Modeling of hydrates forming process during natural gas drying when using 3S Separator at fueling stations systems

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Abstract. Proposal of installation to dry natural gas with combined low-temperature separator with double fitting 3S separator and pressure stabilizer. The installations have to provide conditions for full natural gas drying from moisture by crystallizing hydrates in separation chamber. The issues concerning the first stage of modeling of 3S natural gas drying separator at natural gas transportation and sale facilities are considered, namely by creating of separator model with software in Python 2.7 language and Matplotlib and NumPy libraries to determine the main characteristics of the separator. Provided geometry modeling method of separator nozzle and twister and grid model of separator chamber with gas predetermined parameters of natural gas flow. Combination of k– and k–w turbulence models was used to describe the flow of natural gas in separator. Mathematical model is constructed in such way that is gets advantages of both turbulence models. Border layer calculated via SST-model. Thermodynamic parameters of natural gas flow across separator chamber that are required for hydrates molecules forming are analyzed

1. Introduction

Any types of vehicle constantly affect the environment around us polluting air, water and soil. Vehicles are responsible for 70% of chemical pollution and 90% of noise pollution. Automobiles of different kinds are responsible for 94% of carbon dioxide and 44% of nitrogen oxides (NOx) and almost 60% of cities air pollution is a product of combustion engine automobiles emissions.

For each 15 000 km of mileage an average car consumes 4250 kilos of oxygen and emits 250 kilos of carbon dioxide, 530 kilos of carbon monoxide, 27 kilos of nitrogen oxides and 93 kilos of harmful chemical compounds and hazardous air pollutants due to incomplete combustion of fuel. [1]

One of possible ways to reduce harmful effect vehicles have on environment and human health is to use alternate types of engines and use of natural gas engines.

Experience of using natural pressured gas vehicle filling stations with gases of 0.005-0.009 g/m3 hydrates content points there is no hydrate crystals forming with that moisture values. In cases when volumes of gas changes often with different amounts of gas needed for refueling, usage of solid absorbent proves to be most reliable but most costly due to high energy consuming process of absorbent regeneration [2, 3].

Common flaw of all gas drying installations regardless of working principle is “forced countermeasures against natural process of hydrates forming” concept. In this article we suggest to try different approach – to use technology for get results in drying gas with processes similar to natural:

- gas drying systems would not interfere with natural process;
- gas drying systems should not harm environment, air, flora or fauna.

We propose using drying installation based on specifics mentioned in [4] that is shown at Figure 1, but to add combined low-temperature separator and double fitting 3S separator and pressure stabilizer [5] shown at Figure 2.

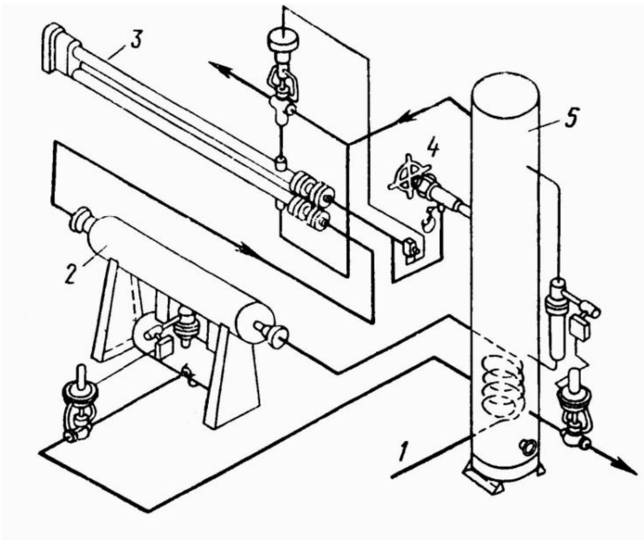


Figure 1. Low-temperature separator installation: 1 - fitting; 2 - fluid separator; 3 - gas heat exchanger; 4 - valve; 5 - low-temperature separator

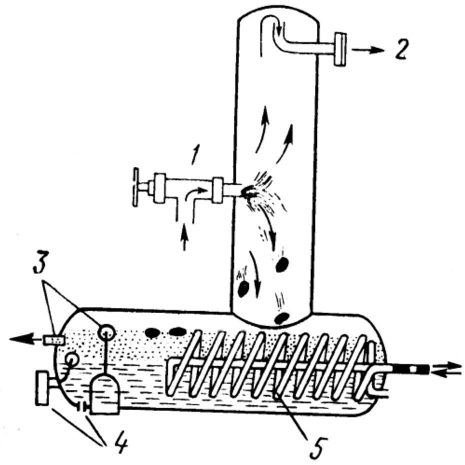


Figure 2. Combined low-temperature separator: 1 - double fitting; 2 - separator; 3 - heat exchanger; 4 - liquid phase section; 5 - coil

Machinery that is used at deposits sites for low-temperature separation of natural gas by heating up the flow consists of liquid separator 2, thermal exchange for gas 3 and low-temperature separator 5. Initial gas flow enters installation via fitting 1 to clear the flow from side products that are collected via pipes for water 4, hydrates 3 and gas itself 2.

For combined separator Figure 2 hard hydrates that are accumulated at the bottom of installation are heated to the point of dissolving with hot flow from coil 5. With this set up the hydrates from gas flow that enters via valve 1 are condensed to be collected at liquid section 4 while output product goes unto separator 2 and kept out of hydrates forming temperature with thermostat 3 that controls the valve.

The set up works satisfactorily in cases where temperature of incoming product is high enough for dissolving hydrates at the bottom of separator and in cases where temperature at fitting is higher then hydrates forming temperature at current pressure.

3S - separator (Super Sonic Separator) - low-temperature supersonic separator, the design of which is based on the use of modern aerodynamics related to aerospace technology. It is used in the oil and gas industry to separate from natural gas target fractions such as hydrocarbon condensate, propane-butane and methane fractions.

3S separator is a cyclone separator, in the channel of which supersonic flow velocities with Mach number from 1.3 to 2 are realized. Due to acceleration it is possible to reduce gas temperature by 70° C and more, providing conditions for condensation and separation of heavy fractions and water contained. in gas [6-8].

The operation of the 3S-separator is as follows. The inlet flow is twisted in the rechamber and fed into the nozzle, where its pressure and temperature drop and the speed increases sharply. As a result of strong cooling, liquid droplets are formed, which are subsequently increased due to coagulation in the boundary layer of the working section, and the central flow is cleaned of target components.

Using of diffuser allows for higher kinetic to potential energy conversion rate and provides a higher gas pressure at the outlet of the diffusers other than the static gas pressure in the supersonic nozzle. Thus, a gas stream, which can contain up to 20% liquid, is fed to the inlet of the 3S separator, and two streams come out of the 3S separator: one is a stream of prepared commercial gas, and the other is a gas-liquid stream enriched with liquid components.

3S-separator is a four-section tubular structure, the elements of which are connected by flanges. All gas-dynamic elements are located inside the pipe sections. There are no moving parts [8, 9].

The design of the 3S separator is shown in Figure 3.

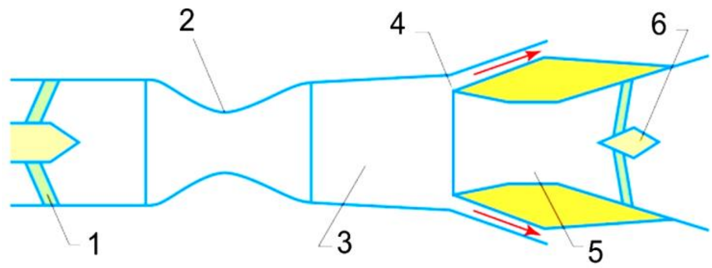


Figure 3. The design of the 3S separator: 1 - twister; 2 - Laval nozzle; 3 - working section; 4 - two-phase gas-liquid separator; 5 - diffuser; 6 - guide device

2. Modeling the geometry of the 3S separator using the program SOLID WORKS

The gas flow in the 3S separator was simulated using the ANSYS CFX software package. A computer three-dimensional model of the swirling gas flow in the 3S separator channel was created by solving the Naiver-Stokes equations using the Shear Stress Transport (SST) model of the turbulence model [10].

The first stage of mathematical modeling is the formation of its geometry. It is performed by using the program SOLIDWORKS, which allows you to change the parameters of the nozzle, scale it, etc.

The twister diagram is shown in Figure 4.

The geometric model (Figure 5) should be a complete reflection of the solid model, i.e. not the sides but the environment are created. This allows you to create a calculated flow grid.

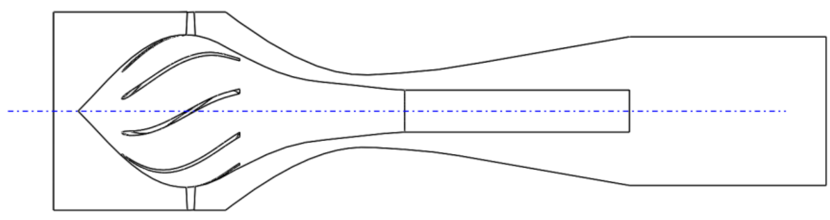


Figure 4. Twister scheme.

The generated model is transferred to the meshing program where a structured tetrahedral grid is generated in the entire volume of the calculation area to create points where the gas-dynamic calculation is performed.

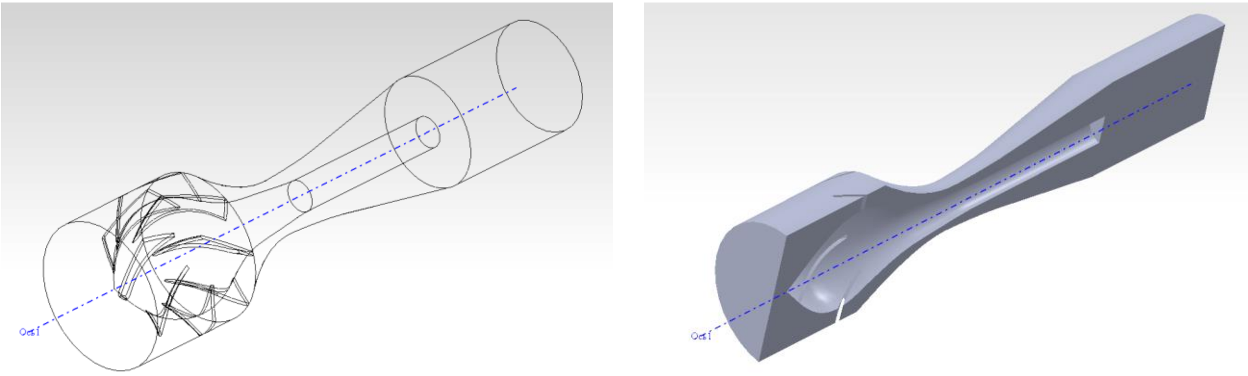


Figure 5. Solid twister model.

3. Export of created geometry to the calculation complex ANSYS

At the stage of exporting the created geometry to the calculation complex ANSYS, the boundaries of the body are determined for faster manipulation of the modeling areas, which is shown in Figure 6 [10].

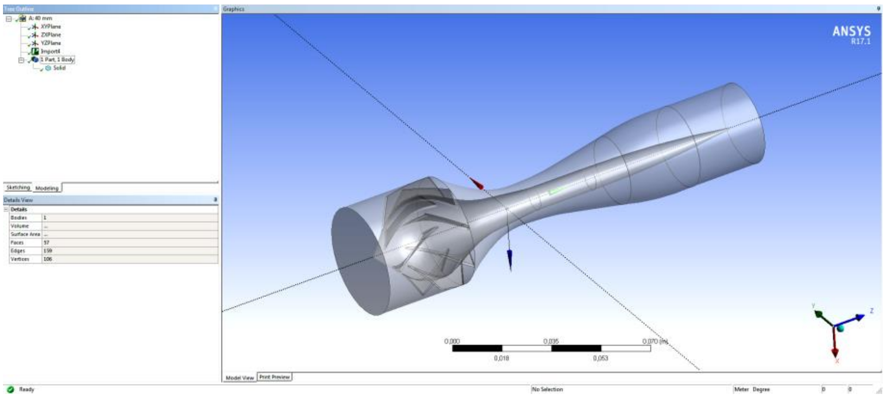


Figure 6. Export geometry to ANSYS.

The principle of calculation is based on the use of the finite element method. Therefore, the density of the grid affects the accuracy of the calculation, as there will be more control points at which the comparison will be performed. The generated grid (see Figure 7-9) is needed for further calculation, so it is exported to ANSYSCFXpre, to enter the input and limit conditions of the flow, presented in Figure 8 [10].

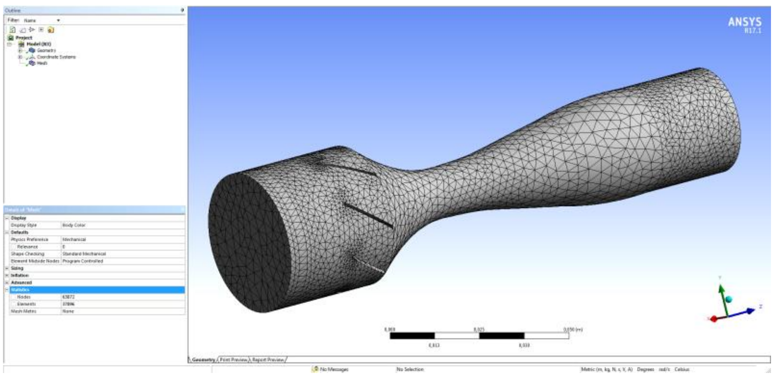


Figure 7. Grid model.

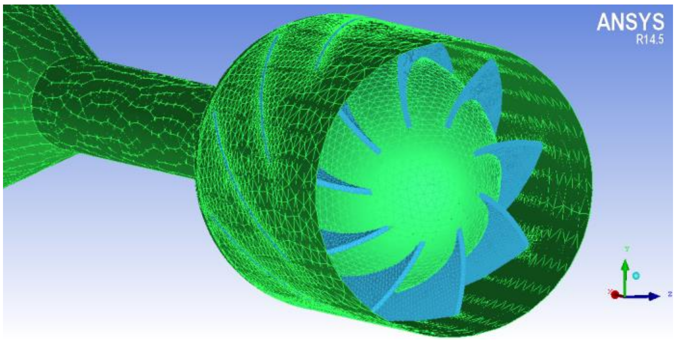


Figure 8. Separator twister output view.

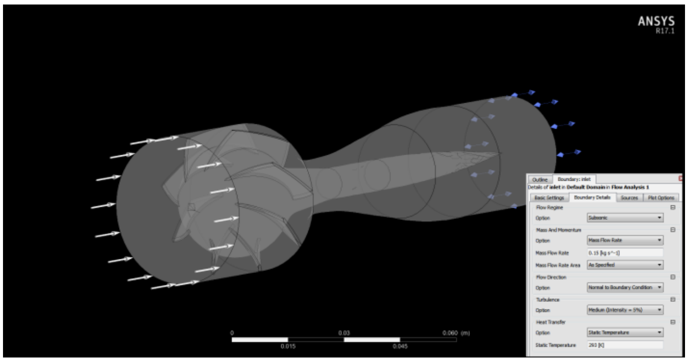


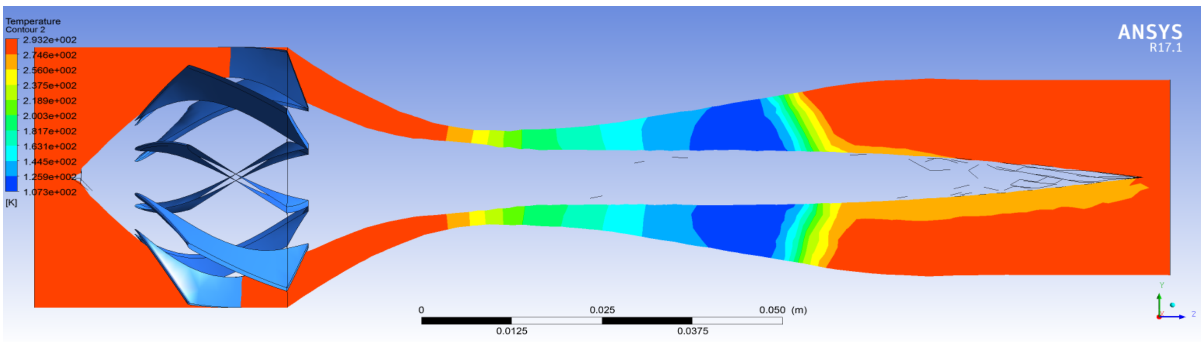
Figure 9. Enter the calculation parameters.

Parameters such as inlet and outlet pressure, inlet temperature and mass flow through the separator were used for this purpose. The generated program is run for calculation in the ANSYSCFXSM program. After performing the required number of iterations, the calculation stops and you can analyze the data.

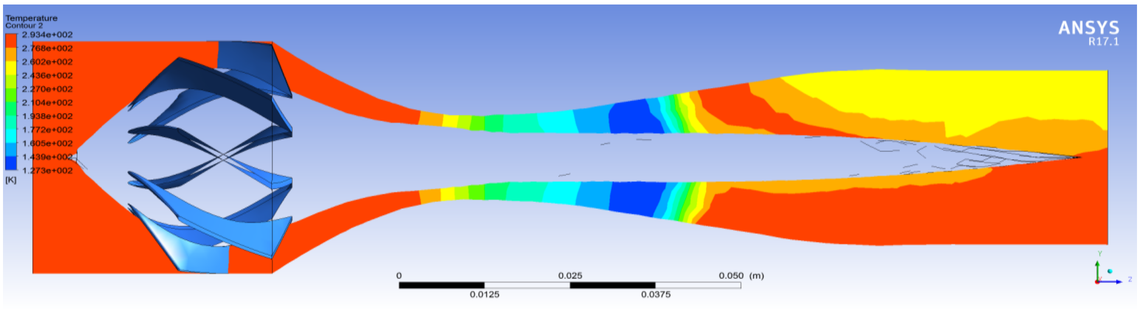
4. Testing of the software package for creating a device for water separation from natural gas with subsequent localization of crystalized hydrates in the separator.

This software allows you to conduct various tests and determine the parameters of the flow at any point. For the convenience of comparing the effect of pressure drop at the inlet and outlet of the twister, calculations were performed at different flow rates and diametrical dimensions of the outlet.

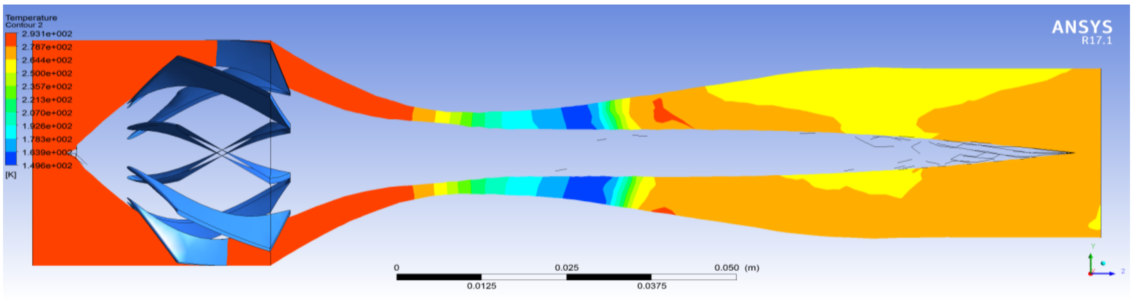
In Figure 10 shows the pressure distribution along the channel depending on the pressure drop at a gas flow rate of 0,2 kg/s.



a) 8 bar;



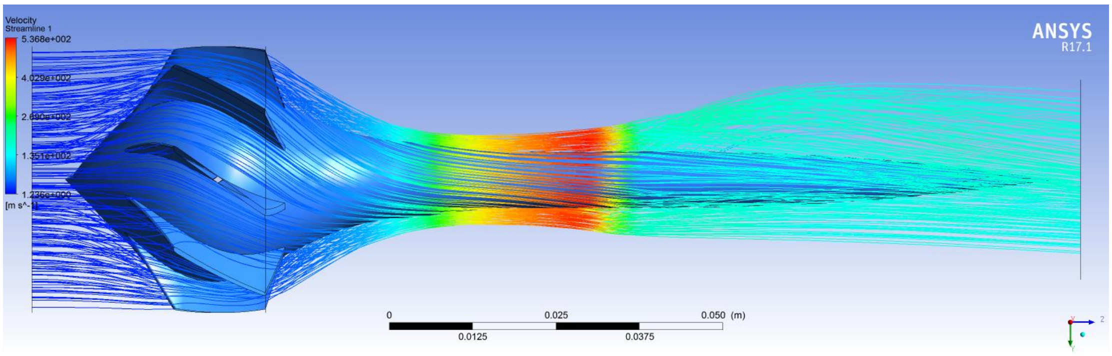
b) 7 bar;



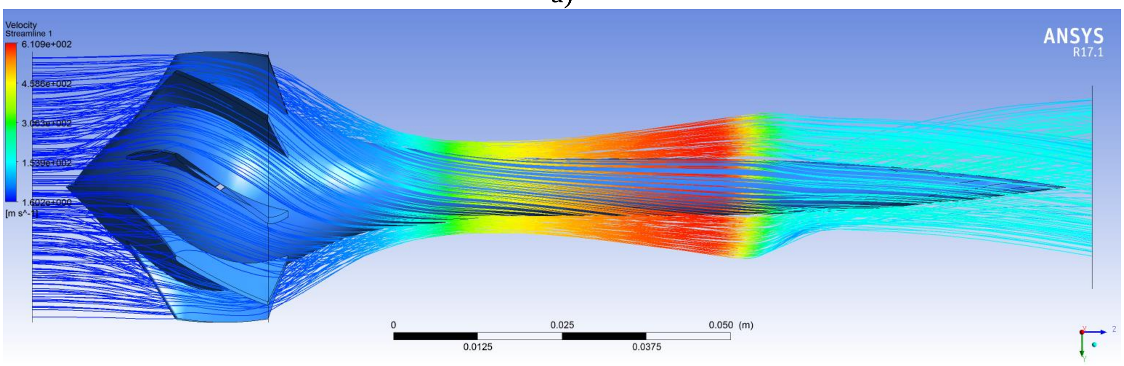
c) 6 bar

Figure 10. Temperature distribution for gas at 0.2 kg/s flow rate with pressure drop.

This software allows you to conduct various studies and determine the flow parameters at any point. For example, in Figure 10 shows the current lines in the separator channel at a pressure drop of 6 and 8 bar.



a)



b)

Figure 11. Current lines in the separator channel at a pressure drop of 6 (a) and 8 bar (b).

Mach number changes across separator channel during pressure drop of 8 bar is shown at Figure 12.

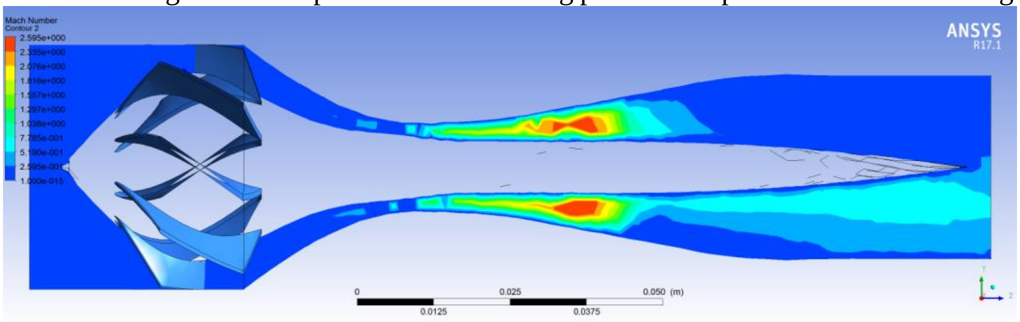


Figure 12. Changes of Mach number during pressure drop of 8 bar.

Conclusions

Model of natural gas dryer that consists of combined low temperature separator with double fitting and pressure stabilizer. Resulted installation should provide full clear of natural gas flow of hydrates and localizing crystallized hydrates in separator. The method of modeling of twister and nozzle in software creation environments of Python 2.7 and Matplotlib and NumPy libraries in order to create and calculate the main characteristics of 3S separator for natural gas drying at natural gas sales and transportation facilities. Presented by figures of pre-formation and discharge into the separator of crystal hydrates to reduce the chance and impact of such process happening directly in the pipes.

Based on the results of the calculation of the flow parameters, it is possible to determine the zones of the beginning of the creation of crystal hydrates with the possibility of further design and technological decisions on the creation of devices for natural gas drying systems for various purposes. Combination of *k*– and *k*–*w* turbulence models was used to describe the flow of natural gas in separator. Thermodynamic parameters of natural gas flow across separator geometry were analyzed to determine the conditions of hydrates crystals forming outside of separator.

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