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CFD Simulation design of compress natural gas shipping transportation, cost and Risk survey

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Abstract

We show how the partners used ESTECO's process automation and web-based communication software to build the system during the project's many phases in this article. Criteria such as ship size and quantity, storage and facility units at ports have been enhanced in relation to each different geographical situation (which includes the East Mediterranean, Barents Sea, and Black Sea) and gas demand in order to minimize transportation costs and hence gas rates. The material and type of fibers that wrap the liner of the gas canisters were then modified to minimize weight while retaining a high value for safety considerations. Finally, a computational fluid dynamics (CFD) analysis is performed to estimate the risks connected with gas leaks and explosions.

INTRODUCTION

Diversifying supply networks is a crucial part of ensuring Europeans have safe and affordable energy. This entails finding and building additional channels to lessen the EU's reliance on a single supply of natural gas and other energy supplies.

This article summarizes the main achievements of the European project known as 'GASVESSEL,' which aims to open up new opportunities to exploit stranded, associated, and flared gas where it is currently not economically feasible (the alternatives are too expensive), as well as to expand the gas transport possibilities of currently exploited gas fields with a new cost-effective CNG (Compressed Natural Gas) transport concept (fig.1). The findings of the study may aid in rebalancing Europe's and the world's energy security equations.

The GASVESSEL project intends to develop a unique, financially feasible offshore and onshore CNG transportation system for collecting, transporting, and discharging natural gas (NG) into the distribution network from offshore and onshore oil and gas (O&G) fields.

Beginning with a decision support model that will simulate and benchmark the costs of the novel CNG concept against alternative gas transporting systems and ending with the ship design and manufacturing process of the innovative lightweight Composite Overwrapped Pressure Vessels (PV's), GASVESSEL will innovate at several points along the value chain. New CNG ship designs with much higher payloads and, as a result, dramatically lower transportation costs per m3 of gas are enabled by a novel patented solution for the manufacturing of up to 70% lighter Pressure Vessels compared to steel alternatives, allowing for new CNG ship designs with much higher payloads and, as a result, dramatically lower transportation costs per m3 of gas.

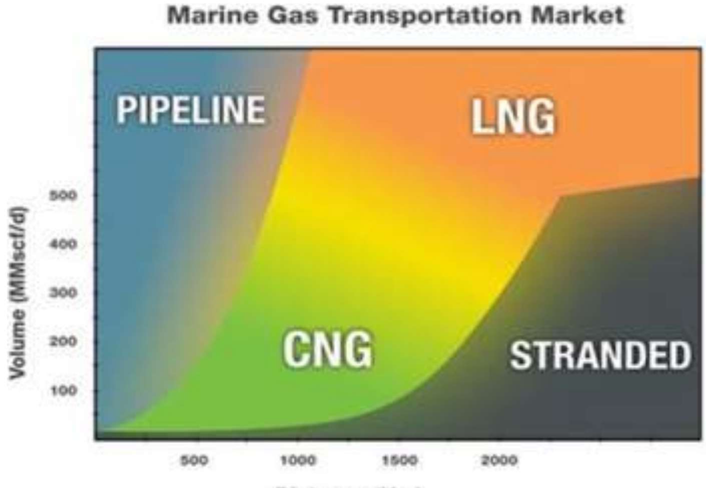

Figure 1: Gas exploitation opportunities with CNG (Compressed natural gas)

1. TRANSPORTATION SCENARIO OPTIMIZATION

One of the GASVESSEL Project's main goals is to optimize gas delivery from recognized source locations to identified markets for various scenarios and geographical areas, including determining the best ship size, ship speed, and fleet number to achieve the lowest gas transport costs per unit volume (fig.2).

ESTECO Enterprise is a business-to-business service. The entire optimization process is managed by VOLTA. VOLTA is a web-based collaboration platform that integrates simulation data with a variety of corporate processes to enable conscious decision-making and the creation of innovative solutions.

Through the customized interface, any authorized user with project access can set the ranges of optimization variables (such as ship capacity and velocity), scenario parameters (such as gas requirements and port distances), and optimization criteria (such as transportation cost or minimum gas storage). The chosen computational queue can then be utilized to run simulations and analyze the results.

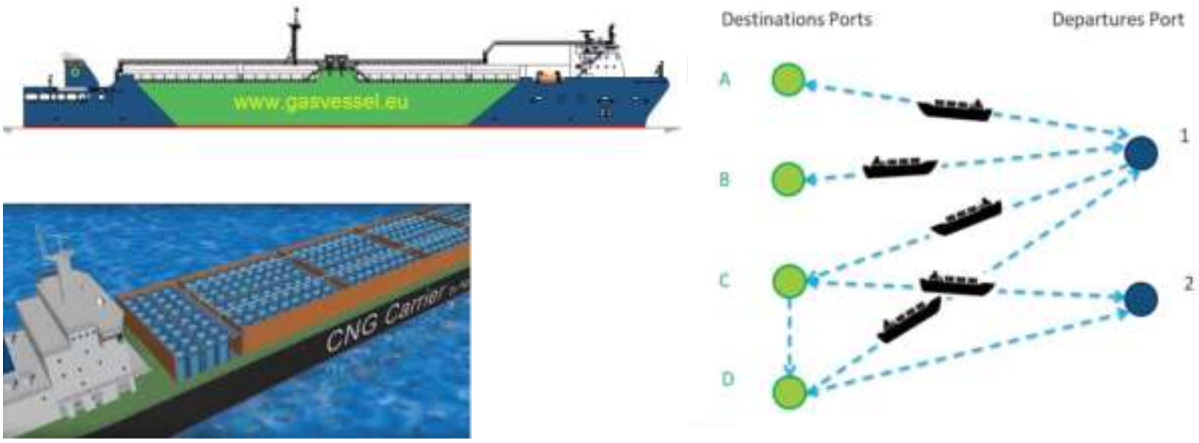

Figure 2: Gasvessel ship and example of CNG transportation scenario

The optimization findings can then be viewed by any authorized VOLTA platform user. A text file reports all of the scenario's information, including fleet size, ship sizes and velocities, ship usages, and destinations, when the optimum configuration is chosen.

The technology will be used in three geographical areas at the moment: the Barents Sea (provided to Norway), the Black Sea (from Bulgaria to Ukraine), and the East-Mediterranean region (from Cyprus to Greece, Lebanon and Egypt).

2. STRUCTURAL OPTIMIZATION OF GAS VESSELS

The use of traditional pressure vessels is not contemplated whenever gas is transported by ship without being liquefied: the relevant thickness of the walls induces both a significant weight of the vessels and a limited ratio between the volume of the transported goods and the total volume, including the tanks themselves. Tanks can be made with an inner thin metal liner wrapped in many layers of fiber-reinforced composite materials (filament winding) to overcome these issues; the resulting structure, which is light and sturdy, assures compressed natural gas transportation can compete in the market (fig.3, left).

The filament winding method (fig.3, right) is a popular manufacturing process for producing light and sturdy axisymmetric structures like pressure vessels and pipes. Strands of resin-impregnated filaments are wound around a spinning mandrel by a translating guide that can move along one or more axes [1]. The wrapped vessels are subjected to autofrettage treatment [2], which involves applying an internal pressure to the tank that is more than (typically 1.5 times) the maximum expected operating pressure, or MEOP, partially deforming the metal liner over its elastic range.

The composite overwrap returns to its original undeformed shape when the internal pressure is released, creating a compressive stress field on the liner. The stresses acting on the structure are lower when the operative load is applied than if the autofrettage treatment had not been employed.

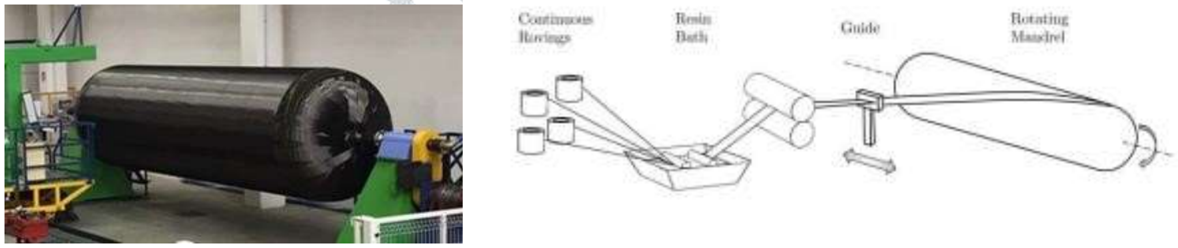

Figure3 Example of vessel storage (left); filament winding process (right)

In order to reduce costs while keeping sufficient safety criteria, it is critical to develop an optimization strategy employing mode FRONTIER software.

Using an analytical model of the mechanical characteristics of the pressure cylinder provided by the project partners, the first section of the optimization workflow (fig. 4) defines an internal (nested) optimization loop to find the minimum number of winding layers required to respect the structural constraints (reach maximum admissible stress in the central cylindrical portion of the vessel at burst pressure 900 bar).

Because the internal optimization only uses a Python script to examine the constraints, the nested optimization technique can be completed in a matter of seconds.

The next automation process application node, the script that controls the execution of the software CADWIND [4], uses the winding data (winding angle as a function of the number of windings) to run the software in batch mode using API commands.

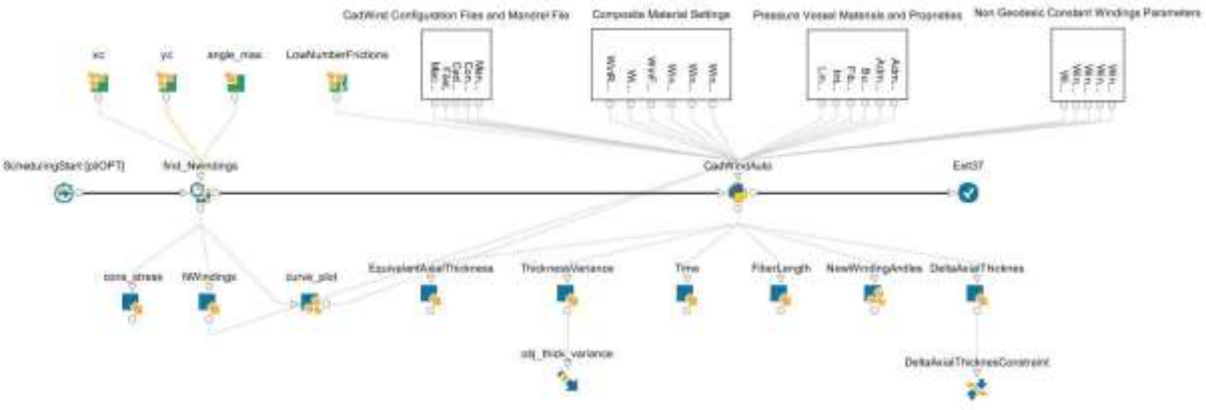

Fig. 4 Workflow in modeFRONTIER for winding optimization

CADWIND adjusts the input data to simulate the winding process from a manufacturing standpoint, which means that winding angles can be varied in relation to theoretical ones to cover every area of the vessel, and then generates the file that the winding machine uses to realize the composite windings around the vessel.

As a result, the data obtained by CADWIND may be used to determine the overall thickness of the composite layers in each point of the vessel, as well as the standard deviation of this distribution: Because it is necessary to avoid an excessive accumulation of layers in some regions at the expense of others, minimization of this value becomes the goal of the external loop of optimization.

The parameters that control the winding angle distribution are thus the design variables that are optimized in the external loop to attain this goal.

The distribution must be a non-decreasing function of the winding pattern number for manufacturing reasons. As a result, we employed a Bezier curve with four control points [6] to design a continuous and regular curve function with the fewest number of parameters (and therefore simplify the optimization effort).

By adjusting the coordinates of the two internal control points, it is feasible to adjust the curve's shape in a continuous and regular manner (the first and last are fixed). An additional parameter, a factor scale, can be used to control the maximum winding angle.

We may compare the various solutions found using the Bezier parameterization in fig.5 as a result of modeFRONTIER's optimization. The ordinate represents the number of winding patterns (the aim of the inner optimization loop), whereas the abscissa reports the variance of the winding layers.

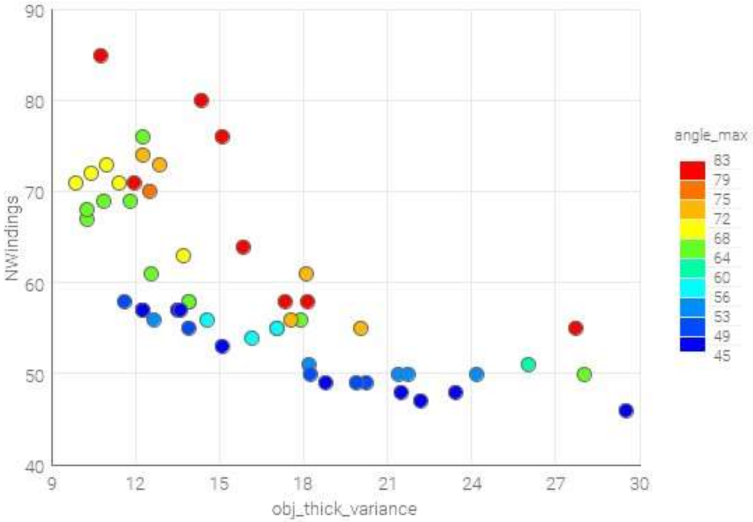

Fig. 5 Optimization results: number of windings vs thickness variance

The color of the dots in the chart denotes the winding layer's greatest angle with respect to the cylinder's axis. In compared to situations where the layers have a higher radial component, optimal outcomes are characterized by a smaller angle (45°). (higher angle).

The partners chose at least four possible ideal configurations and put them to the test using a FEM analysis to confirm that the constraints were met. The analytical results for one of the candidate solutions are shown in Figures 6-7.

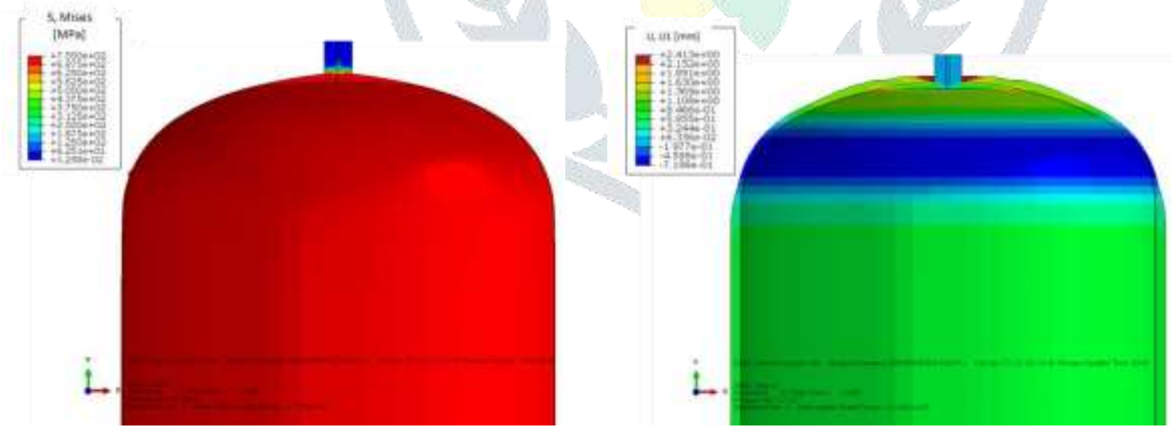

Fig. 6 Autofrettage: Stress (left, Von Mises) and radial displacement (right) after unloading

The steel liner reaches the yield stress at each point during the autofrettage phase (fig. 6 left), yet a considerable region of the cylinder retains a yield stress during the unloading phase. This is unimportant because the residual deformation in the radial direction is only a few millimeters (fig.6 right). Furthermore, the stress on the liner's center section averages around 300 MPa throughout operation (fig.7 left), with maximum radial displacements of around 6mm.

The composite overwrap is subjected to the highest stresses (about 1600 MPa in the central region, with some higher peaks in the spherical component) during autofrettage, which are less than the material limit (2470

MPa). The spherical component of the overwrap achieves strains of less than 1400 MPa during operation (fig.7 right).

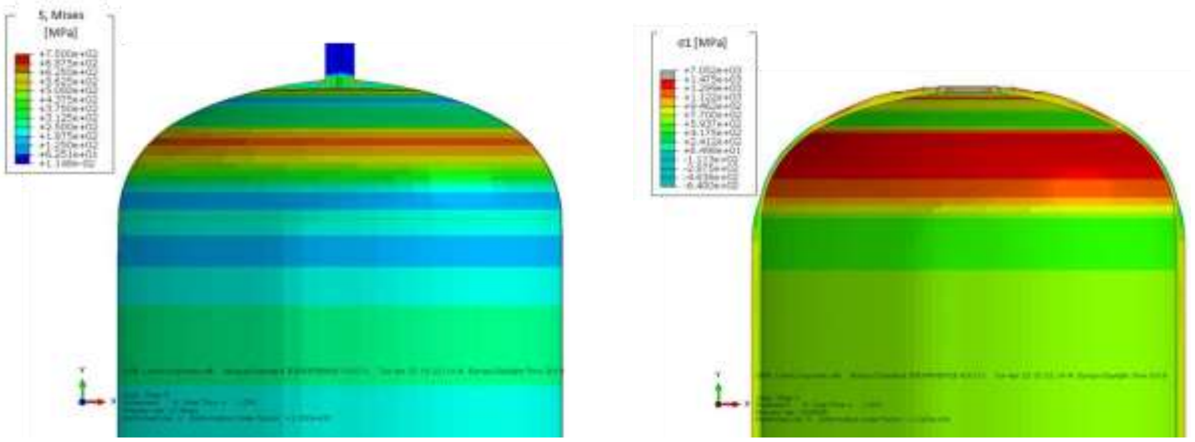

Fig.7 Operative conditions: stress field on steel liner (left, Von Mises) and composite overwrap (right, fiber direction σ1)

3 RISK ANALYSIS

All risks associated with possible gas dispersions from valves, pipes, and flanges inside the ship must be properly examined, and a suitable solution to limit the risk must be devised based on the results of the analysis, according to ABS (American Bureau Shipping) regulations. To analyze the gas concentration locally and hence predict the probability of an explosion, numerical simulations can be used to estimate the effect of gas leaks in different regions of the ship (and at varying intensities).

Although an inert atmosphere protects a few portions of the ship (especially the holds that house the gas vessels, which contain Nitrogen), it is vital to investigate how the gas is disseminated and what temperatures and pressures are achieved in order to establish whether any structures are harmed.

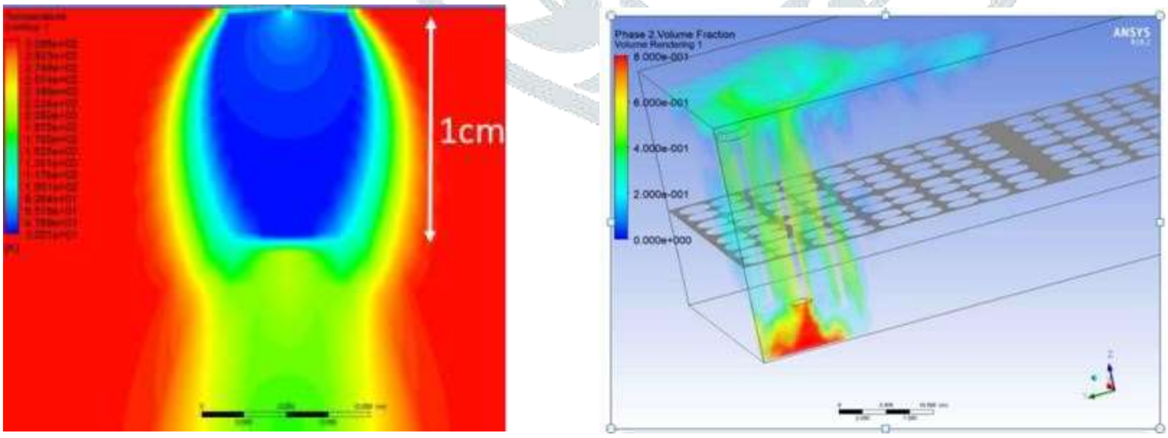

Fig.8 Joule-Thomson effect to define Temperature of gas leakage and CFD simulation of gas dispersion

The temperature of the dispersed gas is much lower than the original temperature when considering an iso-enthalpic expansion of the gas from the cylinders to the surrounding environment [7] and evaluating the gas state proprieties from real gas equations (Joule Thomson effect [8]). For example, with a gas temperature of 40°C and 300 bar of pressure inside the cylinders, the gas will exit in the 1bar Nitrogen protected hold with a (total) temperature of around -52°C In order to avoid structural damage in the event of prolonged gas jets, this value must be taken into account when building the cylinder supports.

In fig.8 left, a local CFD study (2D, transient) illustrates how the rapid expansion of the sonic flow from the orifice causes a supersonic expansion with very low local temperatures (below 100K), which is dissipated within 1cm of distance when the flow returns sonic. The closest steel supports are hit by a jet of -52°C at roughly 80m/s in an area of about 0.005m2, which has no significant dynamic or thermal effects, according to structural analysis.

A transient CFD study (fig. 8 right) can also be performed for a given mass flow leakage to determine how the concentration and pressure inside the hold change over time. This analysis is important because an over-pressure of more than 0.2 bar might cause damage to the hold's internal structure, which could be prevented by installing valves that expel the gas when the critical pressure value is reached inside the hold.

The use of modeFRONTIER to solve this problem is particularly useful for automatically examining the multiple risk scenarios that can be defined by different boundary conditions, such as the location of the gas leakage and the strength of the mass flow. The results of integrating an analytical model of the gas combination (methane with nitrogen) inside the hold in modeFRONTIER, which was validated by CFD analysis, are shown in Fig. 9.

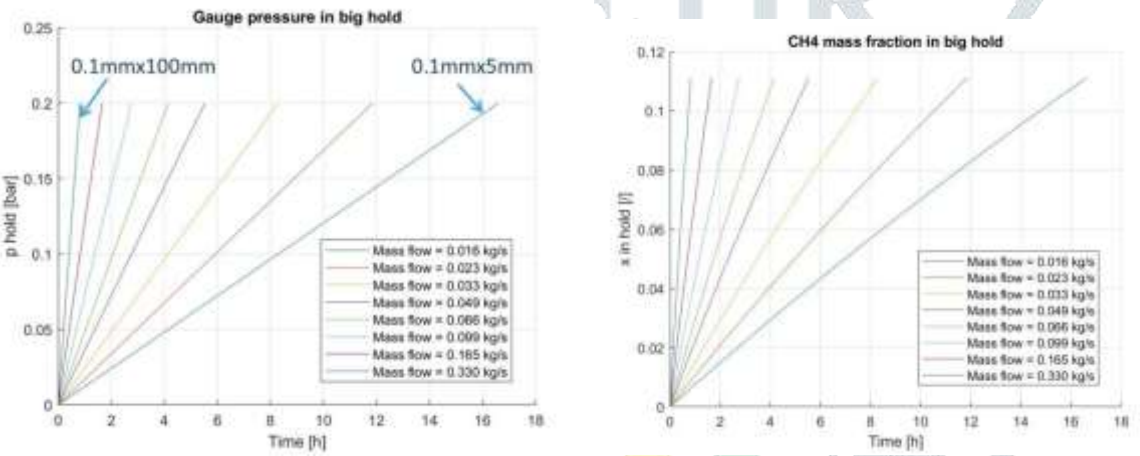

Fig.9 Hold pressure variation (left) and CH4 concentration (right) in function of leakage massflow

Within the hold, a 0.2 bar over-pressure can be achieved in as little as 1 to 10 hours, depending on the amount of the mass flow leakage.

In these situations, a vent mast system is designed to extract the gas content of the cylinders if the critical overpressure in the ship's hold is reached when leakages are present.

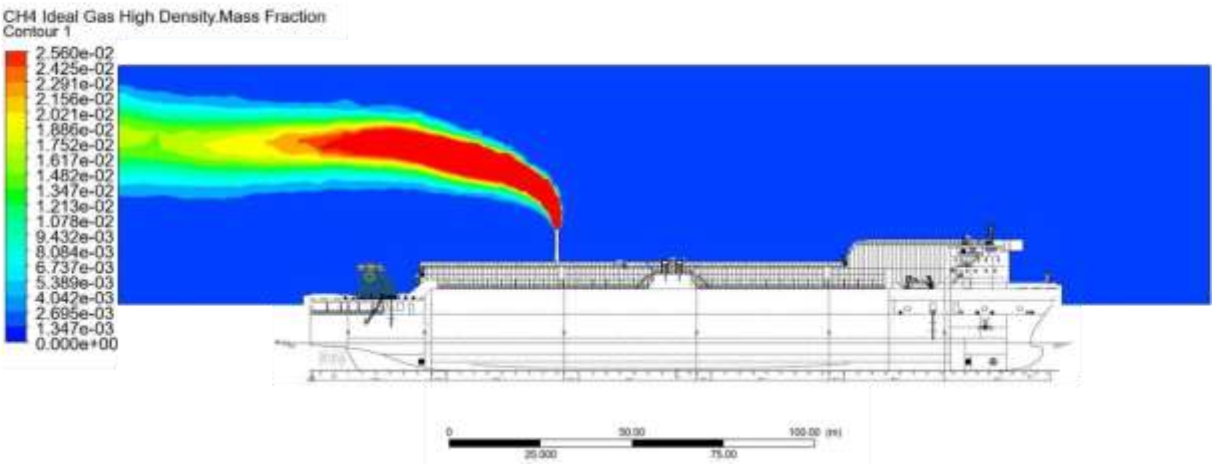

Fig.10 Vent mast system: methane mass concentration for most critical case

The methane concentration is shown in fig.10 when the mast system is engaged at maximum ship speed (16.5kn) and maximum opposing wind (50kn). Only the red area has a methane mass concentration above the combustion limit (2.56 percent), whereas the ship's critical structures (main deck, engine, and guest quarters) are safe (concentration in blue area is less than 0.1 percent).

Finally, a leakage analysis was conducted on the compressor room, which is not protected by inert gas (due to the lack of pressure vessels in the room), but rather by a ventilation system that lowers the critical gas concentration in the event of gas leakage (fig.11 reports a possible ventilation configuration, to be refined when the actual structure is designed).Combining CFD analysis with modeFRONTIER can enhance the position and load of ventilators and extractors, with the goal of reducing methane content in the room.

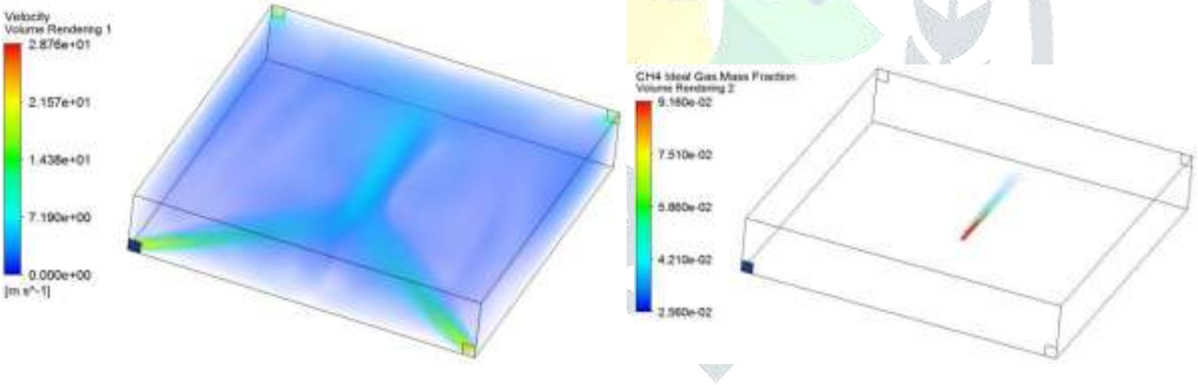

Fig.11: Ventilation system in compressor room: velocity field (left) and critical concentration of methane (right).

CONCLUSIONS

The Gasvessel project, which aims to establish a revolutionary concept of CNG gas transportation employing lightweight composite overwrapped pressure vessels and ships with higher cargoes, conducted exploratory numerical analyses.

The integration of numerical simulation models in a process automation platform for an efficient optimization process, as well as in ESTECO's web-based collaboration platform, which facilitates collaboration and decision making from the proponent's partners, optimizes key design parameters such as transportation logistics, pressure vessel material and geometrical parameters, and specifics of the safety measures to avoid explosion risks.

REFERENCES

[1] Peters, Stanley T., ed. *Composite filament winding*. ASM International, 2011.

[2] G. Fratti. Improved method to produce high-resistance composite vessels with inner metal liner and vessels made by said method, January 2015.

[3] C.C. Chamis and G.P. Sendeckyj. Critique on Theories Predicting Thermoelastic Properties of Fibrous Composites. Journal of Composite Materials, 2(3):332-358, 1968. [4] https://www.material.be/

[5] S. W. Tsai, Theory of composites design. Think composites Dayton, 1992

[6] Bartels, R. H.; Beatty, J. C.; and Barsky, B. A. "Bézier Curves." Ch. 10 in An Introduction to Splines for Use in Computer Graphics and Geometric Modelling. San Francisco, CA: Morgan Kaufmann, pp. 211-245, 1998.

[7] H.J Bomelburg, Estimation of Gas Leak Rates Through Very Small Orifices and Channels, February 1977, BNWL-223

[8] M.W. Zemansky, Heat and Thermodynamics, 1968, McGraw-Hill, pp. 182, 335.