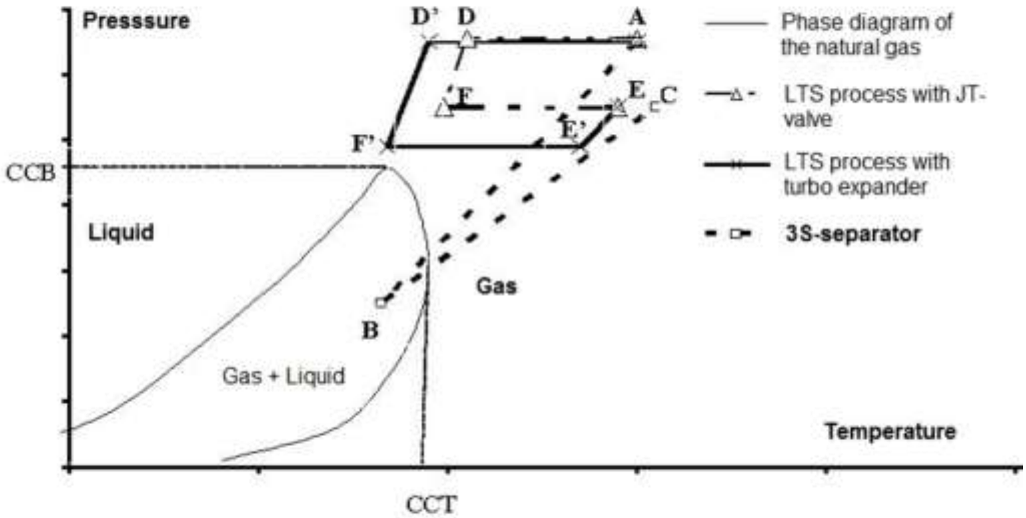

Fig.9 The diagram of different processes of natural gas treatment in case of high pressure of gas at the outlet of the unit

For configurations, shown in Fig.9, neither low temperature separation (LTS) with JT-valve, no low temperature separation (LTS) with turbo expander cannot provide condensing of gas components, and hence cannot provide the separation of target components. Due to the gas expanding up to supersonic velocities, it becomes possible to cool the gas strongly and to separate heavy components in the nozzle passage of 3S-separator.

Thus, the application of 3S-technology provides new significant possibilities fot the gas treatment.

Basic principles of 3S-technology using for carbon dioxide recovery

The process flow scheme of carbon dioxide recovery device, based on the principle of 3S-technology, is shown in Fig. 10.

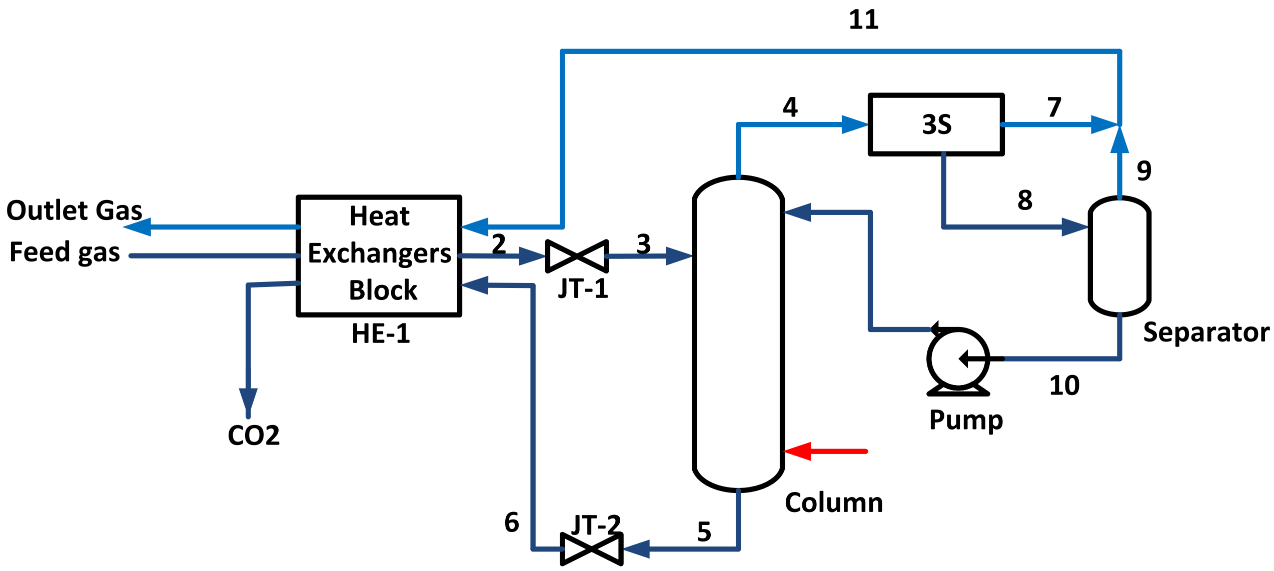

Fig.10 Basic scheme of 3S-separation unit for CO_2 recovery from natural gases

3S-separator functions as follows: dry inlet gas, containing large amount of CO_2, is cooled in heat-exchangers block, and after the preliminary expansion, it is fed to rectification column. In rectification column occurs a fractionating of inlet mixture, at that condensate, generally containing liquid CO_2, is sampled in the bottom of the column; condensate, containing ethane, methane and CO_2, is sampled at the top of the column. Gas from the column is delivered to the inlet of 3S-separator, to be cooled in the supersonic nozzle, and the carbon dioxide, remaining in gas, is condensed. Two-phase flow is directed from 3S-separator to the conventional gas-liquid separator. Separated liquid, containing CO_2, is pumping and then it flows to the column as a reflux liquid. Gas from separator is mixed with processed gas from 3S-separator, cooled in heat-exchangers block and finally fed to consumers. Condensate from the bottom of the column is throttled, heated in heat-exchangers block and directed to the compressor for injection.

The optimum level of gas pressures at the inlet of the unit – more than 40 atm. At that, the range of outlet pressure is usually from 20 to 25 atm.

In proposed device, separation of carbon dioxide is carried out in two stages. In the first stage through the gas cooling in heat exchangers, gas is cooled to temperatures -40 - -70°C (depending on desired level of gas from CO_2 purification and inlet gas pressures). At such range of temperatures a portion of CO_2 is condensed. In this regard, since the condensed carbon dioxide is a good dissolvent, hydrocarbon components of natural gas dissolve rapidly in liquid CO_2. Therefore, the bulk of the input stream before the column is in the liquid phase. Stripping of light hydrocarbons occurs in the column by liquid heating in the bottom part of the column. Owing to this, liquid condensate at the outlet of column, sampled in the bottom of the column, mainly contains liquid CO_2; a gas from the top of the column contains light hydrocarbon components, such as methane, ethane, propane, and CO_2. Depending on selected mode of the column, CO_2 content in gas at the outlet of the column may vary from 10 to 20 mol% at any even very high CO_2 concentration in the inlet gas.

In the second stage, the gas is treated in 3S-separator, where through the extremely strong gas cooling, in a supersonic nozzle could be achieved such low temperatures, that CO_2 concentration in the gas phase could be up to 2% mol or higher, depending on the requirements to the sales gas.

Figure 11 shows the phase diagram of the inlet gas changes on the pressure-temperature plane. The segment *AB* refers to the gas cooling in the block of heat exchangers, the segment *BC* – is a gas flow throttling in the choke, *CD* shows the gas passage through the column, the segment *DE* concerns to the gas cooling in the supersonic nozzle of 3S-separator, the segment *EF* refers to the gas passage through the diffuser of 3S-separator, and the segment *FG* shows the gas heating in the block of heat exchangers.

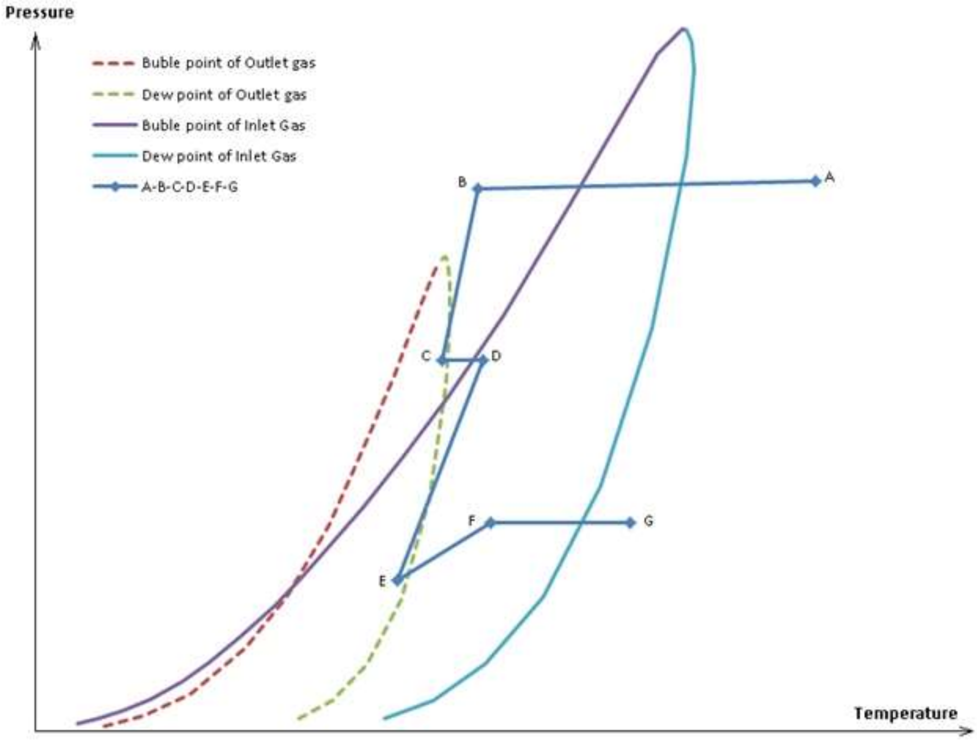

Fig.11 Phase diagram of the inlet gas changes on the pressure-temperature plane

In tables 1 and 2 there are examples of design parameters of flows at the inlet and outlet of 3S-separator for two cases, where the gas at the inlet of the unit has a high carbon dioxide concentration. Table 1 - corresponds to the case, when according to the customer's requirements, the outlet gas may have a CO_2 concentration of 13%, as it will be burned at the power plant. Table 2 presents data for more complex 3S-separation unit than shown in Fig. 10. In this case, CO_2 concentration in the outlet gas is 2%.

Table 1

	Unit	Inlet gas	Outlet CO2	Outlet Gas
Vapour Fraction		1,00	1,00	1,00
Temperature	*C*	45,0	-10,0	-9,6
Pressure	*MPag*	6,7	0,1	2,5
Molar Flow	*m3/h_ (gas)*	11776,6	8351,6	3425,1
Mass Flow	*kg/h*	18053,9	15153,2	2900,8
Mole Frac (Nitrogen)		0,004000	0,000011	0,013727
Mole Frac (CO2)		0,712018	0,949584	0,132736
Mole Frac (Methane)		0,268007	0,030888	0,846199
Mole Frac (Ethane)		0,011000	0,012814	0,006577
Mole Frac (H2S)		0,004975	0,006703	0,000761

Table 2

	Unit	Feed Gas	CO2	Outlet Gas
Vapour Fraction		1,00	1,00	1,00
Temperature	*C*	40,0	19,0	30,0
Pressure	*MPa*	6,0	0,5	2,5
Molar Flow	*m3/h*	145830,0	105100,2	40727,9
Mass Flow	*kg/h*	217924,8	188633,8	29290,5
Mole Frac (CO2)		0,606770	0,831241	0,027542
Mole Frac (Methane)		0,308422	0,056799	0,957700

Mole Frac (Ethane)		0,037684	0,049821	0,006374
Mole Frac (Propane)		0,023786	0,032969	0,000096
Mole Frac (i-Butane)		0,003828	0,005312	0,000000
Mole Frac (n-Butane)		0,008120	0,011267	0,000000
Mole Frac (i-Pentane)		0,001847	0,002563	0,000000
Mole Frac (n-Pentane)		0,004689	0,006506	0,000000
Mole Frac (Nitrogen)		0,002329	0,000020	0,008287
Mole Frac (n-Hexane)		0,000334	0,000463	0,000000
Mole Frac (n-Heptane)		0,001184	0,001643	0,000000
Mole Frac (n-Octane)		0,000667	0,000926	0,000000
Mole Frac (n-Nonane)		0,000231	0,000321	0,000000
Mole Frac (H2S)		0,000005	0,000007	0,000000
Mole Frac (n-Decane)		0,000075	0,000104	0,000000
Mole Frac (n-C11)		0,000022	0,000031	0,000000
Mole Frac (n-C12)		0,000005	0,000007	0,000000
Mole Frac (n-C13)		0,000001	0,000001	0,000000

To prove the efficiency of 3S-technology for above listed schemes, ENGO Engineering developed an experimental setup, which allows testing 3S-separator in a wide range of pressures, temperatures and CO_2 concentrations in the inlet gas.

During experiments, it has been shown, that in order to achieve a high rate of acid gas removal the inlet temperature should be below -60°C. Only at these conditions it is possible to purify natural gas to CO_2 concentration less than 4% mol.

Conclusions

The innovative technology of supersonic gas treatment, described in this paper, provides an efficient natural gas processing. The technology can be used both for the natural gas treatment and for the extraction of separate fractions from a natural gas. Supersonic separation technology can significantly improve the process of gas treatment at gas plants, where the gas is cooled by means of Joule-Thomson valve. At high gas pressures 3S-technology makes it possible to treat the gas even at such gas parameters when the use of Joule-Thomson valve and turbo-expander is impossible.

Available technology of supersonic separation can be used for carbon dioxide removal from natural gases. 3S-technology is most effective for natural gas with high CO_2 content stripping, especially when it is difficult to use conventional technologies.

Proposed schemes of 3S-separation units can provide CO_2 concentration in the outlet of the unit less than 2 % mol. (at any CO_2 content in the inlet gas). Tests of 3S-separators, conducted on hydrocarbon mixtures, containing CO_2, have shown that the developed 3S-separator provides the desired efficiency of CO_2 separation from natural gases.

References

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