„POLITEHNICA" University of Bucharest
Doctoral School of Power Engineering

Ph.D THESIS SUMMARY:

THEORETICAL AND EXPERIMENTAL RESEARCH ON OIL INJECTED SCREW COMPRESSORS

Author: CS. III Eng. Sorin-Gabriel GH. TOMESCU

Scientific Coordinator: Prof.Emer.PhD.Eng. Dan Niculae ROBESCU

Ph.D EVALUATION BOARD

President.	Prof.PhD.Eng. Radu Florin PORUMB	POLITEHNICA University of Bucharest
Ph.D. Coordinator	Prof.Emer.PhD.Eng. Dan Niculae ROBESCU	POLITEHNICA University of Bucharest
Referent	CS.I PhD. Eng. Valentin SILIVESTRU	NRDI COMOTI
Referent	Conf.PhD.Eng. Diana Maria BUCUR	POLITEHNICA University of Bucharest
Referent	Prof.PhD.Eng. Valentin PETRESCU	"LUCIAN BLAGA" university of Sibiu

BUCHAREST,
2023

CONTENTS

KEYWORDS: screw compressor, oil injection, gas-oil separator, oil recovery, efficiency

Acknowledgements

The present doctoral thesis entitled "Theoretical and experimental research on oil injected screw compressors" is the result of the research carried out by the author during the period 2018-2023. The selection of the PhD topic is a consequence of the author's work in the field of research-development of oil-injected screw compressors and the identification of functional elements that required improvement and optimization.

Under the author's coordination, an engineer at NRDI COMOTI, an optimized separation system has been designed, developed, and tested, with improved performances compared to other existing systems used in industry. The developed high-performance system can be used in newly developed applications, but more importantly it can replace previously installed systems with low performance, which are already in operation.

I thank my scientific supervisor, Prof.Emer.PhD.Eng Niculae Dan ROBESCU, for the way he guided and supported me during the PhD research period. Without his support I could not have completed this PhD thesis.

I would like to express my sincere thanks to the members of the supervision committee:

Prof. PhD. Eng. Lăcrămioara Diana ROBESCU ,

CS. I. Phd.Eng. Gheorghe FETEA,

Prof. Phd.Eng. Carmen GEORGESCU,

H.W. PhD. Eng. Corina BONCESCU,

CS. I. Phd.Eng. Radu MIHALACHE, for their constructive recommendations and suggestions for the organization and presentation of the results of the doctoral research.

Thanks for the logistical support provided by the National Institute for Research and Development of Gas Turbines COMOTI, support that has contributed substantially and decisively to obtaining the results and support of this PhD thesis.

Thanks to all colleagues in COMOTI who contributed to the numerical simulations and experimental results.

In conclusion, I would like to thank my wife, my daughter and my family for their unconditional support, moral support, understanding and patience constantly shown during the PhD research.

In the hope that the results of this doctoral research will have a significant impact in the field of research and contribute to the development of new innovative solutions for the operating problems of oil-injected screw compressors.

Introduction

The need to compress air and other working gases led to the advent of the compressor, and its concept and form have evolved perpetually as the applications in which it has been used have become increasingly diverse and complex. The first compressor to be used may be the animal skin bellows, which was used to compress and blow air. This system was operated by handles or a system of levers - bellows. There is information that these devices began to be used as early as 3000 BC [23].
Today, compressors are used in all aspects of life, in household applications, in refrigeration systems, in medical applications and industry, etc. The largest share of use of compressors is in industry, where they are applied to compress air, refrigerants, and combustible gases. The applications of compressors are manifold, the capacity, pressure and nature of the compressed gas depending on the nature of the application and the specific requirements of the technological process.

As in any field of technology, current concerns are focused on the development and realisation of more efficient, robust compressors, with longer operating periods between overhauls and shorter maintenance and shutdown times. In general, compressors have reached technical maturity, with improvements in efficiency and performance being small in relation to the amount of R&D undertaken.

Since 2010, COMOTI has been designing and producing a wide range of compression solutions, both compression units and compression assemblies equipped with oil-injected screw compressors. As a result of an intense applied research activity with appreciable results, COMOTI has become for several years an important manufacturer of natural gas compression units [17] equipped with oil-injected screw compressors. INCDT COMOTI is the only entity in Romania that develops screw compressors and natural gas compression units equipped with oil-injected screw compressors.

The solution of the first screw compressor was developed in an applied research project funded by national research funds in 2000-2003. A prototype was developed, tested and approved for industrial operation in a gas compression station associated with crude oil [24]. The programme, entitled "Equipment for compression and recovery of natural gas accompanying oil in wells", was a great success and was recognised and rewarded by winning the Agir prize in 2005 in the Engineering of Machine Construction section [24].

Areas of use for screw compressor assemblies with oil injection include [24]:

- Compressing air, refrigerants, or combustible gases (methane gas, hydrogen)
- Natural gas and oil extraction stations for transporting or conditioning process gases;
- Fuel gas supply to gas turbines or internal combustion engines - boosters for CHP applications;
- Petrochemical industry or industrial applications.

In general, screw compressors packages developed by COMOTI are used in for fuel gas compressing such as natural gas and well gas. The operating conditions of compressors in these applications can be particularly harsh due to the chemical and mechanical aggressiveness of the compressed gases, which may contain solid suspensions or liquid fractions such as water or gasoline. There may also be compounds in the compressed gas that react chemically under certain temperature and pressure conditions, leading to complex operational problems such as oil contamination, clogging of filters and separation systems, and others.

Under these conditions, gas-oil separation systems for applications in the oil and gas industry differ substantially from those used in air or other clean gas compression applications, requiring special design and construction to perform optimally in service, providing the functions for which it was developed, for an operating period of at least 4000 hours.

Motivation of the topic and the objectives of the doctoral thesis

The doctoral thesis is in line with modern research in the field of oil-injected screw compressors, which is the research and development goal of many research and development teams in institutes and universities. The theoretical and experimental research presented in this thesis is in line with the problem of operation of oil-injected screw compressors, that of separating oil from compressed gas by means of an oil-injected screw compressor.

The general objective of the thesis is to research, develop and experiment an efficient gas-oil separation system for equipping a screw compressor assembly with oil injection, ensuring real improved performances compared to similar systems, with immediate application in the industrial environment and in the series production range of COMOTI.

The main aim of the PhD research carried out is to develop an efficient, compact, and cost-effective gas-oil separation system capable of increasing the recovery of oil suspended in the gas discharged from an oil-injected screw compressor. To demonstrate the functionality and determine the overall performance, theoretical and experimental research will be carried out on the flow of the mixture - compressed gas, mixed with oil droplets, inside the separator vessel, in the composition of compressor assemblies, equipped with screw compressor with oil injection.

Specific objectives of the doctoral research:

i. Determine the need for more efficient operation of the gas-oil separation system in screw compressor assemblies with oil injection

ii. To present the specific problems arising in the case of compressed gas-oil separation systems. In-depth analysis of commercially available separation systems;

iii. Implementation of an economically efficient method to determine the residual oil content in the compressed gas, expressed in ppm, at the outlet of a separation system;

iv. Experimental evaluation of a conventional separation system to determine overall performance;

v. Establishment of functional requirements of an efficient separation system;

vi. Design the efficient separation system so that it can be installed in existing compression assemblies as well as in new applications;

vii. Validation of the geometry of the separation stages using CFD software;

viii. Trace, through experimental investigations, the overall performance of the efficient separation system: separation efficiency, pressure drop;

ix. Carry out experiments to determine the energy efficiency of a compression assembly operating in over compression mode

Notation and Symbols

Symbol	Parameter
SEP	Efficient system for oil-gas separation
CENT	Centrifugal Separator
HMI	Human Machine Interface
PLC	Programmable logic controller)
barg	Relative Pressure
bara	Absolute Pressure
DN	Nominal Diameter
PN	Nominal Pressure
CFD	Computational Fluid Dynamics
ppm	Parts per Million
Skid/ Skid Compressor	Oil Flooded screw compressor Package

CAPITOLUL 1. SCREW COMPRESSORS MAIN FUNCTIONAL CHARACTERISTIC PRESENTATION

The screw compressor is a positive displacement volumetric machine [20] that, in a simplified configuration, consists of two asymmetric helical rotors within shared casing. The helical profiles of the rotors are conjugate, and the engagement is achieved in a manner similar to that of gears with inclined teeth. The rotors of the screw compressor are specially profiled to ensure sealing between successive working chambers, between the working chambers and the casing, as well as to provide maximum suction volume.[18], [20].

Screw compressors are primarily used for compressing air in various industrial processes, compressing, and transporting natural gases and associated gases in the oil production industry, and compressing refrigerants in the air conditioning industry.

Screw compressors have gained widespread use in Romania in recent years, serving as an alternative to traditional piston compressors. Their performance makes them highly suitable for industrial applications.

Although they may appear conceptually similar, oil-free screw compressors and oil-injected screw compressors are structurally and functionally distinct, representing different types of compressors.

The oil injected into the compressor serves five primary functions: cooling, sealing, lubrication, noise reduction, and anti-corrosion protection. Oil injection into the screw compressor improves the volumetric efficiency (compression ratios can reach between 2 and 13 in a single stage [14]), reduces energy consumption (compression behaviour is close to isothermal compression), simplifies the compressor's construction, enables precise control of discharge temperature, and allows efficient operation at low speeds.

The oil injected into the compressor mixes with the gas, and all the oil introduced is discharged along with the compressed gas as a two-phase mixture of gas and fine oil droplets. To reduce technological oil losses, separation of liquid and gas phases is carried out using separation systems whose efficiency depends on the size of the oil droplets in the mixture, as well as the working pressure and temperature.

Therefore, it is necessary to separate the oil from the compressed gas in order to: ensure the quality of the delivered gas, minimize the residual oil content in the delivered gas, and reduce operating costs.

The efficiency of the design solutions for separation is certified through the residual oil content in the compressed gas that reaches the beneficiary. The industry convention for quantifying the amount of oil present in the compressed gas is to use the term parts per million, in mass units, ppm.

CAPITOLUL 2. PRESENTATION OF GAS-OIL SEPARATION SYSTEMS IN SCREW COMPRESSOR PACKAGES

Compressors machines designed for compressing air or natural gases developed by NRDI for Gas Turbines COMOTI belong to the category of oil-injected screw compressors. In the process of gas compression, oil is injected into the compression chambers, between the rotors of the compression unit, for cooling the compressed gas, reducing friction between rotor surfaces, and improving the sealing of isolated volumes within the unit.

Compressor packages based on oil-injected screw compressors are equipped with oil-gas separators in which various technical separation solutions are installed, resulting in generally residual oil content ranging between 100 and 40 ppm. At these levels of residual oil in the compressed gas, the presence of oil cannot be visually observed. The level is sufficiently low to prevent it from serving as a lubricant in downstream equipment through which the compressed gas will pass.

The mechanical methods used for removing oil from compressed gas in gas-oil separators include gravitational separation, separation by changing the flow direction or velocity, separation using centrifugal force, and separation through coalescence. Each of the listed methods requires a specific assembly configuration and has limitations in retaining oil droplets of various sizes. Gas-oil separators used in the industry can be constructed using one or more separation methods.

The efficiency of a structural gas-oil separation solution depends on the accurate analysis of all functional aspects, the correct application of assumptions and calculation methods and the use of high-performance technological solutions [5]–[7]. The analysis of physical processes occurring in the oil-injected compressor has revealed that in the gas-oil mixture, oil can also be present in a gaseous state, but in much smaller quantities, as the state conditions favoring the transition from liquid to gas phase are not met. Consequently, in practical terms, mechanical separation-filtration solutions can be applied for retaining oil in its liquid state in virtually all applications.

The mechanism of droplet formation and the average size of droplets depend on the technological process by which they are generated. The efficiency of droplet separation is influenced by a multitude of factors such as the size of oil droplets suspended in the compressed gas, the flow rate of gas through the separator device, the density and viscosity of the gas, the density and viscosity of the oil, as well as the temperature and pressure in the separator vessel. Following the compression process, the oil suspended in the compressed gas consists of droplets with diameters typically ranging from 0.2 to 500 μm [15], [19]

The mechanical separation of droplets suspended in gas occurs when the droplet meets an obstacle placed in the path of the gas flow. This is possible if the droplet is subjected to sufficiently large external forces to separate it from the gas stream. Particle separation mechanisms can be divided into six categories: gravitational settling, centrifugal separation, inertial impact, direct interception, diffusion, and electrostatic migration. [2], [3] Depending on the separation mechanism used, there are various technical solutions for separating oil droplets from compressed gas. Misunderstanding the gas compression process and the source of liquid in the upstream process of the separator can lead to the incorrect selection of the separator type [6], [7]. It is crucial to accurately estimate the sizes of the oil droplets suspended in the compressed gas [5], [7]. Based on the distribution of droplet sizes, among other functional parameters, the separation method that ensures the best efficiency can be selected.

The performance parameters of a gas-liquid separator are [3]: separation efficiency, pressure drop, separation capacity, blockage tendency.

To design an efficient gas-oil separation system, the operational limitations of each separation solution must be considered. Based on the materials processed by the author, centralized tables 2.1 and 2.2 were created, in accordance with [4], [10], [15].

Table 2.1 presents the materials, separation methods, and the diameter of the blocked/separated droplets. Based on the previously provided information, it becomes clear that to achieve optimal oil retention and prolonged operation, an efficient separation system should incorporate multiple separation stages arranged in a suitable order.

Table 2.1- Materials, separation methods and diameter of retained oil droplets, according to[4], [10], [15].

No.	Separation Design Solution	Diameter of Droplet Retained in Separator [µm]
1	Molecular membrane	Up to 0,004
2	Coalescence (fibers)	0,10-1
3	Metal mesh, with wire diameter d=0,02 mm	2-5
4	Cyclone	5-10
5	Metal mesh, d=0,15 mm	5-12
6	Metal mesh, d=0,3 mm	15
7	Baffle plates	15-30
8	Gravity separation systems	50-150

Table 2.2- Comparison between different separator solutions, according. [4], [10], [15]

	Coalescence (Fibers)	Metal Mesh	Baffle plates	Centrifugal Separators/Cyclones
Cost	Highest	Lowest	Higher than "Metal Mesh"	Higher than "Baffle Plates
Liquid Loading	Lowest	Moderate	High	Highest
Diameter of Retained Droplets	<0,1 µm	2-15 µm	15-30 µm	15-30 µm
Maintenance/Replacement	Replacement at 2000-4000h	Replacement at 16000 h	Easy maintenance	Easy maintenance
Pressure Drop	5-200 mbar	<5 mbar	1-10 mbar	20-30 mbar

Solid Impurity Tolerance	Does not tolerate	Tolerates small quantities	Excellent performance	Excellent performance
Installation	Medium complexity	Mild complexity	Medium complexity	Medium complexity
General Behavior	Very efficient, requires frequent replacement, high cost, high pressure drop. Requires another separation stage before. Requires separate oil recovery.	Easy installation, good efficiency, low pressure drop, low cost. Requires additional fastening and support system.	Maintains excellent performance in separating large quantities of liquid. Can be used with highly viscous liquids with high surface adherence. Requires an intermediate separation stage for handling small-sized droplets.	Ensures compactness of the separator vessel and can separate very large quantities of liquids. Medium pressure drop.

Understanding the concentration of oil in compressed gas is crucial for establishing and sizing a separation system, as previously mentioned. To cool and maintain the temperature at 80°C for a flow rate of 30,000 Nm^3/day of air compressed from 0.9 to 5.2 bar, an injection rate of 108 l/min, at a temperature of 50°C, is required, resulting in an oil concentration of 3608 g oil/kg gas.

To ensure the retention efficiency of a separation system used in the equipment of screw compressor assemblies, combinations of mechanical methods are necessary, such as combinations of cyclones with knit-type demisters and coalescence filters.

The efficiency of a separation system decreases with the number of operating hours of the installation and with an increase in the quantity of oil in the compressed gas mixture. Additionally, the efficiency of a separation system decreases as the droplet sizes in the mixture decrease, with increasing pressure and temperature of the gas-oil mixture.

Defining the operating conditions and the operating point is crucial for selecting a separation method.

CAPITOLUL 3. EXPERIMENTAL ANALYSIS OF A CONVENTIONAL GAS OIL SEPARATION SYSTEM

To determine the oil-gas separation performance of a construction solution commonly used in compression applications developed by NRDI for Gas Turbines COMOTI, a testing campaign was conducted in two distinct stages, each with its own general and specific objectives.

In the first experimental stage, the efficiency of the gas-oil separator was tested using the gravimetric method. In the second stage of the experimentation, the distribution and sizes of oil particles suspended in the compressed air were determined at the outlet of the separator vessel.

3.1. Determination of the residual oil content at the outlet of the separator vessel

The testing setup used for experimentation is a screw electro-compressor, developed by COMOTI, designed for compressing associated gases with oil in the Moinești exploitation area. The main elements of the assembly, encoded as ECS 30/10, installed on a metal structure, include: the screw compressor, the electric motor, the separator vessel, the oil system, the oil cooler, gas and oil filters, process solenoids, measurement systems, and instrumentation. To determine the residual oil content in the compressed gas at the outlet of the separator vessel, "Method A" from the reference standard ISO 8573 was used. This method is advantageous because it can handle significant volumetric flow rates, thereby reducing the potential for errors that can occur in small-scale studies.

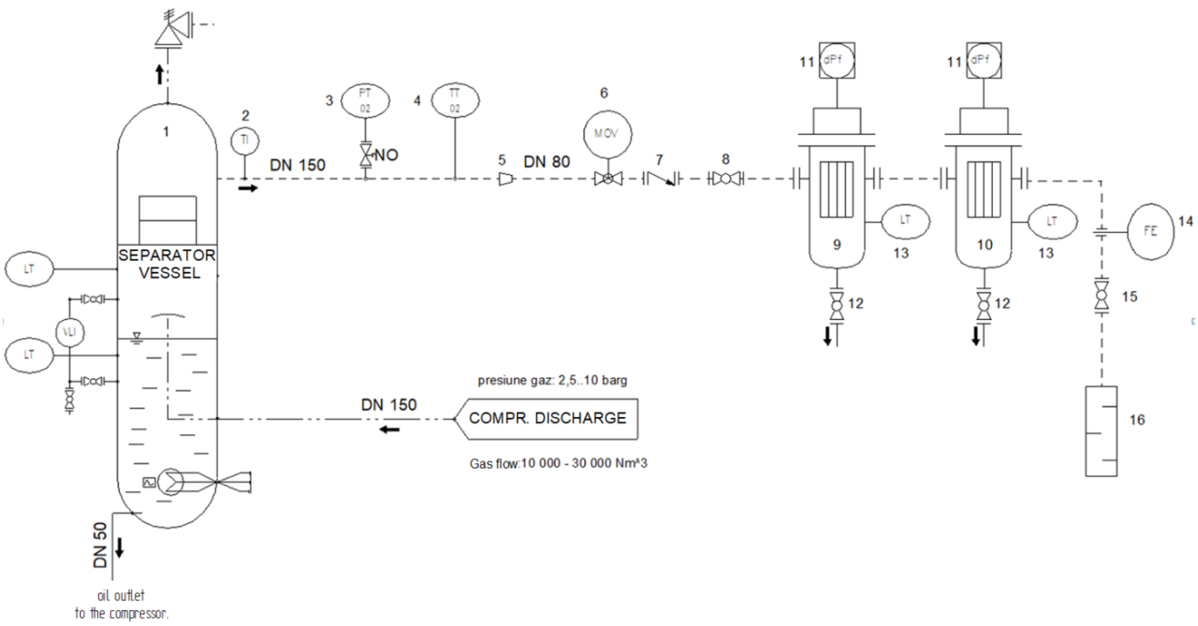


Figure 3.1 The experimental setup for determining the residual oil content in the separator vessel.

1. Vertical gas-oil separator vessel equipped with 2 demister stages;
2. Thermometer;
3. Pressure transmitter;
4. Temperature transmitter;
5. Concentric reducer DN150 - DN80;
6. Electrically actuated ball valve;
7. Check valve;
8. Ball valve;
9. Coalescing filter, first stage - 6CU-280x1, Parker Finite manufacturer;
10. Coalescing filter, second stage - 4CU-280x1, Parker Finite manufacturer;
11. Differential pressure gauge;
12. Collected oil drainage valve;
13. Vibrating fork level transmitter;
14. Diaphragm-type flowmeter;
15. Pressure control valve;
16. Noise attenuator.

Figure 3.1 illustrates the main components of the test setup. The compressed gas mixed with oil passes through the demister stages installed in the vertical separator vessel (1). Depending on the efficiency of the separation stages, the compressed gas exiting the separator vessel will contain a certain amount of oil in liquid and vapor form. A indicative value that would indicate good demister performance is approximately 40 mg/m3.

The two coalescing filters, positioned on the discharge pipe, aim to retain the liquid state oil. The first filter will be equipped with a coalescer element of type 6CU, which, according to ISO 12500-1 and the datasheet, will ensure the retention of 99.97% of oil droplets with diameters between 0.3 and 0.6 µm. The second element, type 4CU, will retain 99.995% of droplets between 0.3 and 0.6 µm.

To ensure optimal flow rates through the coalescing filters, a control valve (15) is provided. The compressed gas flow rate is measured with a diaphragm-type flowmeter (14).

The gas compressor unit was started by command. The control system opens the electrically actuated ball valve (6). The system pressure was adjusted by gradually closing the control valve (15), monitoring the pressure increase on the pressure transducer (3). The system operated for some time to allow for the attainment of steady-state temperatures and functional parameters. The test commenced when the pressure drop values across the coalescing filters stabilized. If the coalescer elements are new, during the first operation, one must wait for the stabilization of functional parameters, indicated by the point at which the pressure drop across the filter becomes stable, in the range of 0.1 to 0.25 bar. Both test coalescing filters were emptied of their liquid content through drain valves (12).

For calculating the amount of residual oil at the outlet of the separator vessel, the formula specified in ISO 8573-2 is used:

:

$$X = \frac{V \cdot \rho}{q \cdot H \cdot 3600} 10^6 \quad (3.1)$$

Where:
X - the amount of residual oil at the outlet of the gas-oil separator (mg of oil/m^3 of air)
V – collected oil volume (ml)
ρ – oil density (kg/m^3)
q – gas volumetric flow (l/s),under normal pressure and temperature conditions
H – test duration (h)

Table 3.1. The calculation of the quantity of residual oil after the gas passes through the separator vessel

Collected volume, first coalescent filter, position 9	300	ml
q	347,2	l/s
H	1	h
ρ	860	kg/m^3
X	206,4	mg/ Nm^3
ppm	160	mg/kg

Under the considered operating conditions, using equation (3.1), it was determined that the residual oil content at the outlet of the separator vessel is 160 ppm. According to the recommendations of coalescent filter manufacturers, for achieving high retention efficiencies, the upstream system, in this case, the separator vessel, should provide 40 ppm. However, during the testing of the separator vessel, it was found that the quantity of oil in the compressed gas is four times higher than these recommendations. If the tested compressor package were to be installed in a compression station without a coalescent filter, it would consume approximately 144 liters of oil in a single month of operation. Such a substantial oil consumption would significantly increase operational costs and could potentially have a detrimental impact on the downstream equipment of the compression assembly.

Table 3.2. The calculation of the residual oil quantity after the gas passes through the first coalescer filter.

Collected volume, second coalescer filter, position 10.	40	ml
q	347,2	l/s
H	1	h
ρ	860	kg/ m^3
X	27,52	mg/ Nm^3
ppm	21,3	mg/kg

In the second coalescer filter, after the same duration of operation, was collected approximately 40 ml of oil. Appling the same relationship (3.1), it results that the oil content at the outlet of the first coalescer filter is 21 ppm. Under these operating conditions, approximately 19 litters of oil would be consumed in one month of operation. Normally, the residual oil content at the outlet of the coalescer filter should be between 2 and 5 ppm. In the experiment conducted, the content was more than 4 times higher. The explanation lies in the fact that at the entry into the coalescer filter, the compressed gas contains too much oil compared to its separation capacity.

It is necessary to integrate a mixed separation solution in the separator vessel that combines various constructive types of separators: cyclone, tricot-type demister, and coalescer filter.

Probable causes of the poor separation efficiency of the separator vessel:

- Too much oil that needs to be separated by the demister stages.
- A large quantity of oil in the form of oil droplets with dimensions smaller than 2 μm, which are normally not retained by tricot-type demisters.
- Too thin demister fabric.
- Low efficiency of the second demister stage due to its positioning in the separator vessel.
- Recirculation of oil droplets that had previously undergone separation in the demister;
- Generation of additional oil droplets beyond those generated in the compressor injection process, as they pass through the discharge bend and the baffle plate.
- Creating a preferential gas flow path through the demisters, leading to oil separation on smaller surfaces than available.

The experimental research conducted has revealed that the technical solution involving two stages of knitted demister does not provide adequate separation efficiency for droplets smaller than 5 μm. Although they perform well in operation without clogging with solid or liquid impurities, functioning with low pressure drops for extended periods, demister separators with two stages of knitted demisters cannot efficiently separate droplets regardless of their size and the way they are configured and installed.

The Parker-type coalescent filters used at the outlet of the separator vessels ensure good separation but require frequent replacement. For proper operation of the coalescent filters, the manufacturer imposes a residual content of 40 ppm at the inlet. From the experimental research conducted, using the gravimetric method according to ISO 8573-2:2007, a residual content at the outlet of the separator vessel of 160 ppm was obtained. Under these operating conditions, the coalescent filter will operate far from its design point and with lower separation efficiency, increasing the pressure drop across it. The increased pressure drop across the coalescent filters will also result in additional energy consumption.

The oil loss during 24 hours of operation will be 4.8 litres, and for continuous operation over 30 days, the loss will be 144 litres. Under these conditions, the operation of the compression assembly will lead to an extremely high oil consumption, requiring periodic oil top-ups at short intervals (once a week). On the other hand, the equipment downstream of the compression assembly will be contaminated with the oil suspended in the compressed air, leading to their operation under different conditions than the design conditions.

3.2. Experimental determination of the characteristics of oil droplets suspended in compressed gas.

For the determination of the velocities and dimensions of oil droplets at the outlet of the separator vessel equipped with two demister stages, a research equipment from the NRDI for Gas Turbines COMOTI was used. The equipment used for this experimentation is produced by LaVision and is commercially known as the Particle Master Shadow. It is a non-invasive optical imaging system that can simultaneously determine the size, shape, and velocity of individual particles of droplets or bubbles dispersed in gas or liquid flows.

The operation of the equipment is based on the optical effect generated by the shadow of the droplets or bubbles in the transparent transport medium. The shadow effect [22], [25] is a widely used technique for particle characterization, allowing for particle identification and property determination with good processing speed.

In Figure 3.3, the experimental setup, developed by the author in collaboration with the authors of the work [22], is presented. This setup is used to determine the characteristics of oil droplets suspended in the compressed gas at the outlet of the separator vessel.

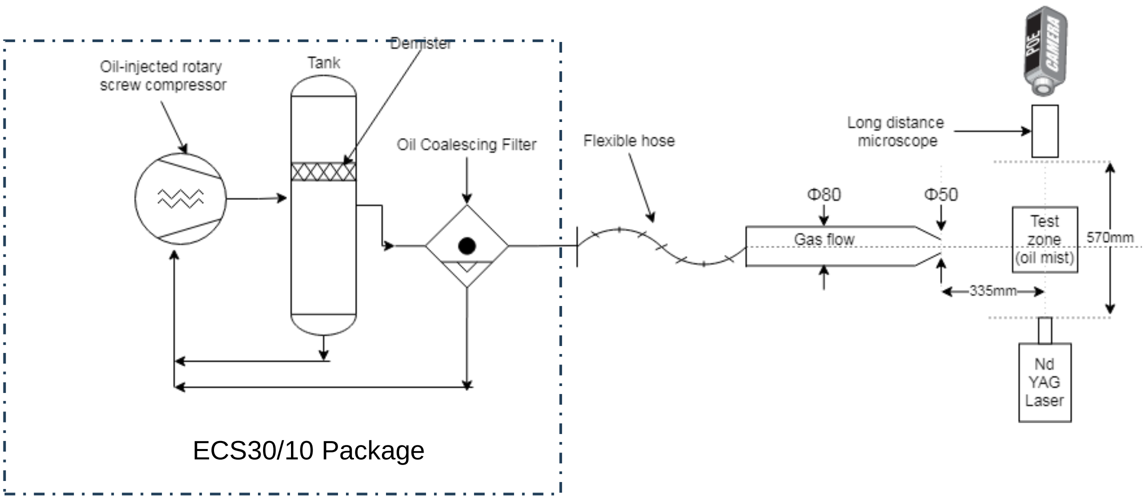


Figure 3.2. The experimental setup, according to [22],

Compared to the testing configuration presented in Figure 3.1, used to determine the quantity of oil in the compressed gas following the experiments presented in subsection 3.2, a single modification was made. The ECS 30/10 compression package operated without a coalescent filter in the first phase and with a single coalescent filter in the second phase. It was decided to conduct two sets of experimental tests to obtain significant information regarding the size and distribution of oil droplets, which could be compared later. It was estimated that in the experimental setup with a coalescent filter, the number and size of detected droplets would be smaller.

The two-phase mixture discharged from the ECS 30/10 compression assembly is collected through a flexible hose and a rigid DN80 diameter pipe. Figure 3.4 presents photographs taken during the tests. The flow of the two-phase mixture can be observed at the outlet of the DN80 pipe, which passes through the detection system.

Subsequently, to concentrate the jet of the two-phase mixture, a concentric reduction from DN80 to DN50 was installed, although this aspect is not captured in the photographs.

Figure 3.3. Photographs taken during the experiments.

At the beginning of the experimentation phase, it was observed that although the presence of oil droplets in the compressed air mixture was evident, confirmed visually by the presence of oil mist, the CCD camera did not capture the droplets that passed through the field of view. Several calibrations of the laser, CCD camera, and configurations in the laser control software - DaVis, as well as various comparative tests, were performed.

The application of the working procedure developed by the author and others [22], yielded good results, enabling the recording of approximately 300 double frames in which shadows of droplets passing through the field of view (FOV) were captured. To obtain the relevant data, the experimentation procedure was divided into three phases: configuring and calibrating the imaging system, conducting the test and recording the data, and processing the recorded data.

The processing software exports processed data regarding the distribution of identified and dimensionally analysed droplets.

Table 3.3 presents cumulative statistics obtained for the dimensional distribution of the recorded droplets.

Tabel 3.3. The cumulative statistics for the distribution of identified oil droplets in the two working scenarios.

	Statistics	Value (with coalescent filter) 18 particles	Value (without coalescent filter) 45 particles	MU
1	D10	6.2	6.4	µm
2	D32	9.9	9.8	µm
3	Dv10	5.9	6.6	µm
4	Dv50	11.1	10.8	µm
5	Dv90	14.9	12.2	µm

Where:

- D10 – is the arithmetic mean of the captured particle diameters.

- D32 – represents the Sauter mean diameter, defined as the diameter of a hypothetical droplet whose volume-to-surface ratio is equal to the volume-to-surface ratio of all analyzed droplets.
- Dv10, Dv50, Dv90 - volume percentiles at 10%, 50%, 90% (Dv50 means that all particles with a diameter up to Dv50 contain 50% of the total volume of particles).

To illustrate the particle sizes that were visualized, histograms were prepared for each of the two operating configurations after image processing. The histograms represent the frequency of each size class. The horizontal axis of a histogram can be divided into equally spaced linear or logarithmic lines. The vertical axis represents probability (frequency) or absolute numbers (absolute frequency).

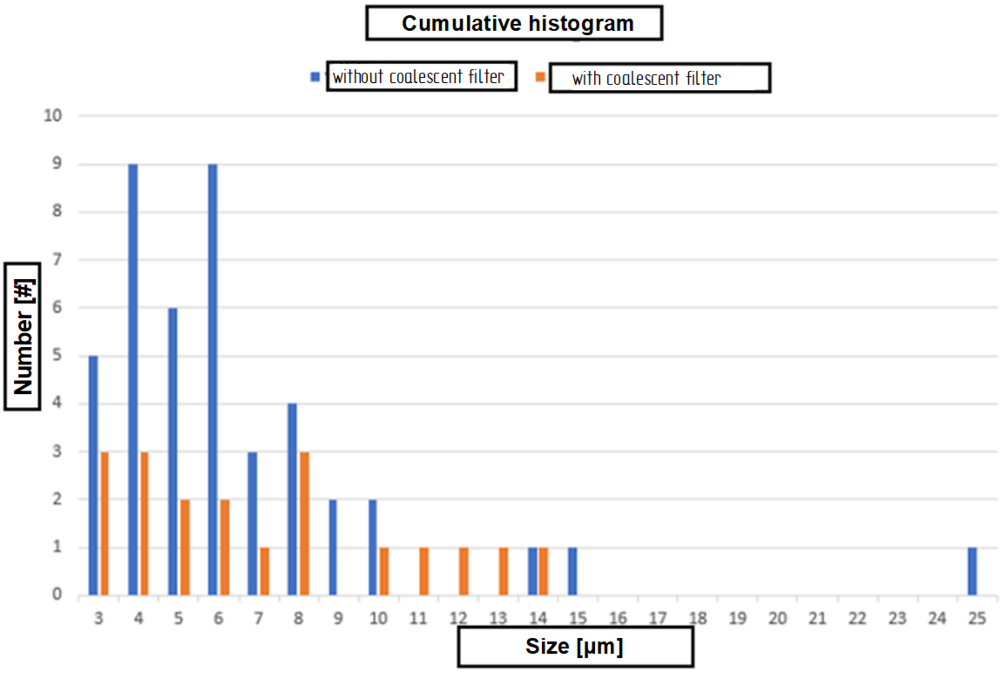


Figure 3.4. Cumulative histogram for both cases.

In Figure 3.5, cumulative histograms of particle size distributions are presented for both cases: operation without a coalescent filter and operation with a coalescent filter. Forty-five particles were detected in the test case without a coalescer filter, and eighteen particles with the coalescer filter. However, a decrease in the number of particles as well as their maximum diameters is observed when the coalescence filter was used.

The small number of detected particles is attributed to the high velocity of the biphasic mixture at the exit of the DN80 pipe and the relatively small sizes of the particles. The calculated velocity of the mixture at the exit of the DN80 pipe is 34 m/s.

The experimental research conducted to investigate the size distribution of oil droplets at the outlet of a conventional gas-oil separation system represents a novelty in terms of the proposed testing configuration and measurement technique used. The results of this study contribute to a better understanding of the oil separation process in the conditioning systems of screw compressor assemblies and help in the design of separation systems with improved performance.

CAPITOLUL 4. NUMERICAL AND EXPERIMENTAL ANALYSIS OF THE EFFICIENT SEPARATION SYSTEM (SEP)

Considering the experimental and numerical results presented in CHAPTER 3, the results that showed the technical solution of the tested separator does not ensure an efficient oil recovery, which generates an increased oil consumption. It is necessary to design, implement and test a new efficient gas-oil separation system (SEP). Considering the experience gained in the field of design, implementation and operation of compression assemblies equipped with screw compressor, the development of SEP is an applicable desideratum.

The design of the SEP will take into account the conclusions drawn from the operation of the equipment under similar working conditions in applications developed by INCDT COMOTI.

For the integrated solution of the efficient separation system the author considered the following requirements:

- compact and simple solution for installation in the vessel; - all separation stages must be installed within the same pressure vessel.
- the residual oil content in the compressed gas must be maximum 20 ppm.
- good performances operating above design point: pressure, temperature, flow.
- pressure drop as low as possible.
- operating life of at least 4000 h until consumable components (coalescing filters) are replaced;
- low investment cost, low maintenance cost.
- possibility of installation in the pressure vessels of existing vertical separator vessels with a nominal diameter of 800 mm;
- possibility of testing under real operating conditions.

Considering the operating parameters in terms of discharge pressure and conveyed flow rates of the screw compressor compression assemblies developed by COMOTI and in service, the following input data were established for the sizing and execution of the filtration solution.

Table 4.1. Operating domain of the efficient separation solution.

Functional characteristics	
Gas flow	10.000÷35.000 Nm^3/day
Type of mixture	Air-oil, natural gas- oil
Nominal pressure	5-15 barg
Oil flow	max. 150 l/min
Mixture temperature	max. 100 °C
Overall dimensions height x diameter	max. 1620x 700 mm
Operating position	Vertical
Overall performances	100% droplets > 3 µm
Pressure drop	Max 0,15 bar
Residual oil content	Max 20 ppm

In the design stage, it was decided to integrate the SEP into a DN800 PN50 gas-oil separator vessel, which is part of COMTO screw compressor testing bench.

The 3D model of this separator vessel, with vertical working position, is shown in Figure 4.1. The layout of the process connections, the instrumentation level and the overall construction of this separator vessel is similar to the vessel shown in Chapter 3.

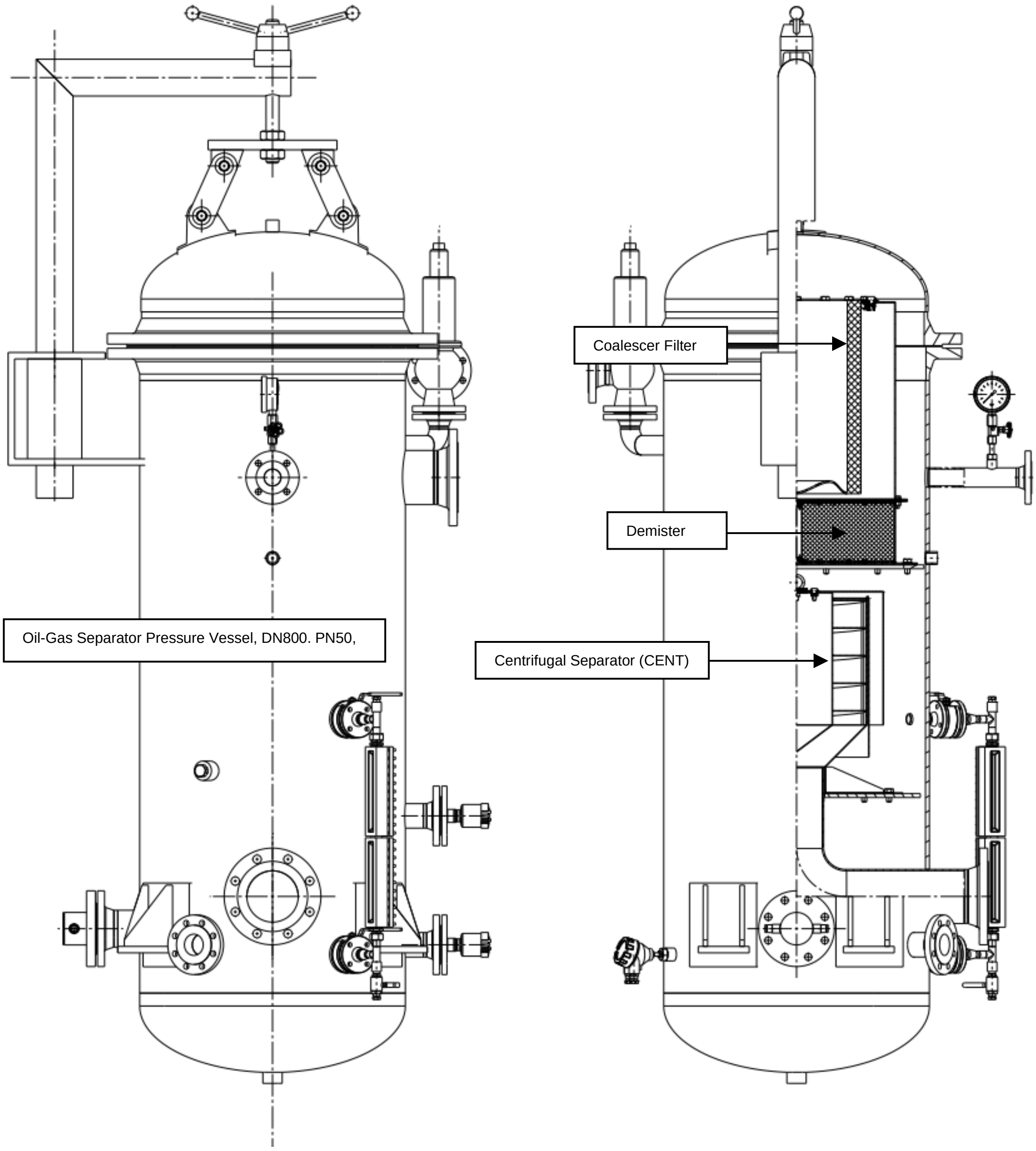


Figure 4.1.Oil Separator Vertical vessel, assembly

The two-phase gas-oil mixture enters the separator vessel changing its direction of flow through the 150 mm diameter elbow, through which the two-phase mixture is directed to the first separation stage, the centrifugal separator.

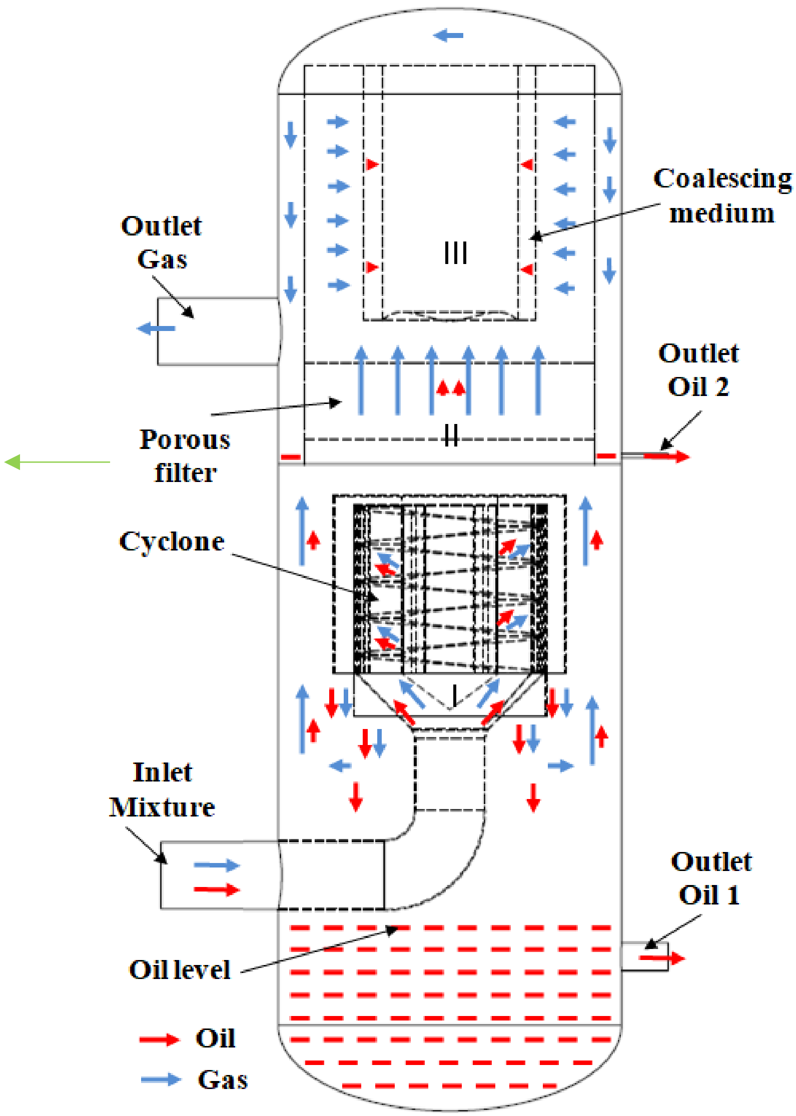


Figure 4.2. Oil-Gas Separator, Assembly DN800

The design of the centrifugal separator induces a rotating (swirling) motion to mixture, providing centrifugal separation of oil from air as well as solid and semi-solid suspensions.
Next, the compressed gas, released from droplets larger than 50 µm , passes through the demister made of 0.2 mm diameter stainless steel wire mesh, through which a fine separation is achieved. In this stage most of the oil is separated from the compressed gas.
The height of the knitted mesh pad should be 150 mm, which is the minimum size for an efficient demister. If a new separator vessel is to be built, with no imposed limitations on its height, it is recommended to use a 300 mm thick knitted mesh. As a final separation step, an air-oil separator filter (coalescer), code NS 009930, has been introduced, which is used specifically to improve the quality of air used in compressed air installations.

4.1. Numerical investigation of Gas-oil separation system

Efficiency evaluation of the two-phase gas-oil separator is performed by applying the volume of fluid flow (VOF) method. This method is widely applied in computational fluid dynamics (CFD) for various flow applications. The method is most suitable because it succeeds in capturing and tracking gas-fluid interference, while providing various alternatives for accurate interface reconstruction [11], [21].

The finite volume discretization technique was used to solve the system of equations. In this technique the region of interest is divided into smaller sub-regions, called control volumes. The equations are discretized and solved iteratively for each control volume.

The thermodynamic model for this case study integrates the input data (geometry) and the properties of the physical models. Figure 4.3 shows the implementation diagram of the thermodynamic model [21]

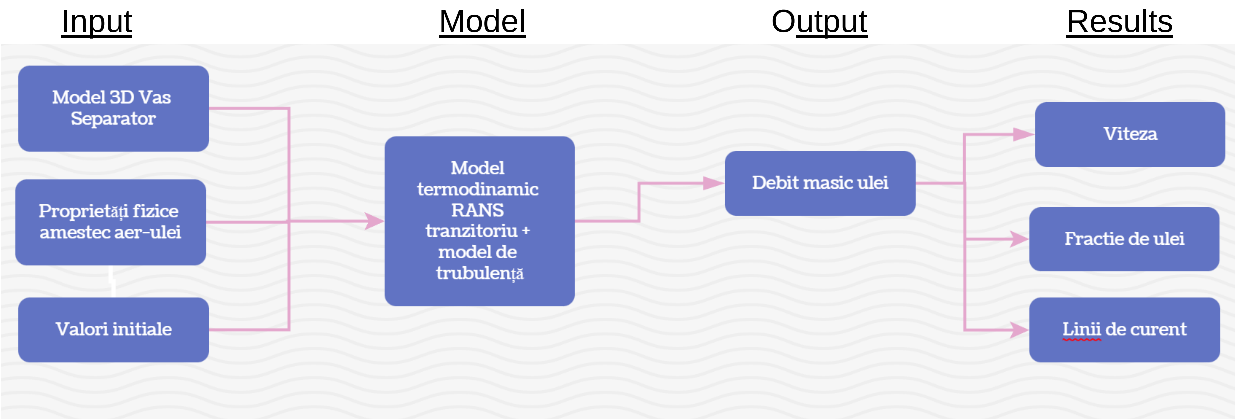


Figure 4.3. implementation diagram of the thermodynamic model

Table 4.1. Working fluid proprieties

	Unit	Gas	Oil
Molar Mass	kg/kmol	28.96	309
Density	Kg/m^3	1,225	827.1
Specific heat capacity	J/kg/K	1004,4	2124
Ref. Temperature	°C	25	80
Ref. Pressure	bar	1	1
Ref. Spec. Enthalpy	J/kg	0	156801
Ref. Spec. Entropy	J/kg/K	0	503
Dynamic Viscosity	kg/m/s·10^{-3}	18,31	11,33
Thermal Conductivity	W/m/K	0.0261	0.1274

To validate the dimensions of the technical solutions presented in the previous sub-chapter, but also to achieve a constructive optimization of the gas-oil separator, three constructive variants were iteratively sized, variants two and three being an improvement of the previous solutions, following the results of the numerical simulations. The first two variants, in order to reduce the complexity and the time required for simulation, do not include the buffer demister. Variant three is the one that was the basis for the design of the efficient separation solution.

In the first stage, the results of the simulations for the first two construction variants will be presented in comparison. Variant 1, shown in the figures framed on the left, is the first iteration of the integrated separation solution as it resulted from the first sizing calculations. Following the CFD results obtained, the centrifugal separator part was revised in order to reduce the cross-section of the working channel, by modifying the spiral, keeping the inner and outer diameter, as well as adding the number of longitudinal slots, resulting in var.2, the working case shown framed on the right side.

4.1.1. Flow simulation through the separation system variants 1 and 2

The initial three-dimensional geometry of the model was imported into the Design Modeler software and a simplification and optimisation was conducted. Constituent elements such as screws, flanges, instrumentation connections, which are not of interest for the simulation, were removed from the model. To facilitate post-processing, the suction and outlet connections of the separator were positioned in the same transverse plane. This modification does not change the way the separator operates. Subsequently, the fluid calculation domain was generated, represented by four subdomains: Tank, Centrifugal Separator, Separator Filter and Discharge.

In Figure 4.4 is presented the solid domain of the vessel during the editing process. It is noted that only the centrifugal separator and separator filter were considered for the study, the demister was excluded. The oil outlet connection, DN50, to the grease plant has also been excluded from the model, also for simplification reasons.The fluid domain of case var.1 is illustrated in Figure 4.5

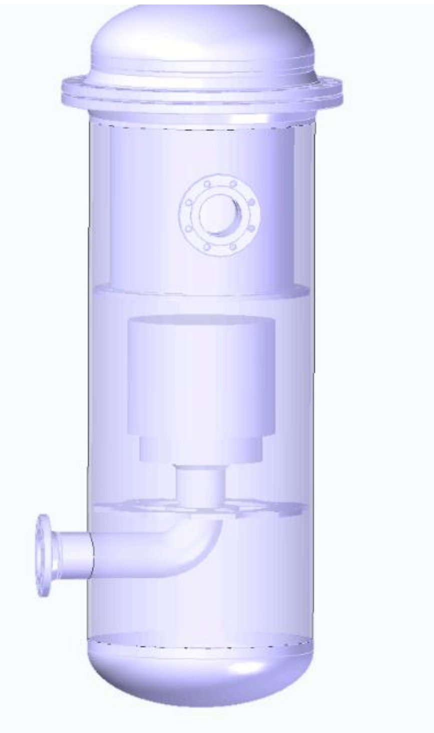


Figure 4.4. Solid Domain

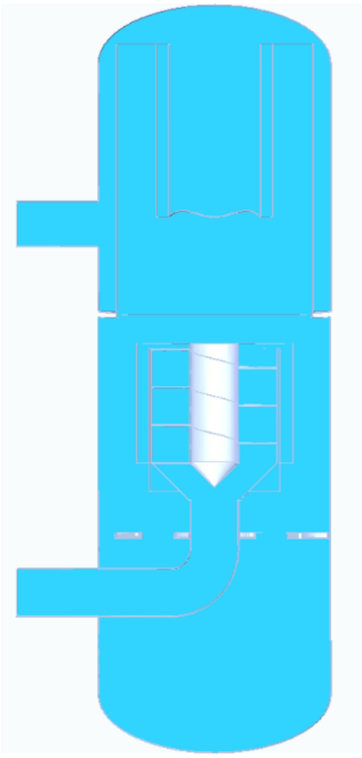


Figure 4.5. Fluid Domain

The computational grid shown in Figure 4.6 and Figure 4.7 was generated using gridding methods based on the maximum element size of 50mm, generating combined (structured and unstructured) grids, 1370641 nodes and 5591750 elements. A condition of grid packing was applied, having a minimum element size of 3 mm at the interface with the spiral and the intermediate cylinder of the separator, as well as for the surface of the separator filter.

In the figures above, the grid is shown in the areas specified above. The grid is filled in to calculate and capture in detail the phenomenon in the areas concerned.

For each location static pressure and mass flow rates of each phase, gas and oil have been defined. For the separator filter, an area with porous media, based on the experience gained in previous simulations but also following an extensive study of the literature, the porosity was chosen 0.95, the isotropic loss model and the permeability 2.286e-10 m^2.

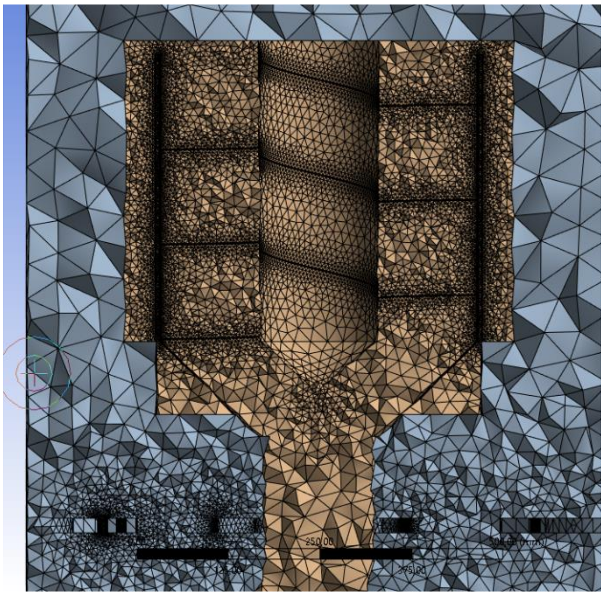


Figure 4.6 Mesh grid detail cross section

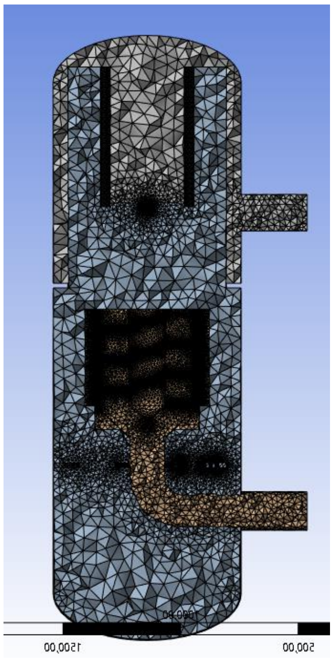


Figure 4.7. Mesh grid cross section

The four computational subdomains of the work case, reservoir, centrifugal separator, outlet domain, are defined as fluid subdomains and the separator filter subdomain is defined as porous subdomain. The four subdomains generate 8 interfaces.

Table 4.2. Boundary conditions used for case setup.

Location	BC Description	Connection
INLET OIL-GAS MIXTURE	Boundary condition Mixture velocity 3,7 m/s Relative pressure [bar]: 6 Static Temperature [ºC]: 80 Oil-gas fractions according to Table 4.3	DN150
OULET	Boundary condition: Gas flow [kg/s] Pressure drop [bar]: 0,1	DN150
WALLS	Boundary condition: Wall, wall velocity zero	

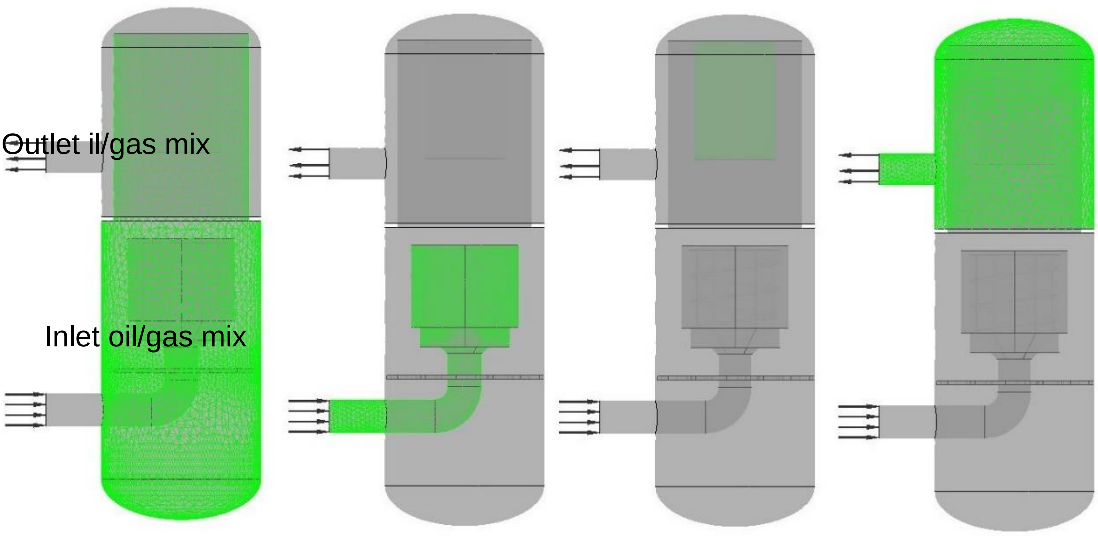


Figure 4.8. Computational subdomains

In Table *4.3* are presented input data used for this simulation. These values are entered as input data in the implementation of the work case and follow the parameters and requirements imposed in the design of the efficient separation solution.

Table 4.3. Oil and air flow rates and volume/mass fractions

Oil flow	139	l/min	
Air flow	35.000	Nm^3/zi	
	kg/h	m^3/h	
Oil	7506,497	8,340552	
Air	1885,9	242,4994	
*	gas (air)	oil	total
Masic fraction	0,200788	0,799212	1
Volumic fraction	0,96675	0,033251	1

To reduce the effort of the analysis and the time required to run the work case, the oil level in the vessel was initially set below the inlet elbow of the gas-oil mixture. Thus at the time of initialization, the software no longer introduces oil and inlet elbow as an initialization condition.

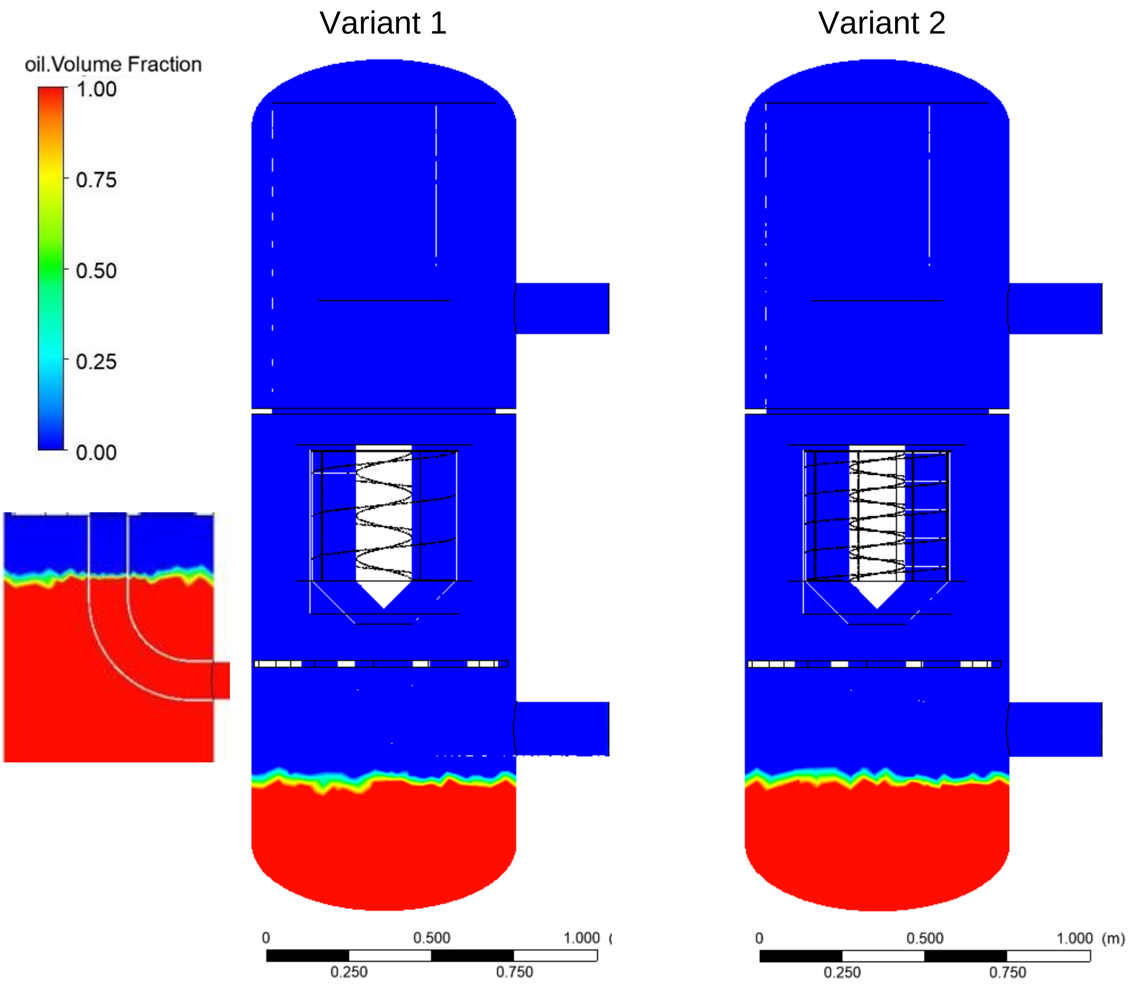


Figure 4.9. Gas and oil fractions, time of initialization, 0s

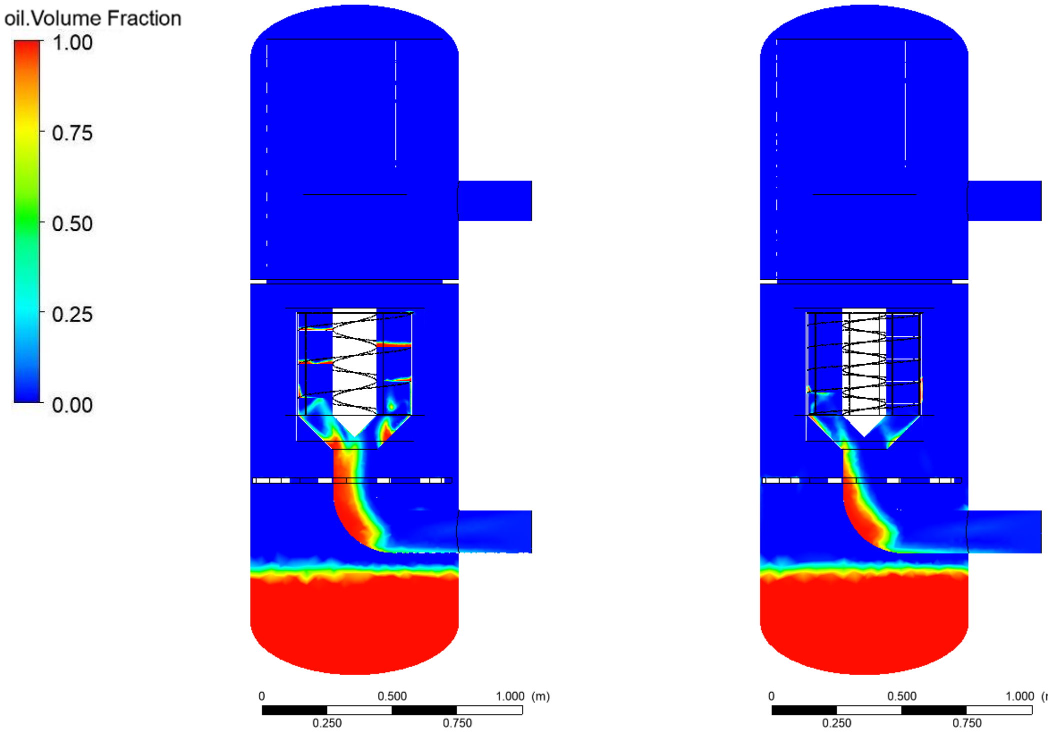


Figure 4.10. Gas and oil fractions, time step 5s

The penetration of the gas-oil mixture into the inlet account is observed. The flow direction changes and under the effect of the central cone the mixture is distributed to the inlet in the centrifugal separator.

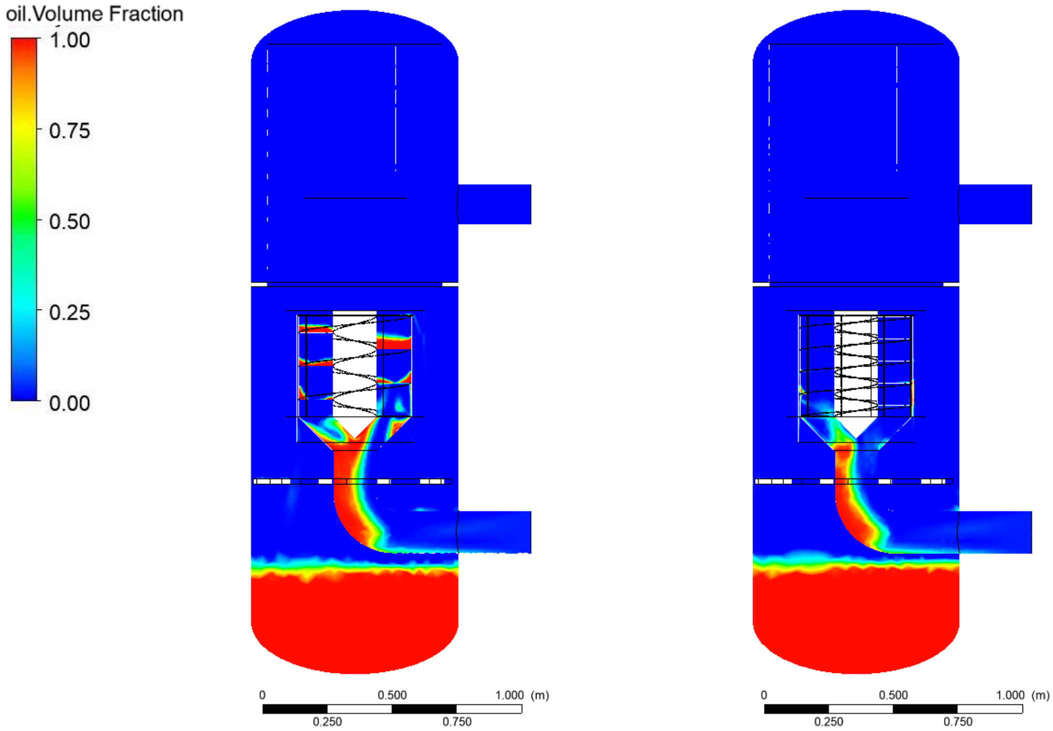


Figure 4.11. Gas and oil fractions, time step 10s

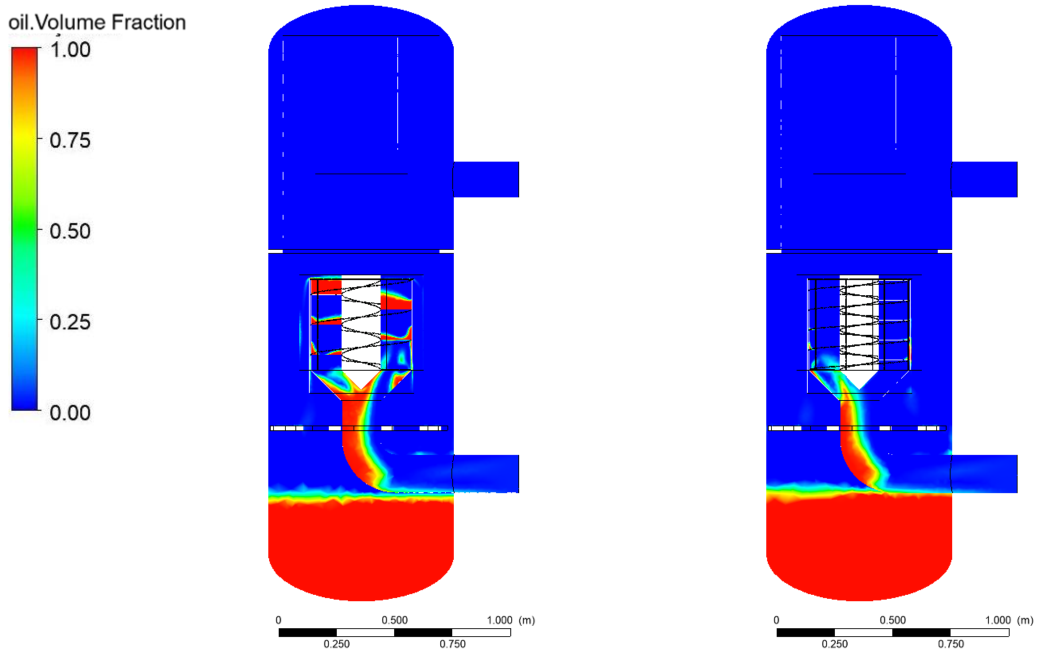


Figure 4.12. Gas and oil fractions, time step 20s

The centrifugal separator var. 1 is not working properly, because a considerable amount of oil is flowing through the spiral and has reached the top, in the flow separation area. Var.2 shows proper functioning, the oil is directed onto the side cylinder walls and drained later through the slots. The number of slots has been increased from 4 to 8 and their width has been increased to 1.5 mm.

In both calculation variants there is a substantial accumulation of oil in the inlet elbow, which makes the separation process more difficult and is an additional source of oil droplet generation. The solution to this functional problem proposed by the author is the installation of a pipe that continuously collects the oil accumulated in the elbow. A 3D model (version 1.1) has been made containing this modification and a CFD calculation has been made with this configuration. The 3D model, version 1.1, is identical to version 1, with the addition of the oil recovery pipe in the elbow. For the running of the case the same initial conditions were kept, to which the condition of oil exit through the collection pipe was added.

The results of this case were in line with the initial estimates - decreasing the amount of oil accumulating in the elbow. However, this configuration cannot be implemented in the case of existing separator vessels, because the introduction of an additional pipe, passing through the outer jacket, implies modifications of the pressure body, which is forbidden by the requirements of the Pressure Directive (PED). The developed configuration can be implemented in the case of construction of a new separator vessel. The results of running case var.1.1 have not been presented in the thesis. Two images illustrating the introduced pipeline configuration and the oil-gas fraction at the time of the 15 s simulation are presented informative below.

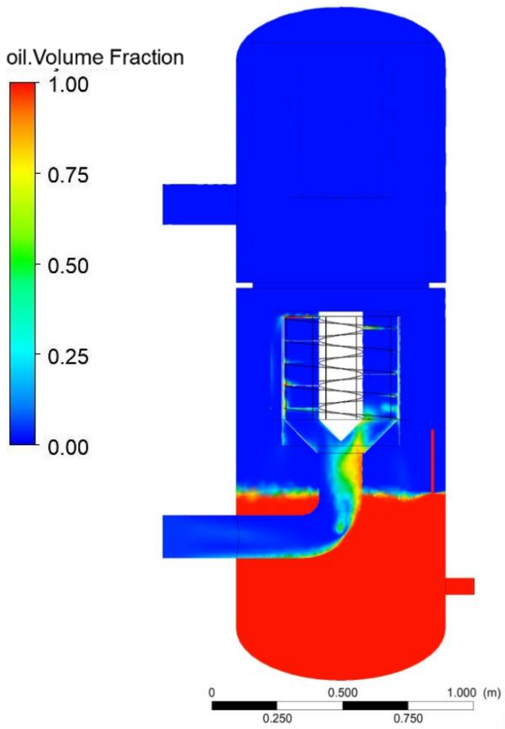


Figure 4.13. Gas and oil fractions, time step 15s

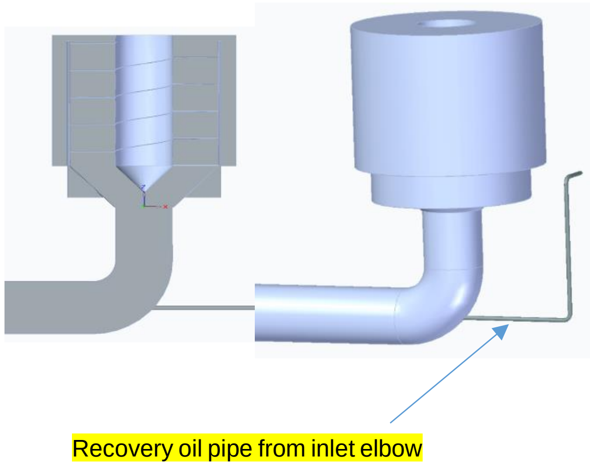


Figure 4.14. Oil recovery layout pipe

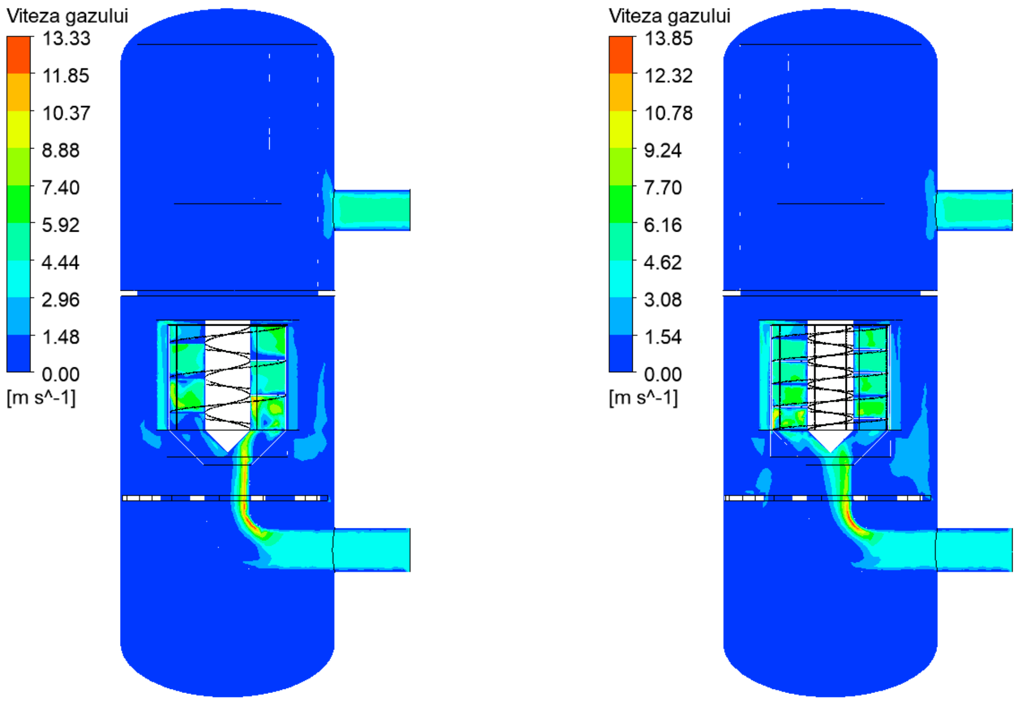


Figure 4.15.Gas velocity, time step 5s

The increase in the travel speeds of the centrifugal separator in var.2 equipment is observed. The effect of the reduced cross-section is beneficial.

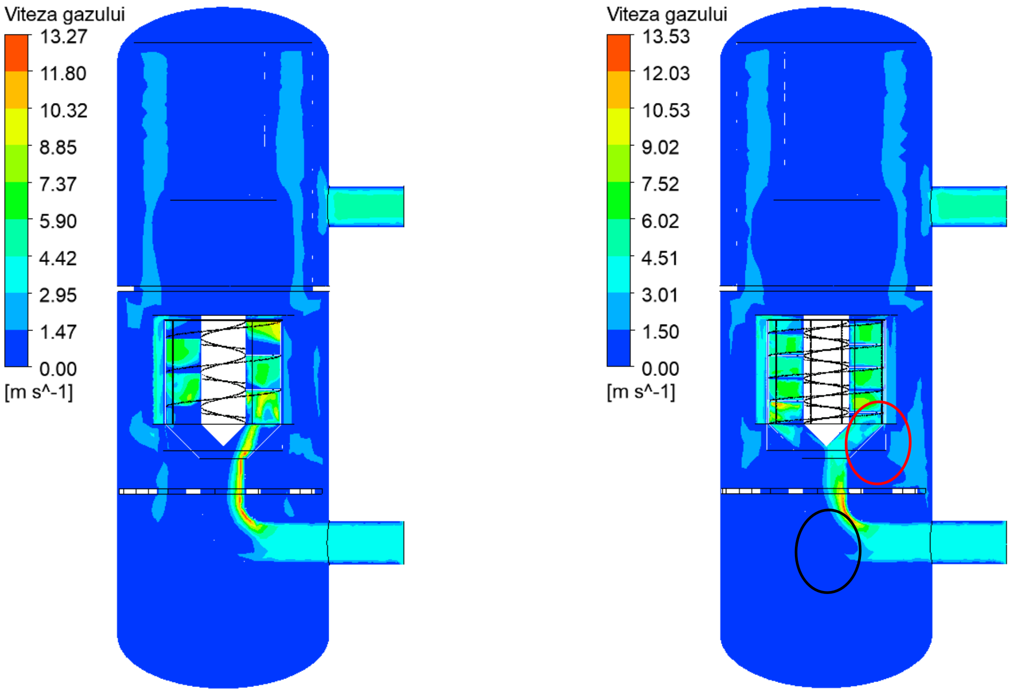


Figure 4.16. Gas velocity, time step 10s

Due to the narrowing of the cross-section due to the presence of oil in liquid state, it is observed that the vertical entry into the separator is not uniform. The presence of the central cone improves the distribution of the gas-oil mixture at the separator inlet.

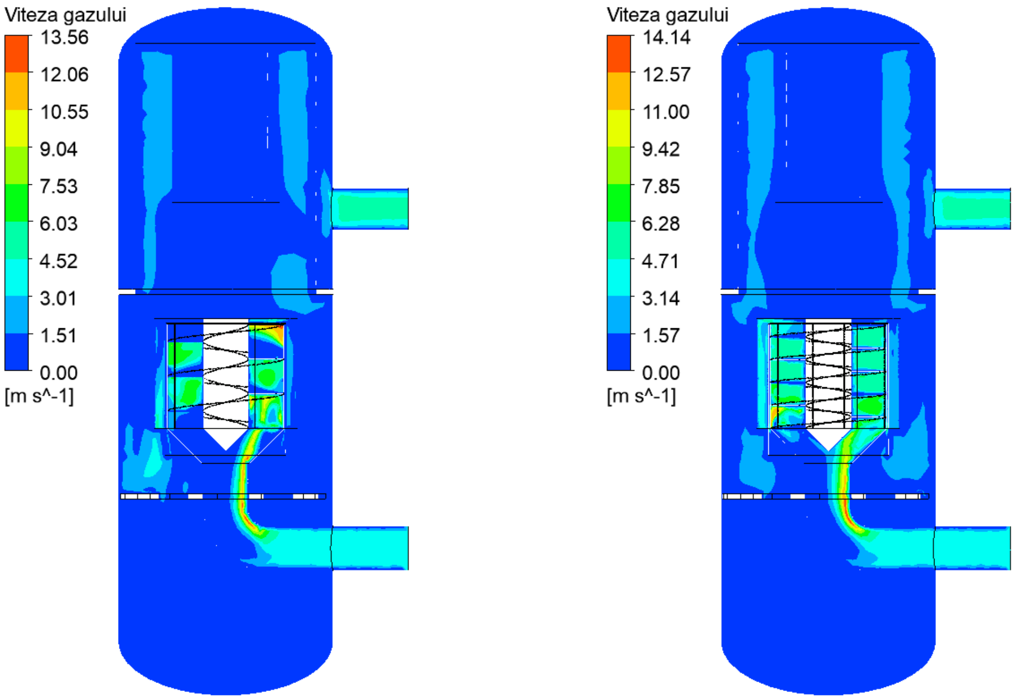


Figure 4.17. Gas velocity, time step 20s

Travel velocities of the two separation solutions - centrifugal separator and coalescing final filter - are within operating limits. There is a possibility that the separator can work at higher mass flow rates than the one selected for this case, SEP can equip a wide range of compression units.

4.1.2. Flow simulation through the separation system variants 3

Considering the corresponding results of the numerical simulation of SEP, variant two, it was decided to conduct an extended numerical study in the full version of the interior outfitting. As previously stated, the exclusion of the demister from the previous simulations was done to simplify the work case and shorten the time required for the calculation. Two process connections have also been introduced, a DN50 pipe through which oil is taken from the separator vessel to the conditioning system and injected into the compressor, and a DN10 pipe to collect oil that may accumulate on the upper vessel cover and inner walls after passing through the separator filter.

For this study, the same conditions were kept for the preparation of the work case. The differences consisted in the introduction of another porous subdomain - the demister, with the implications produced by this modification: the creation of a new calculation grid, the establishment of conditions for this subdomain.

Figure 4.18 shows the solid domain of the separator vessel in the complete equipment configuration: centrifugal separator, demister and final coalescer filter.

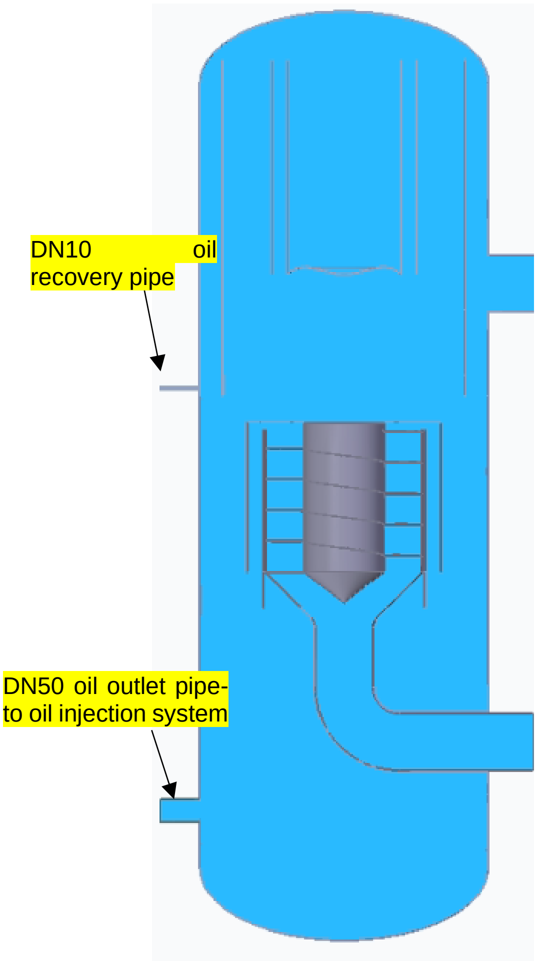


Figure 4.18. Fluid domain, var. 3

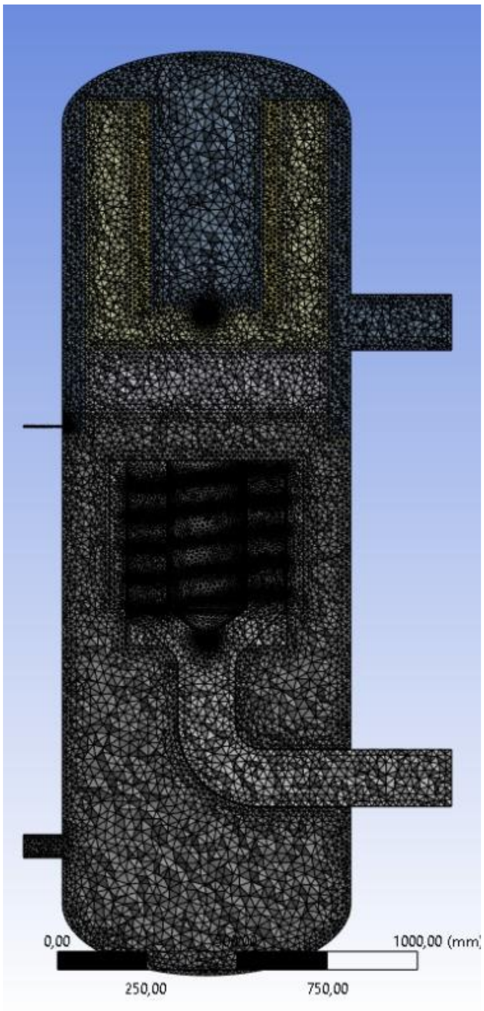


Figure 4.19. Mesh grid cross section , var.3

The computational grid shown in Figure 4.19 was generated using grid methods based on the maximum element size of 20mm, generating combined (structured and unstructured) grids, 4261516 nodes and 11906316 elements. A grid packing condition was applied, having a minimum element size of 3mm at the interface with the separator intermediate spiral and cylinder and for the surfaces of the separator demister and filter.

For the demister porous subdomain, the porosity was chosen 0.95, the isotropic loss pattern and the permeability 2.286e-10 m2.

The work case ran for about 5 days, resulting in a flow simulation in the separator vessel of about 20 seconds. In order not to burden the present material further, as some results are similar to those presented above, for the work case variant 2, only results obtained at time points 15 and 20 seconds will be presented.

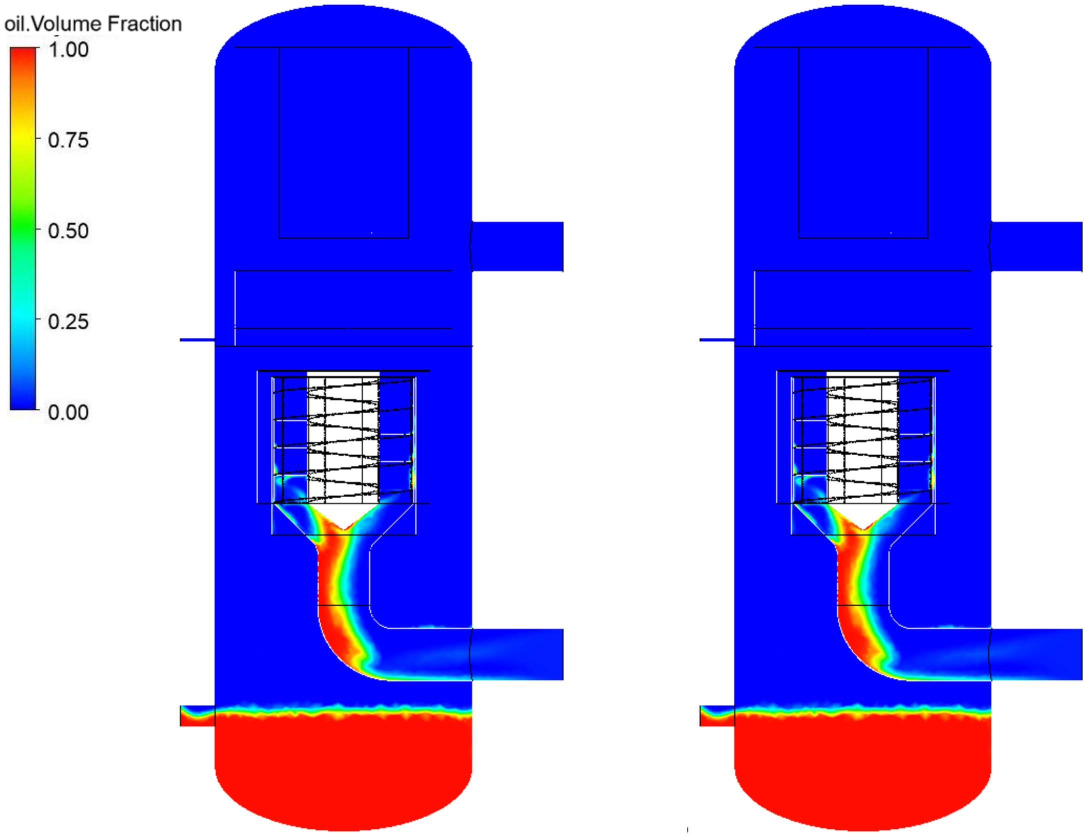


Figure 4.20. Gas and oil fractions, time step 15 and 20s

Similar working behaviour is observed as in variant 2. The introduction of demister does not change the way the biphasic mixture evolves. The proper functioning of the whole assembly is confirmed, the oil being properly separated from the spiral of the centrifugal separator.

The figures below illustrate the modifications made by the author to optimise the operation of the CENT centrifugal separator. These modifications were confirmed by the results of running the cases in variants two and three of the SEP.

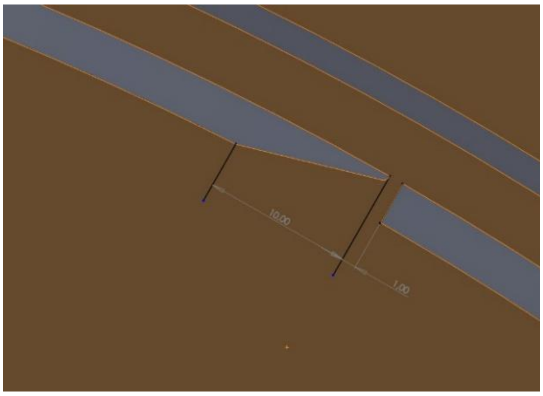


Figure 4.21. .Centrifugal separator geometry with four longitudinal slits design, Var.1

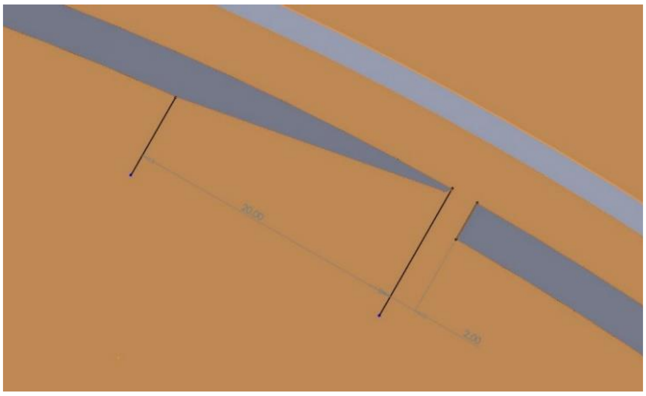


Figure 4.22. Centrifugal separator geometry with four longitudinal slits design Var.2

The cross-sections in the images below capture the changes made to the geometry of the centrifugal separator. Keeping the gauge dimensions, outer diameter and overall height, the working channel has been narrowed by increasing the number of full spiral rotations.

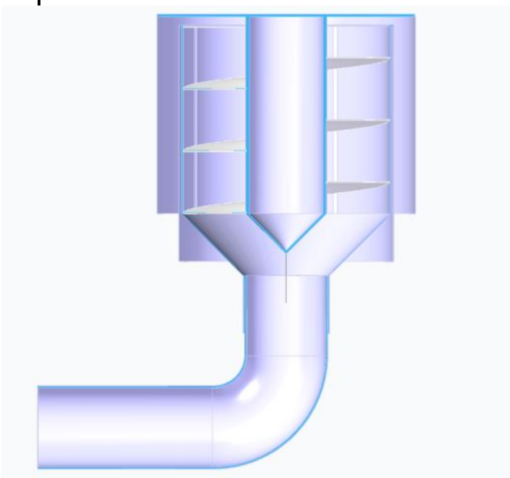


Figure 4.23. Spiral three turns Var.1

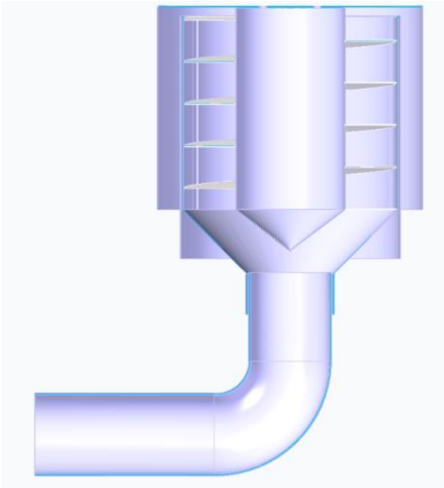


Figure 4.24. Spiral 4,5 turns Var 2.

To illustrate how the centrifugal separator works, a series of suggestive pictures have been taken to show how the separator spiral and longitudinal slots conveniently work. The oil is centrifuged on the side wall of the cylinder and discharged through the longitudinal slits, thus separating the separate oil stream from the two-phase mixture.

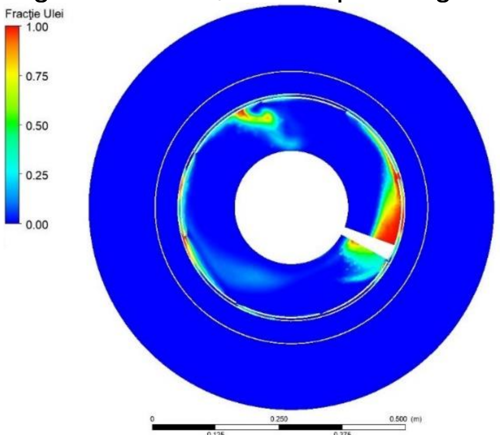


Figure 4.25.CENT cross section Var.2

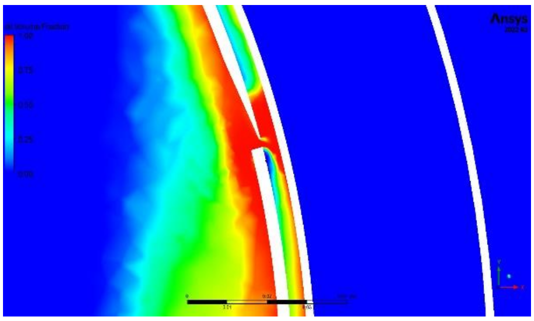


Figure 4.26. CENT cross section detail

The fact that the oil is centrifuged and discharged through the longitudinal slots is also revealed in the pictures below. A large amount of oil can be seen at the base of the spiral, in the area that is completely red. As the two-phase mixture travels through the spiral, the oil is progressively separated and drained. In the upper zone of the spiral there are no more oil zones, in volume fraction =1

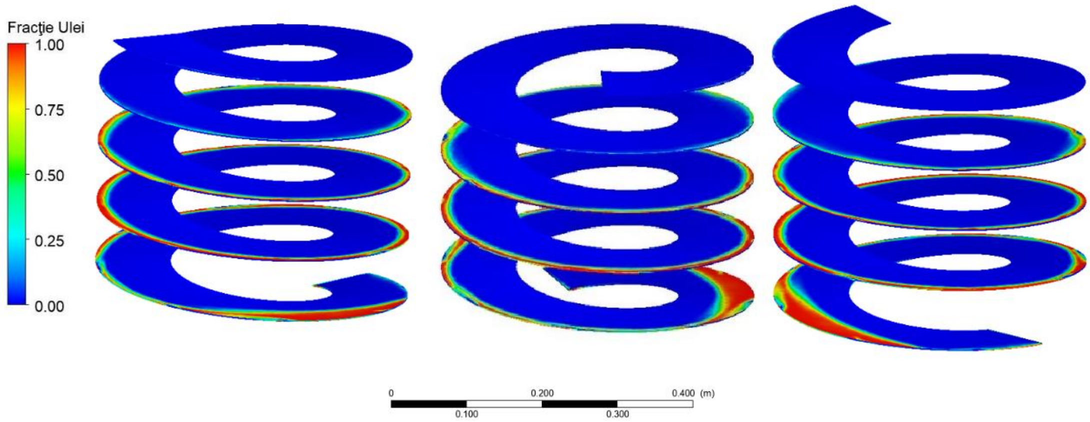


Figure 4.27. CENT working sequence.

The speeds of the separation steps are within the limits of optimum operation. The maximum speeds of 17.94 and 19.14 m/s respectively are recorded only locally, at the entrance to the spiral of the centrifugal separator. The average flow velocity through the centrifugal separator is 9.5 m/s.

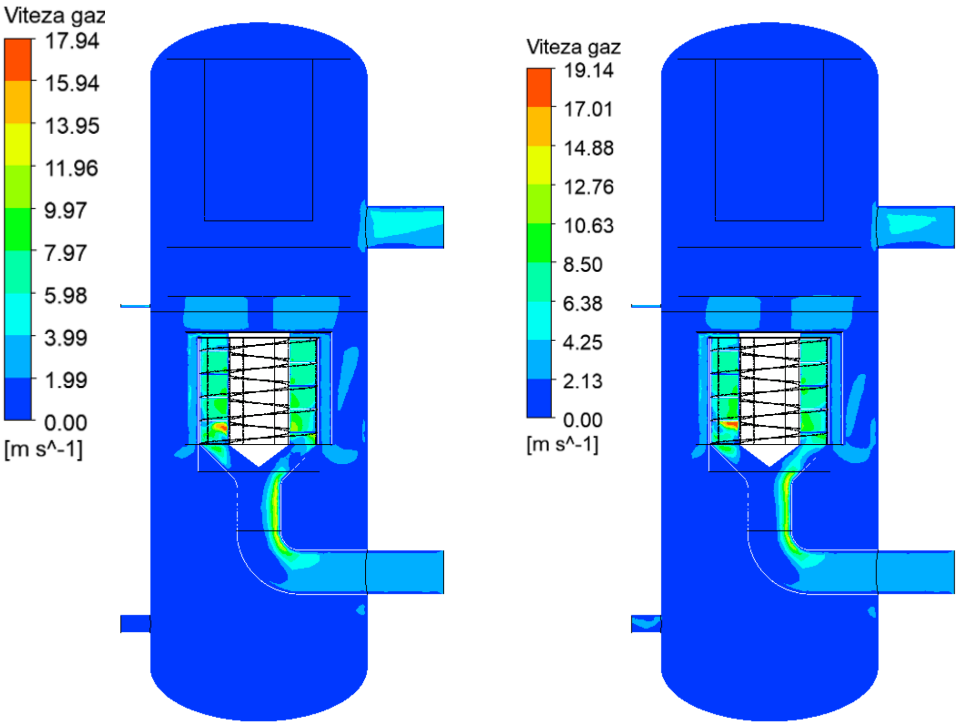


Figure 4.28. Gas velocity, time step 15 and 20s

After running the three cases, in addition to speed distributions, gas-oil volume fractions, absolute pressure and streamlines, of interest for geometric and constitutive validation of the separator vessel equipment is the amount of oil that is discharged on the discharge together with the compressed gas. It has been checked for all cases presented what is the quantity of oil at the time step 20 seconds and the separation efficiency has been calculated using formula (4.1). SEP variant 3 provides a better separation due to the modification of the geometry of the centrifugal separator and the introduction of the demister in the simulation.

It can be concluded that the modification of the propeller pitch and the addition and widening of the number of slots contributed to the improvement of the separation performance of the SEP in variant 2 and variant 3 respectively.

$$\eta_g = 100 \cdot \frac{m_{oil,inlet} - m_{oil,outlet}}{m_{oil,inlet}} \tag{4.1}$$

Table 4.4. Separation efficiency of of the three calculated variants

	Oil flow at inlet [kg/s]	Oil flow at outlet [kg/s]	Day oil consumption [kg]	Month oil consumptio n [kg]	η_g [%]
Var.1	1,946	7,4912E-06	0,6472	19,4172	0,9999962
Var. 2		1,3292E-06	0,1148	3,4453	0,9999993
Var. 3		1,0711E-06	0,0925	2,7763	0,9999994

4.2. Presentation of the design and execution phase of the construction solution

In the context of this thesis, CAD design combined with CFD simulations were used to analyse the flow characteristics of a two-phase mixture within the separation system in order to facilitate the process of optimizing geometric configurations and validating corresponding solutions. The separator's primary components are constructed from a universally applicable material, namely carbon steel plate (S235 JR), in accordance with SR EN 10025-2 specifications. The selected thicknesses for the utilized sheets are either 3 or 5 mm. While it is recommended that the inner components of the separator vessels be fabricated from stainless steel variants, such as 308 or 316 L, for enhanced performance, a preliminary decision has been made to initially employ S235 JR material to evaluate the SEP's operational functionality and to mitigate costs.

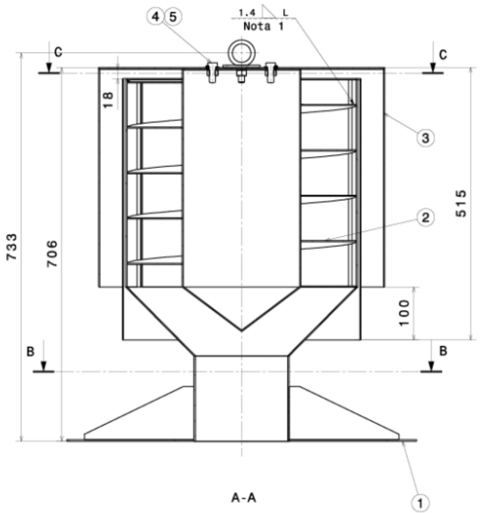


Figure 4.29. CENT assembly

Figure 4.30. CENT manufacturing detail

The segregation of the two fluid streams has introduced notable challenges pertaining to the rigidity and assembly of the centrifugal separator. These intricacies have been meticulously addressed through an extensive investigation, leading to the implementation of well-considered technical resolutions. Specifically, within the context of Figure 0.1, the attachment and alignment of the outer cylinder designated as "item 4" in relation to the compressed air outlet have been accomplished by utilizing a system of four screws.

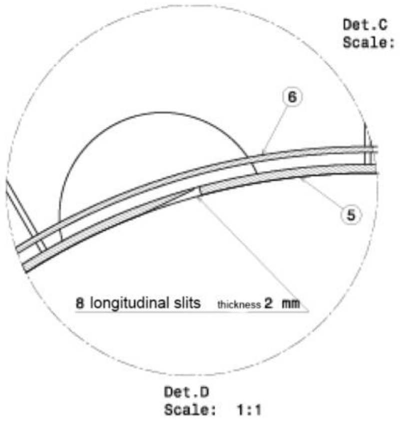


Figure 4.31. Longitudinal slits design detail

Figure 4.32. Manufacturing detail inner cylinder with longitudinal slits

During the initial phase of design, four longitudinal slits were incorporated into the configuration. After conducting numerical simulations to analyse the flow dynamics within the separator vessel, it was observed that an accumulation of oil occurred on the external surfaces of the cylinder marked as "5" in Figure 4.3. This accumulation gradually ascended along the separator spiral. Consequently, a decision was made to augment the number of slots, resulting in the final iteration of the centrifugal separator featuring eight longitudinal slits. To enhance the process of evacuating the separated oil, a novel approach was employed. This involved the creation of specialized drain pockets, as intricately illustrated in Figure 4.31. These pockets were realized by progressively reducing the wall thickness of the inner cylinder over a span of 20 mm. This design alteration induced a “wedge effect”, which significantly aids in detaching the oil film adhering to the cylinder wall. It's worth noting that this innovative pocket design represents a departure from conventional technical solutions.

Figure 4.33. Manufacturing details inner cylinder with longitudinal slits

Figure 4.34. Manufacturing details inner cylinder with longitudinal slits

Figure 4.35. Manufacturing details outer cylinder filter separator

Figure 4.36. Manufacturing details demister T600-ø650x150 mm

Figures 4.33 and 4.34 show the manufacturing details of the centrifugal separator, namely the longitudinal slotted cylinder and the oil separation cylinder. The gap between the two cylinders is approximately 5 mm and can be seen in 4.34.

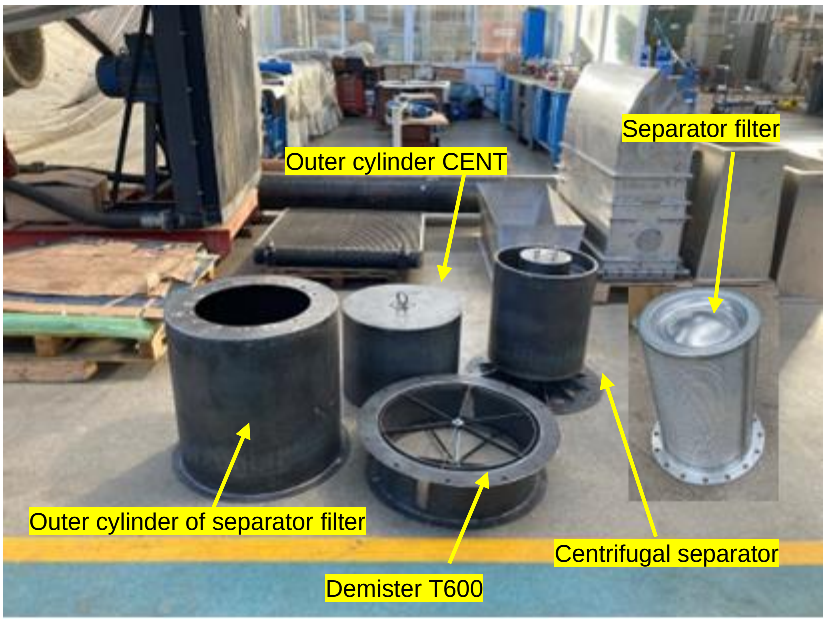


Figure 4.37. Components of the efficient separation system

4.3. Experimental research on efficient gas-oil separation system

The screw compressor test bench offers an ideal platform for conducting experiments and determining the performance characteristics and operational limitations of the gas-oil separation solution. This test bench enables the manipulation of key functional parameters within a broad range, allowing for comprehensive investigations.

Within the compressor test bench several pivotal parameters can be subject to variation, encompassing the following key factors:

- Discharge pressure, with a dynamic range spanning from 2 to 40 barg.
- Compressed air flow rate, amenable to manipulation within the extensive range of 200 to 2500 Nm3/h.
- The rate of oil injection into the compressor, constituting an integral component of the mixture, and modifiable within the bounds of 50 to 300 l/min.
- Compressed air temperature, a critical parameter that can be adjusted across a spectrum of 60 to 95 °C.

The test stand is built and equipped with command-and-control instruments according to ISO 1217 and ASME PTC9 requirements.

Measurements of the main functional parameters of the technological process are conducted with the following transducers, devices and apparatus with local indication:

Table 4.5. List of instrumentation of interest for SEP experimentation

Measured parameter	Measuring device	Signal / ∅ dial	Manufacturer	Model	Measured range	Accuracy
Air and oil pressure	Pressure transducer	4÷20mA	Endress+ Hauser	PMP-51	0÷60 bar	0,15%
	Pressure gauge with elastic element	∅100	Badotherm	BDT18A	0÷60 bar	1.6%
	Differential pressure gauge	∅ 80	Hirlekar Precision	200 DGP	0÷0,6 bar	±2%
Air/oil/cooling water temperature	Thermoprobe Pt100	4÷20mA	Endress+ Hauser	TR10	-30÷150°C	AA*
	Mechanical bimetal thermometer	∅100	Badotherm	BDTE18	-30÷150°C	1%
Oil flow rate	Turbine flow meter	4÷20mA 0÷5 VDC	Flo-tech	F6204-A	3-151 lpm	±1%
Compressed air flow rate	Multivariable transducer	4÷20mA	Rosemount	305S		0,05
Compressor shaft torque	Torque converter	−10÷10V	HBM	T40B	Max 2 kN	0,05
Compressor shaft speed	Inductive speed sensor	40 V (P-P)	AI-Tek+ Tachpak30	70085-1010-137		

± (0.1 + 0.0017 (Absolute value temperature, °C))

The acquisition of all functional parameters data is accomplished through the Programmable Logic Controller (PLC), which translates the electrical signals generated by the process transducers as detailed in Table 4.5. These values, corresponding to the parameters of interest, are systematically logged at 1-second intervals within the memory of the process computer, subsequently being exported to an Excel file for further analysis.

The configuration and arrangement of the testing apparatus adhere to the specifications outlined in API619 and ISO 1217 [12], [13]., as illustrated in Figure 4.38. Upstream of the compression unit, a DN200 PN16 suction filter is installed with the primary objective of comprehensive removal of solid particulate matter in the air, specifically particles exceeding 20 µm in size.

The compressed air is measured on the suction line of the compressor using a flow restrictor (diaphragm) in accordance with ISO 5167 Parts 1 and 2. The value of the pressure drop measured on both sides of the diaphragm and the value of the air temperature measured behind the diaphragm are processed by a multivariable flow transducer, resulting in the compressor flow rate.

The admission of air into the compressor is facilitated through a DN200 PN6 flexible hose, a component chosen for its versatility in accommodating the swift installation of various compression units earmarked for bench testing. This flexible hose also serves as a critical buffer, effectively dampening the transmission or amplification of vibrations originating from the compression unit to the rigid pipes connected to the suction system.

The speed multiplier, an essential component of the setup, is meticulously designed to amplify the rotational speed of the electric motor, thereby spanning a broad spectrum of operational speeds. The multiplier ratio is set at 3. The electric drive motor, manufactured by Electroputere, boasts a power rating of 550 kW and achieves a peak speed of 3000 rpm. This motor is driven by direct current.

In ensuring the optimal functioning of the compressor, the lubrication system is equipped with a primary lubrication pump, a feature that facilitates the operation of the compressor even at low discharge pressures. Each individual oil injection pathway into the compressor is outfitted with a pressure transducer and a flow meter for precise monitoring and control. Additionally, each route is equipped with a flow control valve, enabling meticulous adjustment of the oil injection rates, which serve the dual purpose of lubrication and cooling.

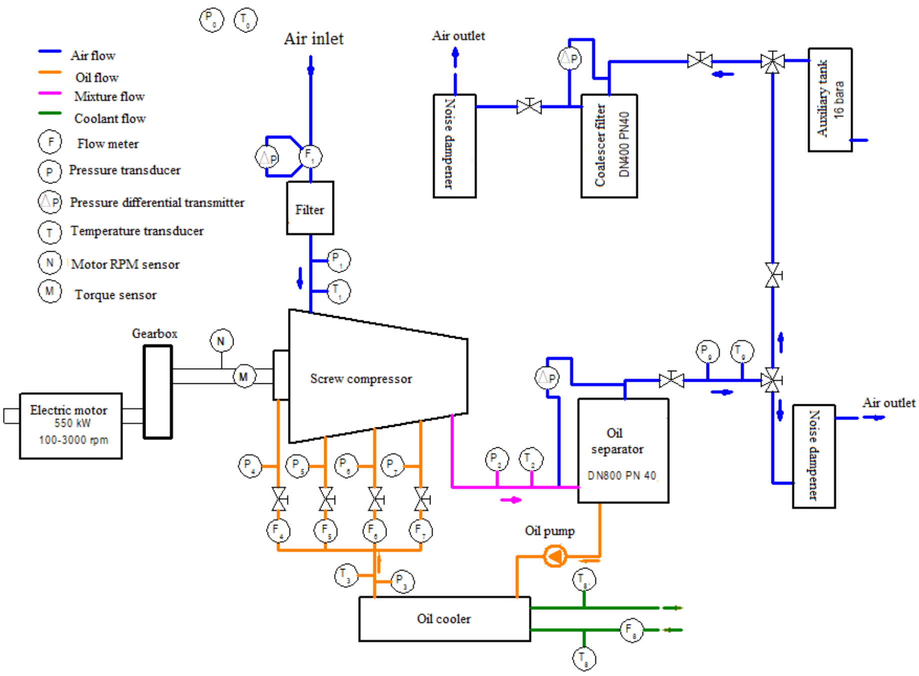


Figure 4.38. The test configuration of the separation system [13]

The process of cooling the oil involves a water-oil heat exchanger designed with a tubular construction. To maintain precise control over the temperature of the injected oil within the range of 40 to 60°C, a variable-speed pump governs the flow of cooling water.

To ensure comprehensive monitoring, both pressure and temperature transducers are strategically positioned before and after each primary unit in the system. Local instrumentation includes pressure gauges and thermometers, integrated into the plant for on-site measurement. For a visual representation of the instrumentation setup within the separator vessel, please refer to

Figure 4.40. The instrumentation of DN800 PN50 separator vessel

The following parameters of interest were meticulously recorded to facilitate a future in-depth analysis of the gas-oil separation solution's performance:

- Pressure and temperature of the compressed air upon discharge and at the inlet to the separator vessel.
- Compressor shaft speed, which plays a vital role in the overall system dynamics.

- Pressure and temperature of the compressed air upon exiting the separator vessel. Those are critical indicators of the oil separation overall efficiency.
- Power consumption by the electric motor that drives the compressor, offering insights into energy utilization.
- Oil pressure and temperature measurements following the oil cooler, assessing the oil's thermodynamic characteristics.
- Air inlet flow rate, crucial for understanding the overall test bench dynamics and efficiency.
- Oil flow rates at specific oil injection points, including seals, inlet bearings, rotors, and discharge bearings, which enable a comprehensive view of the oil distribution throughout the system.
- Oil pressure readings at each oil injection point, providing valuable data on the oil's behaviour and its impact on system performance.

, which aligns with the technological schematic previously delineated.

At the exit point of the separator vessel, the compressed air, following its trajectory through the three-way valve, can be selectively directed to either silencer 1 for eventual discharge into the atmosphere, or routed through the coalescing filter DN400 PN40 before passing into silencer 2. This crucial diversion point is illustrated in the diagram.

To comprehensively assess the overall effectiveness of the high-efficiency separation system, an essential step involves the collection of droplets that remain suspended in the compressed air at the system's exit. Subsequently, the residual oil content within the compressed air, following its exit from the separation system (SEP), can be accurately determined employing the gravimetric technique elucidated in subchapter 2.5.

The coalescer filter within the experimental setup, bearing a nominal size of DN400PN40 with a diameter of 400 mm and a nominal pressure rating of 40 bar, comprises two distinct containment stages: an inertial stage and a stage composed of five coalescer filters designated as 6CU-280x1, fabricated by Parker Finite. It's noteworthy that these filter elements possess the capability to effectively capture all droplets exceeding 1 µm in size.

To systematically monitor the performance of the separation stages, the experiment utilizes two pressure transducers, denoted as P_2 and P_9, positioned at the inlet and outlet of the vessel, in conjunction with a differential pressure gauge. These instruments collectively enable the real-time tracking of pressure differentials across the separation stages, allowing for the observation of variations in pressure drops concerning changes in flow rate and discharge pressure throughout the experimental proceedings.

Figure 4.39. Experimental test bench.

Figure 4.39 shows the main sub-assemblies of the compression unit test stand. The screw compressor used is an oil-injected type CHP220 with the overall performance shown in the table below. The compressor covers a wide range of operating regimes and is generally used as an air source for various research projects carried out in COMOTI.

Tabelul 4.2. Technical characteristics of the test compressor - CHP220

Parameter	UM	Value range
Suction volume	m^3/h	440-2145
Speed (min.-max.)	Rpm	600-3000
Suction pressure (max.)	bara	9
Discharge pressure (max.)	bara	45
Volumetric ratio		3.5
Overall dimensions (LxWxH)	mm	1242x818x706
Weight	kg	1686
Power consumption (max.)	kW	1000

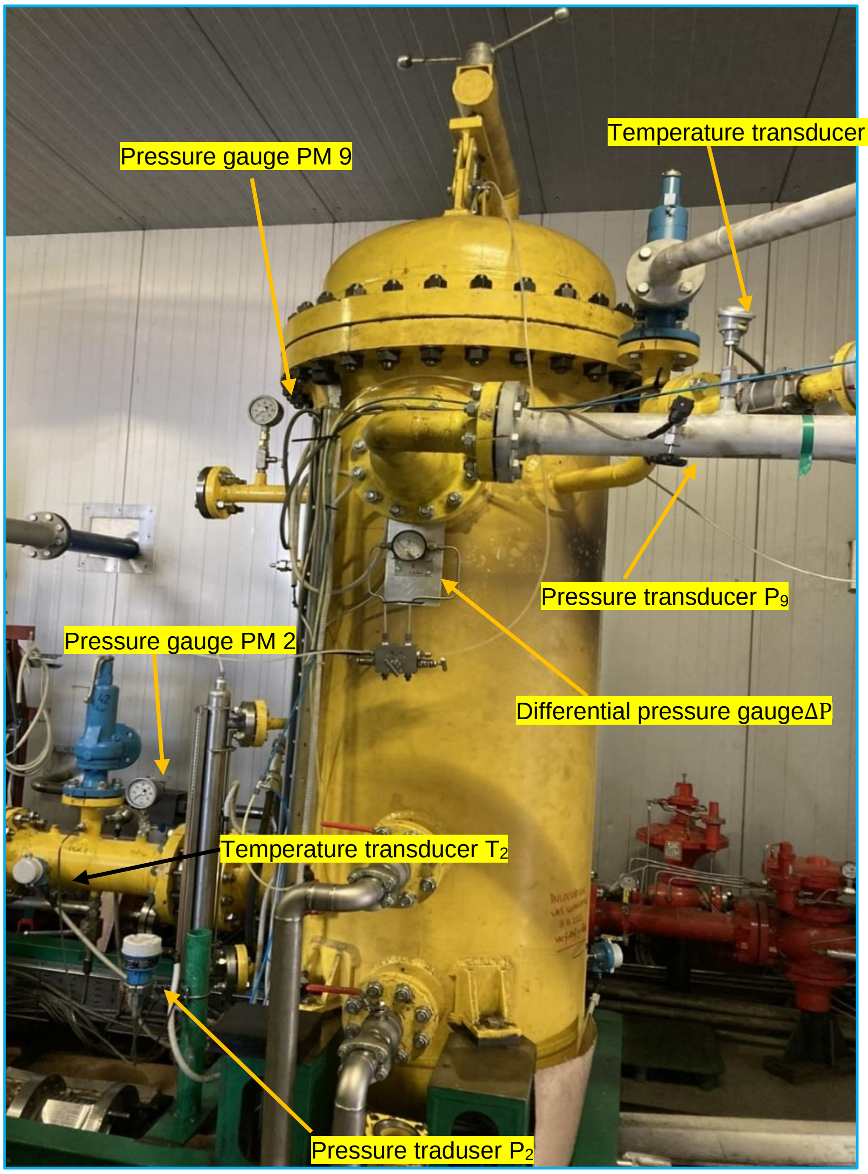
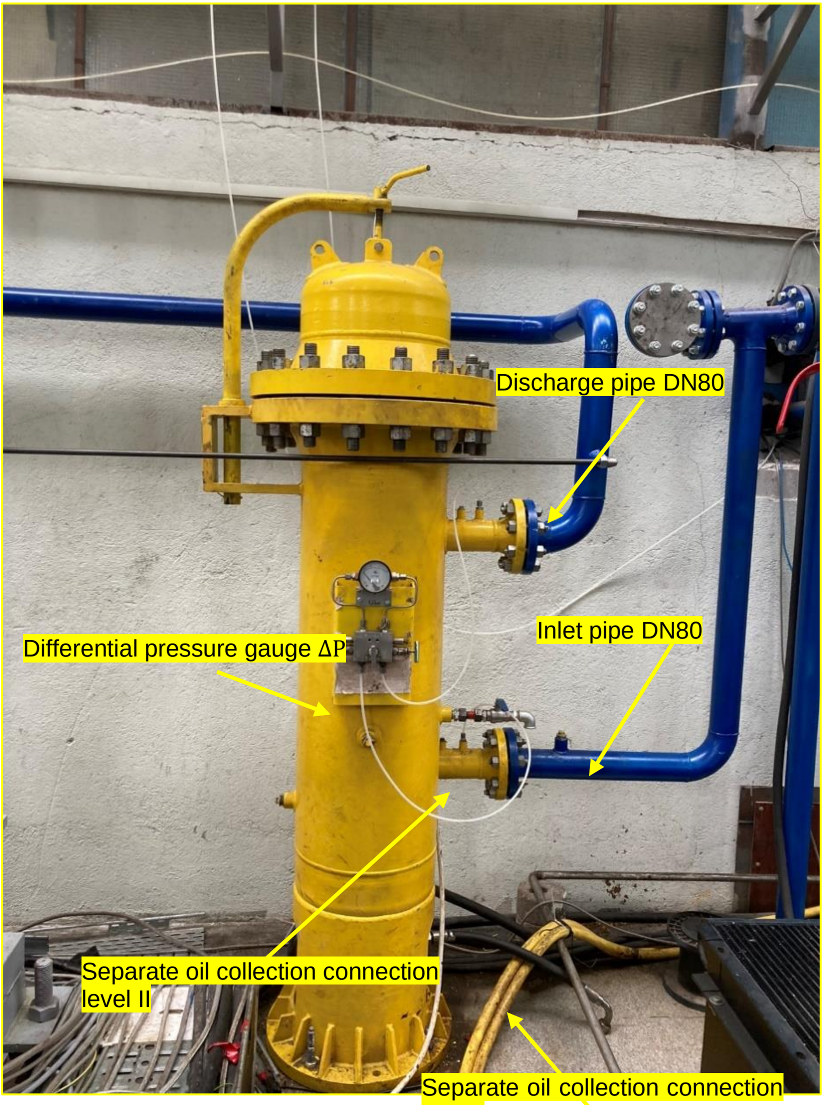


Figure 4.40. The instrumentation of DN800 PN50 separator vessel

The following parameters of interest were meticulously recorded to facilitate a future in-depth analysis of the gas-oil separation solution's performance:

- Pressure and temperature of the compressed air upon discharge and at the inlet to the separator vessel.
- Compressor shaft speed, which plays a vital role in the overall system dynamics.
- Pressure and temperature of the compressed air upon exiting the separator vessel. Those are critical indicators of the oil separation overall efficiency.
- Power consumption by the electric motor that drives the compressor, offering insights into energy utilization.
- Oil pressure and temperature measurements following the oil cooler, assessing the oil's thermodynamic characteristics.

- Air inlet flow rate, crucial for understanding the overall test bench dynamics and efficiency.
- Oil flow rates at specific oil injection points, including seals, inlet bearings, rotors, and discharge bearings, which enable a comprehensive view of the oil distribution throughout the system.
- Oil pressure readings at each oil injection point, providing valuable data on the oil's behaviour and its impact on system performance.



A differential pressure gauge has been installed to monitor the operation of the coalescing filter, which will show the pressure drop variation at different operating conditions.

At the beginning of the experimental campaign the coalescer filter was cleaned and the coalescer filter elements were replaced with new ones.

For the separate oil collection there are two fittings equipped with manual valves.

It is estimated that a small amount of oil will be collected in inertial separation stage I, because the oil droplets escaping from the SEP are small and they can no longer be retained by centrifugation.

Separation stage II will retain all droplets above 1µm.

Figure 4.41. Coalescent filter DN400 PN 40

It is noteworthy that during the experimentation phase, the test installation operated under a variable regime owing to its simultaneous role in supplying compressed air to two other experimental installations developed by COMOTI. These co-existing experimental setups were also actively engaged in their respective experimentation stages. Consequently, the compression assembly, along with the entire separation system, operated under a distinct operating regime during the experimentation phase, deviating from the originally established regime based on the design stage and the numerical flow simulations conducted beforehand.

In Table 4.6 are shown the main parameters of interest that determine the performance of the separation solution

Table 4.6. Mean and maximum values of the main parameters recorded during the experiment.

Parameter	Symbol	Avg.	Max.	Units
Compressor speed	NCHP	699.97	2041.39	rpm.
Gas flow	QV	637.58	1845.65	Nm^3/h
Inlet pressure	P2	5.64	13.35	bar_g
Outlet pressure	P9	5.59	13.28	bar_g
Pressure drop	ΔP	0.05	1.89	bar
Total oil flow	Qu	122.72	229.29	l/min
Gas temperature	T2	58.69	81.15	°C
Power consumption	P ax	58.69	252.80	kW

The quantity of oil injected into the compressor appeared to exceed the anticipated levels relative to the prevailing operational parameters, including discharge pressure and compressed air flow. It is notable that the mean temperature of the compressed air maintained at an average of 58.69 °C.

During the observation of specific operational points, an elevation in pressure drop across the separation system was detected. Upon scrutinizing the recorded data, it was evident that during the compressor shutdown sequence, when the manual back pressure valve initiated the release of pressure from the system, the pressure within the separator vessel swiftly decreased to zero within a few seconds. As a consequence of this rapid depletion, the gas velocity within the system surged, leading to a flow rate through the separator that surpassed its intended design. It should be emphasized that this behavior of the solution is considered typical.

During periods of steady-state operation, the pressure drop exhibited variations ranging from 0.05 to 0.15 bar, demonstrating consistent behaviour irrespective of the prevailing working pressure and flow rate, prevailing working pressure and flow rate.

In the context of an industrial settings, the compression assembly typically operates within a framework of gradually evolving operating parameters. Transient operational states in a screw compressor assembly primarily manifest during the commencement and conclusion phases. One distinctive scenario, akin to the system's test configuration, occurs during emergency shutdown instances, such as a emergency stop button press or a station wide power drop. In these cases, the entire volume of compressed gas within the assembly, pressurized to operational levels, undergoes rapid evacuation via a PLC-controlled actuation of a solenoid valve through the exhaust system.

Throughout the operational lifespan, the pressure drop across the separation system stands as a critically significant parameter. Utilizing a gas compression system that functions with a pronounced pressure drop across the gas-oil separation system leads to an augmented energy consumption, emphasizing the paramount importance of monitoring and optimizing this aspect.

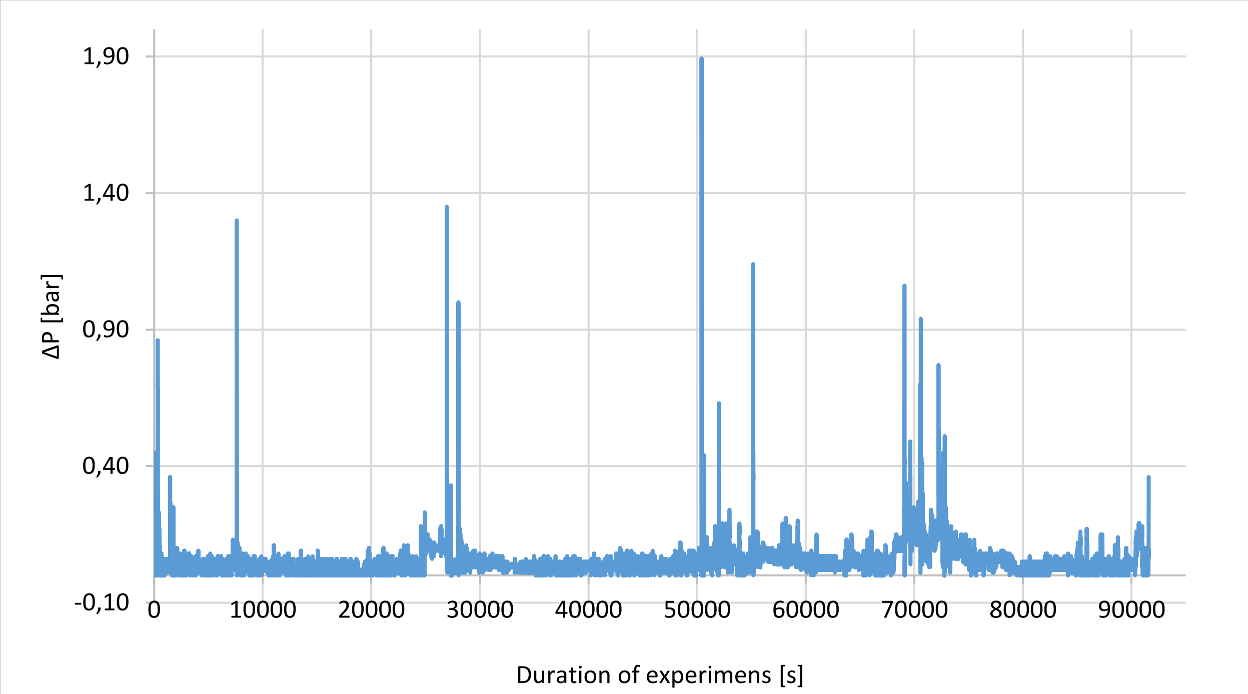


Figure 4.42. The pressure drop in the system in 25 hours of operation.

By considering the system's overall piping volume along with the separator vessel, it becomes feasible to compute the mass of compressed gas contained within the system. Subsequently, this enables the determination of the average gas flow rate through the separator during the depressurization phase. Over the 5-14 second interval, a total mass of 8 kg, encompassing both the piping system and the separator vessel, has undergone expansion. Assuming an average flow rate of 0.8 kg/s, in addition to the compressor's fixed-speed flow rate of 0.22 kg/s, we can calculate a combined flow rate of 1.02 kg/s through the SEP over a 10-second duration, resulting in a pressure drop of 1.89 bar.

Upon a comprehensive analysis of these values, it can be confidently concluded that the Separator exhibits commendable performance in terms of pressure drop across various operational regimes.

Table 4.7. Parameters recorded prior to compressor shutdown.

time [s]	P_2 [barg]	T_2 [°C]	P_9 [barg]	T_9 [°C]	ΔP	time [s]	P_2 [barg]	T_2 [°C]	P_9 [barg]	T_9 [°C]	ΔP
1	5,29	65	5,26	57,15	0,03	11	2,12	64,85	0,91	56,8	1,21
2	5,29	65	5,25	57,15	0,04	12	1,71	64,85	0,70	56,4	1,01
3	5,29	65	5,25	57,15	0,04	13	1,39	64,85	0,58	55,7	0,81
4	5,29	65	5,26	57,15	0,03	14	1,16	64,75	0,50	55,15	0,66
5	5,29	65	4,54	57,15	0,75	15	0,97	64,75	0,46	54,65	0,51
6	5,01	64,9	3,38	57,2	1,63	16	0,86	64,75	0,39	54,4	0,47
7	4,39	64,95	2,50	57,15	**1,89**	17	0,73	64,7	0,34	53,75	0,39
8	3,67	64,9	1,91	57,1	1,76	18	0,62	64,65	0,33	53,1	0,29
9	3,09	64,85	1,48	57,1	1,61	19	0,58	64,55	0,32	52,5	0,26
10	2,53	64,85	1,16	57,05	1,37	20	0,53	64,5	0,27	52,05	0,26

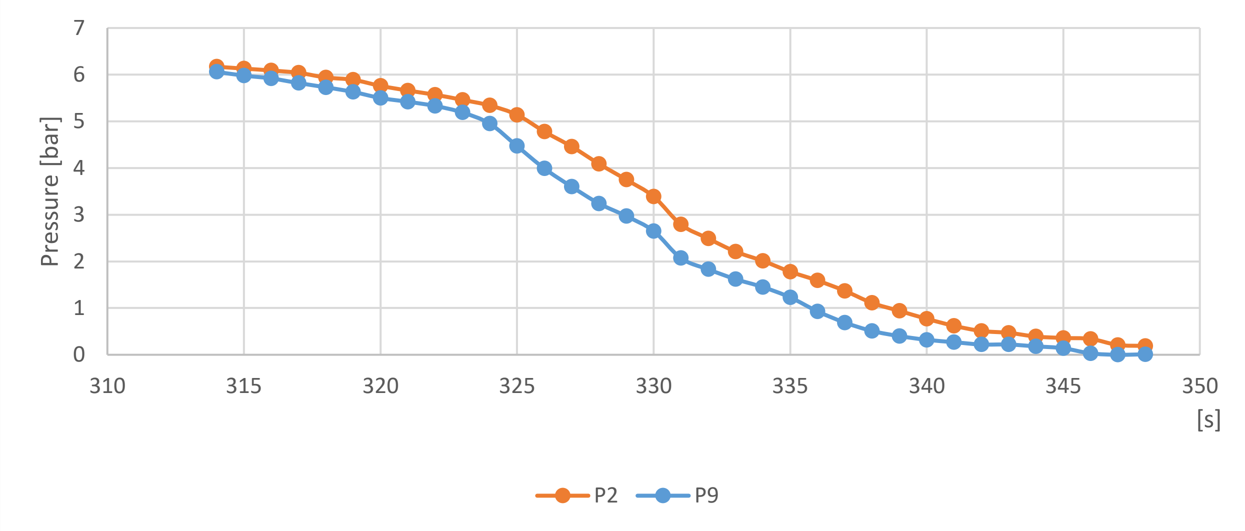


Figure 4.43. SEP inlet/outlet pressure in compressor stop sequence.

For the smooth operation of the separation system, it is highly advisable to adopt a gradual approach when opening the back pressure check valve. The sudden release of compressed gas from a separator vessel can lead to adverse consequences, notably the inundation of gas-oil separation stages and oil loss within the exhaust system. This occurrence is particularly pronounced under specific temperature and pressure conditions where compressed gas may dissolve in the oil. Upon reaching its destination, the dissolved gas molecules mixed with the oil undergo rapid discharge, resulting in the entrainment of oil droplets.

To anticipate issues associated with oil entrainment, it is imperative not only to employ manual or controlled gradual opening mechanisms for operational components but also to equip the stack exhaust system with precisely calibrated orifice nozzles. These nozzles are meticulously calculated to facilitate a controlled release of the compressed gas. It's important to underscore that restrictors should never be affixed to the basket system interconnected with the safety systems of the separator vessel, including the relief valve or rupture diaphragm, as this can compromise the system's integrity.

From the experimental data recorded in the first stage of experiments, the following operating regime was extracted, graphically illustrated in Figure 4.44, in which the compressor operated at a higher discharge rate, delivering compressed air that was stored in a buffer tank.

The duration of this operating regime was 0.57h (20500 s). From the case presented, the SEP operated in good conditions, without high pressure drops even when the operating limits were exceeded, since the maximum flow rate of separated gas was 44,296 Nm3/day, compared to the maximum 35,000 Nm3/day proposed at the design stage. Under these conditions, the pressure drop was maximum 0.770 bar.

Table 4.8. Average, minimum, and maximum values of the parameters in the analysed operating mode

Parameter	Symbol	Avg.	Min.	Max.	Units
Compressor speed	NCHP	1.743,81	765,35	2.038,56	rpm.
Gas flow	QV	1.551,31	713,57	1.845,65	Nm^3/h
Inlet pressure	P2	9,04	2,04	13,29	bar_g
Outlet pressure	P9	8,85	1,89	13,20	bar_g
Pressure drop	ΔP	0,18	0,03	0,77	bar
Total oil flow	Qu	178,57	104,80	222,58	l/min
Gas temperature	T2	71,69	54,50	81,15	°C
Power consumption	P ax	182,27	43,48	252,80	kW

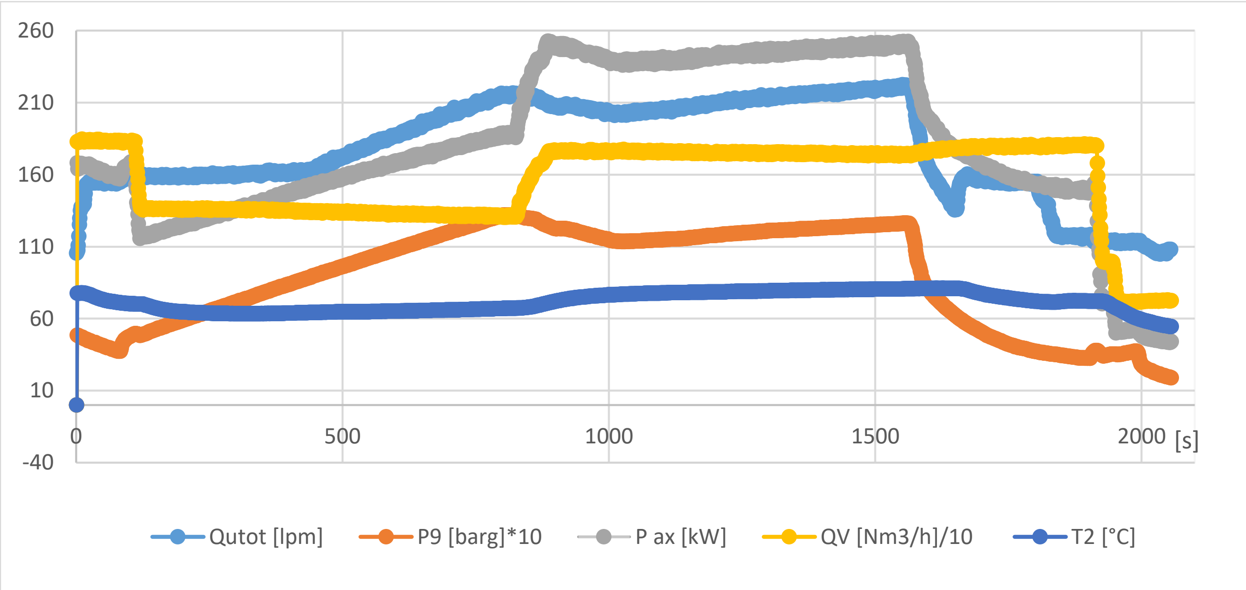


Figure 4.44. Variation of the main functional parameters of interest during a buffer vessel loading regime

To fit all the variation curves of the analysed parameters within the same graph, the values of the discharge pressure P9 were multiplied by 10 and the values of the air volume flow were divided by 10.

During the experimental phase, the liquid retained in the two collection compartments of the ASF400PN40 coalescer filter was collected twice, at 14 and 25 hours of operation respectively.

$$X = \frac{V \cdot \rho}{q \cdot H \cdot 3600} 10^6 \quad (4.2)$$

Table 4.9. Calculation of residual oil after 12 h of operation

V- volume of oil collected (l)	0,25
q- average gas volume flow (l/s) expressed at standard conditions	204,72
H- test duration (h)	12
ρ- oil density (kg/m^3)	880
X- quantity of residual oil at the exit of the separator (mg oil/Nm^3 air)	24,88
X- ppm(mg/kg)	19,28

After 13 h of operation, the collected amount of oil retained by the coalescer filter was 200 ml. Applying relation (4.2) resulted in a residual oil content of 20.554 ppm, expressed in mass ratio.

Table 4.10. Calculation of residual oil after 25 h of operation

V- volume of oil collected (l)	0,45
q- average gas volume flow (l/s) expressed at standard conditions	190,28
H- test duration (h)	25
ρ- oil density (kg/m^3)	880
X- quantity of residual oil at the exit of the separator (mg oil/Nm^3 air)	23,12
X- ppm(mg/kg)	17,93

After 25 h of operation, considering the average compressed air flow rate, the collected amount of oil retained by the coalescer filter was 200 + 250 ml. Applying again relation (0.1) resulted in a residual oil content of 17.93 ppm, expressed in mass ratio.

The experimental validation of the separation system has substantiated the anticipated performance envisioned during the design and flow simulation phases, thus underscoring its practical applicability and robust attributes.

The incorporation and utilization of the separation system have yielded discernible enhancements in the overall oil retention capabilities within the enclosed screw compressor operational framework. Notably, the recorded average pressure drop across all stages of the separator remained consistently below 0.15 bar. Furthermore, when the processed flow rate exceeded the designed flow rate by approximately 50%, a modest pressure drop of 1.89 bar was documented. This pivotal performance parameter achieved by the separation system stands as a testament to its capacity for delivering remarkable energy efficiency during continuous operation within an industrial context.

The residual oil content measured at the separation system exit consistently fell within the range of 19 to 17 ppm. This remarkable performance attests to the efficacy of the separation system and warrants its endorsement for subsequent deployment in industrial air or fuel gas compression contexts. By integrating the SEP with a coalescing final filter, an even more impressive oil separation capability of less than 5 ppm can be realized. This ensures uninterrupted operation for at least 4000 hours, without incurring additional pressure drops or necessitating changes to the coalescing filter elements.

The implementation of the separation system has notably enhanced the operational efficiency of the screw compressor test stand, particularly when this stand serves as an air source for diverse R&D programs conducted at INCD Turbomotoare COMOTI. Furthermore, the versatility of the separation system extends its utility to both existing separator vessels, augmenting their performance, and future projects requiring separator vessels, encompassing a wide gamut of compression applications.

CAPITOLUL 5. ENERGY EFFICIENCY OF GAS COMPRESSION PLANTS USING VOLUMETRIC COMPRESSORS

The experimental investigations presented in this chapter were carried out on the COMOTI test bench and reveal that by reducing the pressure in the main discharge line below the theoretical pressure value obtained by internal compressor compression, lower levels of energy consumption will also be achieved. This behaviour contradicts theoretical concepts presented in some scientific papers on the concept of over compression in screw compressor units.

For compressing the same gas flow with a back pressure of 1.5 barg in the discharge line, a 33% reduction in energy consumption was found compared to compressing at 4.5 barg.

It was concluded that the reduction in energy consumption occurs due to the loss of gas from the compression chamber into the discharge line due to pressure differences, which is beneficial for the overall operation.

In the paper [63] aspects of the operation of a compression assembly in which the main oil pump was introduced are presented. By fitting it, the discharge pressure in the compressor could be maintained at values between 2 and 2.5 bar, achieving significant savings by reducing energy consumption. The authors estimated that the installation of the oil pumps (one in permanent service and one in standby) would result in a significant reduction in energy consumption, and that the value of the investment (the work of upgrading and repairing the skid) could be fully recovered in 2 years of continuous operation.

CAPITOLUL 6. GENERAL CONCLUSIONS, ORIGINAL CONTRIBUTIONS, FUTURE RESEARCH DIRECTIONS

6.1. General conclusions

For the first time, under the direction of the author of this thesis, extensive research has been carried out on oil-injected screw compressors with the aim of achieving a high degree of oil recovery. The SEP system experimentally confirmed the performance predicted in the design and flow simulation stage, demonstrating its practical utility and strengths.

By implementing original engineering solutions, the overall oil retention performance was improved, reducing the oil concentration in the compressed gas at the exit of the efficient separation system to less than 20 ppm compared to 160 ppm for the conventional system.

The SEP was found to operate with an average pressure drop of 0.15 bar, even when exceeding the proposed operating parameters, which is advantageous in terms of energy efficiency.

The implementation of the SEP has resulted in an improved operation of the screw compressor test stand, especially when the stand is used as an air source for various research and development programmes of NRDI COMOTI.

The numerical simulations presented in this thesis, iteratively for the three constructive variants of the SEP, highlighted the key role that CFD plays in the design and optimization of the separation stage geometry. The optimization of the CENT because of the CFD numerical study allowed to reduce manufacturing, assembly and experimentation costs.

The developed separation system will be able to be used both for separator vessels already in service, improving their performance, and will be able to be used for separator vessels required in new projects, covering a wide range of compression applications.

The efficient SEP separator system was developed at COMOTI under the coordination of the author and equips in the first phase the DN800PN50 separator vessel of the screw compressor test stand, a facility that is an integral part of the Screw Compressor Assemblies, Compressor and Screw Expander Section of the INCD Turbomotor COMOTI.

The experimental investigations presented in Chapter 5 were carried out on the COMOTI test bench and reveal that by reducing the pressure in the main discharge line below the value of the theoretical pressure obtained by internal compressor compression, lower levels of energy consumption will also be achieved. This behaviour contradicts theoretical concepts presented in several scientific papers on the concept of overcompression in screw compressor units. The screw compressor, with fixed compression ratio, proves to have a wide operating range in terms of discharge pressures.

For compressing the same gas flow with a back pressure of 1.5 barg in the discharge line, a 33% reduction in energy consumption was found compared to compressing at 4.5 barg.

It was concluded that the reduction in energy consumption is due to the loss of gas from the compression chamber into the discharge line due to pressure differences, which is beneficial for the overall operation.

6.2. Original Contributions

Under the coordination of the author, engineer at COMOTI, an optimized separation system has been designed, developed and tested, with real improved performances compared to other existing systems used. The developed high-performance system can be used in newly developed applications, but more importantly it can replace previously installed systems with low performance, which are already in operation.

The thesis contains several original scientific and technical contributions, presented in detail below:

1. In the research phase the author identified specific problems that occur in compressed gas-oil separation systems: oil consumption, oil contamination of downstream equipment and systems, increased power consumption due to high pressure drop in the separation system, specific operation and maintenance problems.

2. The author defined the experimental setup and methodology to determine the separation performance of an existing conventional system, consisting of two stainless steel wire tricot demister steps, used in the equipment of a screw compressor assembly, in the COMOTI equipment.

3. Based on the experimental results, using the gravimetric calculation method, the residual oil content for a conventional separation system was determined. The determination of the separation performance of a gas-oil separator is also the author's own contribution.

4. A first-of-its-kind national experiment was conducted to determine the characteristics of oil droplets (size and velocity shape of individual particles) suspended in compressed gas using an optical Particle Master Shadow Particle Shadow imaging system.

5. The use of three separation stages in the proposed combination for equipping a vertical separator vessel is a novelty compared to similar solutions analysed. The centrifugal separator is a novelty because of its design, which allows the separation of the two flows, oil and compressed gas-oil mixture, by means of longitudinal slots and cylinder-in-cylinder construction.

6. The SEP, in construction version three, was designed and installed in a vertical separator vessel DN800, part of the equipment of the COMOTI compressor unit test stand, under the coordination of the author. The author defined the configuration and the experimental methodology for determining the separation performance of the efficient separation system.

7. Engineering solutions have been found to solve some technical problems, which affect the optimal operation of vertical separators - installation of an oil drain pipe from the discharge elbow, avoiding oil accumulation, shrinking of the flow cross-section and additional generation of oil droplets;

8. The operation of the plant in the compression unit test stand has been made more efficient by improving the existing separation solution, ensuring the appropriate quality of compressed air required in various COMOTI R&D projects;

9. The results of the author's concerns in the field of energy efficiency of compression units operating in overcompression mode, with immediate applicability in the industrial environment, were presented

6.3. Future research directions

The author, together with COMOTI's research and development collective "Screw Compressor Assemblies, Compressors and Screw Expansion", will consider the following possible directions for further development:

1. Testing the SEP under industrial operating conditions in a gas compression application associated with crude oil;
2. Adaptation of the SEP for integration into a DN600 horizontal separation vessel. Horizontal separator vessels are suitable for compact compression assemblies, such as those mounted in containers, for various industrial applications.
3. Construction of a new vertical gas-oil separator vessel, DN800 PN16, in the construction of which the novelty and improvement elements that emerged from this PhD study will be implemented.
4. Continuation of experiments to determine the oil droplet distribution at the outlet of the screw compressor.
5. Development of methane gas-liquid (gas-water or gas-gasoline) separator vessels that can be mounted on supply pipelines for gas conditioning prior to delivery to the final consumer.
6. Continue experiments on the energy consumption of the screw compressor in sub-compressor operation by monitoring the pressure in the last volume of the compression chamber.

Published papers List.

I. Published papers in ISI ranked jurnals

1. **Tomescu S**., Ion M., Contiu R., Voicu S., ”Experimental validation of the numerical model for oil-gas separation,” Eng. Technol. Appl. Sci. Res., XX(X), pp. 1–8. (Impact factor) (accepted paper)

2. Nechifor C., Năvrăpescu V., **Tomescu S**., Săvescu, C., Roman M., Conţiu R., Stoicescu A., “Optimizing The Electronic Control of Suction Valves For Gas Compression Units“, Revue Roumaine Des Sciences Techniques-Série Électrotechnique Et Énergétique, VOlume 68, Issus 2, Pages: 182-187, (Jun. 2023), **WOS:001026628400011**, DOI:10.59277/RRST-EE.2023.68.2.11**,** (factor de impact 0,7)

II. Published papers indexed WOS or IEEE Explore,

1. **Tomescu S**., Bucur I.O., “Numerical Investigation of Oil Gas Separation with the Use of VOF CFD”, Engineering Technolology & Applies science Research, Volume, no. 6, Pages: 7841-7845, (Dec. 2021). **WOS:000731398100016**, DOI:10.48084/etasr.4446

2. Petrescu V., **Tomescu S**., Vasile E., Teodor S., Slujitoru C., “The Influence of Clearances on Energy Efficiency in Screw Compressors”,11th International Conference on Energy and Environment (CIEM 2023), Bucharest, 26-27 October 2023, accepted paper

3. Petrescu V., Săvescu C., Stănescu T., Nechifor C., Vasile M., **Tomescu S**. „Experimental analyses of twin-screw compressors’ energetic efficiency depending on the volume ratio”, 11th International Conference on Thermal Equipment, Renewable Energy and Rural Development (TE-RE-RD 2023), **IEEE Explore** [Preprint].

4. **Tomescu S.**, Petrescu V., Serban A., Voicu S., “Energy Efficiency of an Oil Injected Screw Compressor Operating at Various Discharge Pressures,” 10th International Conference on ENERGY and ENVIRONMENT (CIEM), **IEEE Explore**, 2021, pp. 1–5., DOI:10.1109/CIEM52821.2021.9614754

5. Vlăducă, I., Stanciuc, R., Bimbaşa, R. and **Tomescu, S.** “Waste-Energy (Heat) Recovery System from the Gases Compressed by an Oil-Free Screw Compressor,” *E3S Web of Conferences*, vol. 112, p. 01012, Aug. 2019. **WOS:000619989000012**, DOI:10.1051/e3sconf/201911201012

III.Published papers indexed BDI

1. Serban A., Tomescu S., Vlăducă I., Voicu S., “Energy improvement of an oil injected screw compressor skid”, EMERG - Energy. Environment. Efficiency. Resources. Globalization, vol. 7, no.1, pp. 51–59, 2021, DOI:10.37410/EMERG.2021.1.04**,** ISSN 2668-7003, ISSN-L 2457-5011

2. **Tomescu S**., Enache M., Visan N., Florean F., “Experimental Measurements Using Shadowgraph System On The Screw Compressor”, *U.P.B. Sci. Bull., Series D*, vol. 84, no. 1, 2022, ISSN 1454-2358

3. Petrescu, V., Vasile E., Serban, A, **Tomescu, S**., “Energy Efficiency of Screw Compressor”, EMERG: Energy. Environment. Efficiency. Resources. Globalization, Volume IX, Issue 2, Pages: 27-36, (2023), DOI: 10.37410/EMERG.2023.2.02

4. Nitulescu M., Slujitoru C., Petrescu V., Silivestru V., Fetea G., **Tomescu S.**, “Reducing rotors clearance-a way to increase the performance of a screw compressor”, *IOP Conference Series: Materials Science and Engineering*, Vol. 1180, No. 1, p. 012007, DOI:10.1088/1757-899X/1180/1/012007

5. Nitulescu M., Silivestru V., Toma N., Slujitoru C., Petrescu V., Șerban A., **Tomescu S**., “Multifunctional stand for testing screw compressors in closed loop test configuration”, *EMERG - Energy Environment Efficiency Resources Globalization*. 2022;8(2):56–67, ISSN 2668-7003, ISSN-L 2457-5011

6. Vlăducă, I**., S. Tomescu**, M. D. Ionescu, R. Nedelcu, S. Popescu, and I. Ilie, “Research activity in air and other gases compression and energy storage,” *EMERG - Energy. Environment. Efficiency. Resources. Globalization*, vol. 7, no. 1, pp. 40–50, 2021, DOI:10.37410/EMERG.2021.1.03**.**

IV. Published paper in journals indexed WOS not related to the doctoral thesis.

1. Buzescu D. M., **Tomescu S. G**, ”Failure Analysis Of A High-Speed Offset Bearing”, Transportation Research Procedia, Volume 29, Pages: 34-45, (2018). **WOS:000454701600004**, DOI:10.1016/j.trpro.2018.02.004

V. Book Chapter.

1. Barbu, E., R. Petcu, V. Vilag, V. Silivestru, T. Prisecaru, J. Popescu, C. Cuciumita, **Tomescu, S** , "Gas Turbine Cogeneration Groups Flexibility to Classical and Alternative Gaseous Fuels Combustion," *Progress in Gas Turbine Performance*, InTech, 2013. DOI:10.5772/54404**.**

VI. National patents.

1. Patent application a202300103/ 2023: Automatic system for determining, confirming, and continuously adjusting the angular position of a valve driven by an electric actuator, Silivestru V., **Tomescu S**., Contiu R., Nechifor C., Rosca E., Voicu S.
2. Patent application A002100186: Test stand for electric drives in the range 50-500 Nm, Silivestru V., **Tomescu S**., Ciobanu R., Nechifor C., Petrescu V., Ungureanu A., Vasile E., Taranu A., Ionescu A.

VII. Participation in conferences.

1. Energy Efficiency of an Oil Injected Screw Compressor Operating at Various Discharge Pressures
   Tomescu S., V. Petrescu 10th International Conference on ENERGY and ENVIRONMENT 2021 (CIEM), 14-15 October 2021, Bucharest, Romania

2. Multifunctional stand for testing screw compressors in closed loop configuration
   Tomescu S. 11th International Conference on Compressors and their Systems, City, University of London 2019, 9th – 11th September 2019, London, United Kingdom

VIII. Awards and other distinctions

1. 2021 AGIR Award - „ CAES Energy storage solutions for energy balancing in Romania as a result of the increasing share of electricity production from renewable sources", Ionescu M.D., Silivestru V., **Tomescu S.**, Toma N., Vladucă I., Săvescu A., Ungureanu A., Petrescu V., Șerban A.

2.

SELECTIVE BIOGRAPHY

[1] Brown, R. N., *Compressors selection and sizing*. Gulf Professional Publishing, 1997.

[2] Brunazzi, E. and A. Paglianti, “Design of complex wire-mesh mist eliminators,” *AIChE Journal*, vol. 46, no. 6, pp. 1131–1137, 2000, doi: 10.1002/aic.690460605.

[3] Brunazzi, E. and A. Paglianti, “Conventional and complex knitted mesh mist eliminators,” *Chem Eng Technol*, vol. 24, no. 11, pp. 1199–1204, 2001, doi: 10.1002/1521-4125(200111)24:11<1199::AID-CEAT1199>3.0.CO;2-O.

[4] Chandranegara, A., “Review : Improving Mist Eliminator Performance in Gas-Liquid Separators,” no. July, 2016, doi: 10.13140/RG.2.1.3342.4885.

[5] COMOTI, “Memoriu Tehnic: ‘RECONFIGURARE SISTEM DE CONDITIONARE’ - Documentație internă INCDT COMOTI.”

[6] COMOTI, “Memoriu Tehnic: ‘INTEGRARE SISTEM DE CONDITIONARE. ETAPA 1’ - Documentație internă INCDT COMOTI.”

[7] COMOTI, “Memoriu Tehnic: ‘INTEGRARE SISTEM DE CONDITIONARE. ETAPA 2’ - Documentație internă INCDT COMOTI,” PROIECT: PN 09-07.08.02 Faza 21, 2015.

[8] COMOTI, “Memoriu Tehnic: "Modernizare compresor ECS 20/10 (CF180GK) și transformare in ECS 30/10. Stația de comprimare Tasbuga.”- Documentație interna INCDT COMOTI,” 2019.

[9] Dragan, V., I. Malael, and B. Gherman, “A Comparative Analysis Between Optimized and Baseline High Pressure Compressor Stages Using Tridimensional Computational Fluid Dynamics,” *Engineering, Technology & Applied Science Research*, vol. 6, no. 4, pp. 1103–1108, 2016, doi: 10.48084/etasr.696.

[10] El-Dessouky, H. T., I. M. Alatiqi, H. M. Ettouney, and N. S. Al-Deffeeri, “Performance of wire mesh mist eliminator,” *Chemical Engineering and Processing: Process Intensification*, vol. 39, no. 2, pp. 129–139, Mar. 2000, doi: 10.1016/S0255-2701(99)00033-1.

[11] Laleh, A. P., W. Y. Svrcek, and W. D. Monnery, “Design and CFD studies of multiphase separators-a review,” *Can J Chem Eng*, vol. 90, no. 6, pp. 1547–1561, Dec. 2012, doi: 10.1002/cjce.20665.

[12] Nitulescu, M., V. Silivestru, N. Toma, C. Slujitoru, V. Petrescu, M. Leahu, C. Oniga, *et al.*, “New projects developed by COMOTI in gas industry,” *IOP Conf Ser Mater Sci Eng*, vol. 90, no. 1, 2015, doi: 10.1088/1757-899X/90/1/012015.

[13] Nitulescu, M., V. Silivestru, N. Toma, C. Slujitoru, V. Petrescu, A. Șerban, and S. Tomescu, “Multifunctional stand for testing screw compressors in closed loop test configuration,” *EMERG - Energy. Environment. Efficiency. Resources. Globalization*, vol. 8, no. 2, pp. 56–67, 2022, doi: 10.37410/EMERG.2022.2.05.

[14] Nitulescu, M., C. Slujitoru, and V. Petrescu, “Case Study regarding the test of the new screw compressor with high delivery pressure - 45 bara - on the test bench (with air),” vol. 4, no. 4, pp. 151–159, 2012, doi: 10.13111/2066-8201.2012.4.4.14.

[15] O’Neill, P. A., *Industrial compressors : theory and equipment*. Butterworth Heinemann, 1993.

[16] De Schepper, S. C. K., G. J. Heynderickx, and G. B. Marin, “CFD modeling of all gas-liquid and vapor-liquid flow regimes predicted by the Baker chart,” *Chemical Engineering Journal*, vol. 138, no. 1–3, pp. 349–357, 2008, doi: 10.1016/j.cej.2007.06.007.

[17] Silivestru, V., M. D. Ionescu, and P. Despa, “Instalații complexe pentru comprimarea gazului natural produse de COMOTI,” *Market Watch Nr 152*, 2013.

[18] Stosic, N., “MATHEMATICAL MODELLING IN COMPUTER AIDED DESIGN OF SCREW COMPRESSORS,” 2001.

[19] Stošic, N., L. Milutinović, K. Hanjalić, and A. Kovačević, “Investigation of the influence of oil injection upon the screw compressor working process,” *International Journal of Refrigeration*, vol. 15, no. 4, pp. 206–220, 1992, doi: 10.1016/0140-7007(92)90051-U.

[20] Stosic, N., I. K. Smith, A. Kovacevic, and E. Mujic, “Geometry of screw compressor rotors and their tools,” *Journal of Zhejiang University-SCIENCE A*, vol. 12, no. 4, pp. 310–326, 2011, doi: 10.1631/jzus.A1000393.

[21] Tomescu, S. and I. O. Bucur, “Numerical Investigation of Oil Gas Separation with the Use of VOF CFD,” *Engineering, Technology & Applied Science Research*, vol. 11, no. 6, pp. 7841–7845, 2021, doi: 10.48084/etasr.4446.

[22] Tomescu, S., M. Enache, N. Visan, and F. Florean, “EXPERIMENTAL MEASUREMENTS USING SHADOWGRAPH SYSTEM ON THE SCREW COMPRESSOR,” *U.P.B. Sci. Bull., Series D*, vol. 84, no. 1, 2022.

[23] “www.en.wikipedia.org/wiki/Bellows.”

[24] “www.comoti.ro.”

[25] “LaVision GmbH, "Product - Manual for ParticleMaster Shadow ", Item-Number(s): 1105032, Anna – Vandenhoeck - Ring 19, D-37081 Göttingen, 2009.”