SUPERSONIC GAS TECHNOLOGIES

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1. INTRODUCTION

The 3S technology is the modern technology intended to extract target components from natural gases. The technology is based on cooling of natural gas in a supersonic swirling gas flow. The supersonic flow is created using a convergent-divergent Laval nozzle. In such a nozzle, gas is accelerated up to velocities exceeding the sound propagation velocity in gas. Due to transformation of a part of the potential energy of flow to kinetic energy the gas is cooled greatly.

If condensed drops containing basically heavy components C3+ are separated from the gas flow in the supersonic nozzle, then the gas at the nozzle exit will primarily consist of light components, such as methane, ethane etc.

In the 3S-technology, separation of condensate drops with target components condensed in the supersonic nozzle is performed under action of centrifugal forces. The field of centrifugal forces is created by means of flow swirling at the supersonic nozzle entry.

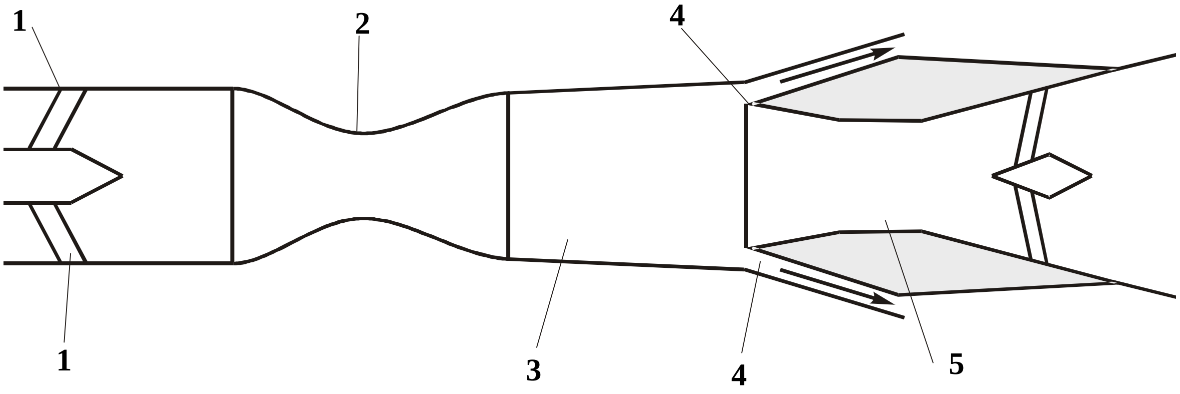

Figure 1. Schematic of 3S-separator

The schematic of the facility (hereinafter the 3S-separator) with the implemented 3S-device is presented in Figure 1. The 3S-separator includes: 1 – swirling device, 2 – supersonic nozzle, 3 – working section, 4 – device for extraction of gas-liquid mixture, 5 – diffuser.

The application of the diffuser at the 3S-separator working section exit makes it possible to transform a part of kinetic energy of the flow to potential energy to obtain the gas pressure at the diffuser exit larger than the static gas pressure in the supersonic nozzle.

The international patents for the 3S-technology and the 3S-separators are the property of TransLang Technologies Ltd ([1,2] and others).

2. PILOT AND PRODUCTION PLANTS OF THE 3S-TECHNOLOGY

For improvement of the technology and for its commercial use, the TransLang Technologies Ltd. has developed a number of facilities. By now, the “3S”– type facilities developed are as follows:

- The test complex at Didsbury (Calgary, Canada). The facility provides the gas flow rate of up to 12 kg/s at the initial gas pressure of 50 – 70 bar and the outlet gas pressure of not below 40 bar. The facility is intended to investigate extraction of components C5+ from natural gas.

The bench is designed for a long period tests and equipped with a measuring complex to measure pressure, temperature and component concentrations in the 3S-separator elements.

- The experimental bench with the "3S"-type facility in Moscow region (Russian Federation) provides the gas flow rate of 1.5 – 2.5 kg/s and the working pressure of up to 150 bar. The initial temperature can be varied from –60 ^{0}C to +20 ^{0}C. The bench is equipped with special devices to specify required hydrocarbon gas mixture compositions at the 3S-separator entry.
- The production facility in Western Siberia. In September, 2004, a complex consisting of two "3S" facilities with a capacity of above 400 mmscm per year each was successfully put into pilot production operation at one of the gas treatment plants in Western Siberia as a part of the LPG complex. The initial gas pressure at the 3S-separator entry is 32 bar, the initial gas temperature is minus 30 ^{0}C. The 3S-separator provides extraction of components C3+ in the complex of LPG recovery.
- To investigate various fundamental physical aspects of applying the "3S" technology, two laboratory facilities are used in Moscow region. In one of them the working gas is air, while in the other the mixture of nitrogen and propane–butanes is used.

Over the last five years, more than 400 tests of "3S"-type facilities have been carried out at different temperatures, pressures and gas mixture compositions. Subsonic, transonic and supersonic separation modes were tested. Optimal 3S-separator structures were designed to provide extraction of components C3+, C5+ from natural gas.

A range of experimental investigations was conducted under conditions up to those approaching industrial applications. Experiments confirmed the main results and conclusions made in the laboratory test facility, in particular the suggested conclusion regarding the high level of effectiveness of the 3S-separator.

Relying on the data obtained from these test facilities, a specific software was developed to calculate the 3S-separator physical components under various operating conditions.

The diagram in Figure 2 clearly demonstrates the results of a series of test runs with 3S-separator and their comparison with corresponding results for *JT- valve*.

Each point on the diagram corresponds to a specific experimentally achieved result. The extraction effectiveness for heavier components of natural gas (pentane, butanes+propane) in the 3S-separator is plotted on the vertical axis of the diagram and the effectiveness calculated for the facility with the JT valve for the same condition (at the same differential pressure) is shown on the horizontal axis. The separation effectiveness is measured by $\Delta\alpha=\alpha_0-\alpha_\kappa$, where α_0, α_κ are the initial and final (at the facility exit) mole concentrations of components C$_{3+}$.

It is perfectly clear from these data that there exists a range of conditions, (especially where small initial concentrations of heavier hydrocarbons are present) when it is possible to extract such liquid components using the 3S-separator while it would be impossible if a JT valve were to be used.

In the tests, the results of which are presented on the above diagram, the initial concentrations of components, gas pressure and temperature at the 3S-separator entry, differential pressure through the facility and gas dynamic flow condition were varied. The results were obtained for conditions at Mach Number M<1.5 in the 3S-separator working section.

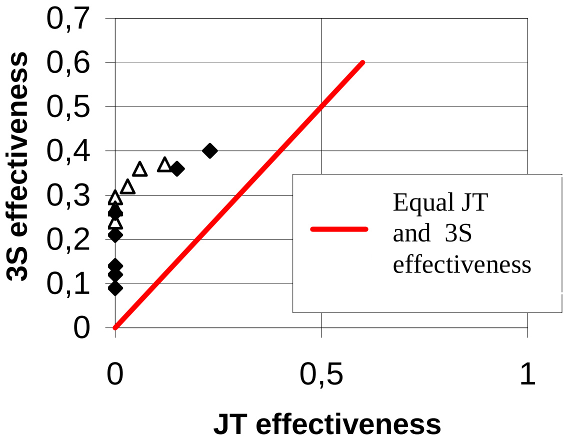

Figure 2. Comparison of 3S and JT effectiveness

Comparison of the 3S-technology with *turboexpanders* shows that there exist schemes in which the 3S-technology provides better extraction of target components as compared with the schemes in which only the turboexpander is used. In some cases the 3S-separators provide extraction of target components for parameters when the operation of turboexpanders is impossible (see below).

3. ADVANTAGES OF THE 3S-TECHNOLOGY

Some advantages of the 3S-technology as compared with traditional technologies of hydrocarbons separation from natural gas are as follows:

- small size and therefore reduced space requirements, greater portability and reduced handling and installation costs,
- low capital and operating costs,
- no adverse environmental impact,
- the absence of moving parts,
- no requirement for routine maintenance,
- conservation of reservoir energy,
- superior performance capabilities compared to conventional separation equipment and configurations.

There are a wide range of potential applications for 3S-separators to solve the following problems of gas industry:

- gas conditioning (dehydration and extraction of heavy hydrocarbons);
- separation of propane-butanes (LPG);
- extraction of ethane
- production of LNG.

The calculations based on the experimental data for particular fields reveal that the application of the 3S-technology could result in a recovery of heavier gas components to be increased by more than 30% for the same power of requirements.

The application of 3S-separators instead of *JT-valves* on existing gas processing and extraction plants makes it possible, utilizing the same compressor power, to increase the LPG extraction by 10 – 20%. Similarly if satisfied with the current extraction level, it would be possible to decrease the required compressor power by 10 – 20%.

At gas processing plants for LPG extraction equipped with *turboexpanders* and coolers (high LPG extraction – GSP), the application of 3S-extractors could lead to reduction in the required compressor power by 15 – 20% at the same extraction level.

These examples offer the possibility of increasing the profitability of gas processing plants by means of an inexpensive reconstruction.

4. APPLICATION OF THE 3S-TECHNOLOGY TO FACILITIES OF GAS CONDITIONING (HYDROCARBON DEWPOINTING)

Relying on the results of pilot production tests of the 3S-separator obtained, in particular, on the test bench at Didsbury, it is easy to show the advantages of using the 3S-technology under conditions of the facility of natural gas preparation for transportation.

The main aim of these facilities is to extract heavy components C5+ (C3+) from natural gas and to provide a required dew-point level for hydrocarbons in natural gas at the facility exit.

The process of natural gas dehydration is conducted either upstream of such a facility or water extraction is performed simultaneously with heavy components C5+ (C3+) extraction. If separation of components C5+ (C3+) and water is performed simultaneously, inhibitors of hydrate-formation, for example, ethylene glycol, are added to natural gas.

The functional diagram of the commercial facility of gas conditioning using the JT-valve is given in Figure 3. This diagram with similar parameters is typical, in particular, for various fields in Alberta (Canada).

Let us consider the operational parameters of the facility for one of the fields.

Natural gas is delivered to the facility at pressure of 18.9 bar. In the compressor C-1 it is compressed up to 76.3 bar, as a result the gas temperature increases up to 140 ^{0}C. Then gas is cooled in the air cooler down to 48 ^{0}C and delivered to the recuperative heat exchanger. In the heat exchanger, gas is cooled down to -6 ^{0}C and supplied to the JT-valve entry. When the gas pressure in the JT-valve is reduced from 75.6 bar to 58.8 bar, gas is cooled down to -15 ^{0}C and there occurs condensation of heavy gas components. The condensed liquid fraction is then extracted in the three-phase separator V-1. After the separator, the gas fraction is supplied to the recuperative heat-exchanger and then to the gas main. The liquid fraction after the separator is supplied to the stabilization facility and then to the storage for condensate.

The mole composition of natural gas at the facility entry is as follows:

N2 – 1.65%, CO2 – 0.44%, CH4 – 87.49%, C2H6 – 7.00%, C3H8 – 2.07%, i – C4H10 – 0.35%, n-C4H10 – 0.46%, i – C5H12 – 0.17%, n – C5H12 – 0.14%, C6+ - 0.23%.

The parameters of main flows for JT-valve LTS Process are summarized in Table 1.

For the above process the extent of extraction of C_{5+} from natural gas flow is 38%, the dew-point for hydrocarbons being –15 ^{0}C (at gas pressure of 58 bar).

Figure 3 shows the diagram of the facility of gas conditioning using the 3S-separator. In this scheme the 3S-separator is installed instead of the JT-valve. In this case, the gas-liquid flow from the 3S-separator is delivered to the same three-phase separator V-1. Gas from the three-phase separator is mixed with purified gas from the 3S-separator and supplied to the recuperative heat exchanger.

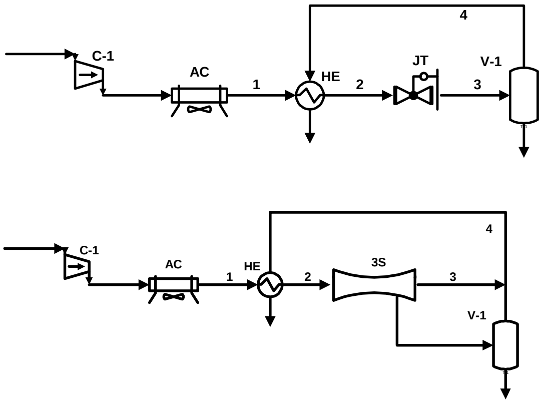

Figure 3. JT-valve LTS Process and 3S-separator LTS Process

Flow	1	2	3	4
Pressure, bar	76.3	75.6	58.8	58.8
Temperature, ^{0}C	48	-6	-15	-15
Content of Components C5+, % mass.	2.27	2.27	2.27	1.43

Table 1. The parameters of main flows for JT- valve LTS Process

Flow	1	2	3	4
Pressure, bar	76.3	75.6	58.8	58.8
Temperature, ^{0}C	48	16.8	11.3	9.93
Content of Components C5+, % mass.	2.27	2.27	0.71	1.15

Table 2. The parameters of main flows for 3S-separator LTS Process

The calculated parameters of main flows for 3S-separator LTS Process are summarized in Table 2.

The calculation of the natural gas purification effectiveness in the 3S-separator is based on the results of its tests on the bench at Didsbury. For the scheme in Figure 3 the extent of extraction of C_{5+} from natural gas flow at given parameters of the 3S-separator operation is 50%, while the mass fraction of gas-liquid flow delivered to the secondary gas-liquid separator from the 3S-separator is 20 – 30 % of the total flow supplied to the 3S-separator entry. Thus, simple replacement of the valve with the 3S-separator in the LTS facility of gas conditioning makes it possible to improve the C5+ extraction by a factor of 1.32. This is equivalent to reduction in the dew-point of the output gas by 4 ^{0}C.

Some modification of the scheme of using the 3S-separator, in particular, introduction of an additional recuperative heat exchanger allows the differential pressure through the facility to be decreased considerably. During the test carried out at Didsbury it is shown that for gas pressure after the compressor of 66.3 bar the gas purification from components C5+ in the case under consideration can be 49%. Thus, with significant reduction in the compressor compression ratio and, respectively, with reduction in the compressor unit power by ~12% the application of the 3S-technology allows increase in extraction of components C5+ from natural gas by a factor of 1.3. In this case, the compressor power required for extraction of target components decrease two times.

5. APPLICATION OF THE 3S-TECHNOLOGY FOR OFFSHORE AND SUBSEA PROCESSING

Offshore Processing

It is believed that the advantages of 3S-technology listed above make the application of 3S-technology especially promising for fields located in offshore locations.

The application of 3S-technology for subsea processing of gas from the fields located at sea bed is especially effective. At the present time, the main scheme of natural gas conditioning on offshore fields at medium and high field pressure is the scheme of low-temperature gas separation (LTS). The purpose of such gas preparation can be provision for both the dew-point for hydrocarbons (water) and, in some particular cases, achievement of required level of HV (Heat Value) of the prepared gas. At the initial stage of operating the fields, only the Joule-Thomson effect is basically used in the LTS schemes for gas cooling. This effect is realized by reducing the gas pressure in the JT-valve. When the field pressure decreases, the turboexpanders are generally used in which gas cooling is attained not only due to the Joule-Thomson effect but also due to additional work performed by gas.

The model LTS schemes with use of the JT-valve and the turboexpander are given in Figure 4.

Natural gas is cooled in the heat-exchanger by sea water or in the air cooler AC and the recuperative heat-exchanger HE and supplied to the primary separator V-1 in which the liquid fraction (water and heavy hydrocarbons) is separated from gas. Then the gas phase from the separator V-1 is delivered to the JT-valve or to the turboexpander TE. The cooled gas from the JT-valve or the turboexpander turbine is supplied to the secondary low-temperature separator V-2, in which condensed components are separated, and then to the heat exchanger HE. Downstream the heat exchanger gas is supplied to the gas main according to the JT-valve LTS Process, but according to the Turboexpander LTS Process gas is compressed in the turboexpander compressor, cooled in the air cooler and also supplied to the gas main.

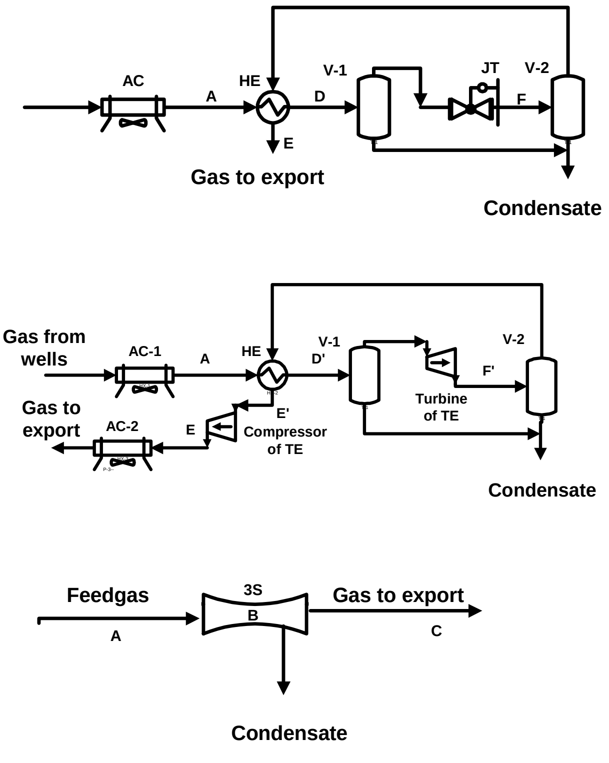

Figure 4. JT-valve LTS Process, Turboexpander LTS Process and 3S-separator

The application of the 3S-separators developed by TransLang Technologies Ltd makes it possible to improve the operation of the considered schemes of gas processing.

The advantages of the 3S-separator as compared with the JT-valve are demonstrated in detail in the previous Section. Here we consider the cases when the 3S-technology offers advantages as compared with the schemes in which the turboexpander is used.

In this connection, of most interest is the case of using the 3S-technology in

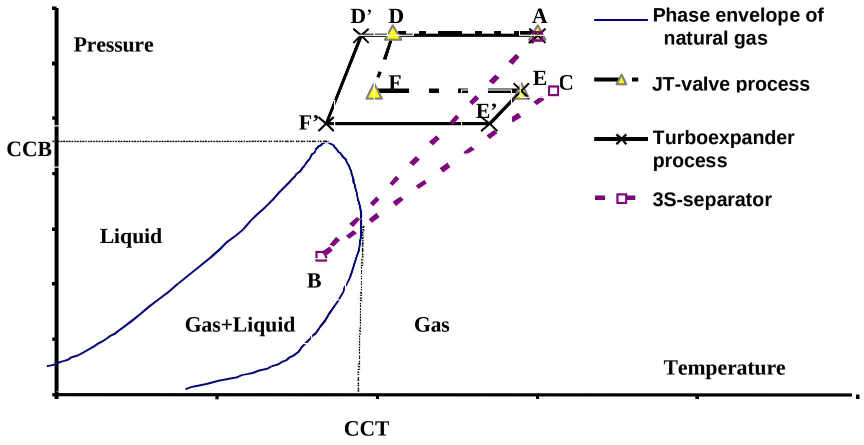

Figure 5. Diagrams of different processes of natural gas processing for high gas pressure at the facility exit

fields when it is necessary to maintain the pressure of the prepared gas at the gas preparation facility exit at the level of ~100 bar and more. The high gas pressure level at the facility exit can be dictated by the necessity of gas transportation for long distances. This is of particular importance for versions when the prepared gas must be transported through the subsea pipe-line to the shore and then, without additional treatment, to the customer. In most cases, it is impossible to provide the natural gas conditioning using the JT-valve or the turboexpander. The reason is that in the standard schemes the condensation of target components at pressures approaching 100 bar proves to be unfeasible.

Figure 5 shows the phase envelope of natural gas in the “temperature –pressure” coordinates. Inside the phase envelope, natural gas represents a two-phase gas- liquid mixture. For natural gas components to be separated in the low-temperature process, it is necessary that natural gas at any process point should be in the two-phase state. At the same time, for any natural gas there are pressure Cricondenbar (CCB) and temperature Cricondentherm (CCT) above which the formation of liquid phase is impossible. For natural gases, Criconcenbar often does not exceed 100 bar, that is why at pressures above 100 bar the condensation and separation of natural gas components in the standard low-temperature processes prove to be unreal.

Figure 5 represents the diagrams of variations in the thermodynamic state when natural gas successively passes through different facility sections the schemes of which are shown in Figures 4. The P-T diagram A-D-F-E corresponds to the scheme of the facility with the JT-valve, the diagram A-D’-F’-E’-E refers to the scheme with the turboexpander, and the diagram A-B-C relates to the 3S-separator scheme. The segments A-D, A-D’ and F-E, F’-E’ show the gas passage through the cooling and heating channels of the recuperative heat exchanger HE, the segment D-F concerns the gas throttling in the JT-valve, the segment D’-F’ reflects the gas passage through the turbine of the turboexpander TE, and the segment E’-E relates to the gas compression in the compressor of the turboexpander TE.

The diagram A-B-C corresponds to the gas passage through the 3S-separator. The segment A-B refers to the natural gas expansion in the 3S-separator nozzle accompanied by gas cooling, condensation of target components and separation of condensed drops of condensate, the segment B-C shows the gas compression in the 3S-separator diffuser.

In cases presented in Figure 5, neither the LTS process with the JT-valve nor the Turboexpander process provide condensation of gas components and, hence, separation of target components. While due to gas expansion up to supersonic velocities in the nozzle channel of the 3S-separator it is possible to cool gas to a sufficiently great extent and provide separation of heavy components. Thus, the application of the 3S-technology opens up new capabilities for gas processing in offshore gas fields.

Subsea Processing

On most gas production platforms the gas pressure is limited to 100 bar. from considerations of platform and personnel safety. The gas pressure at the well-head often exceeds this by a considerable margin. This results in the necessity of installing a JT-valve at the well-head to reduce the gas pressure on the platform.

Replacement of the JT-valve with the 3S-separator will allow simultaneous solution of several problems: pressure reduction, gas dehydration, condensate (LPG) extraction together with dew-point control.

A possible schemes utilizing 3S-separator application for condensate (LPG) extraction in Subsea Processing is shown in Figure 6.

In these Figures, the following designation are used: 1 - Well , 2 - Well head, 3 - Condensate extraction facility, 4 - 3S-separator, 5 - Gas-liquid separator, 6 - Heat-exchanger, 7, 11 - Pipeline for condensate transportation, 8 - Gas pipeline for purified gas, 9 – offshore platform, 10 - Facility for preparing condensate for transportation, 12 – Sea land.

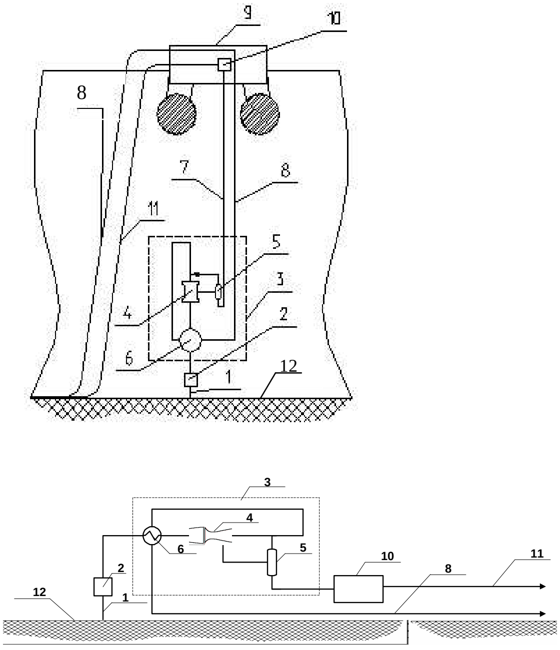

Figure 6: Application of the 3S-technology subsea

Gas from the well, after passing the well-head, is delivered to the processing facility with the 3S-separator mounted near the well-head located at the subsea. The facility consists of a recuperative heat-exchanger, a 3S-separator and a secondary separator for separation of the gas-liquid flow coming from the 3S-separator. The liquid mixture of hydrocarbons and water separated from the natural gas in the facility are supplied along pipelines to the platform facility to prepare condensate (LPG) for transportation.

The important application of the 3S-separator is the fully subsea scheme.

6. CONCLUSIONS

A new group of technologies has been developed for the separation and processing of natural gas components based on the adiabatic cooling of swirling gas flow in a supersonic nozzle.

New, highly efficient, technological schemes for gas processing and treating with 3S-separators have been designed and have been tested in test facilities.

There are a wide range of potential applications for 3S-separators in facilities for natural gas processing such as:

- facilities for gas preparation for transportation;
- facilities for LPG extraction (shallow cut and deep cut);
- offshore gas separation and treatment facilities etc;
- plus many others (CO_2 extraction, Ethane recovery and LNG are under extensive investigation).

In all cases considered, the technology supplied using 3S-separators makes it possible to provide a cost effective and highly efficient extraction process for C_{3+} gas components combined with a potential reduction in energy consumption.

7. REFERENCES

1. European Patent № 1131588.
2. United States Patent № 6372019.