

Estudio y optimización de un separador de crudo trifásico de recipiente horizontal

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Carrera de Ingeniería Mecánica

Trabajo de titulación, previo a la obtención del título de Ingeniero Mecánico

Ing. Carrión Matamoros, Luis Miguel, PhD

01 de septiembre del 2023



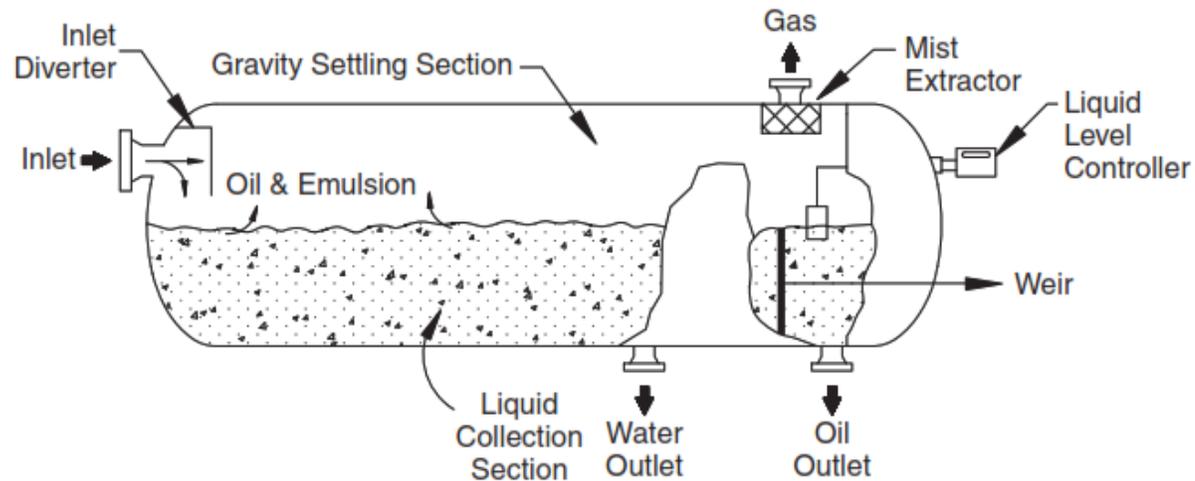
ÍNDICE



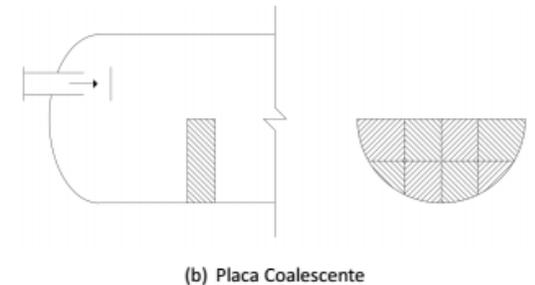
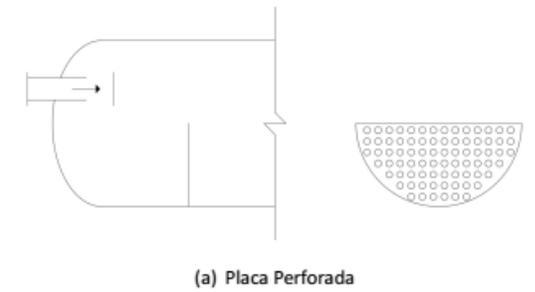
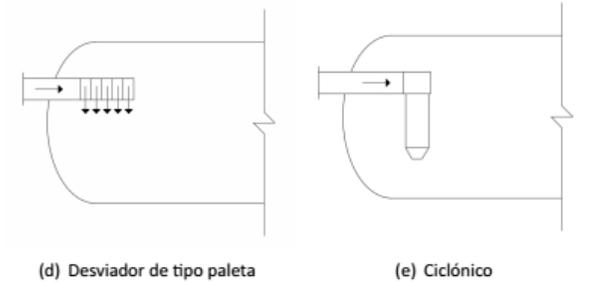
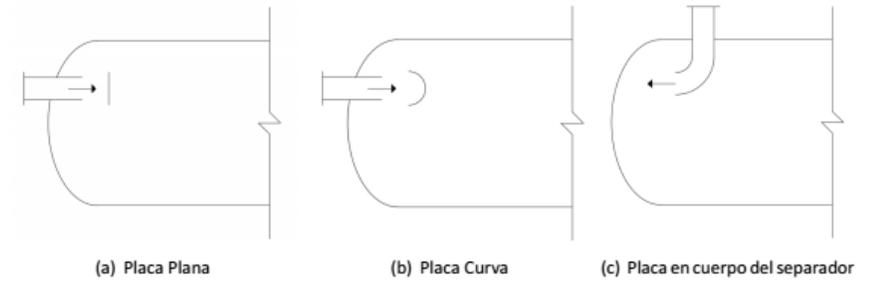
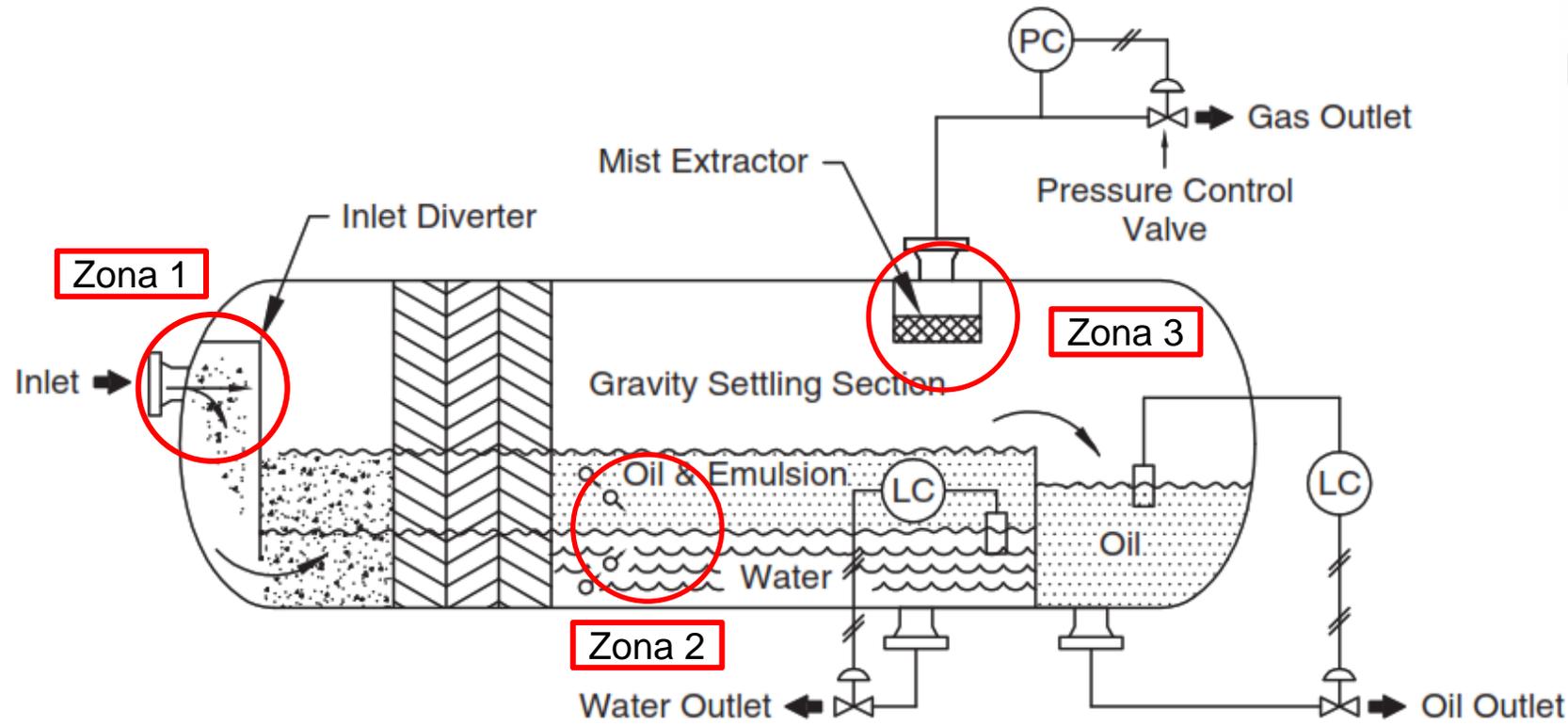
Antecedentes

Una vez el crudo es extraído, este se presenta como una emulsión, en la cuál coexisten las fases de gas, crudo y agua.

De esta manera un separador lo que hace es separar esta emulsión en sus fases individuales.



Antecedentes



Antecedentes

Métodos clásicos

Monnery y Svrcek
(1994)

Arnold y Stewart
(2008)

API 12J
(2008)

Gravedad API del Crudo	Tiempo de retención típico [min]
Por encima de 35° API	3 - 5
Por debajo de 35° API	
100+°F	5 - 10
80+°F	10 - 20
60+°F	20 - 30

Tabla adaptada de la Normativa API 12J pg. 16.

Gravedad API del Crudo	Tiempo de retención típico [min]
Crudo Liviano (30° - 40°)	5 - 7.5
Crudo Intermedio (20° - 30°)	7.5 - 10
Crudo Pesado (menor a 20°)	10+

Tabla adaptada del libro Gas-Liquid And Liquid-Liquid Separators pg. 150

$$V_a = K \cdot \sqrt{\frac{\rho_L - \rho_G}{\rho_G}}$$

$$K = \sqrt{\frac{4d_p g}{3C_D}}$$

Tipo de separador	Altura o Longitud (L[ft])	Rango típico del factor K
Vertical	5	0.12 - 0.24
	10	0.18 - 0.35
Horizontal	10	0.4 - 0.5
	Otras longitudes	$0.4 - 0.5 \times (L/10)^{0.56}$
Esférico	Todas	0.2 - 0.35

Tabla adaptada de la Normativa API 12J pg. 13.

Presión de operación [Pa]	Rango típico del factor K
1 - 15	$0.1821 + 0.0029P + 0.0460 \ln(P)$
15 - 40	0.35
40 - 5500	$0.43 - 0.023 \ln(P)$

Tabla adaptada del estudio publicado por Monnery y Svrcek



Antecedentes

3D Computational-Fluid-Dynamics Modeling of Horizontal Three-Phase Separators: An Approach for Estimating the Optimal Dimensions

Ahmadreza Ghaffarkhah, Mohammadjavad Ameri Shahrabi, and Mostafa Keshavarz Moraveji, Amirkabir University of Technology

Summary

This study presents an approach to determine the dimensions of three-phase separators. First, we designed different vessel configurations depending on the fluid properties of an Iranian gas/condensate field. We then devised a comprehensive computational-fluid-dynamics (CFD) method for analyzing the phenomena of three-phase separation. The results in terms of separation efficiency and behavior of secondary-phase particles were reviewed to choose the optimal configuration. Only a slight difference in the length of this vessel and the existing separator was found. In addition, simulation data were compared with industrial data pertaining to a similar existing separator. The results of this work showed that the CFD model used is capable of investigating the performance of three-phase separators.

Journal of Petroleum Exploration and Production Technology (2019) 9:353–382
<https://doi.org/10.1007/s13202-018-0460-5>

ORIGINAL PAPER - PRODUCTION ENGINEERING



Coupling of CFD and semiempirical methods for designing three-phase condensate separator: case study and experimental validation

Ahmadreza Ghaffarkhah^{1,2} · Zahra Azimi Dijvejin³ · Mohammadjavad Ameri Shahrabi¹ · Mostafa Keshavarz Moraveji⁴ · Masood Mostofi⁵

Received: 29 September 2017 / Accepted: 3 April 2018 / Published online: 11 April 2018
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Computational Fluid Dynamics-Based Study of an Oilfield Separator— Part I: A Realistic Simulation

Ali Pourahmadi Laleh and William Y. Svrcek, University of Calgary, and Wayne D. Monnery, Chem-Pet Process Tech Limited

BRAZILIAN JOURNAL OF PETROLEUM AND GAS | v. 14 n. 4 | p. 205-220 | 2020 | ISSN 1982-0593



MODELING AND SIMULATION OF A HORIZONTAL THREE-PHASE SEPARATOR: INFLUENCE OF PHYSICOCHEMICAL PROPERTIES OF OIL

^a Carvalho, A. J. G. [†]; ^a Galindo, D. C.; ^a Tenório, M. S. C.; ^a Marinho, J. L. G.

^a Federal University of Alagoas, Technology Center, Maceió – AL, Brazil

Received: 04.08.2020 / Revised: 27.11.2020 / Accepted: 05.12.2020 / Published on-line: 07.01.2021



Justificación

La justificación e importancia del proyecto, radica en que el crudo que tiene el Ecuador, es generalmente un crudo pesado, el cual, debido a su alta viscosidad dificulta en gran medida su separación.

Por otra parte el estudio que se realiza pretende mejorar la eficiencia de la separación, a partir de experimentación computacional, lo que permite obtener una representación más realista del proceso de separación.

Objetivos

Objetivo General.

- Realizar el estudio y optimización para un separador trifásico horizontal.

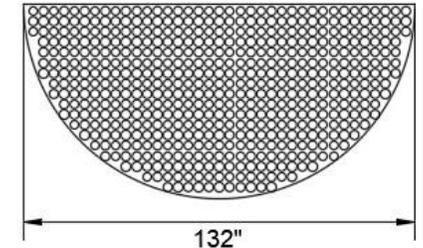
Objetivos Específicos.

- Desarrollar el estudio CFD del separador en estado actual.
- Detectar problemas presentes en el separador.
- Realizar optimizaciones en el separador para reducir el impacto de los problemas detectados y mejorar su eficiencia.
- Desarrollar el estudio CFD del separador con los cambios propuestos.

Información preliminar



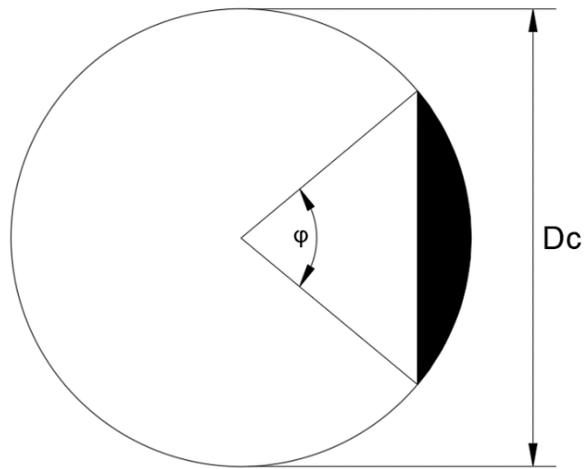
El diámetro de los agujeros son de 3[in] y ocupan el 50% del área de la placa perforada



	VOF [%]	ρ [kg/m ³]	μ [Pa · s]	\dot{m} [kg/s]
Crudo	18	953.26	0.437	28.554
Agua	75	982.73	5e-4	90.425
Gas	6	5.67	1.4e-5	0.108

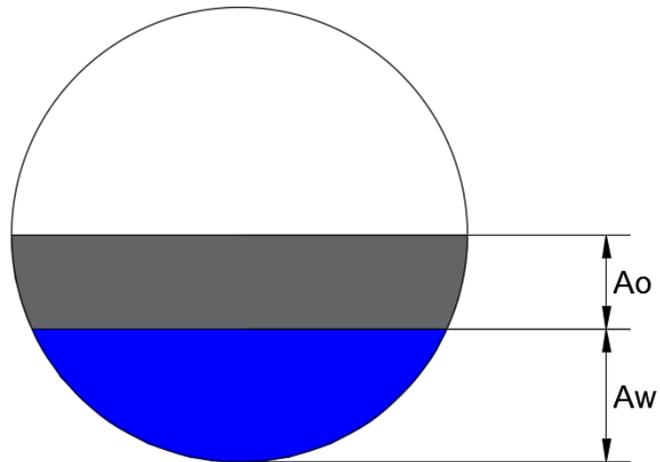


Modelo CAD



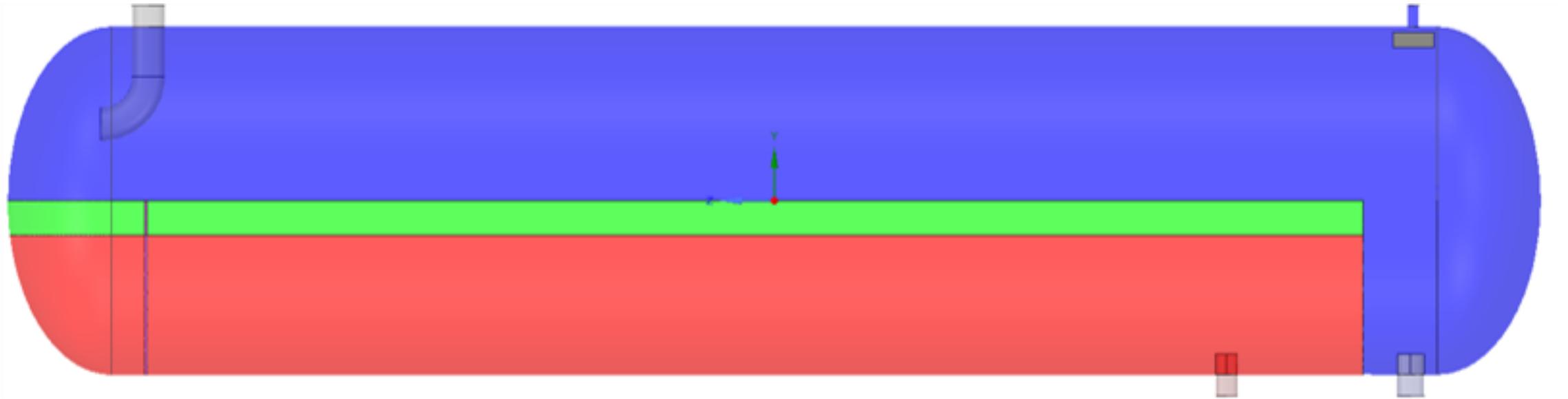
$$A_{sc} = \frac{\varphi - \sin(\varphi)}{2} \cdot \left(\frac{D_c}{2}\right)^2$$

$$\varphi = 2 \cdot \frac{A_{sc}}{\left(\frac{D_c}{2}\right)^2} + \sin(\varphi)$$



Fase	Área [m ²]	Altura [m]
Crudo	1.104	0.330 (A _o)
Agua	3.311	1.346 (A _w)

Modelo CAD



Preprocesamiento

Crudo/Gas [N/m]	Agua/Gas [N/m]	Crudo/Agua [N/m]
0.02054	0.06475	0.04123

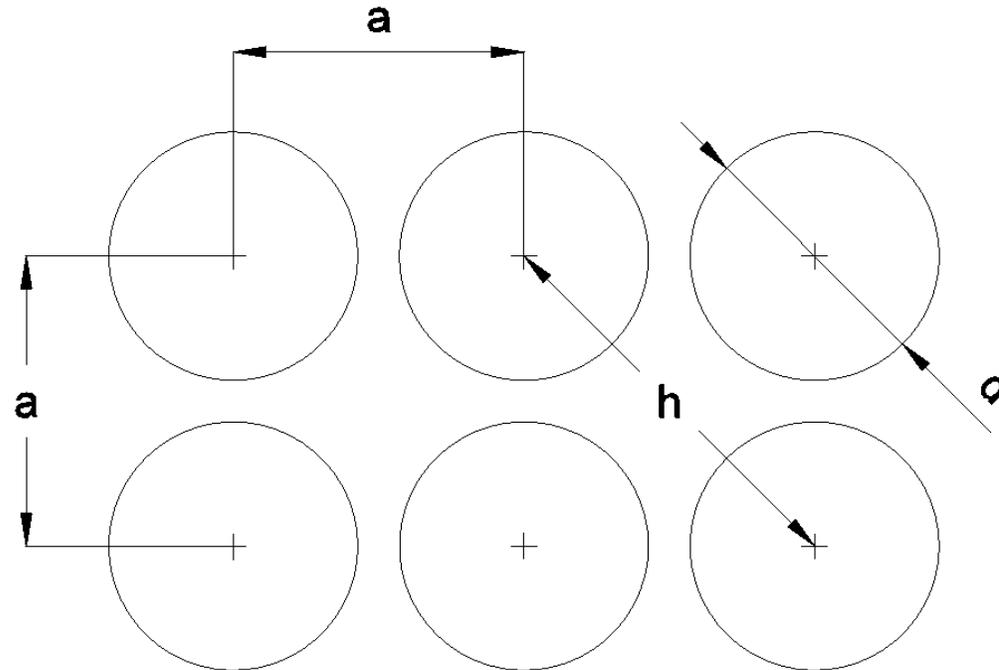
Tensión superficial

ϵ [%]	C_2 [m ⁻¹]	K_d [m ⁻²]
97.7	126	3.846e+6

*Propiedades del medio poroso
Separador de partículas*

C	C_2 [m ⁻¹]
0.932	135.945

*Propiedades del medio poroso
Placa perforada*

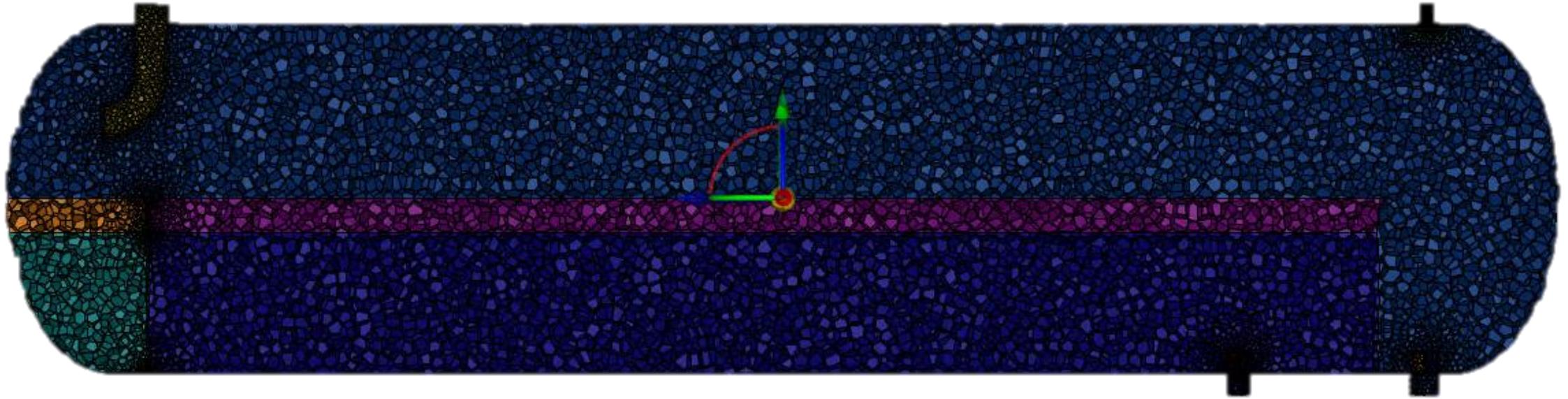


$$C = 0.98 \left(\frac{d}{h} \right)^{0.1}$$

$$C_2 = \frac{1}{C^2 \cdot \delta} \left[\left(\frac{A_p}{A_f} \right)^2 - 1 \right]$$



Mallado



N. Elementos	Oblicuidad máxima	Ortogonalidad mínima	Relación de aspecto
115584	0.5	0.1	3.5

Modelos numéricos

Modelo VOF

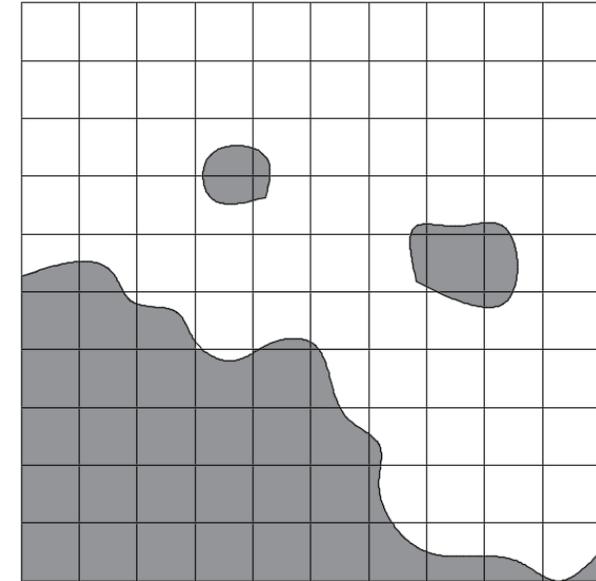
$$\frac{\partial}{\partial t}(\alpha_i \rho_i) + \nabla \cdot (\alpha_i \rho_i \vec{v}_i) = 0$$

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \cdot \vec{v}) = -\nabla p + \nabla \tau + \rho g + \vec{F}$$

Modelo de Turbulencia ($k - \varepsilon$)

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho \varepsilon$$

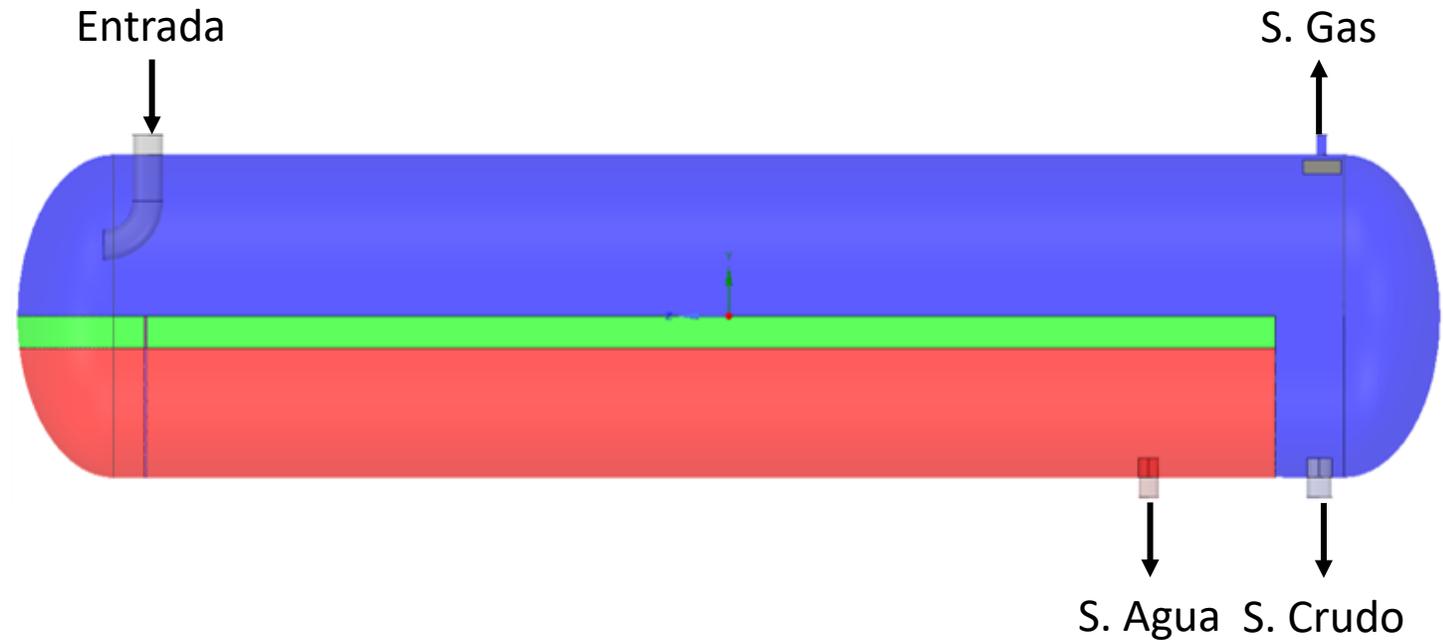
$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} (G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k}$$



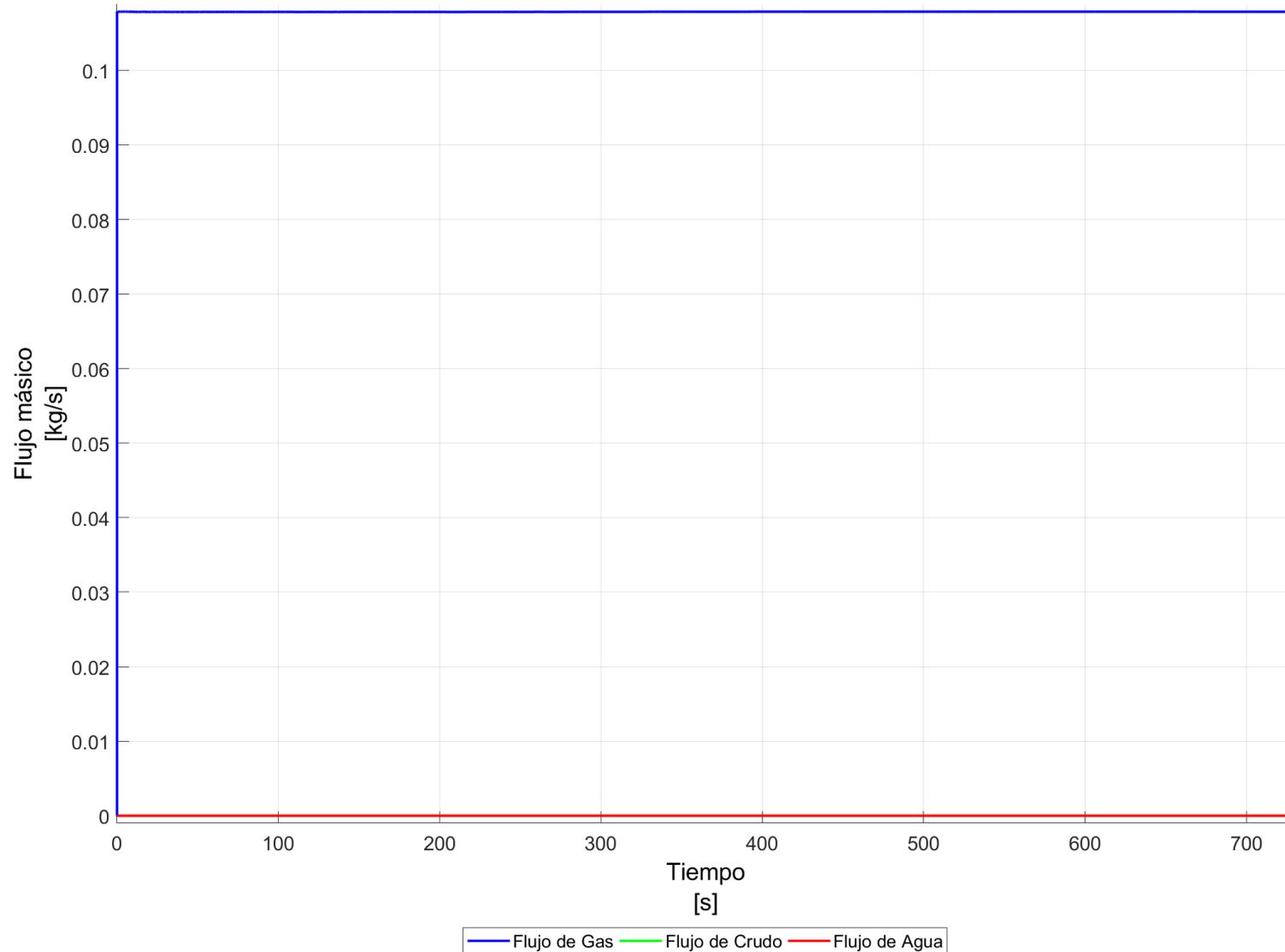
$C_{1\varepsilon}$	1.44
$C_{2\varepsilon}$	1.92
$C_{3\varepsilon}$	0.09
σ_k	1.0
σ_ε	1.3

Condiciones de contorno

Localización	Descripción
Entrada	<i>BC:</i> Velocidad de entrada v [m/s]: 1.56 I [%]: 3.96 D_h [m]: 0.315
Salida de Gas	<i>BC:</i> Flujo másico \dot{m} [kg/s]: 0.108
Salida de Crudo	<i>BC:</i> Flujo másico \dot{m} [kg/s]: 28.554
Salida de Agua	<i>BC:</i> Flujo másico \dot{m} [kg/s]: 90.425

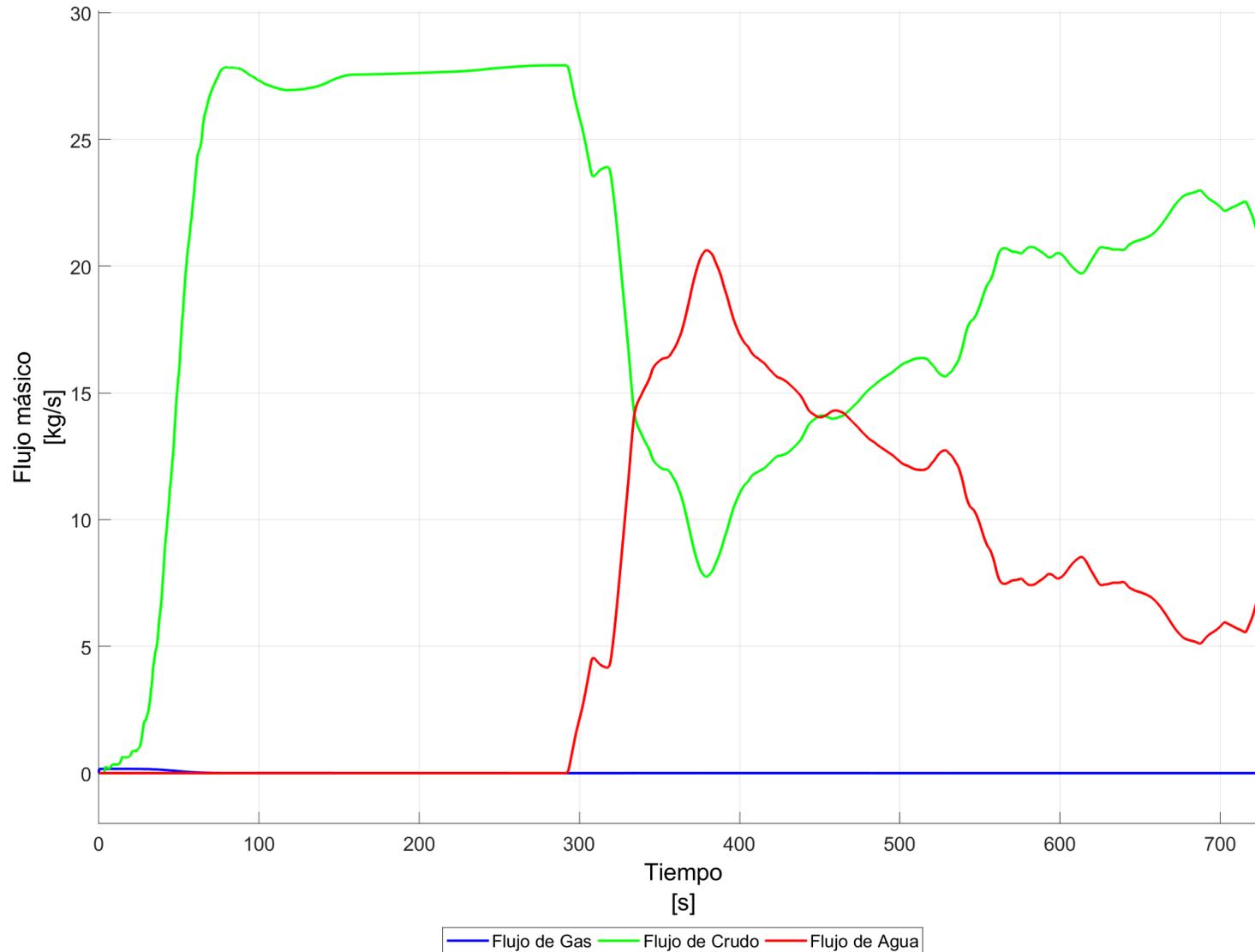


Flujo másico – Salida de Gas



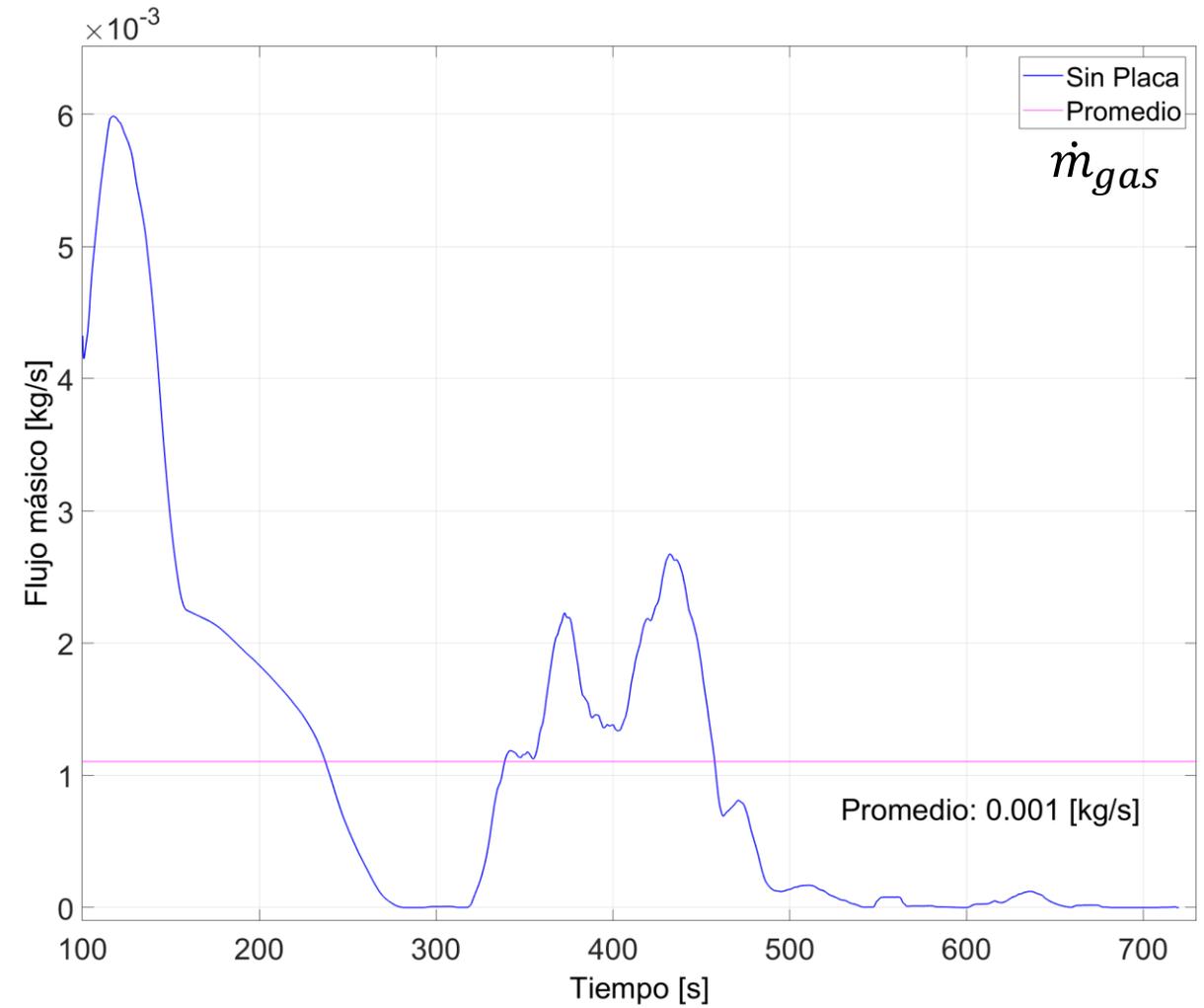
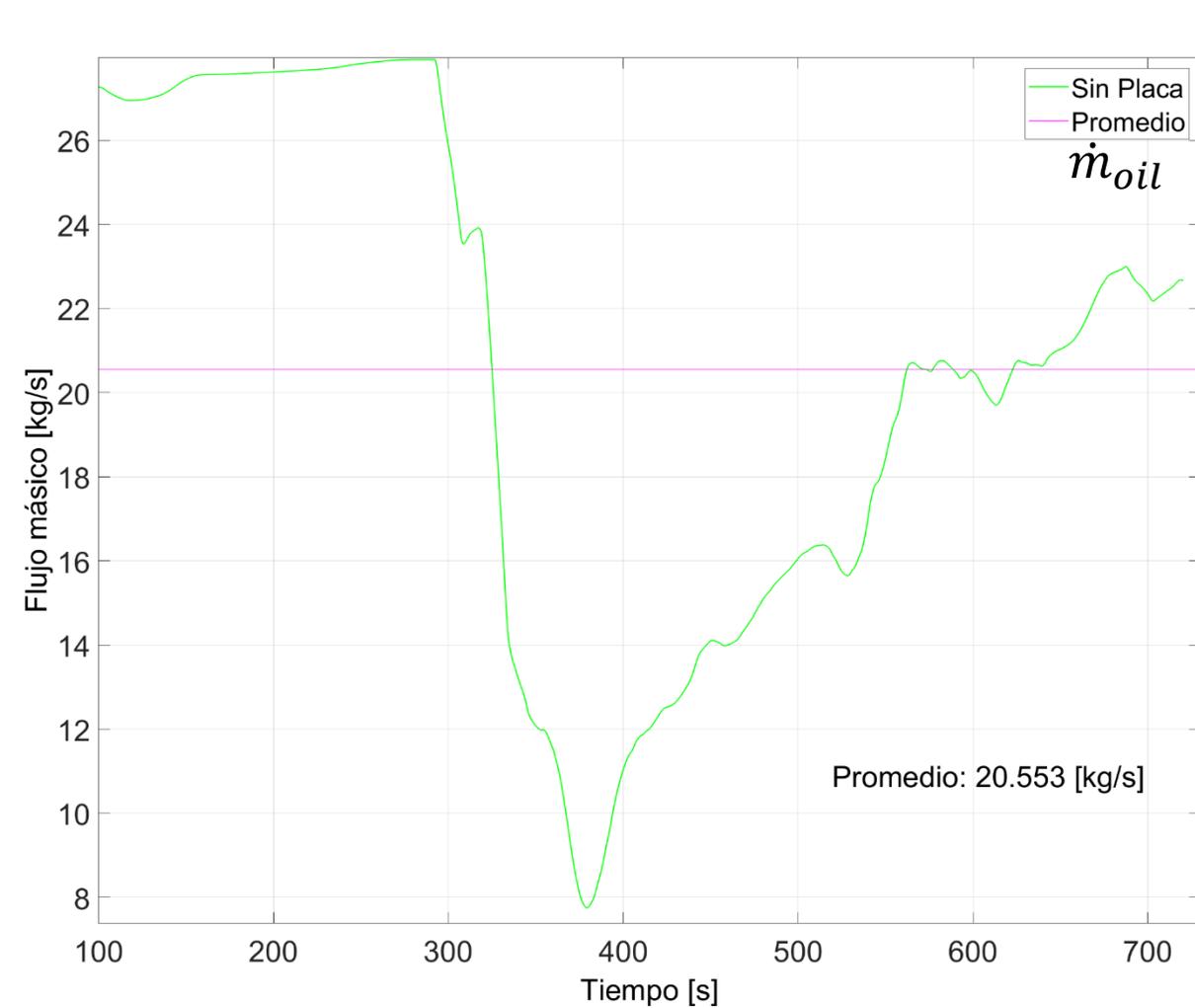
El promedio de gas en la salida de gas es de 0.108 [kg/s]

Flujo másico – Salida de Crudo

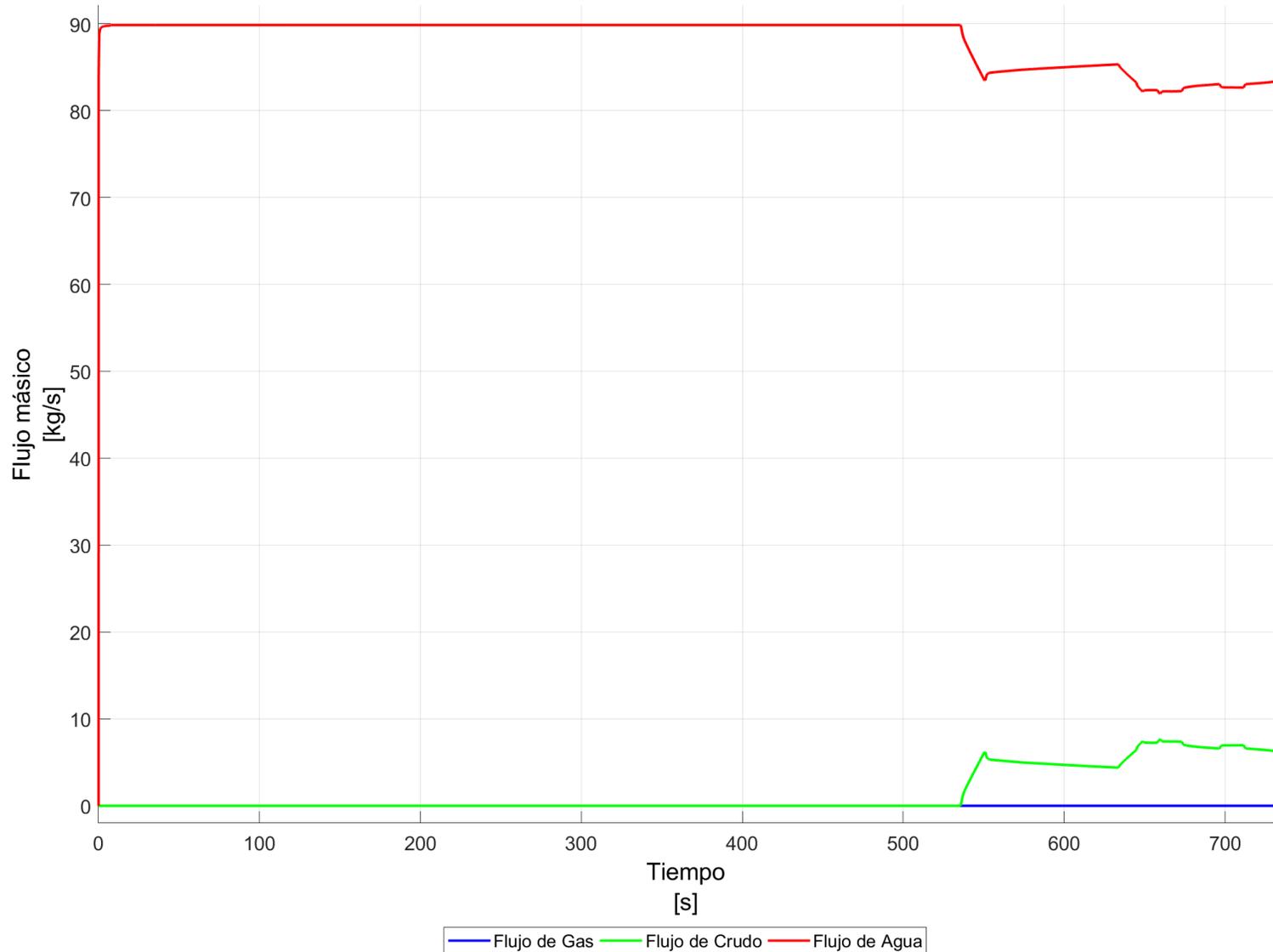


El promedio de crudo en la salida de crudo es de 20.553 [kg/s]

Flujo másico – Salida de Crudo

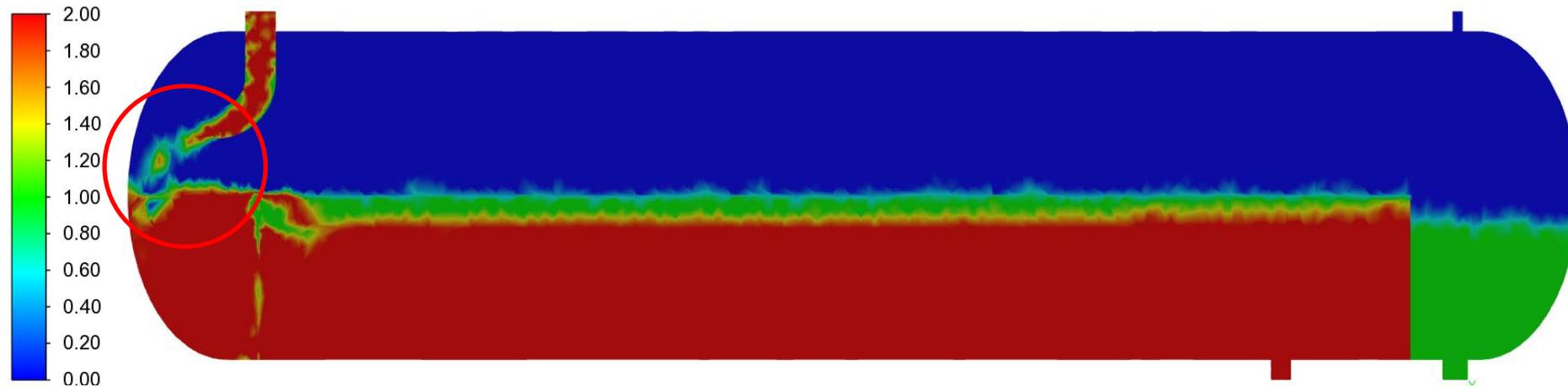
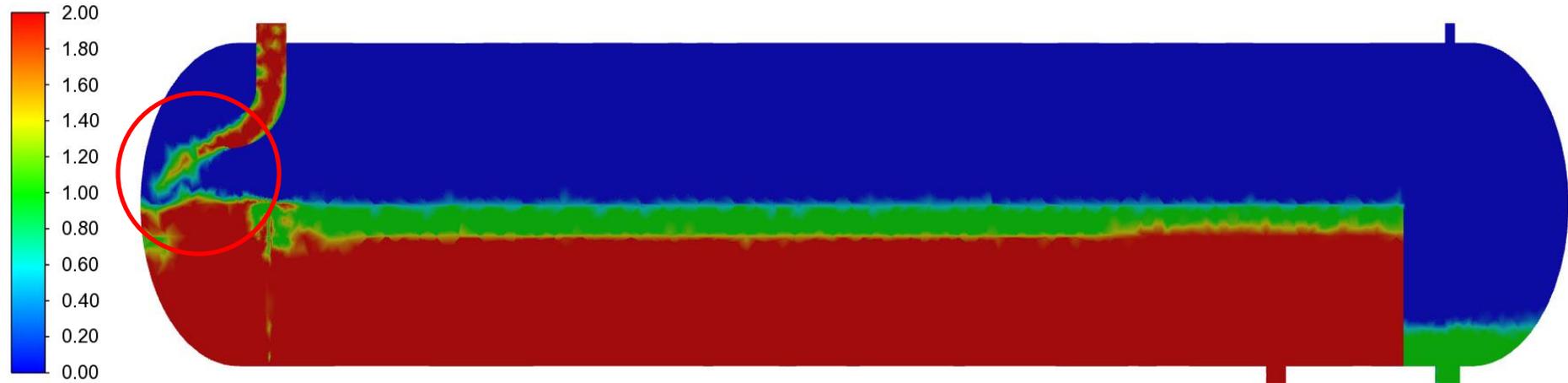


Flujo másico – Salida de Agua

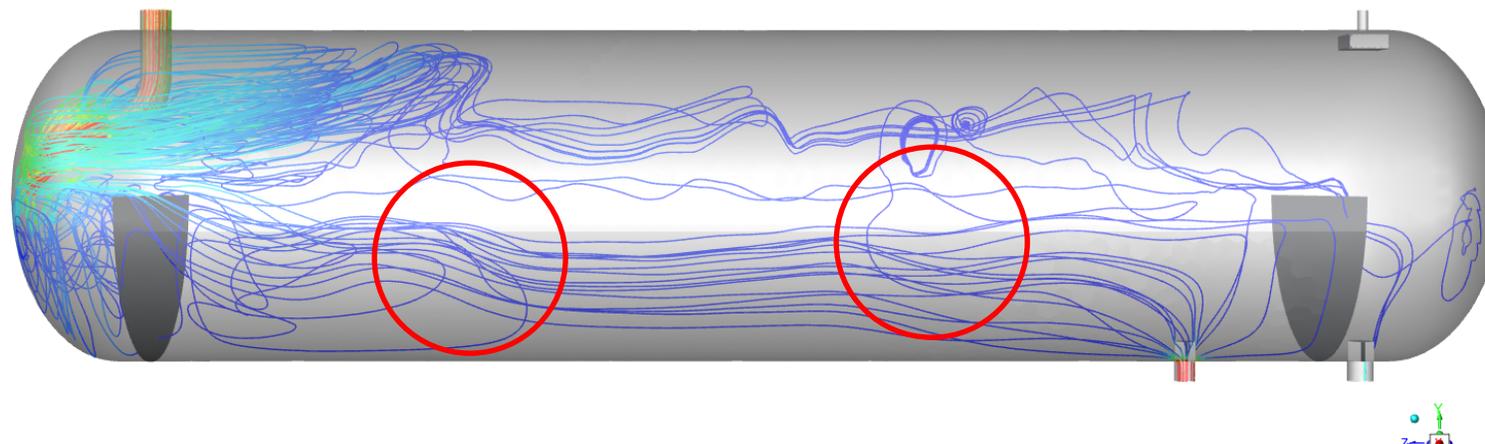
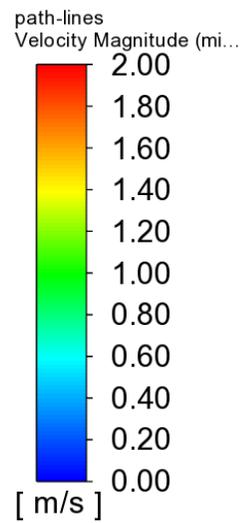
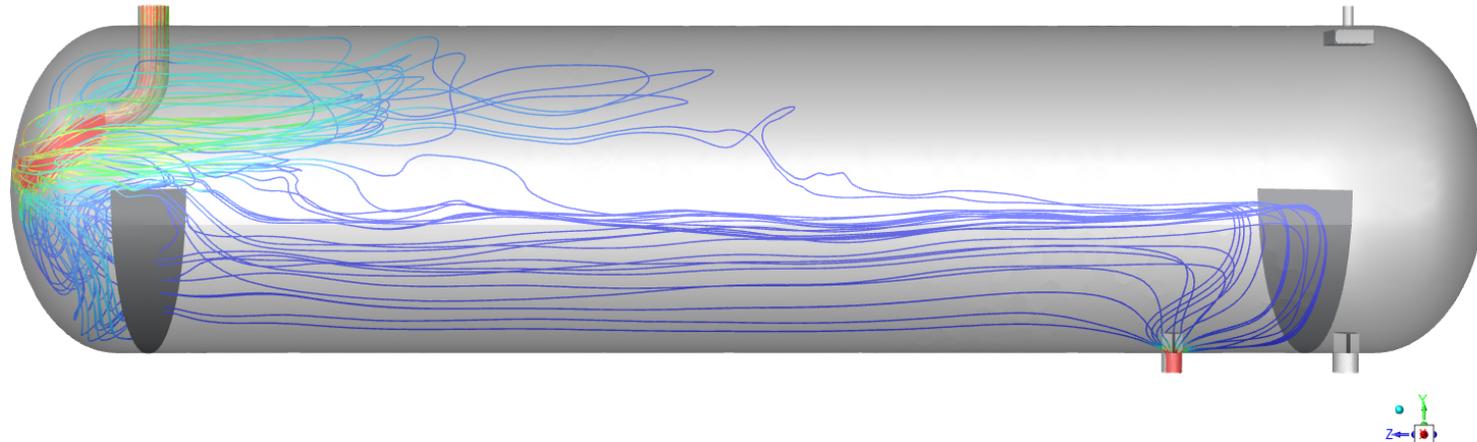
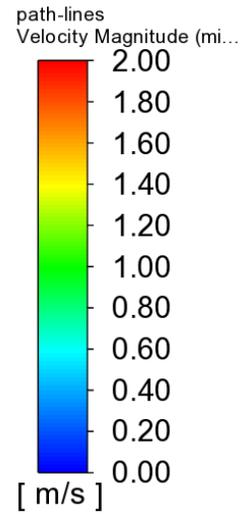


El promedio de agua en la salida de agua es de 88.111 [kg/s]

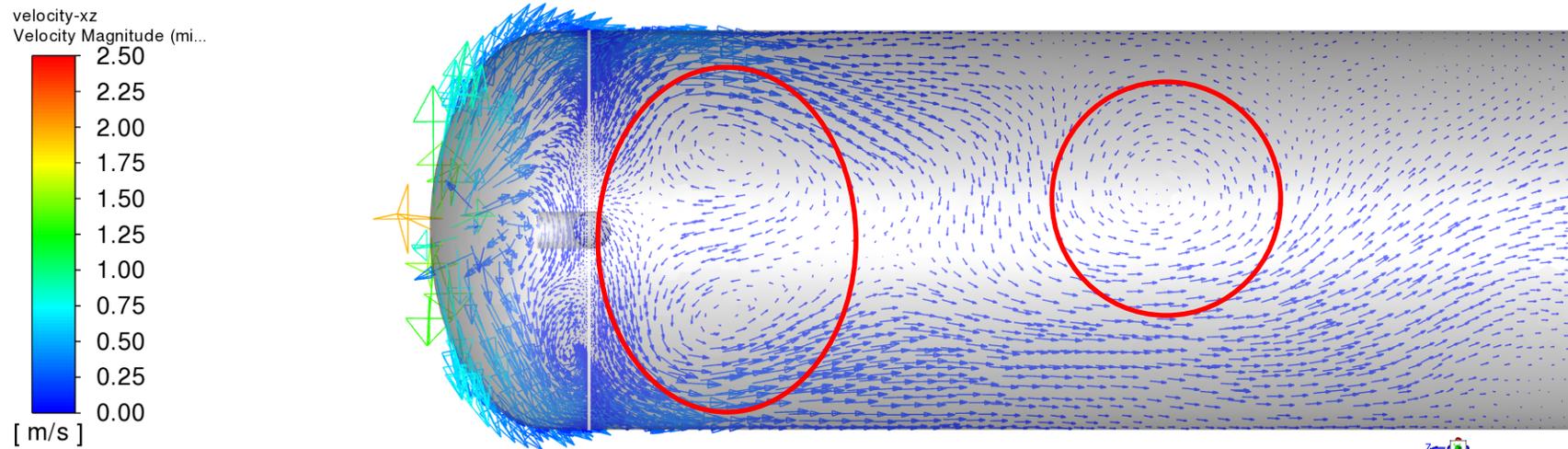
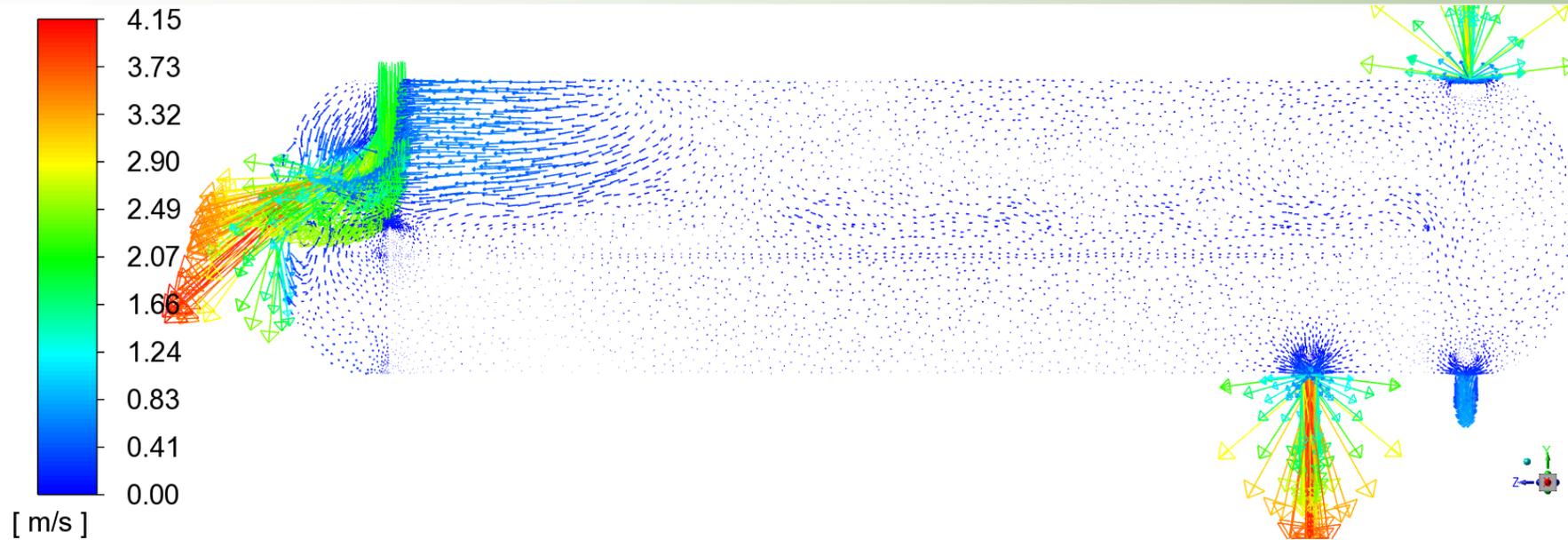
Contornos de fases



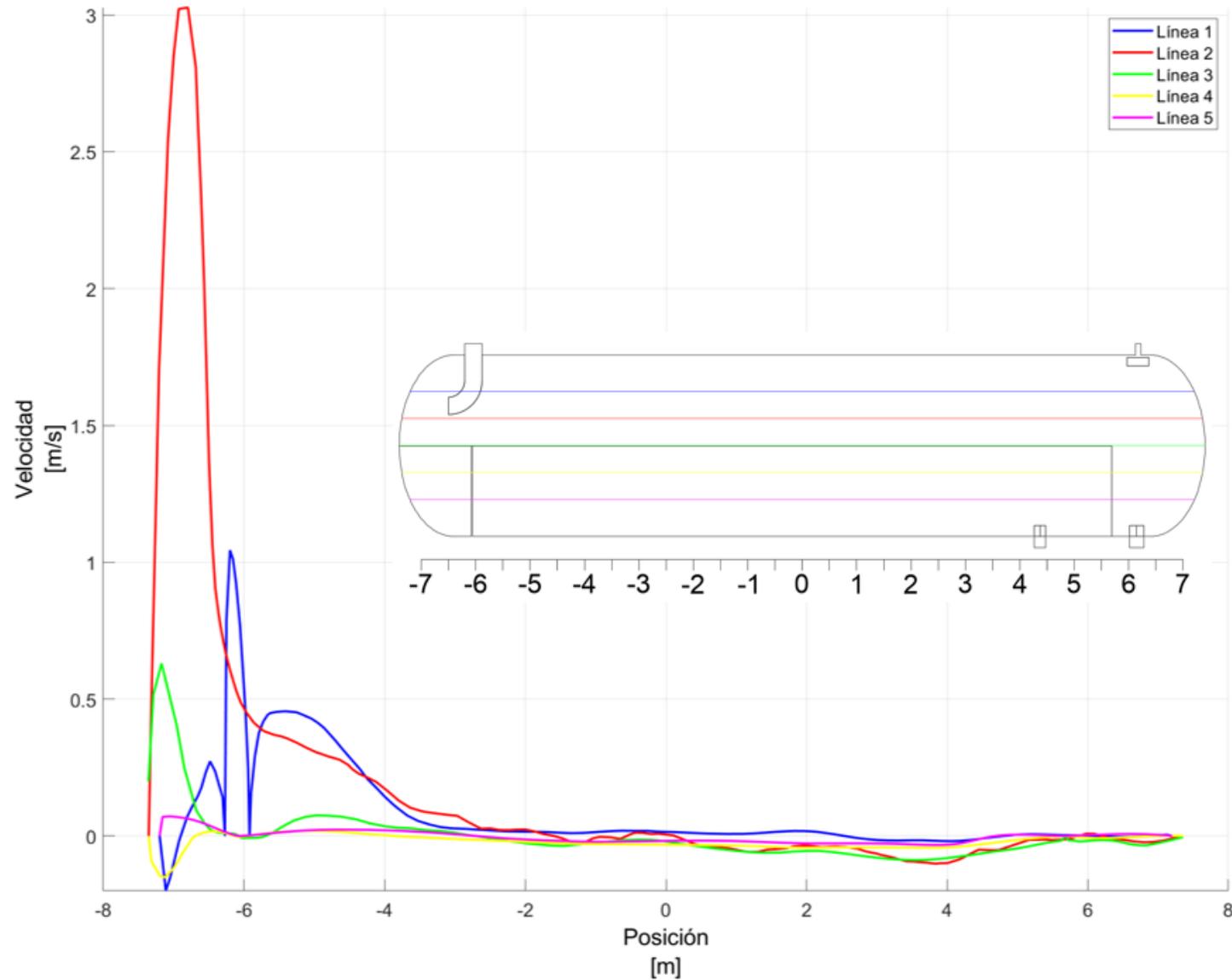
Líneas de corriente



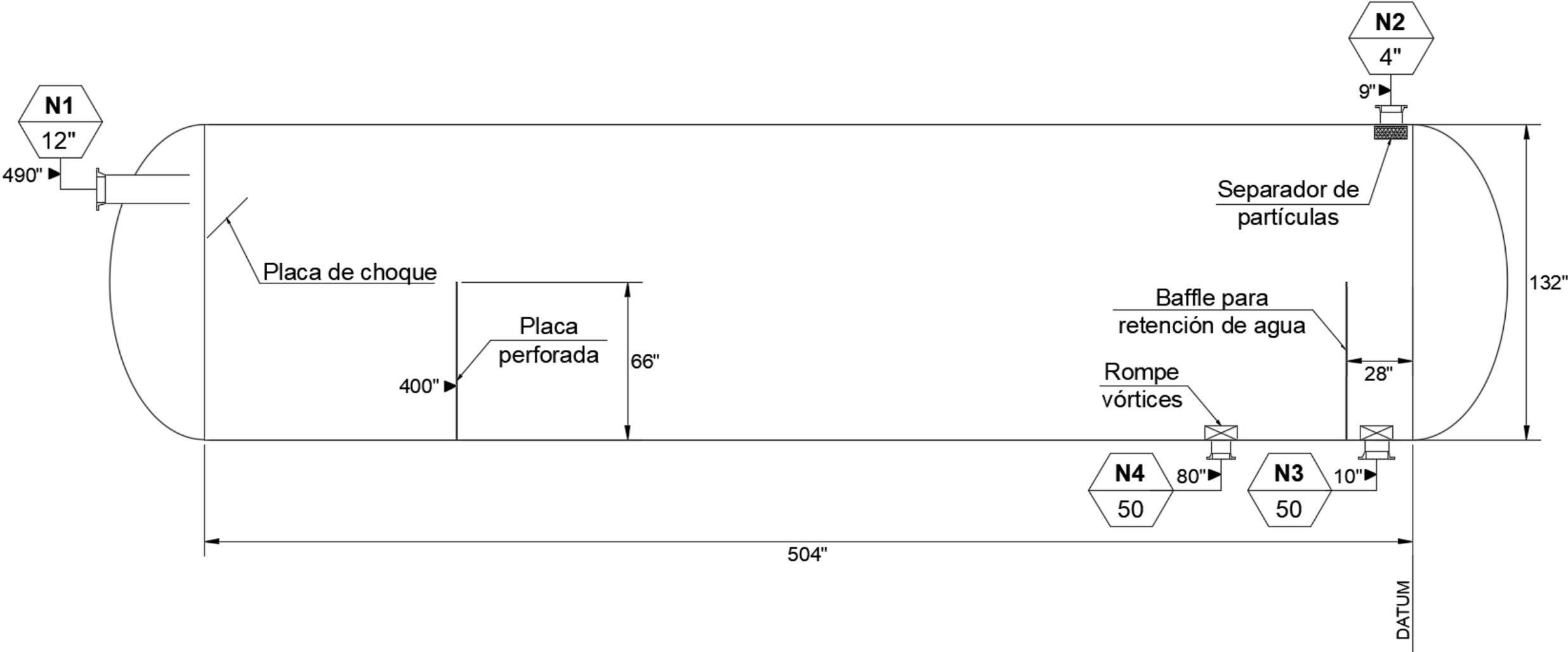
Perfiles de velocidad



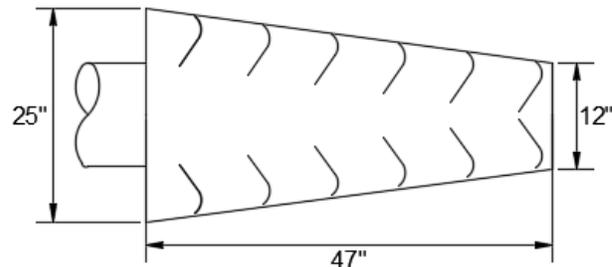
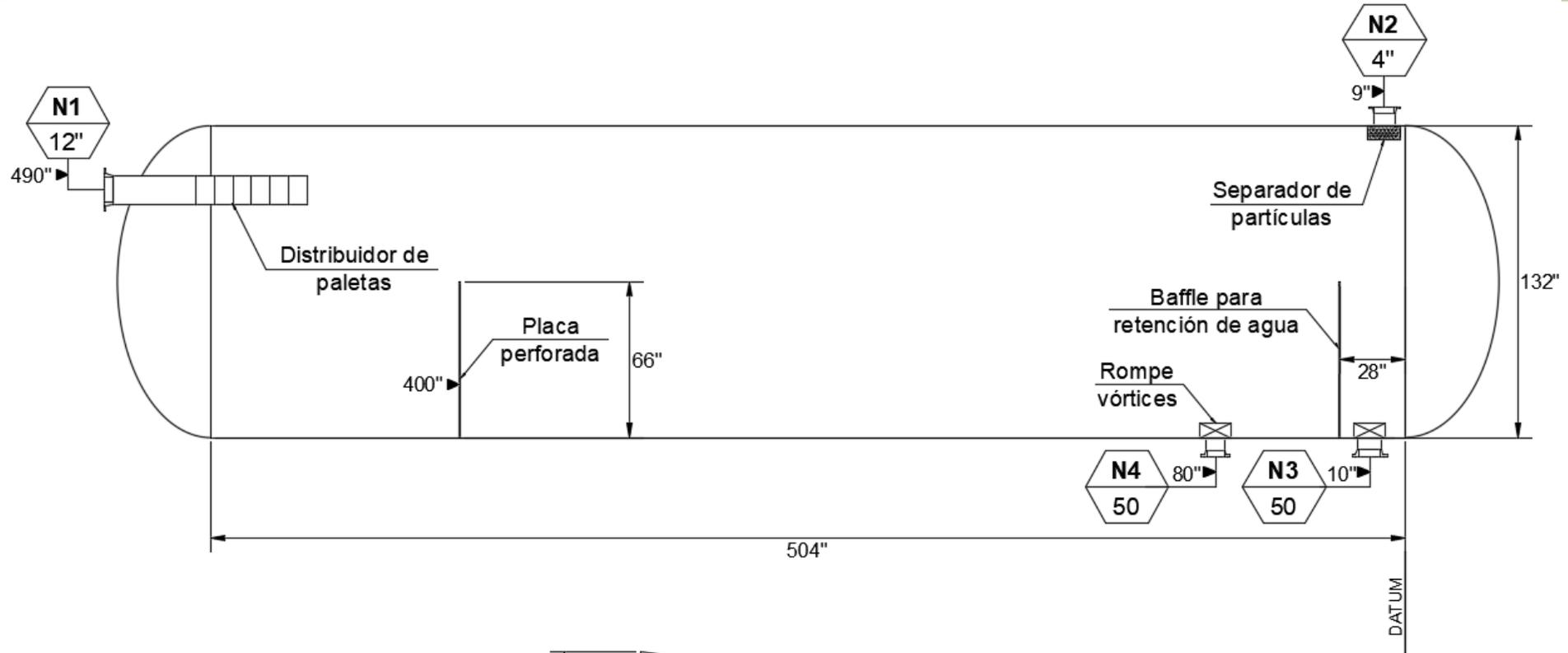
Perfiles de velocidad



Escenario 2



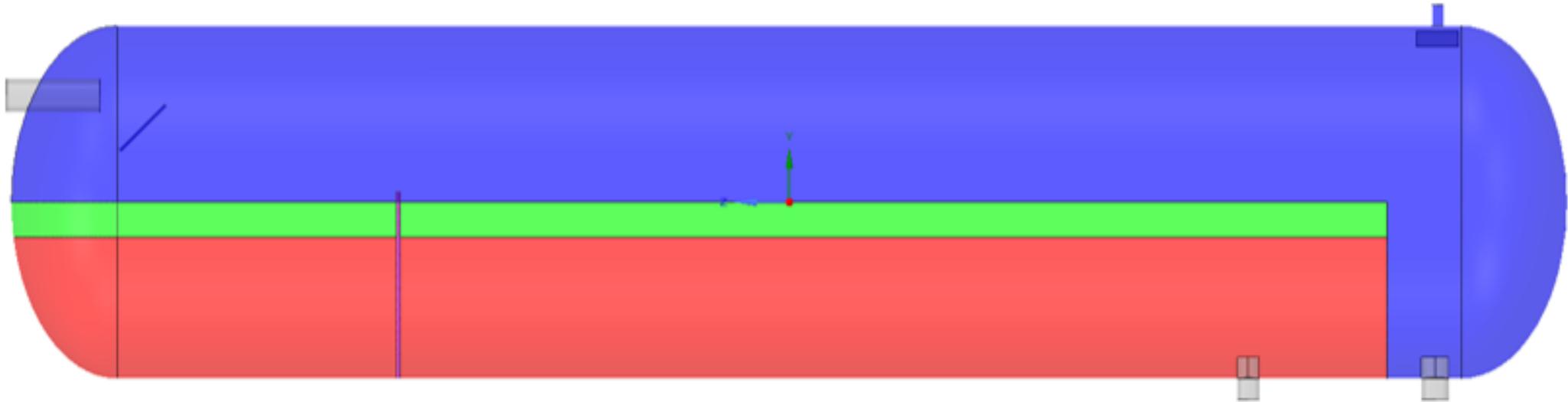
Escenario 3



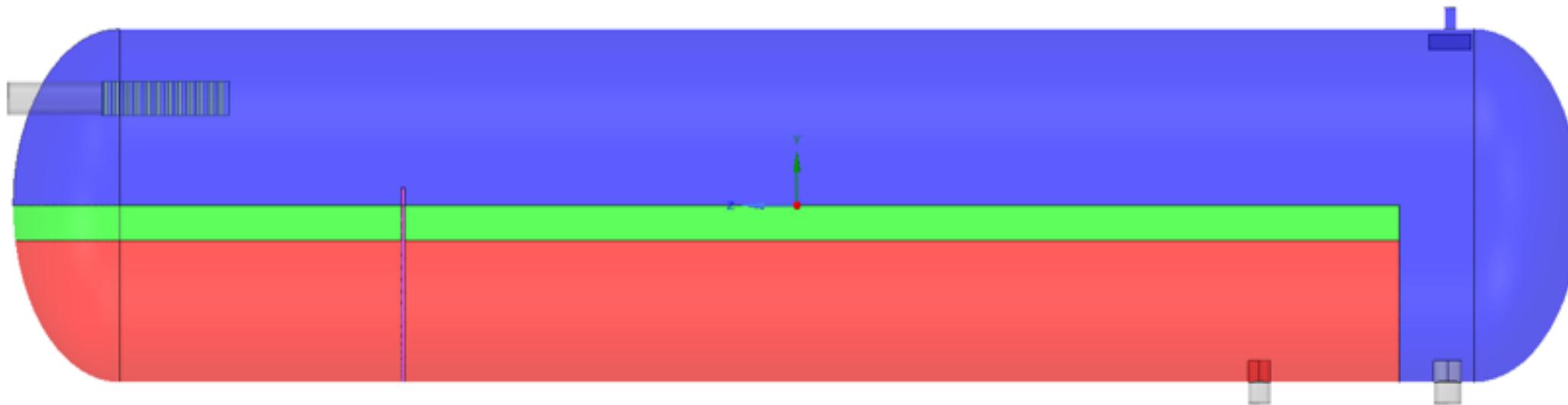
DISTRIBUIDOR DE PALETAS
ESCALA: 1:3



Modelos CAD

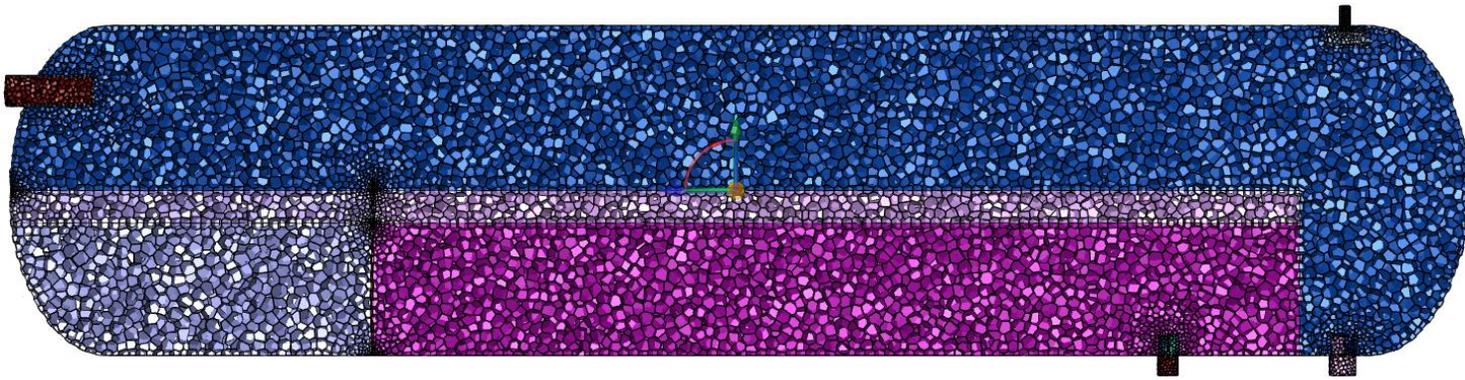


Esc. 2

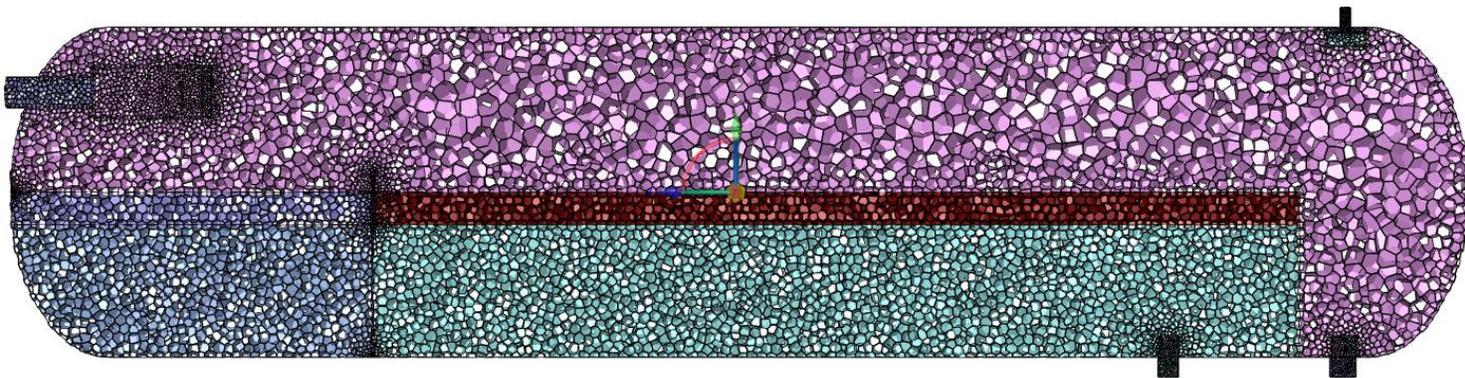


Esc. 3

Mallado

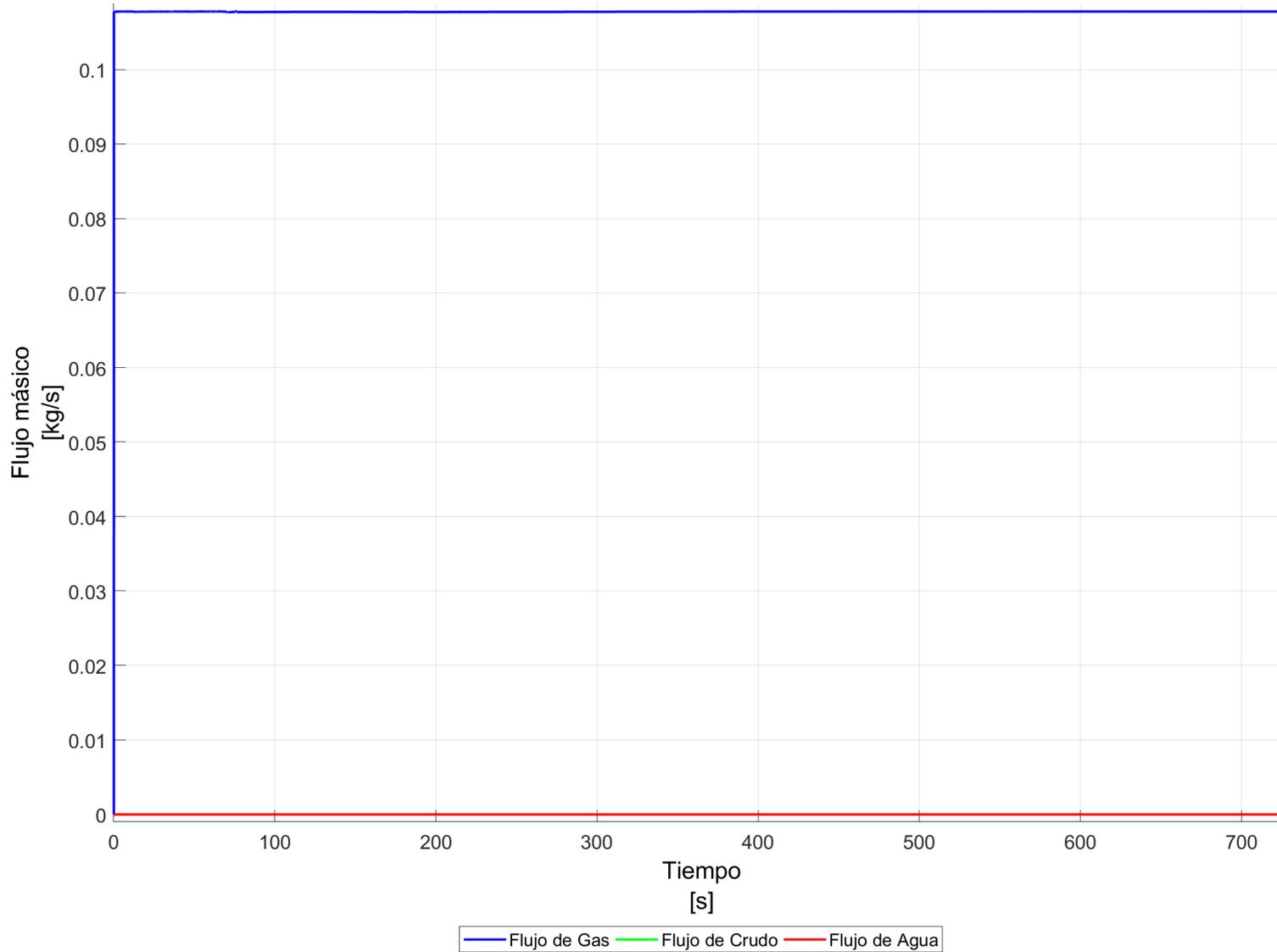


# E.	Oblicuidad máxima	Ortogonalidad mínima	Relación de aspecto
183245	0.5	0.2	3



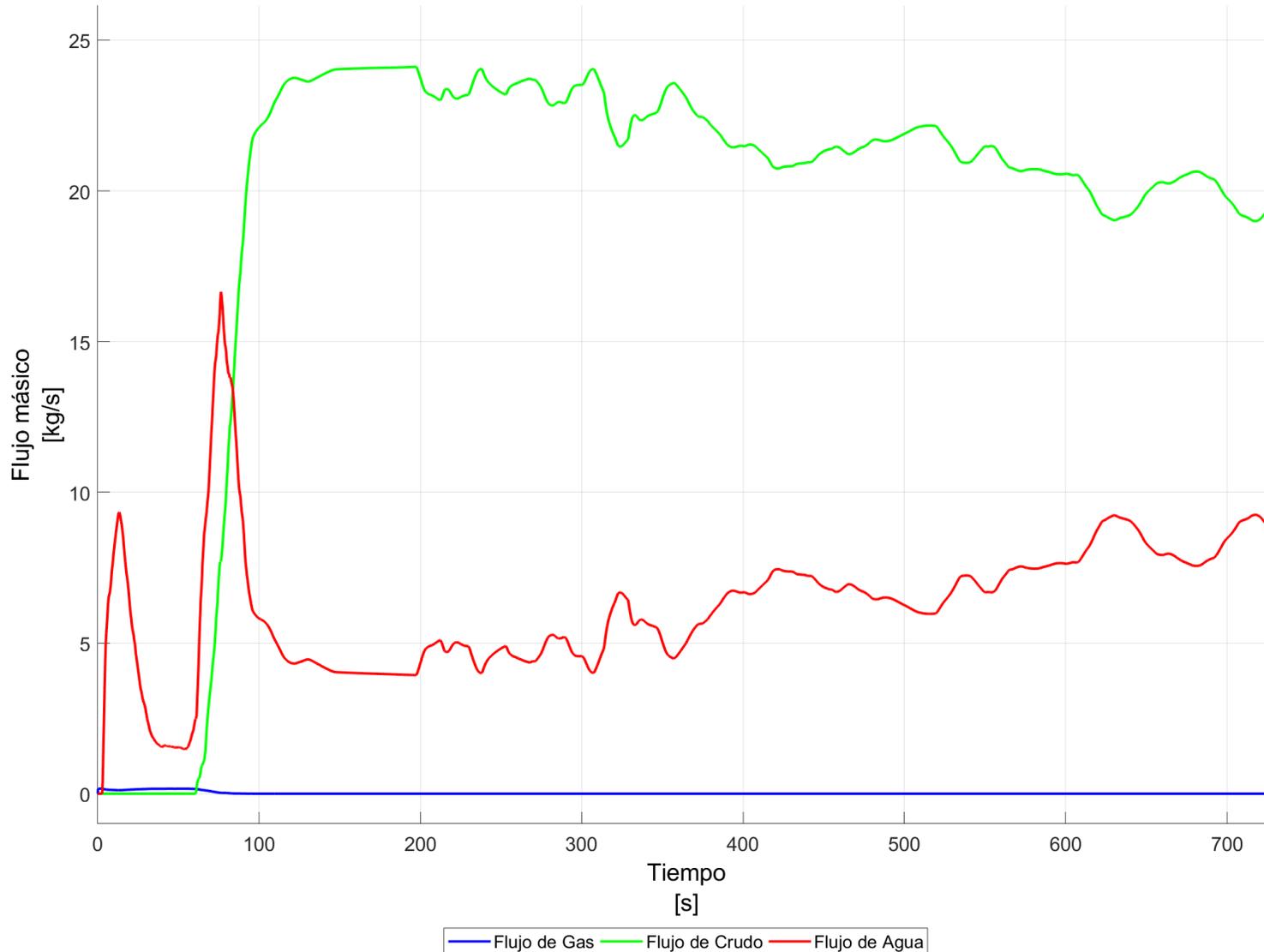
# E.	Oblicuidad máxima	Ortogonalidad mínima	Relación de aspecto
264891	0.3	0.1	2.8

Flujo másico – Salida de Gas



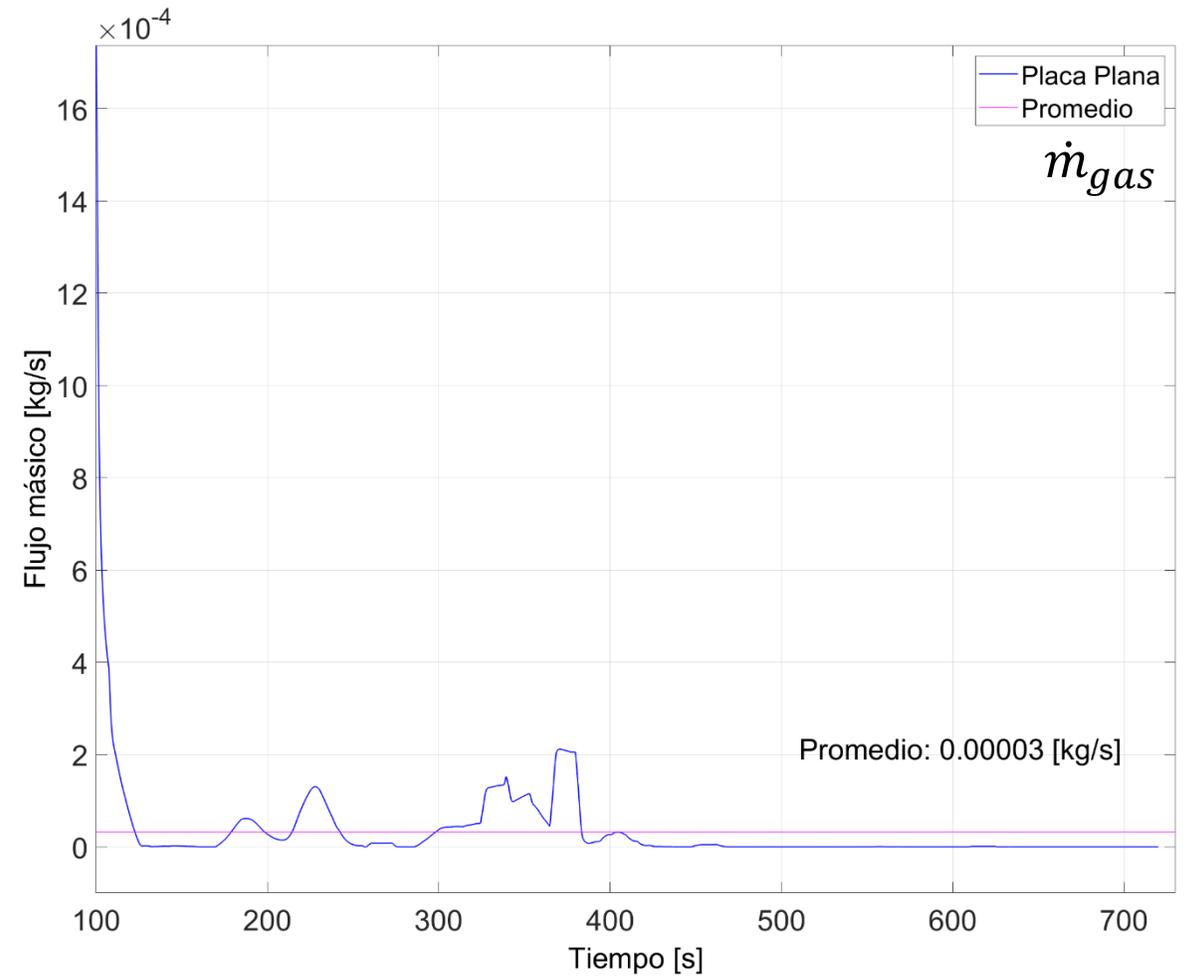
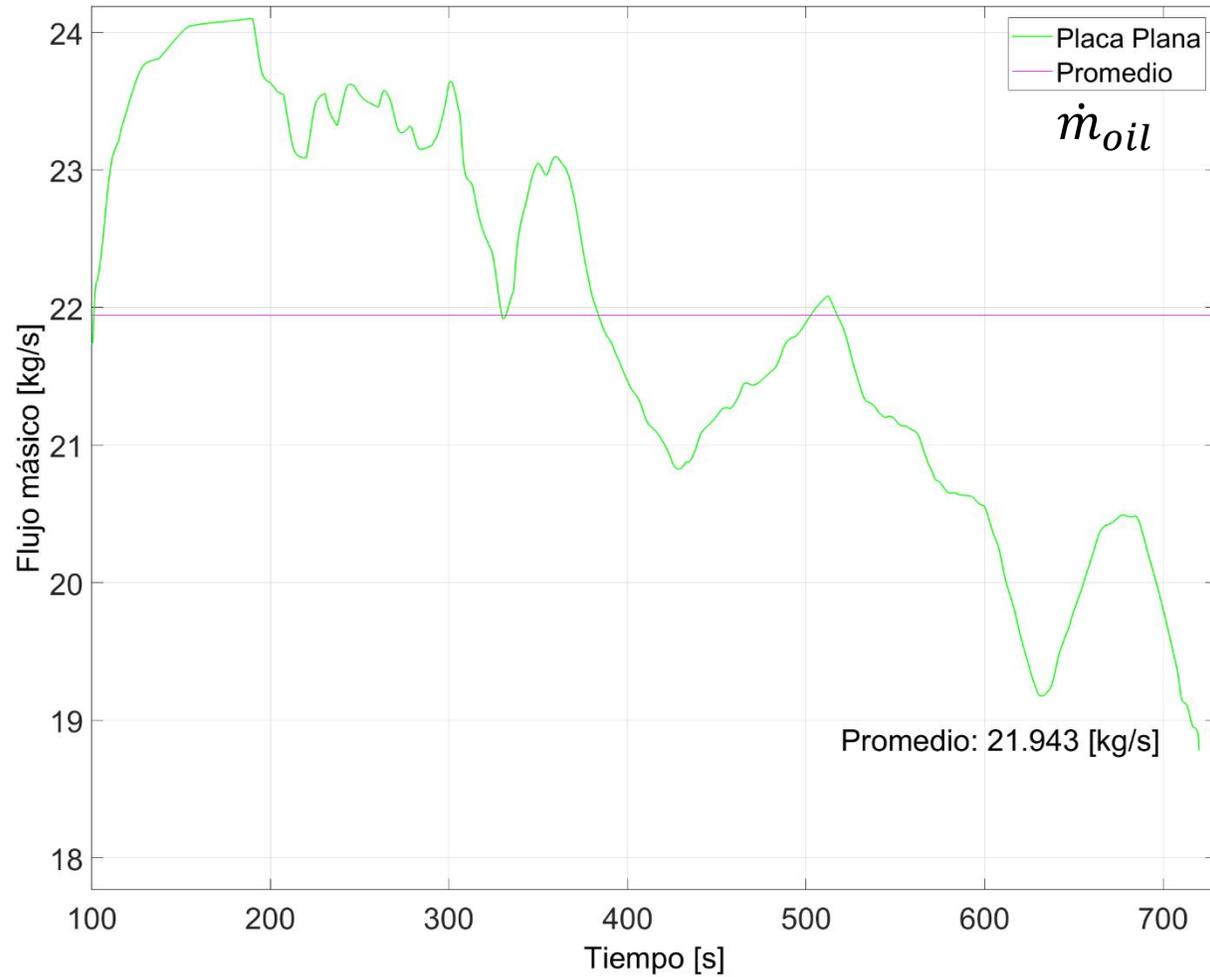
El promedio de gas en la salida de gas es de 0.108 [kg/s]

Flujo másico – Salida de Crudo



El promedio de crudo en la salida de crudo es de 21.943 [kg/s]

Flujo másico – Salida de Crudo

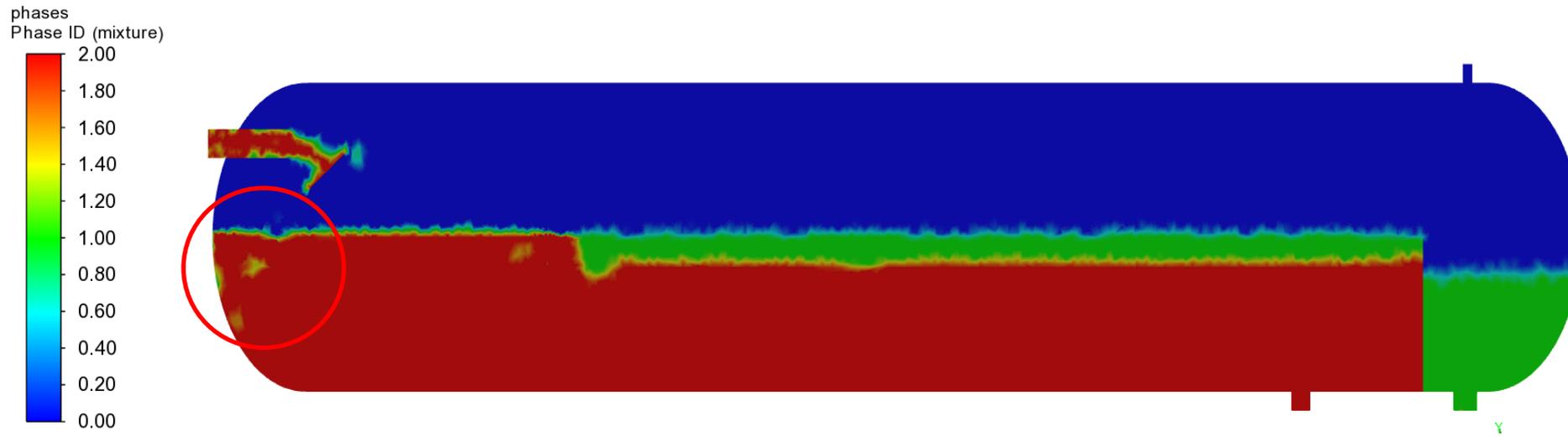
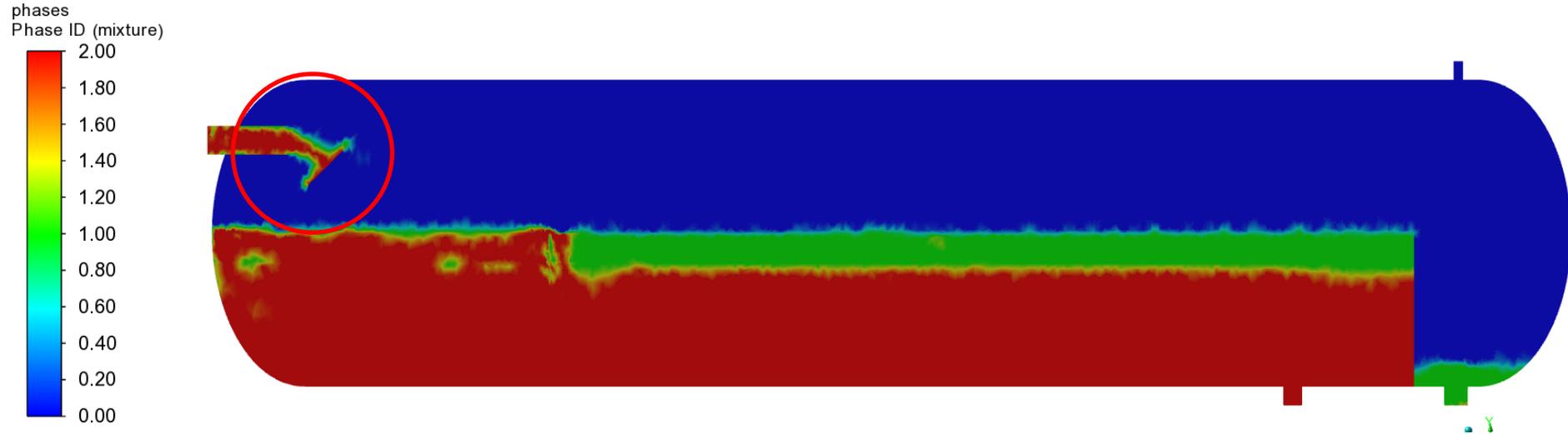


Flujo másico – Salida de Agua

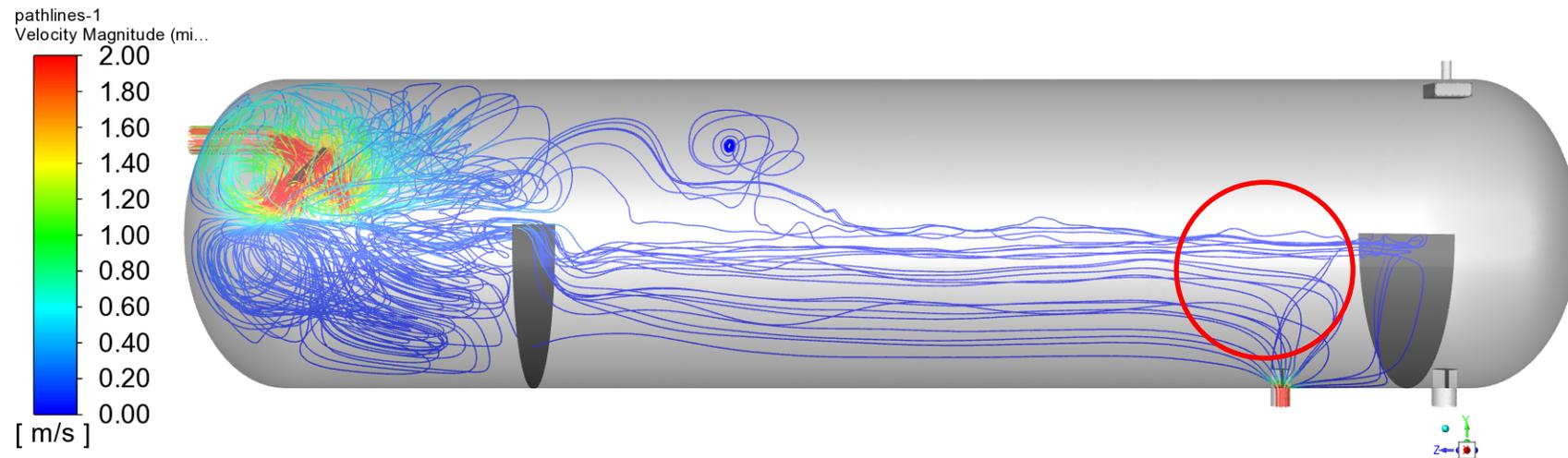
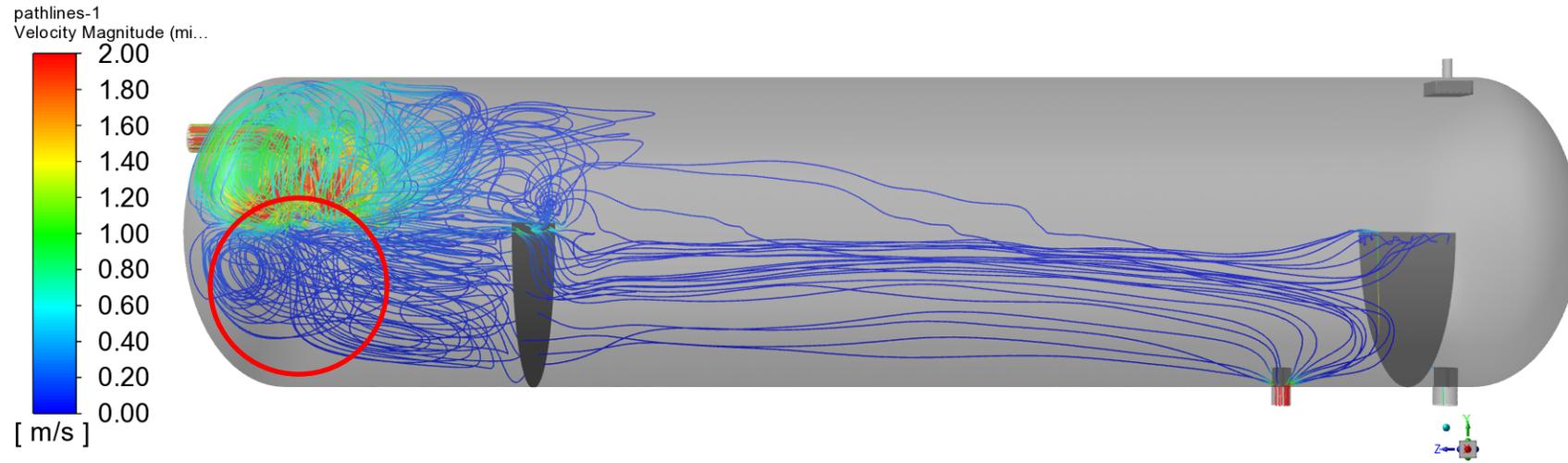


El promedio de agua en la salida de agua es de 89.808 [kg/s]

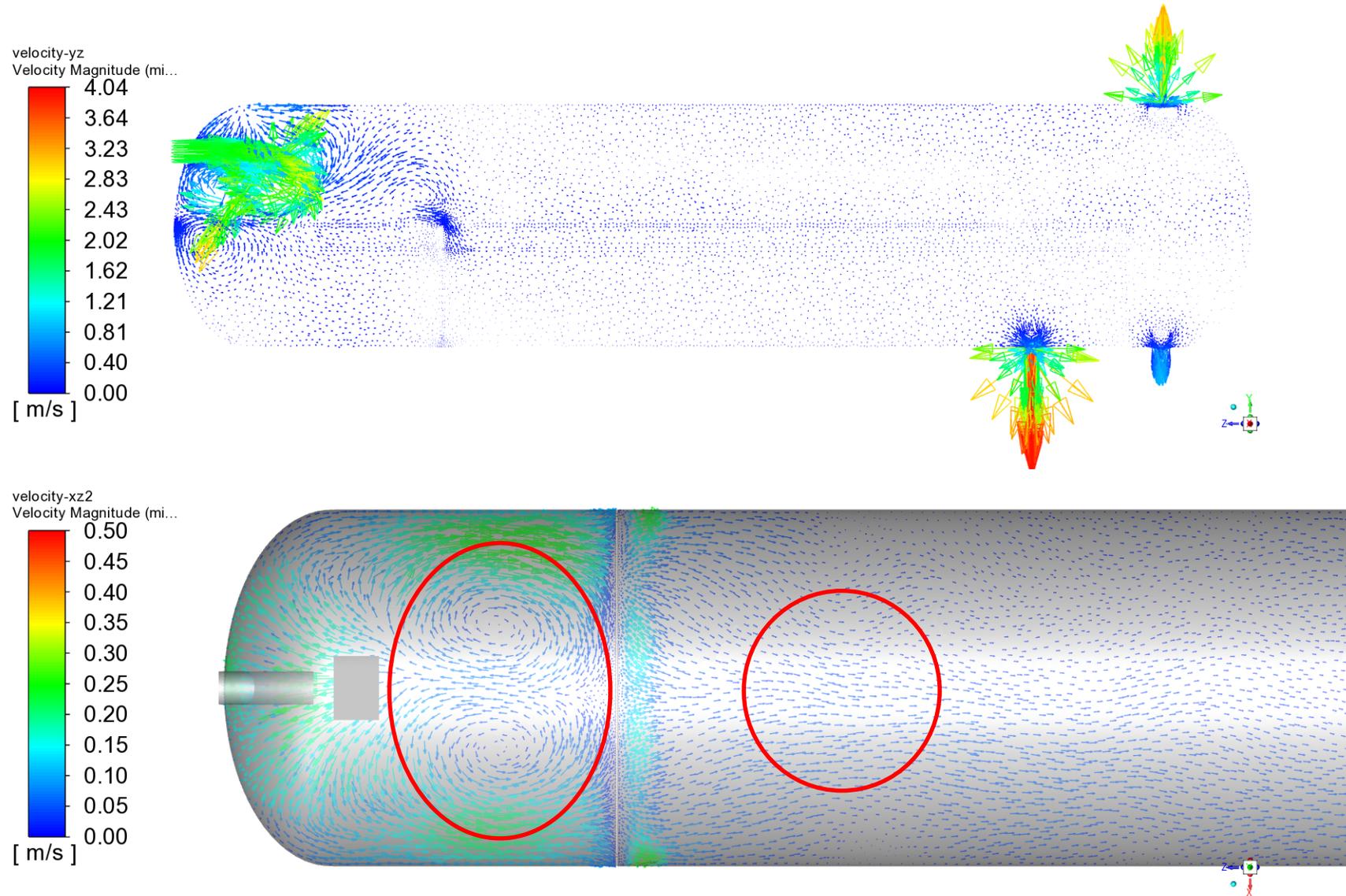
Contornos de fases



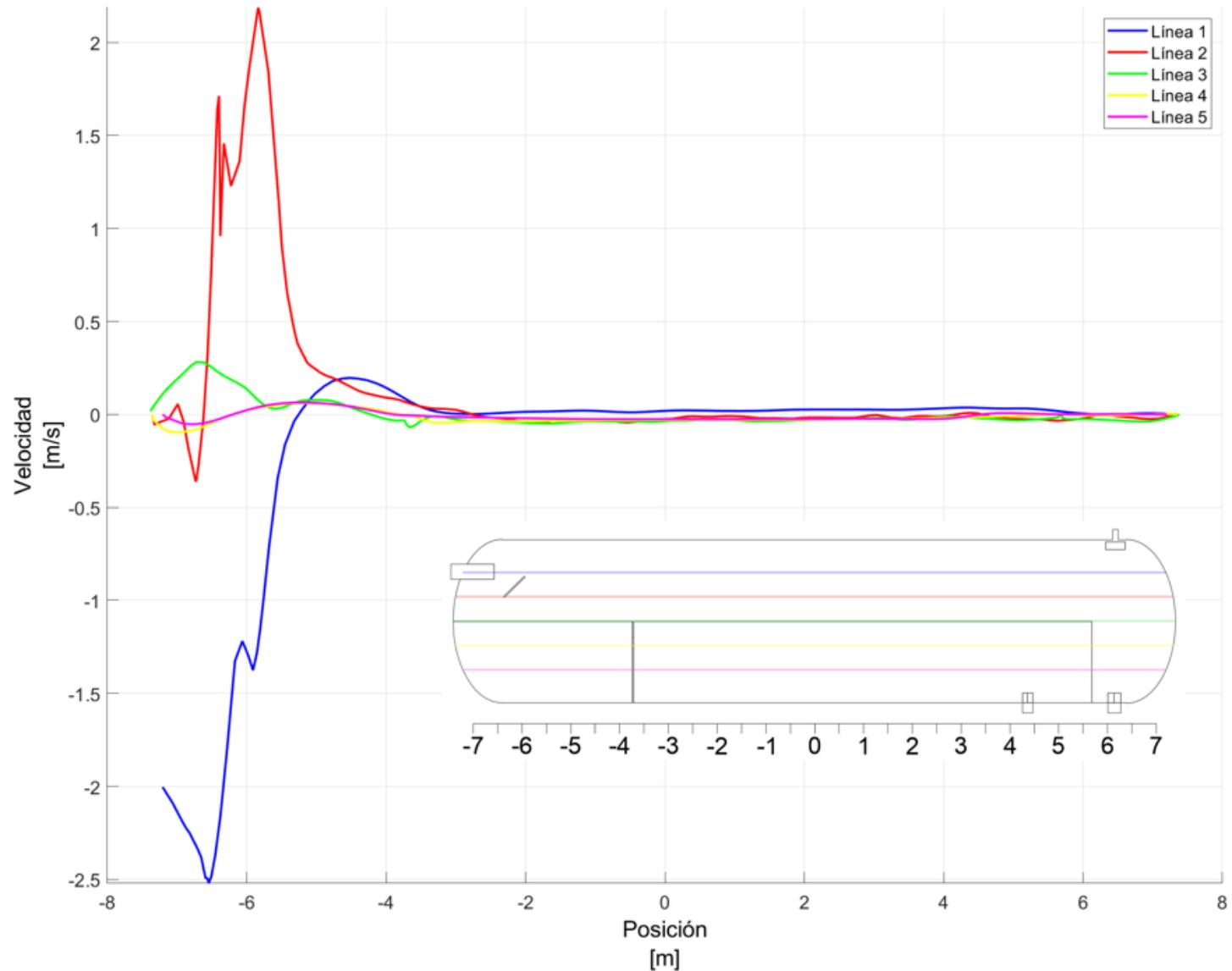
Líneas de corriente



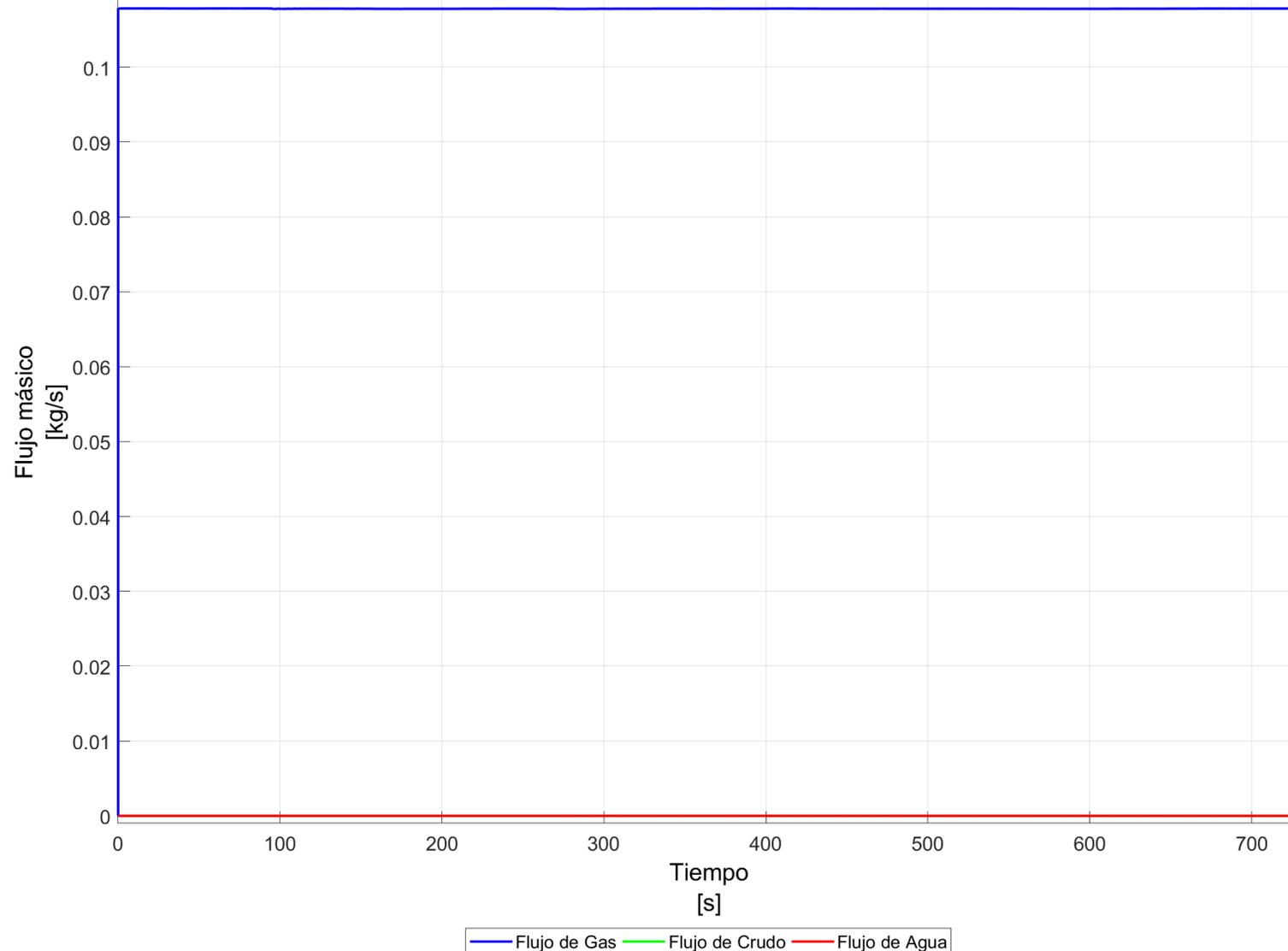
Perfiles de velocidad



Perfiles de velocidad



Flujo másico – Salida de Gas



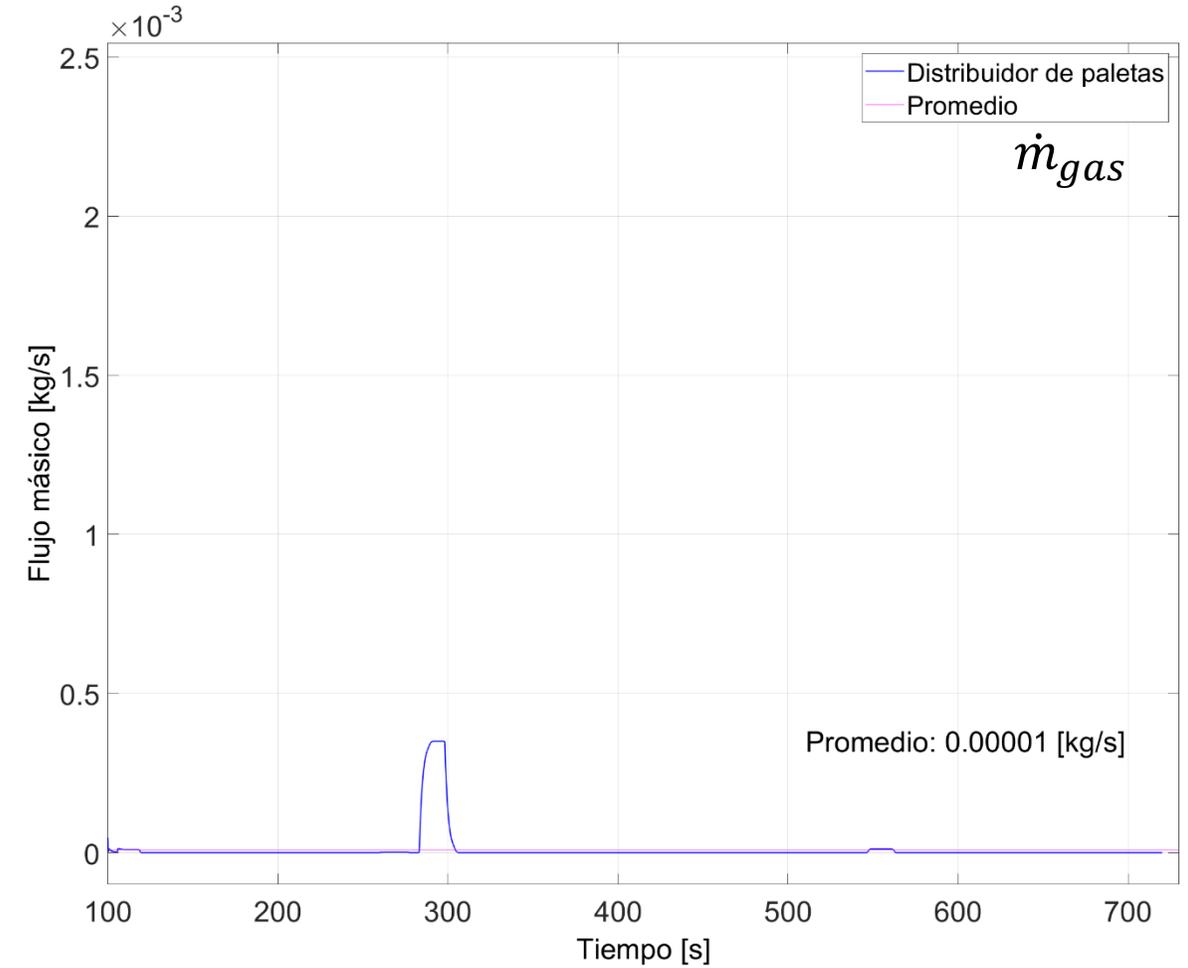
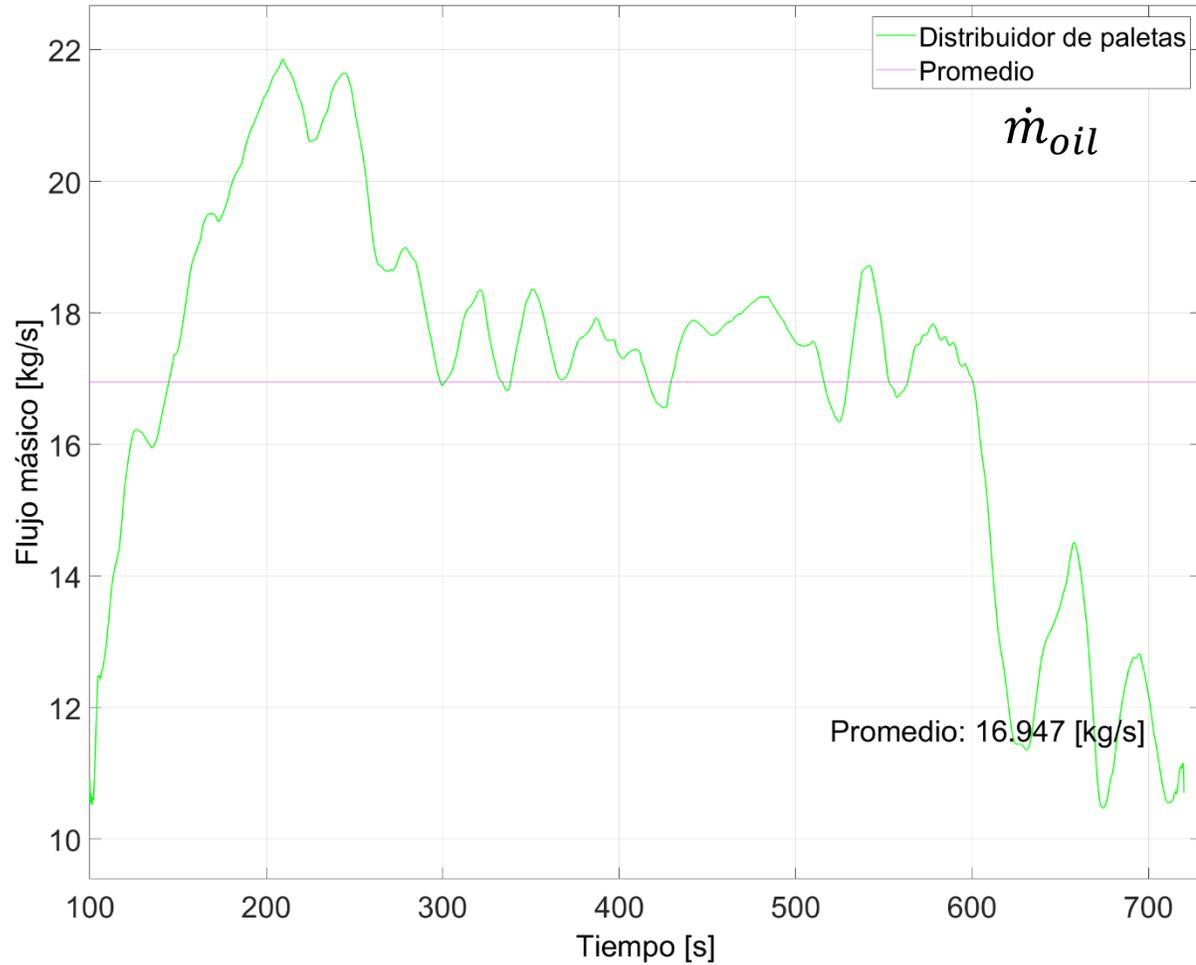
El promedio de gas en la salida de gas es de 0.108 [kg/s]

Flujo másico – Salida de Crudo

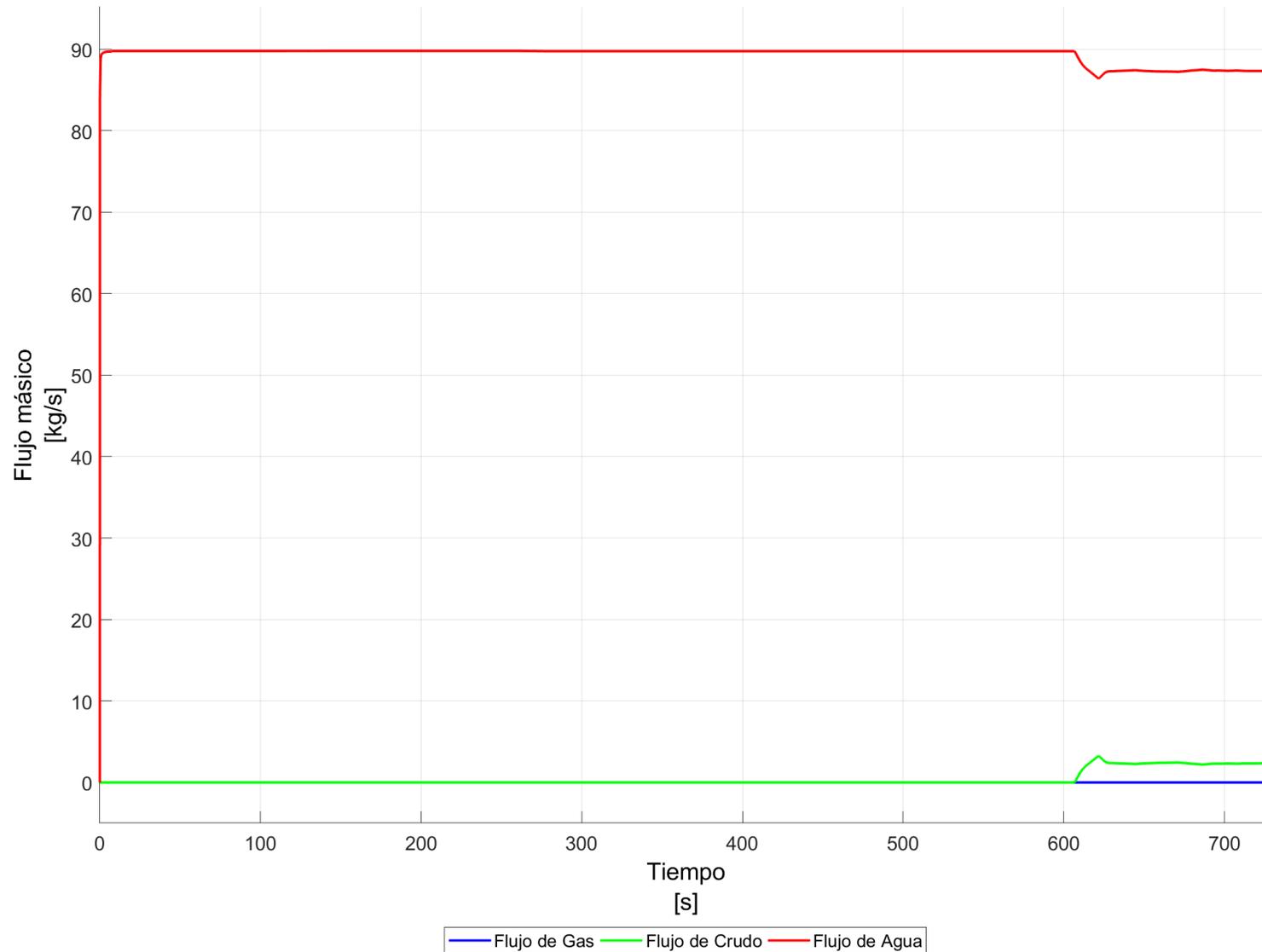


El promedio de crudo en la salida de crudo es de 16.951 [kg/s]

Flujo másico – Salida de Crudo

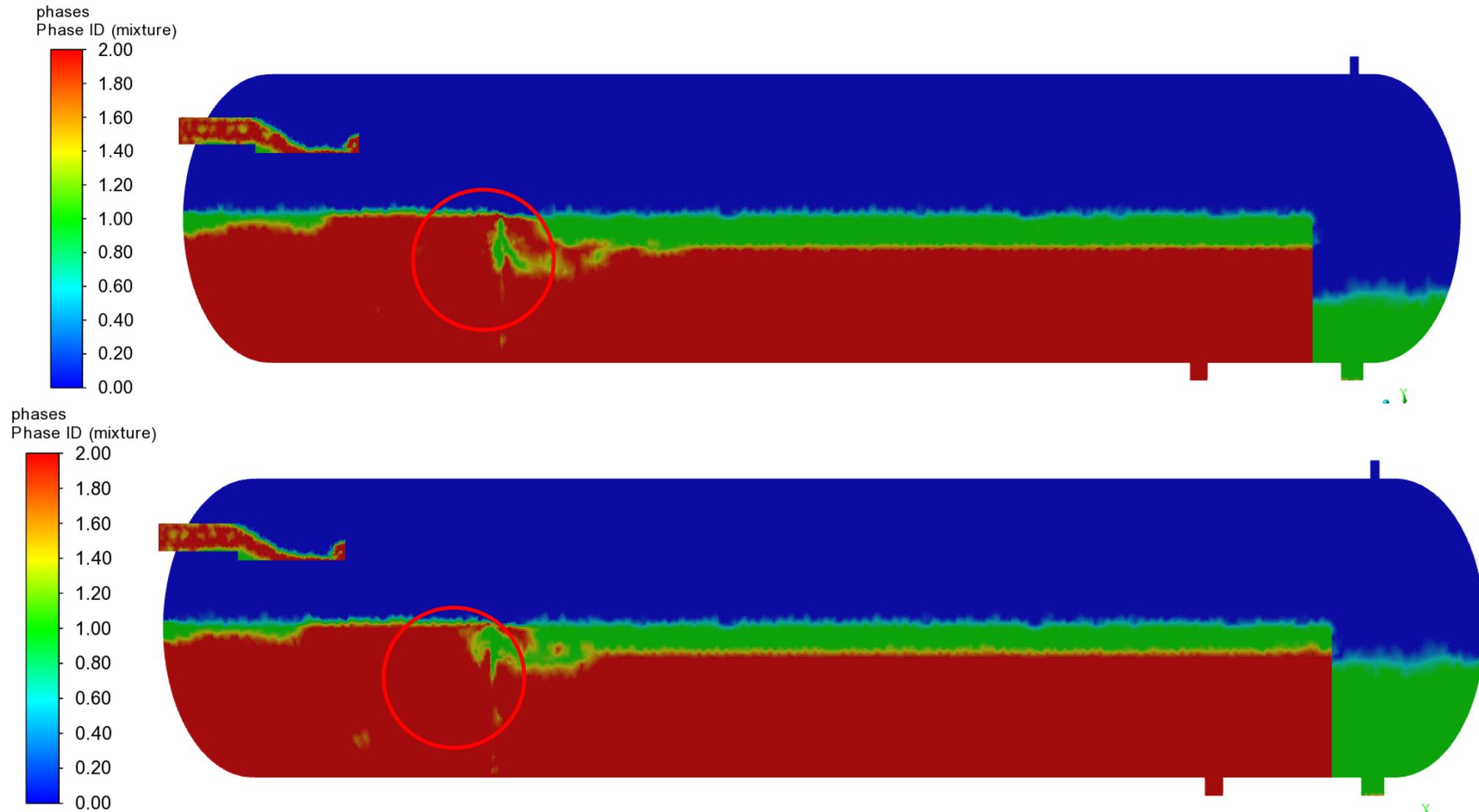


Flujo másico – Salida de Agua

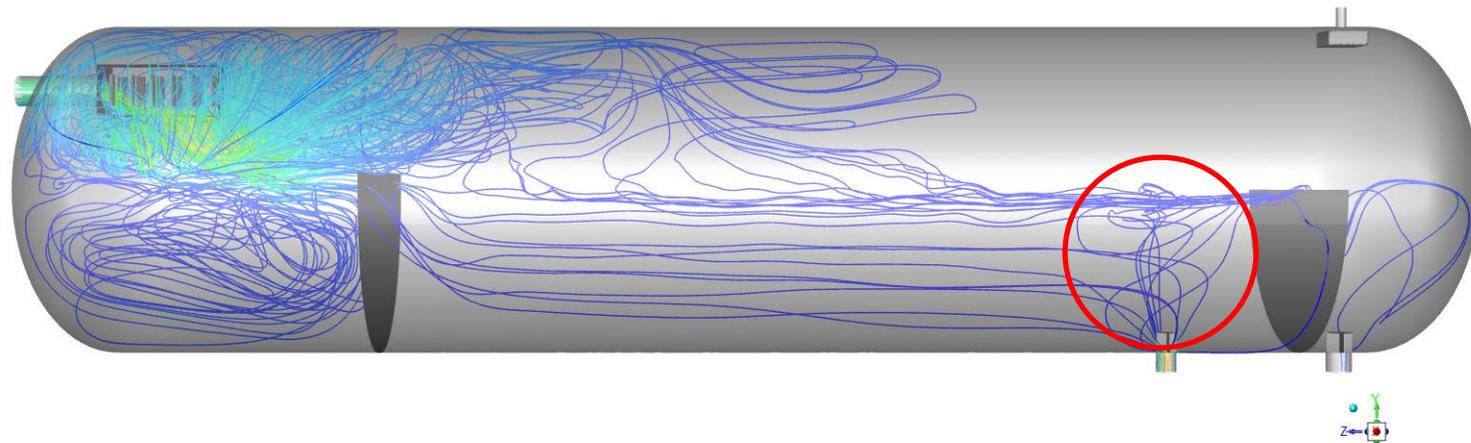
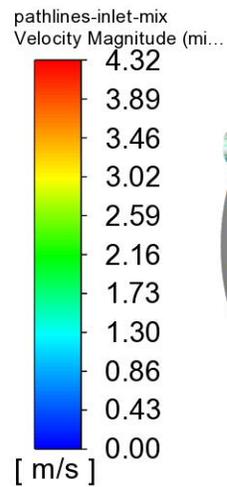
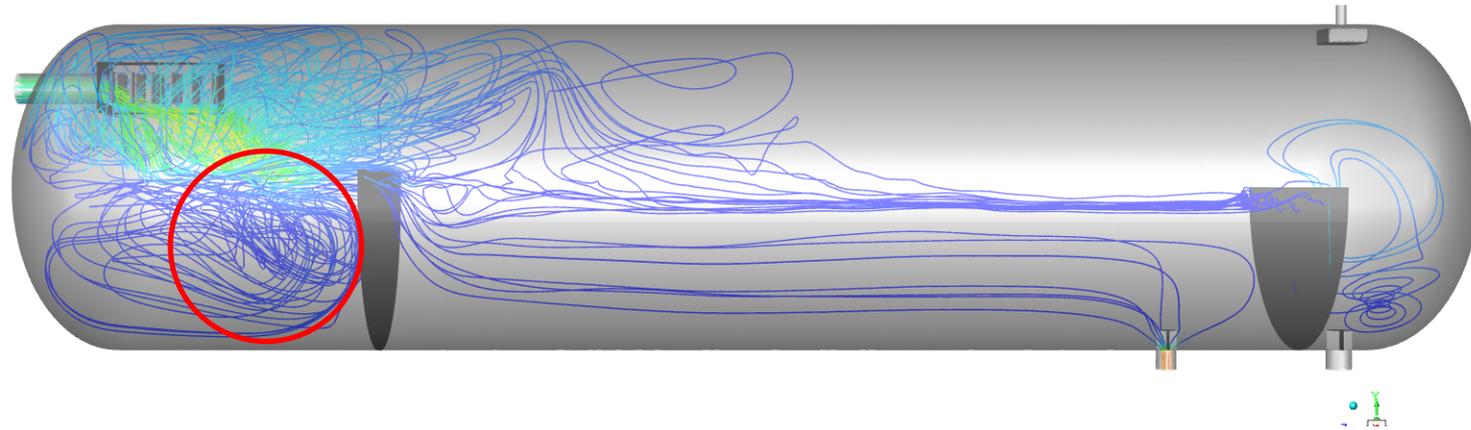
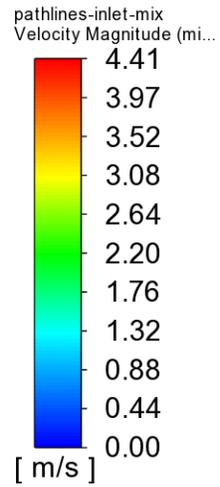


El promedio de agua en la salida de agua es de 89.337 [kg/s]

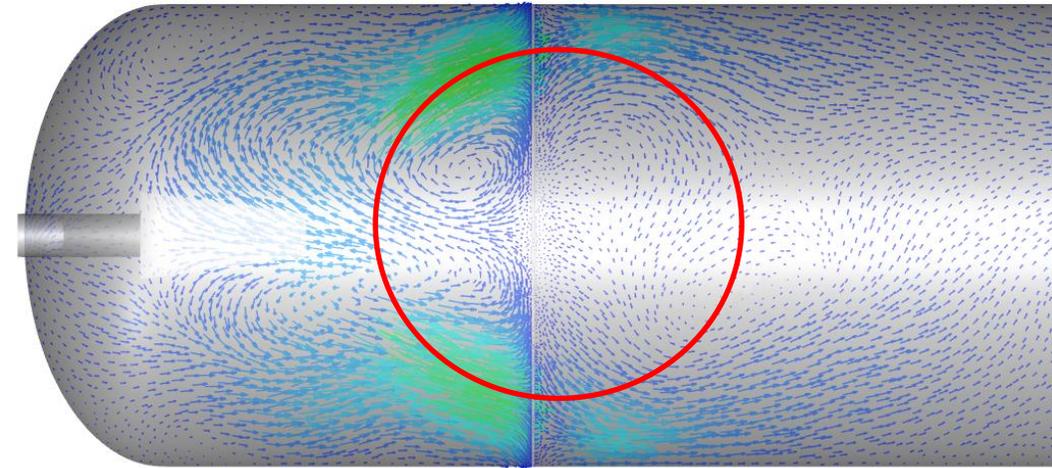
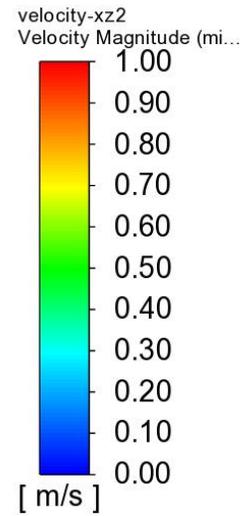
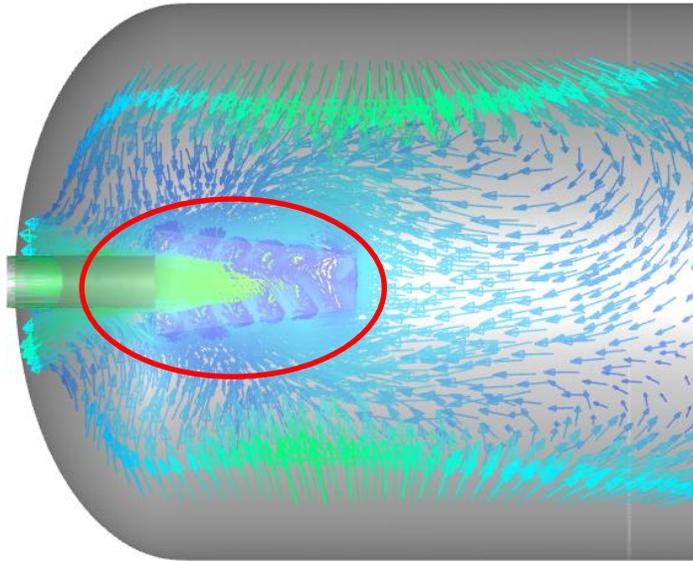
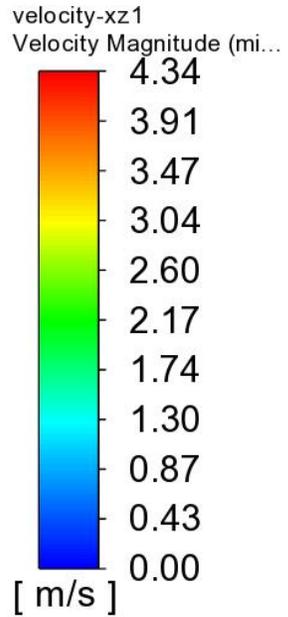
Contornos de fases



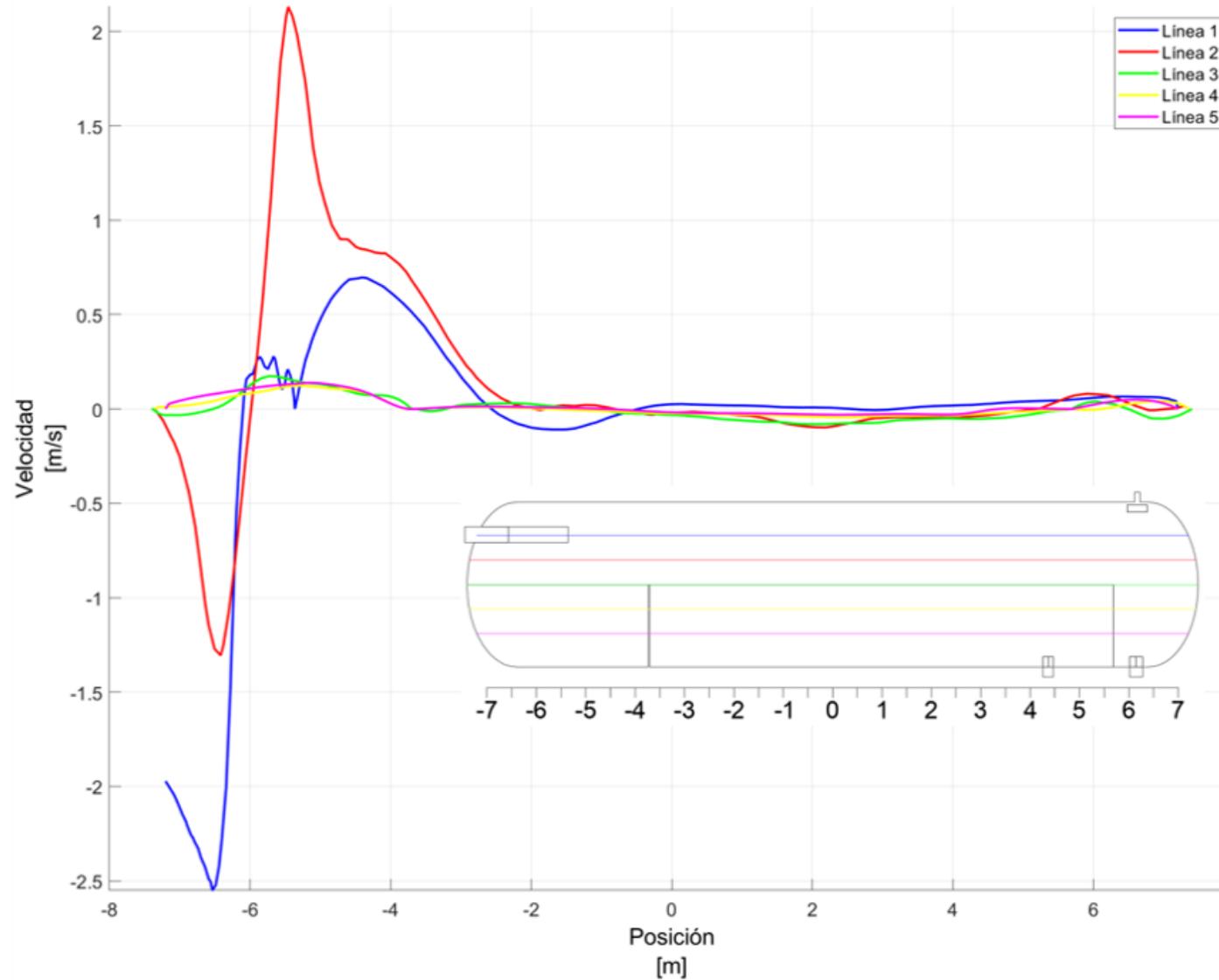
Líneas de corriente



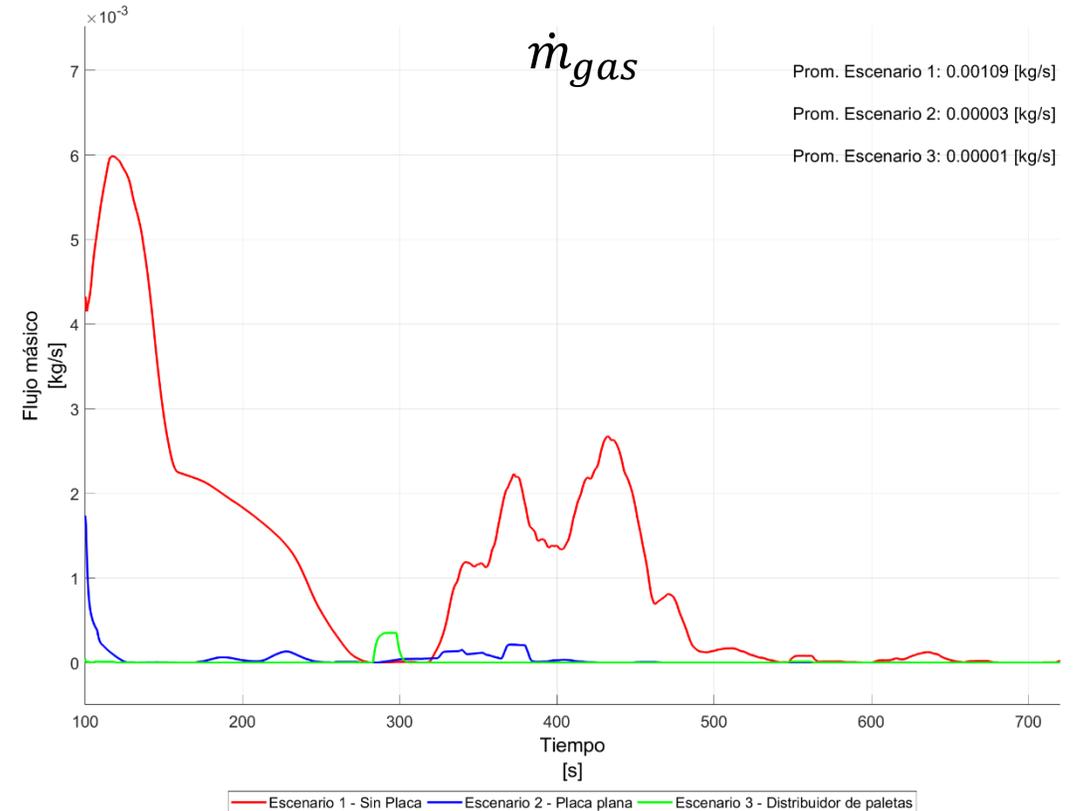
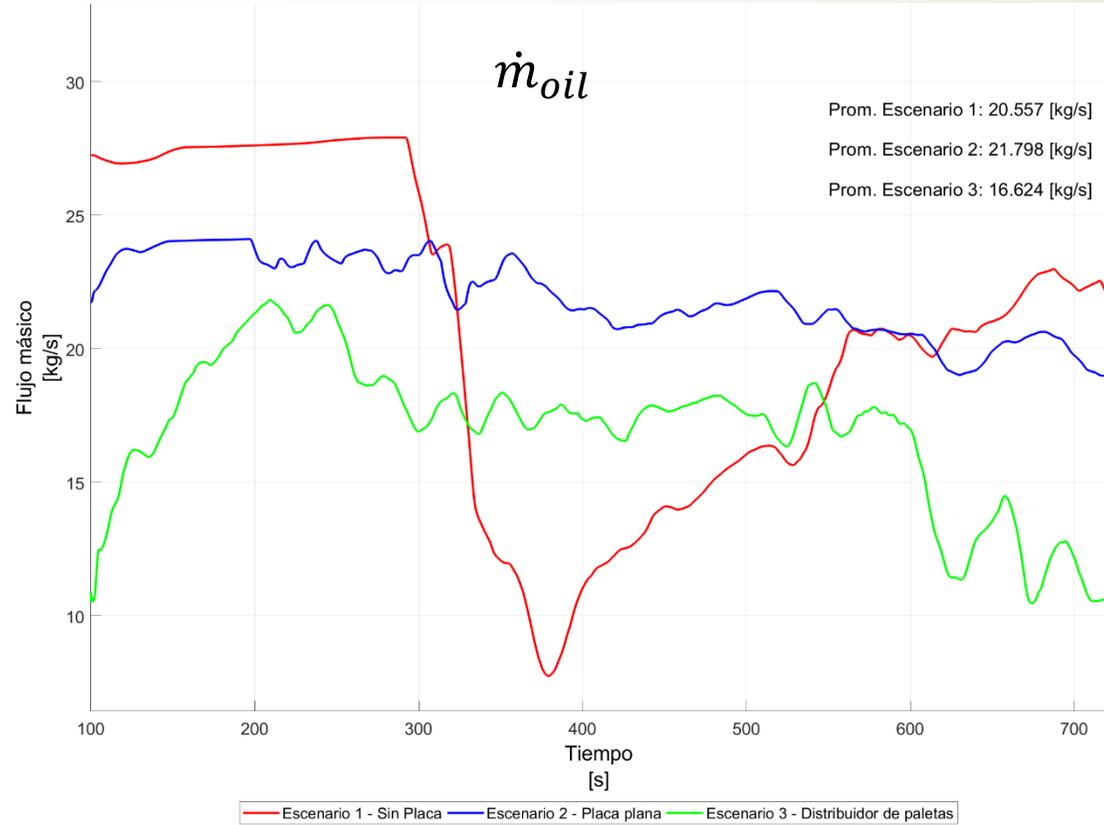
Perfiles de velocidad



Perfiles de velocidad



Conclusiones



	Separación de Gas [%]	Separación de Crudo [%]	Separación de Agua [%]
Escenario 1	98.86	66.1	89.19
Escenario 2	99.75	76.85	92.47
Escenario 3	99.82	57.89	86.43