The International Journal of Engineering and Science (IJES)
|| Volume || 13 || Issue || 10 || Pages || PP 50-56 || 2024 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Analysis of supersonic techniques for separating water from extracted natural gas

Doru Bârsan[1], Laurențiu Prodea[2], Timur Chiș[1]
[1]*Oil and Gas Enginering Faculty, Petroleum and Gas University, Ploiesti, Romania*
[2]*Mechanical Faculty, Lucian Blaga University, Sibiu, Romania*
Corresponding Author:Timur Chis

---***ABSTRACT***---
The article analyzes the supersonic techniques for separating impurities from natural gas extracted from Romanian deposits.
One of the newest techniques used in separating water from natural gas is their treatment in a supersonic flow (flow field) using a device (the supersonic separator). The article describt this technique of separating water (the dewatering process) and condensate (the separation petroleum liquid process), which is increasingly used (especially in the limited spaces of offshore platforms).

KEYWORDS; *Water, Supersonic. Separation, Natural gas,*

Date of Submission: 06-10-2024 Date of acceptance: 18-10-2024

I. INTRODUCTION

Given the increase in global energy consumption and the implementation of legislation to reduce carbon dioxide emissions, it is necessary to restrict the use of fossil energy resources with major polluting emissions (crude oil, coal) and increase the use of methane as a transition fuel [1,2,3,4].
Thus, the US Department of Energy predicted that natural gas use will increase consumption by about 31% in 2035 compared to 2015 [1].
In China, the energy mix is expected to contain 10% natural gas (in 2025), and in Romania, it is expected to reach 11% in 2026 [2,3].
The increased demand for natural gas consumption has also led to their extraction from deposits with a high condensate content or oil structures with active saline aquifers.
That is precisely why there is a development of treatment techniques (drying, conditioning, separation) for contaminated natural gases, the role of these processes being to remove water taken from the aquifer (saline or fresh), detritus (sand) and impurities associated with extraction (paraffin, ceresin, clay, traces of chemical substances from the treatment stage of the productive layers), condensate (the upper fractions from hydrocarbons), hydrogen sulfide, carbon dioxide, nitrogen, mercury, impurities that would affect the transport, processing, and transformation process, in energy or chemical products with high marketability, of extracted natural gas.

The removal of water from natural gas is the most critical process, considering that the existence of this chemical compound can lead to:
a. Formation of cryohydrates (gas hydrates),
b. The appearance of galvanic cells in the areas of its accumulation,
c. Errors when measuring gas flows,
d. The appearance of explosive atmospheres by extinguishing the combustion torch as a result of water entering the nozzles or hearths of ovens and cooking and heating appliances,
e. There is a possibility of entrainment of liquid fractions in the separation facilities (due to their vaporization and the entrainment of condensate particles during the movement of vapors to the condensers).

The absorption processpassed on the surface of a solid (or through the pores formed by particles of a solid substance).
As a result of the contact between them, the adsorption of the necessary substance on the surface of the adsorbent takes place to be adsorbed.

The process can be physical or chemical and is based on the adsorption of the liquid phase on an active solid bed (the best-known adsorbents are alumina, silica gel, and molecular sieves).
Another physical process used to separate water and wellbore condensate from natural gas is related to the property of separate condensation of fractions contained in natural gas (different condensation points).
This technology (cryogenic process) can ensure a very low dew point (water condensation point), but it requires large investments, high-pressure losses during condensation and expansion, and high energy consumption.
The use of ceramic membranes or synthetic membranes made of polymers (polyamide or cellulose acetate) ensures good water separation (by creating a pressure difference) due to its retention in the sewers of solid structures and the passage of natural gas particles between them.
This process requires periods of restoration of the polymer structure, and oil liquids can be lost by forming solid and stable emulsions [5,6,7,8,9].
One of the newest techniques for separating water from natural gas is treating them in a supersonic flow (flow field) using a device (the supersonic separator).
This technique of separating water (dehydration process) and condensate (desalination process) is used more and more (especially in the small spaces of offshore platforms); the first research on the separation of fluids in the sonic field was carried out in 1972 [10,11].
Supersonic field fluid separation techniques were first patented by Alferov and his collaborators in 2002 and Betting with an advanced research group in the petroleum industry in 2003 [12].
However, the first industrial application of this separation technique was realized in 2003, when a team of engineers from the company Twister BV patented and presented an industrial separator (both for water and natural gas—figure 1 [12]).
These devices have been installed in the offshore oil fields of Petronas and Sarawak Shell Berhad (SSB).
Alferov and his collaborators [12] also developed a supersonic separator, which they called Supersonic Separator Technologies ("3S"). Its structure is shown in Figure 2.

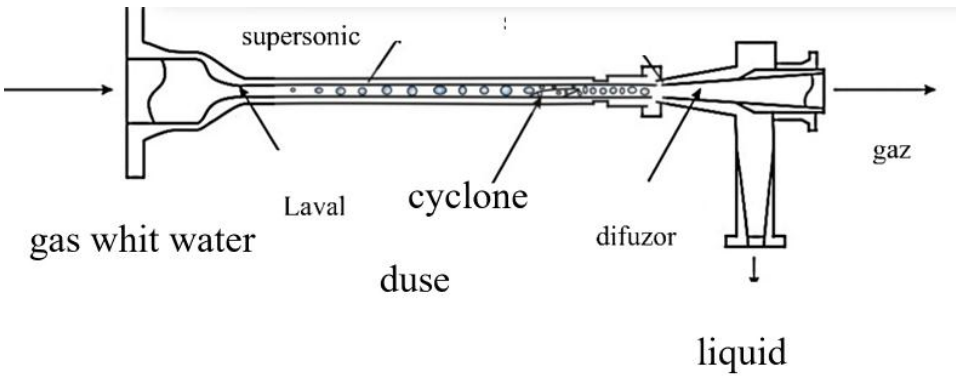

Fig.1. Sonic field water separator from natural gas (Twister)

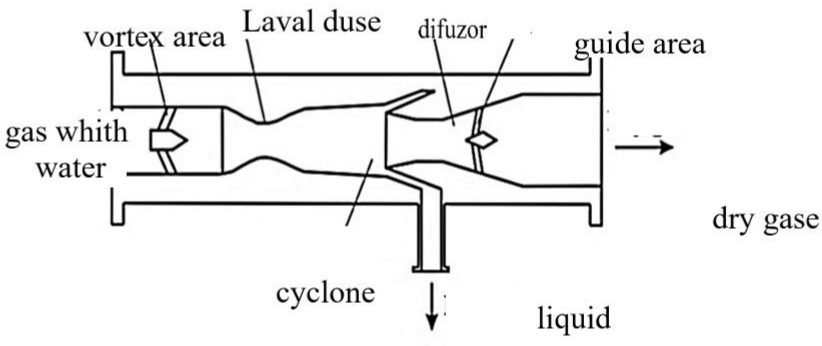

Fig.2. Sonic field water separator from natural gas (3S technology)

The supersonic separator provides condensation of water and wellbore condensate, preventing subsequent gas hydration in the treatment process.

It is a static device, requiring little maintenance and can be placed in production areas where human activity is reduced.

At the same time:

- does not need moisture inhibitors,
- it has no moving parts,
- is environmentally friendly,
- ensures energy conservation,
- does not produce industrial waste.

The liquid-solid multiphase phase will consist of water, condensate and structural particles of the natural gas that must be removed (carbon dioxide, hydrogen sulphide, etc.).

In a classic process of transporting natural gases through pipelines, they settle at the bottom of the internal walls of the pipeline, but in the supersonic separator this two-phase flow is centrifugally separated and directed to collection facilities as an additional flow of liquid fractions.

The dry gas then continues to be delivered (pumped) in transport pipelines to further processes.

The supersonic separator has many advantages compared to traditional methods and thisprocedures regarding the transport, labeling and storage of chemical substances are eliminated,

Also emissions with a greenhouse effect are eliminated, so the regulations regarding the protection of the quality of the environment are fully respected.

II. CURRENT STATE OF RESEARCH IN SUPERSONIC FLOW SEPARATION OF WATER FROM NATURAL GAS

The works analyzing the supersonic separation of natural gas are extremely diverse and multidisciplinary.
In general, the studies published and studied in this article:
a. addresses the thermodynamic transformations of natural gas mixed with water, impurities and well condensate,
b. studies the behavior of the system with the help of computational dynamic analysis (CFD),
c. describe the behavior of natural gas (mixed with water, impurities and wellbore condensate) during supersonic flow through various constructed mechanical systems,
d. presents computational models of some experiments carried out in the study of the supersonic flow of natural gas mixed with water, impurities and well condensate through various nozzles.

As I highlighted above, the thermodynamic and numerical simulation studies on the supersonic separation of natural gas are diverse and multidisciplinary, in what follows I manage to present a study of the specialized literature that deals with these aspects.
The first research on the supersonic behavior of natural gases was carried out after the 2000s, in 2006 Zhao et al. (2006) [5] investigated (by numerical simulation) the effect of the diameter of the divergent and convergent orifice on the separation performance of the two-phase mixture
The installation created for this purpose had (figure 3) the convergent diameter of 60 mm and the divergent diameter of 100 mm.
They also defined a condensation factor (this being the numerical ratio between the diameters of the exit area of the divergent section (Fig.1 section Ⅱ-Ⅱ) and the neck area (Fig.3 section Ⅰ)).

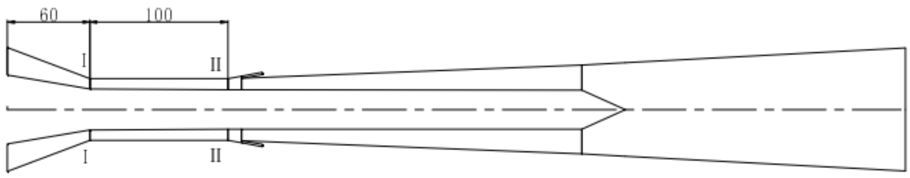

Fig.3. The installation created to study the separation of water from natural gas (in supersonic flow) [5]

They also determined the surface ratio (1.063) and the pressure drop (1.25-1.75) at which the shock wave (water-gas separation wave) is no longer present.
Secchi and other collaborators (2011) [6] started from the study of the movement of natural gas and water particles after the passage of this mixture into the convergent zone.
Starting from the equation of state developed by GERG (Groupe Européen de Recherches Gaziéres) [7,8], the numerical model developed by Secchi, included a separation of the phases of the biphasic mixture (as a result of the application of the centrifugal movements of the chemical particles (fig. 4)), as well as a definition of the types of flow of the biphasic mixture (depending on the working areas of the separation device).

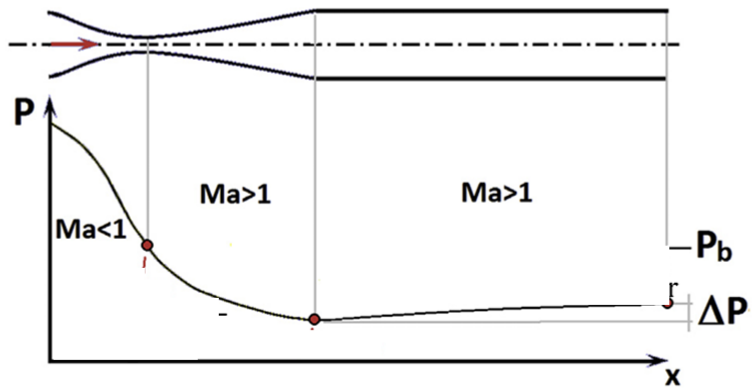

Fig. 4. The areas of flow (separation) of the chemical particles of the biphasic mixture [7]

Machado et al (2014) [8] created installations were simulated in Chemcad, the results leading to the conclusion that the profit is obtained in the case of separation with the supersonic separator in a maximum of 4 years (compared to 8 years for the other two separation systems).
Castier (2017) [9] analyzed the separation process, introducing into the systems of mass, energy and momentum conservation equations and the equations of state, created by Peng-Robinson.
The developed calculation method is suitable for the preliminary design of separation plants (but does not provide profiles of the parameters over time).
The calculation technique provides accurate results regarding the location of the shock wave, the number of phases along the separation system as well as the profiles of the fluid properties.
Wen et al. (2018) [10] created the supersonic separator being constructed and having the design input working parameters of 0.6 MPa, 30°C, 300 Nm3/h).
The length of the separator created was 945.3 mm, the diameter of the inlet zone was 80 mm, the diameter of the inner wall in the beginning of the choke zone and the diameter of the central choke zone were 15.94 mm and 12.00 mm, respectively, and the inside diameter of the wall at the outlet into the diffuser and the diameter of the central body at the outlet of the gas being 15.94 mm and 6.4 mm, respectively.
The effects of the pressure recovery coefficient (the ratio of the liquid outlet pressure to its inlet pressure) on the performance of the designed supersonic separator were analyzed (γ_p) .

$$\gamma_p = \frac{\gamma_{ie}}{\gamma_{in}} \cdot 100\% \quad (1)$$

Dew point depression (ΔT_d) was the criterion chosen to evaluate the dewatering performance of the separator.

$$\Delta T_d = T_{din} - T_{die} \quad (2)$$

Where T_{din}n and $T_{die}$are the dew point of the gas entering and exiting the separator, respectively.

In the first part, the effect of the pressure drop on the efficiency of the separator was studied, the experiments demonstrated the very good performance of the slotted separator.
The maximum dew point depression was determined at 34.9 °C, the pressure recovery coefficient (pressure drop) being 20.6%.
At the same time the pressure recovery coefficient (pressure drop) was 69.8% at a dew point depression of 18 °C, which showed that this factor (pressure drop) is the main factor affecting the performance of the designed separator .
The dew point depression decreases as the pressure recovery coefficient increases, showing that a better dewatering performance can be obtained with a higher energy loss (due to pressure drops) in the separator.
Inlet pressure and inlet temperature have little influence on the dewatering performance of the separator, demonstrating once again its very good efficiency (adaptability).
Studies have also shown that the dewatering performance is not affected by the outlet pressure of the liquid, which can be increased to a greater extent.
Castier [5,7] continued the previous experiments by developing a one-dimensional numerical model, absolutely necessary to understand the steady-state supersonic separation of multiphase fluids.
The solution algorithm of the model consisted in solving the equations of the speed of movement of the mixture and the thermodynamic separation of its phases, introducing into the study the thermodynamic models described by the Peng-Robinson state relations and also analyzing the effect of the two-phase flow on the convergent-divergent nozzle systems .

Wen and other collaborators [4] numerically simulated the flow of the multiphase mixture in the central body of the supersonic separator, studying the behavior of the fluid in the three sections, namely in the convergent section (subsonic), in the throttling zone (critical zone) and in the divergent section (zone supersonic).
The analysis carried out confirmed the fact that a convergent-divergent nozzle ensures the separation of the component phases of some wet gases if there is a vortex-type movement creation system in the body of the separator.
So said in this vortex type system (system of creating vortices-swirling motion) the gas expands at supersonic speeds, resulting in much lower temperatures (–80 °C) and therefore the separation of the C3+ components.
This created process leads to the condensation and nucleation of water and heavy hydrocarbon fractions (well condensate).

The tangential velocity and fluid temperature are uniformly distributed in the central radial region of the channel, with condensation (dew point) values between temperatures of –80°C and –55°C.
The geometry of the nozzle significantly affects the natural gas separation process, at a divergent half-angle of 2°-6°, the natural gases entering the vortex and thus ensuring a whirling movement (at a divergent half-angle less than 2° or more than 6°, nozzle separation performance decreases).

Sun et al [6] analyzed the flow of CH_4-CO_2 binary mixture to observe the effect of the Laval nozzle on the CO2 condensation process.
The results of the simulation on a device show that the homogeneous nucleation of CO_2 vapor occurs at a suitable level of supercooling, the condensation process taking place much earlier, with a decrease in the droplet number density at a higher inlet temperature low, a higher inlet pressure and a higher concentration of CO_2 in the gas mixture.
The residual CO_2 in the outlet gas can be reduced to less than 3% when the molecular fraction of CO_2 in the feed gas is 10%, the ability of supersonic separation technology to separate CO_2 from CH_4-rich natural gas is applicable .
Following the study of the flows in this type of separator, they created a physical model, later simulated in CFD.
Following the physical and mathematical simulation it was shown that:
a. The shock wave occurs behind the cyclone and the improved supersonic separator can provide a lower dew point value,
b. The shock wave moves backward as the pressure loss ratio increases,
c. When the pressure loss ratio increases from 35% to 70%, the position of the shock wave moves back towards the inlet (x = 300 mm),
d. The secondary evaporation of the condensed droplets before the cyclone and the reduction as much as possible of the gas pressure loss can be avoided if a pressure loss ratio between 35% and 70% is ensured,
e. The inlet pressure must be ensured at a minimum value of 600 kPa and the pressure loss ratio must be located at the value of 47.5% for the shock wave to form at a distance of 446 mm from the gas inlet in separator,
f. The supersonic separator, created for this purpose, ensured an increased quality of natural gas with a maximum dew point value of 199.43 K and a high vortex acceleration of 297442 g (g is the gravitational acceleration).

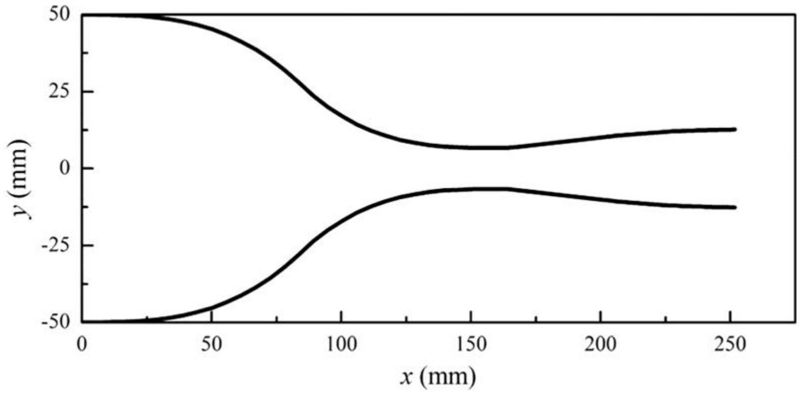

Fig.5 Separator CO_2-CH_4 supersonic [6]

And Bian and other collaborators [6] managed to study the structure of the supersonic separator, creating a

Shawlikaev and Gunmero [6] analyzed the effects of inlet temperature, pressure and composition as well as nozzle pressure drop on the flow behavior and separation performance of supersonic gas separator.
The study was carried out using UniSim Design R400 software.

Mohd Hashim and Ahmad [6] analyzed the use of supersonic separator in gas separation facilities on Offshore platforms, simulating the behavior of gas extracted from the Santos extraction structure in Brazil. The study included numerical modeling of the process, analysis of multiphase flow characteristics and temperature distribution during the separation process. Through this report, the efficiency of supersonic installations in the separation of gases from marine platforms (Offshore) has been demonstrated.

Arinelli et al [7] investigated the supersonic separator performance for treating a natural gas with 44 mol% CO_2 in the mixture. Through this study they demonstrated the efficiency of supersonic separation by comparing it with the results obtained in conventional water and heavy hydrocarbon condensation technologies. Several configurations and combinations of the supersonic separator and other traditional separators were considered, with analysis performed using Hysis software.
They also demonstrated that the supersonic separator, if used as a single unit, manages to reduce the CO_2 content from 44% to 22 mol%, which is a sufficient option for the use of natural gas in electricity generation, with a limit allowed by about 20% CO_2 in the flue gases.

In the paper Prediction of Mass Flow Rate in Supersonic Natural Gas Processing by Wen et al [8], the evaluation of the separation of a mass flow rate of wet natural gas in the supersonic separator was numerically investigated using several equations of state.
It was shown that at high pressure, the compressibility factor calculated using the real gas models was significantly different from the results obtained using the equations of state used to calculate the ideal gas behavior, showing the real effects of the gas on the supersonic separation process. In the real gas calculation model, the specific heat ratio increased in the Laval nozzle and decreased sharply at the shock wave location.
Also, the variation of the specific thermal ratio at the nozzle neck had an important effect on the evaluation of the mass flow rate of natural gas, the deviation of the mass flow rate of the ideal gas compared to the real (processed) one being more than 10%.

The natural gas mass flow deviation increased with decreasing inlet temperature regardless of inlet pressure, with the calculation error being over 16.5% at higher inlet pressure and lower inlet temperature (100 atm, 15ºC)
.
The position of the shock wave moved upstream from the diffuser to the nozzle as the back pressure increased.

III. CONCLUSION

Notable disadvantages of the existing works in the literature include the following aspects:
- Multiphase flow was not taken into account,
- The modeling of nozzles without lateral flows is mostly abandoned,
- Performance and composition of working fluids has been simplified,
- The methods for calculating the thermodynamic speed of sound, which is an essential parameter for finding the Mach number, are insufficiently analyzed,
- Eddy flow is not taken into account,

REFERENCE

[1]. R.F. Aguilera, (2014). The role of natural gas in a low carbon Asia Pacific, Appl. Energy 113, 1795–1800.

[2]. W.S. Lin, N. Zhang, A.Z. Gu, (2010). LNG (liquefied natural gas): a necessary part in China’s future energy infrastructure, Energy 35, 4383–4391.

[3]. https://www.contributors.ro/colapsul-energetic-al-romaniei/, accesat 1.5.2024.

[4]. https://www.transgaz.ro/ro/clienti/servicii-de-transport/calitatea-gazeloraccesat 1.5.2024.

[5]. T. Chis, R. Radulescu, (2021). Prelucrareașitransportulgazelor, EdituraUniversitatii Petrol-Gaze , ISBN 9878-973-719-822-8.

[6]. T.Chis, (2019). Cercetariprivindoptimizareaproceselor din transportulsidepozitareatiteiului, produselorpetrolieresi a gazolinei, EdituraEstfalia, I.S.B.N. 978-606-757-026-7.

[7]. R. S. Mohammad, D. Barsan, T. Chis, D. Stoianovici , (2023). NumericalModeling of GroundWaterTreatmentthrough Ceramic Membranes, Engineering and Technology Journal e-ISSN: 2456- 3358, Volume 08, Issue 08, August, Page No.2635-2643, DOI: 10.47191/etj/v8i8.21, http://everant.org/index.php/etj/article/view/1003/701.

[8]. R. S. Mohammad, D.Stoianovici, T. Chis, D. Iancu, (2023). Neuronal Moddeling of Water Properties on Oil Field, **International Journal of Engineering Research and Reviews, ISSN 2348-697X (Online), Vol. 11, Issue 3, July 2023 - September 2023, Page No: 48-58,** https://www.researchpublish.com/papers/neuronal-moddeling-of-water-properties-on-oil-field**.**

[9]. W. Ye, J. Lin, H.T. Madsen, E.G. Søgaard, C. Hélix-Nielsen, P. Luis, B. Van der Bruggen, (2016). Enhanced performance of a biomimetic membrane for Na2CO3 crystallization in the scenario of CO2 capture, J. Membr. Sci. 498, 75–85.
[10]. M. Betting, T. Van Holten, C.A. Tjeenk Willink, (2003). US Patent, 6,513,345, April 2.
[11]. J. Brouwer, H. Epsom, (2003). Twister supersonic gas conditioning for unmanned platforms and subsea gas processing, Offshore Europe Conference.
[12]. https://www.twisterbv.com/about/accesat 5.5.2024.