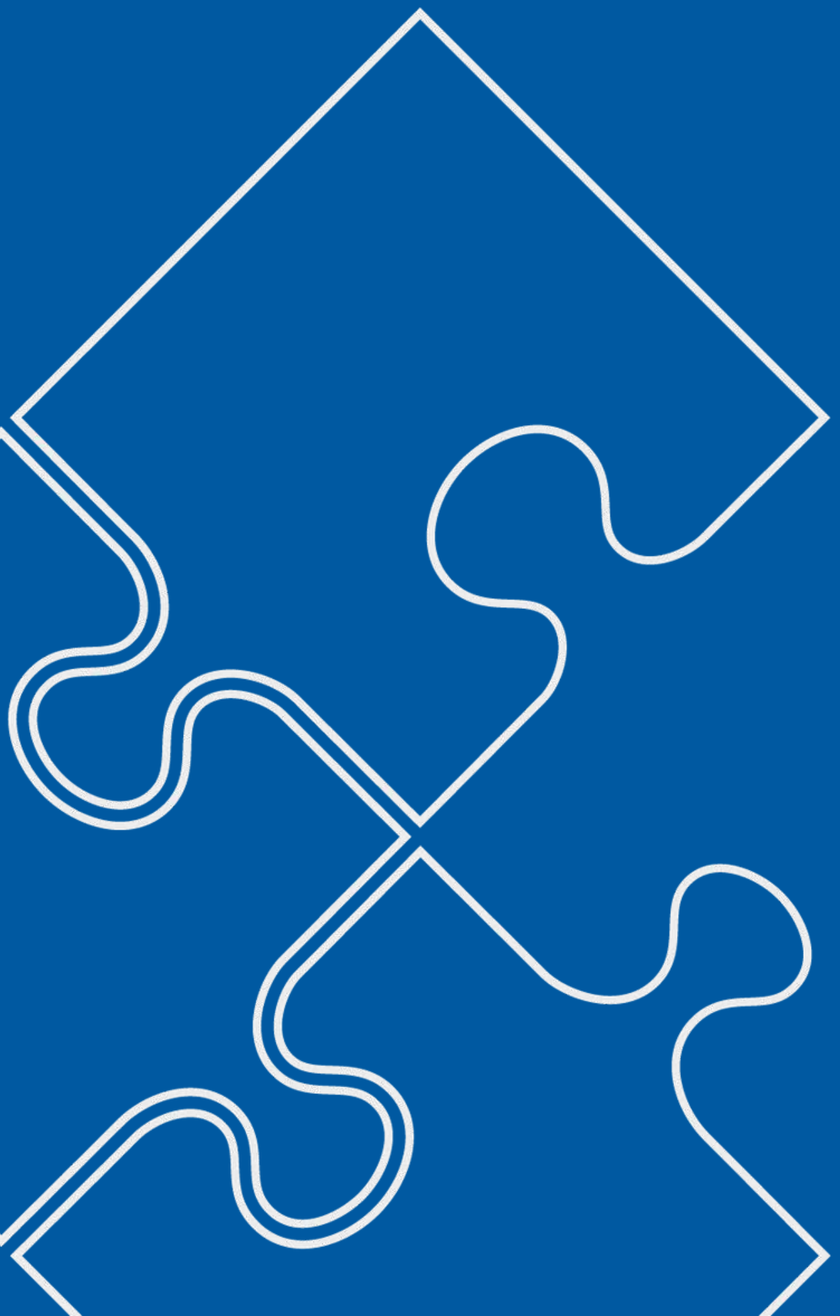
Encontro Nacional do Programa de Formação de Recursos Humanos da ANP - 2026

Geração de Dados Sintéticos por Simulação Numérica para o Estudo de Anomalias em Garantia de Escoamento

João Paulo Póvoa; Eugênio Fortaleza; Taygoara Felamingo

PRH ANP/57
Tipo de bolsa: Graduação
Universidade de Brasília (UnB)

Gestão:



#1

Detecção Antecipada Importa

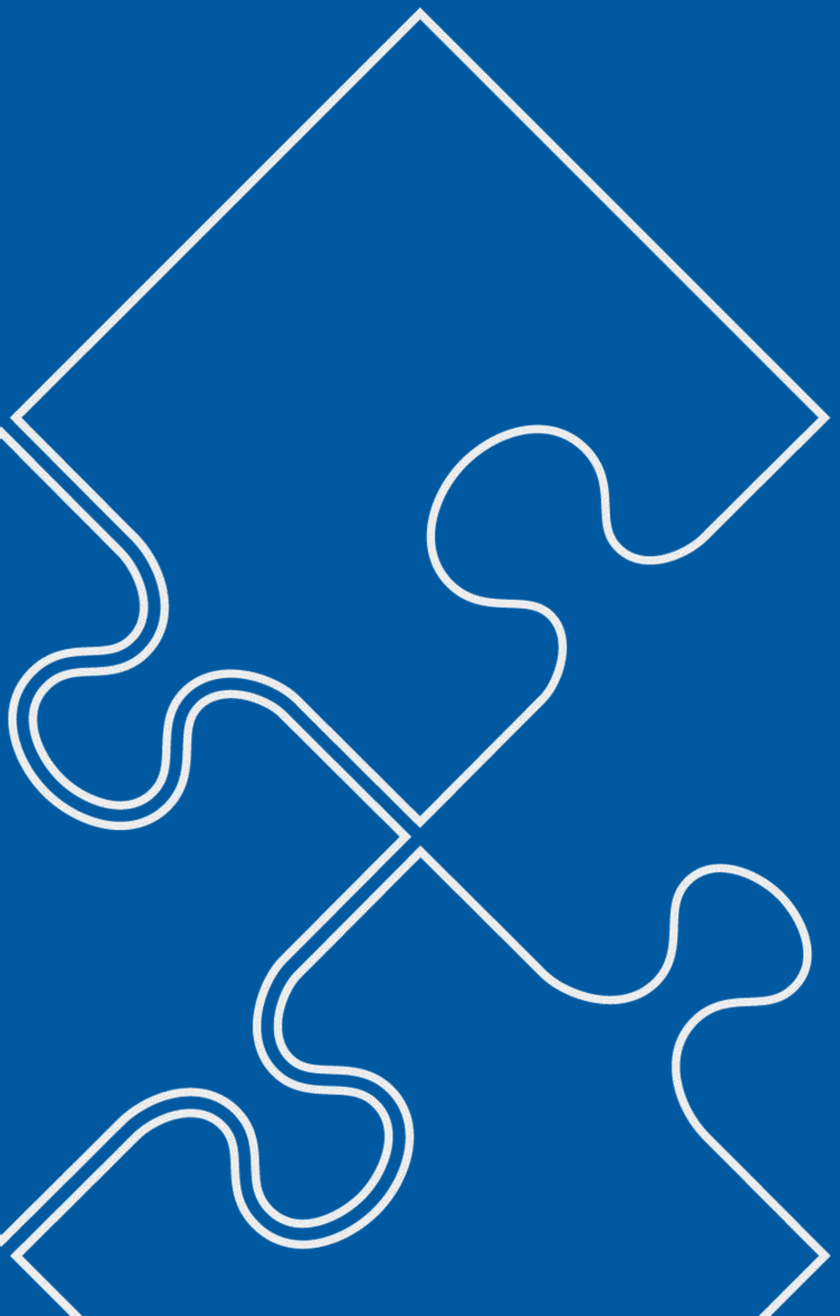
Detecção Antecipada de Problemas Operacionais Reduz Prejuizos e Aumenta Segurança



Detecção Antecipada → **Ação Preventiva**

Dados Sintéticos para o Estudo de Anomalias em GARESC

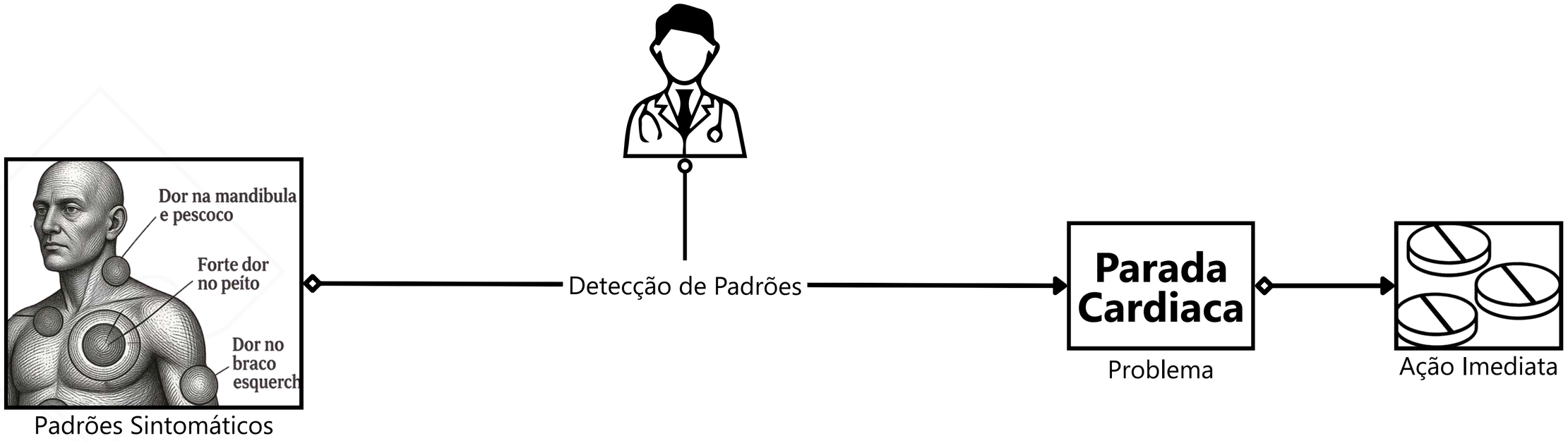
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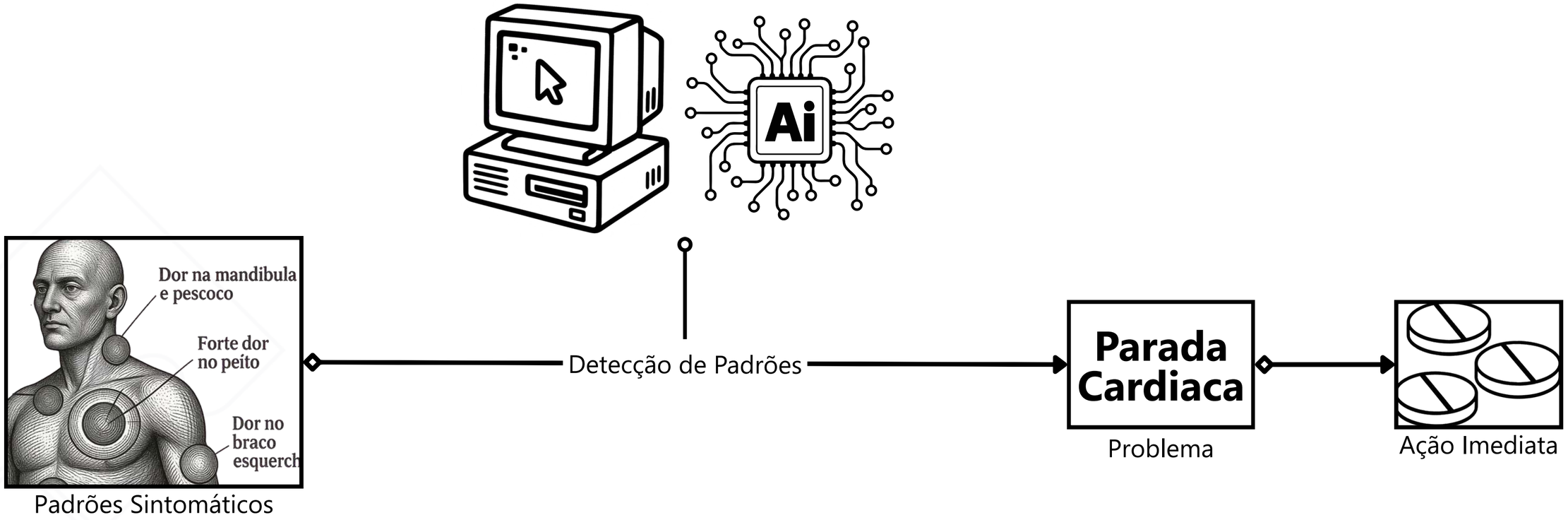
#2

Detecção é Feita pelo Reconhecimento de Sinais

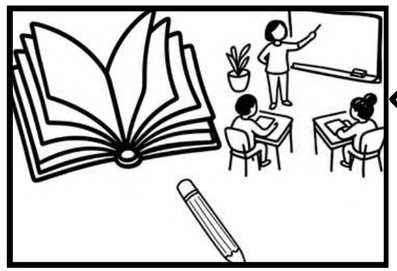
Detecção de Problemas
é Feita Pelo Reconhecimento de Padrões e Sinais



Aprendizado de Máquina
Tornou Computadores Excelentes em Reconhecer Padrões



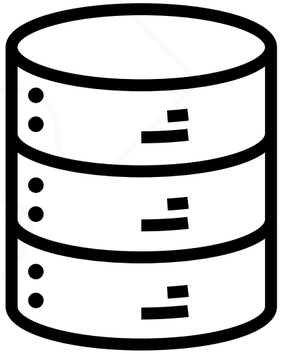
Aprendizado Depende de Informação (Dados)



Aulas, Estudos de Caso, Livros

Treinamento

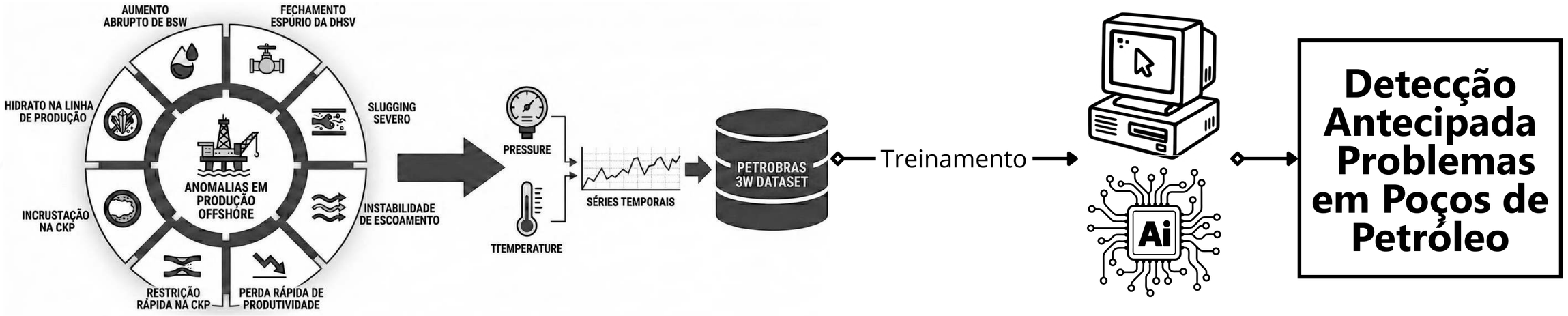
Habilidade de Detecção Antecipada



Informação Interpretada

Treinamento

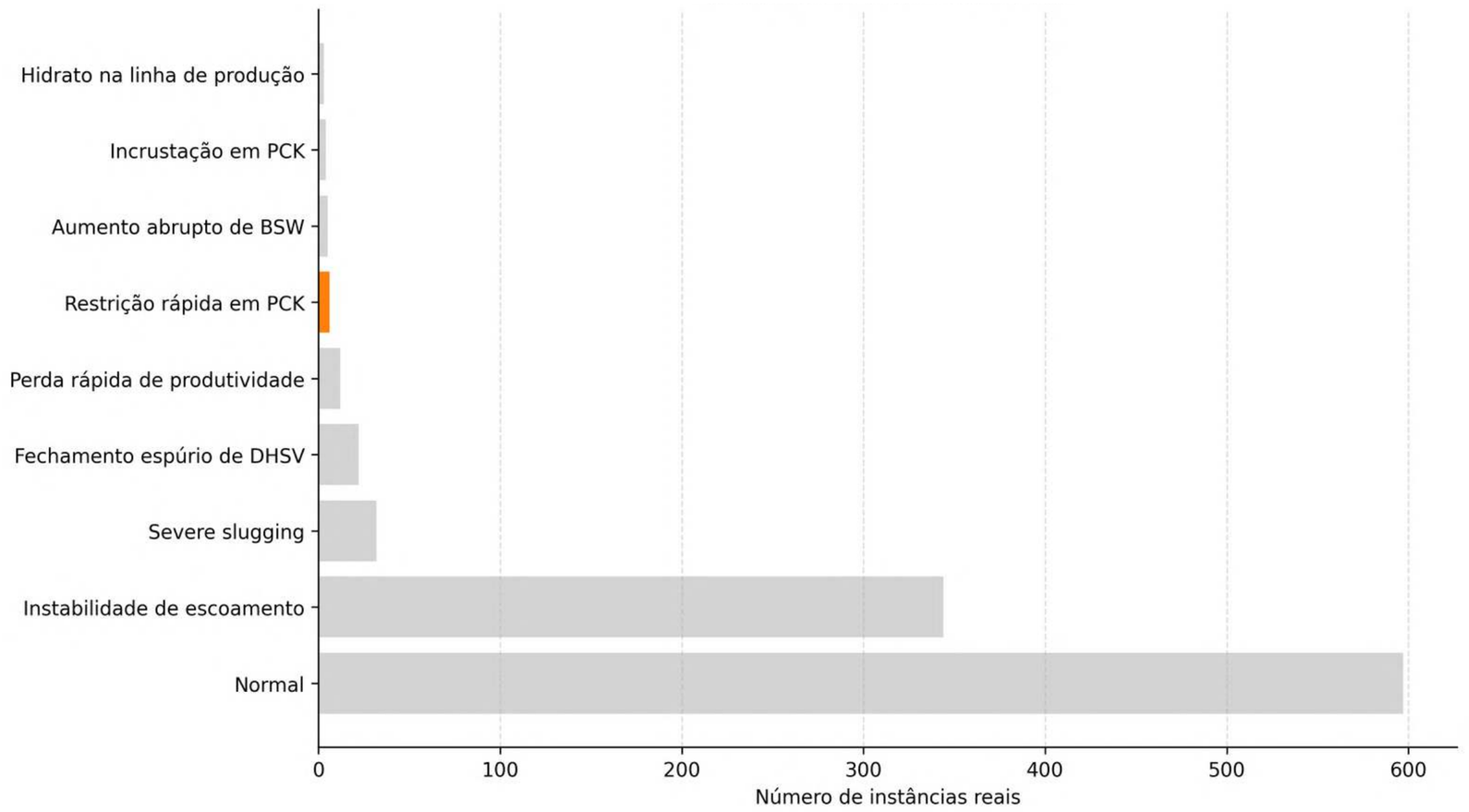
3W Dataset - Fonte de Informação Para Máquinas Aprenderem a Reconhecer Problemas de GARESC

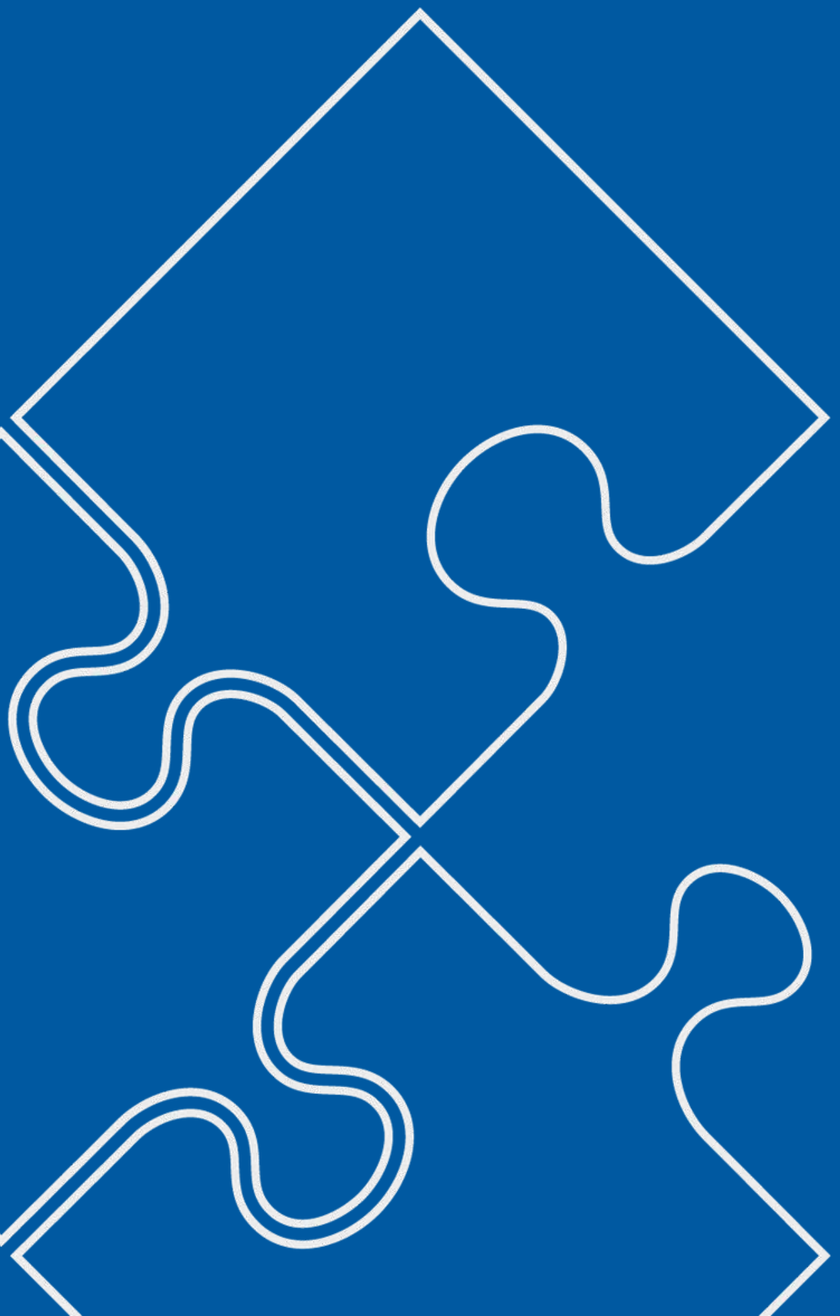


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Desafio: 3W Necessita de Mais Dados

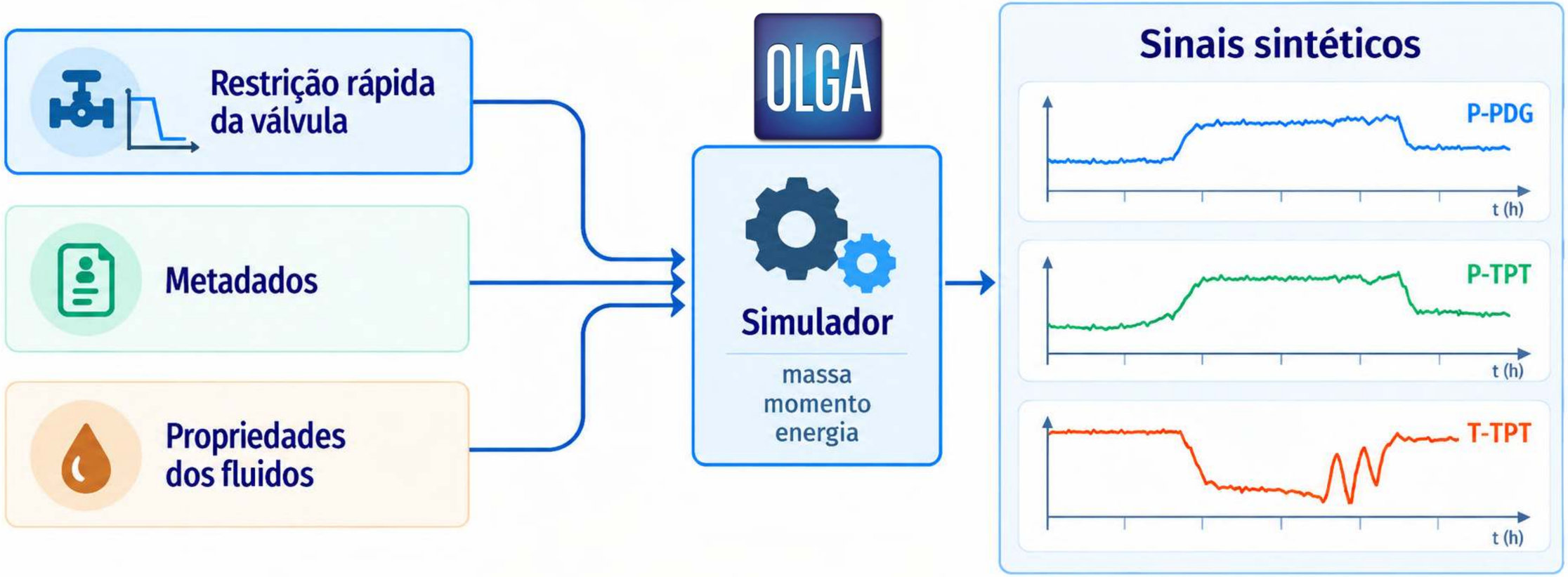




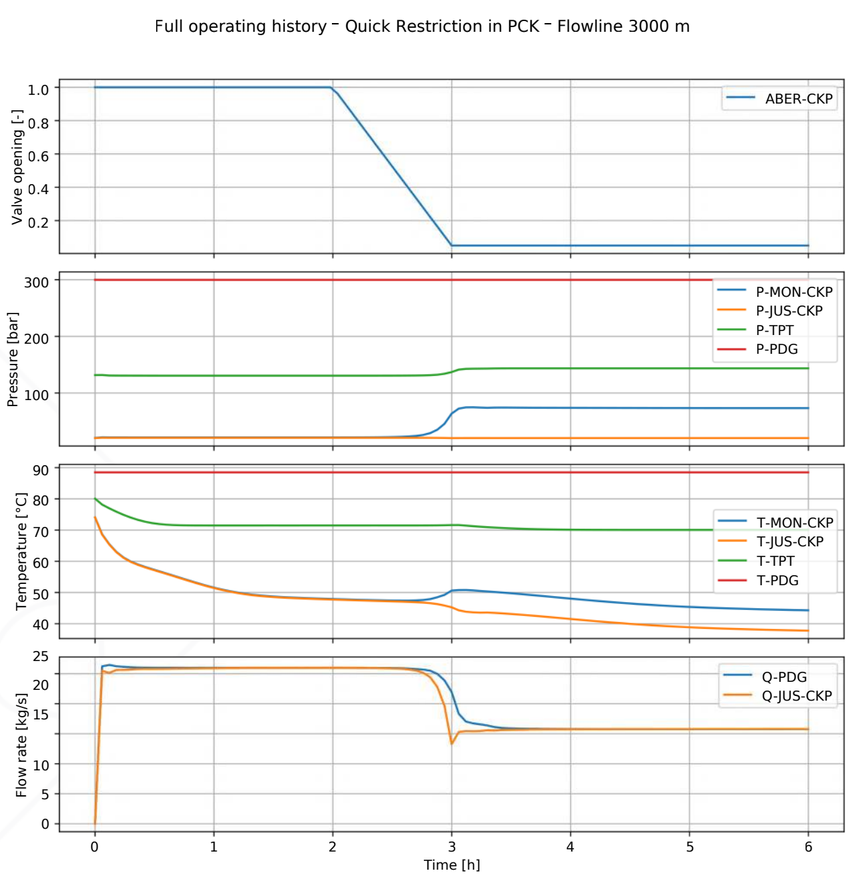
#3 Objetivo:

Gerar Dados desses Problemas Operacionais por Simulação Numérica

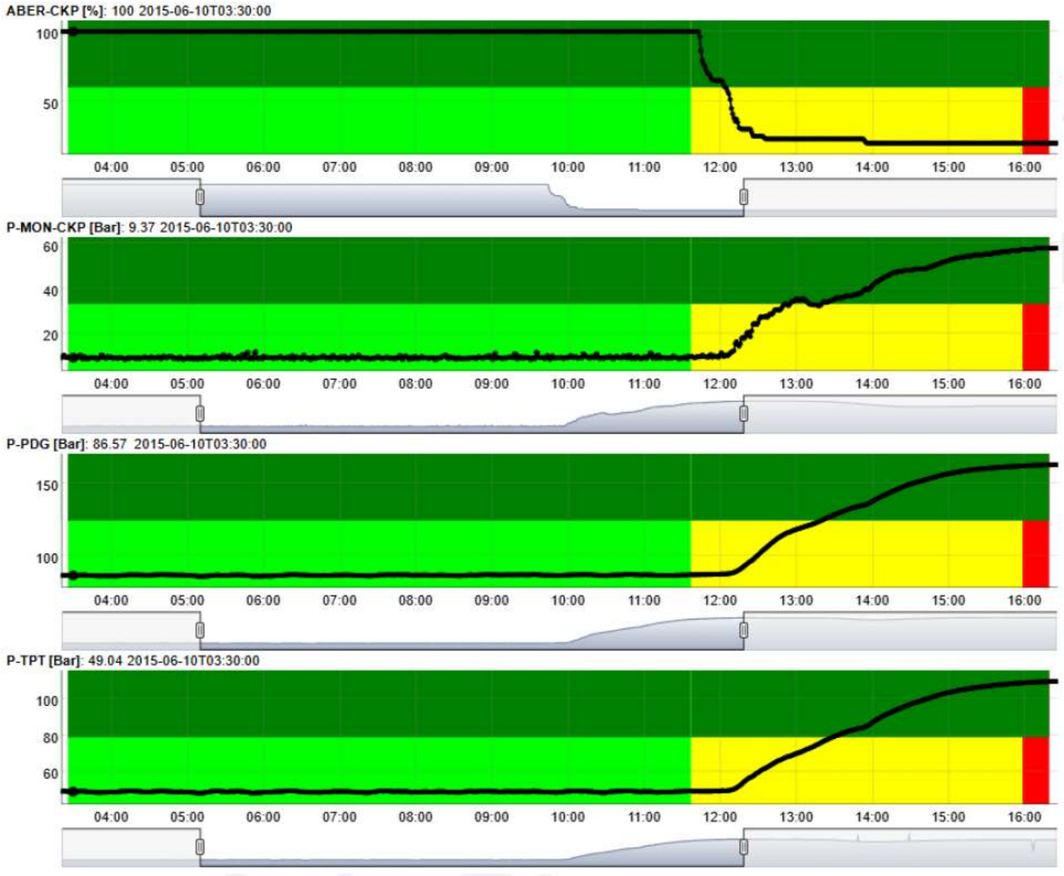
Metodologia



Resultados

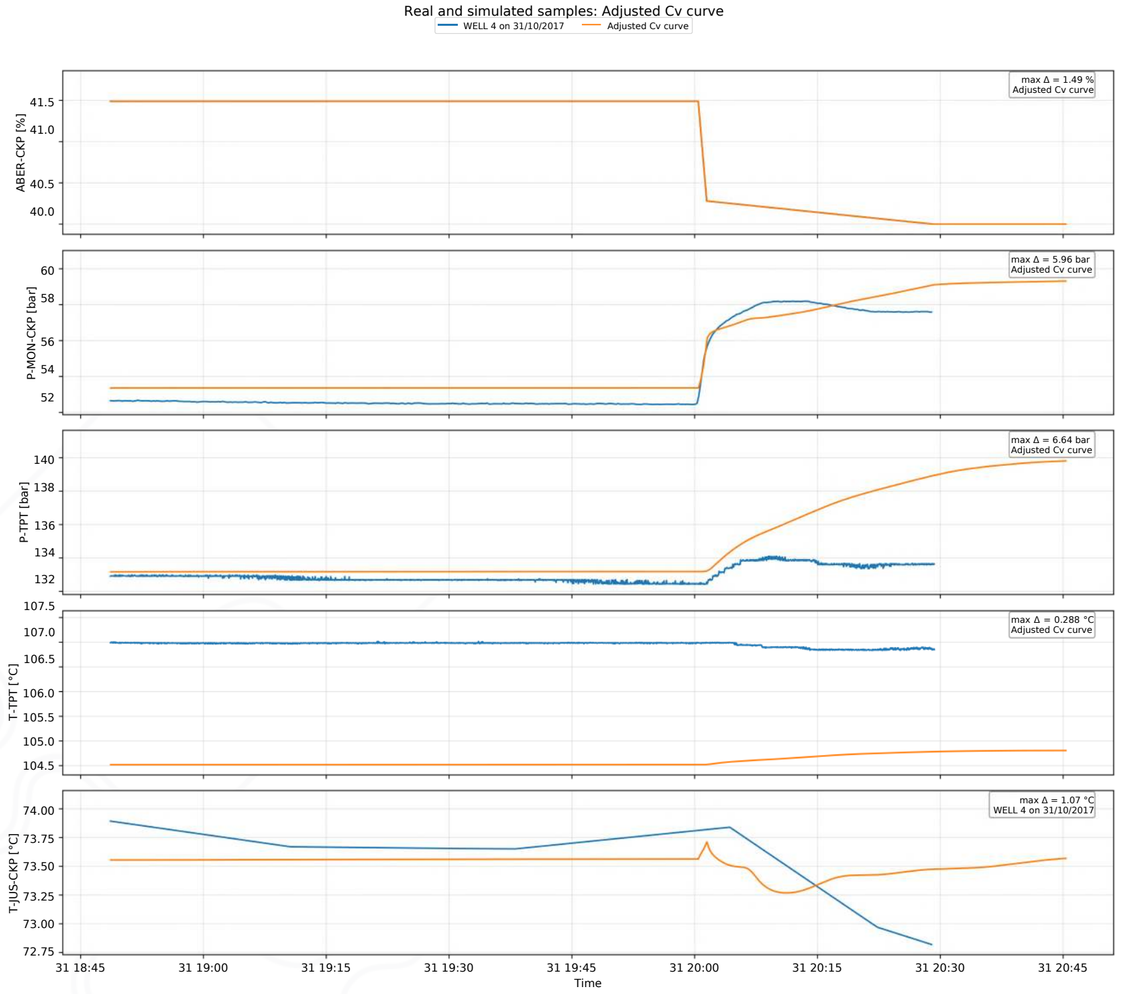


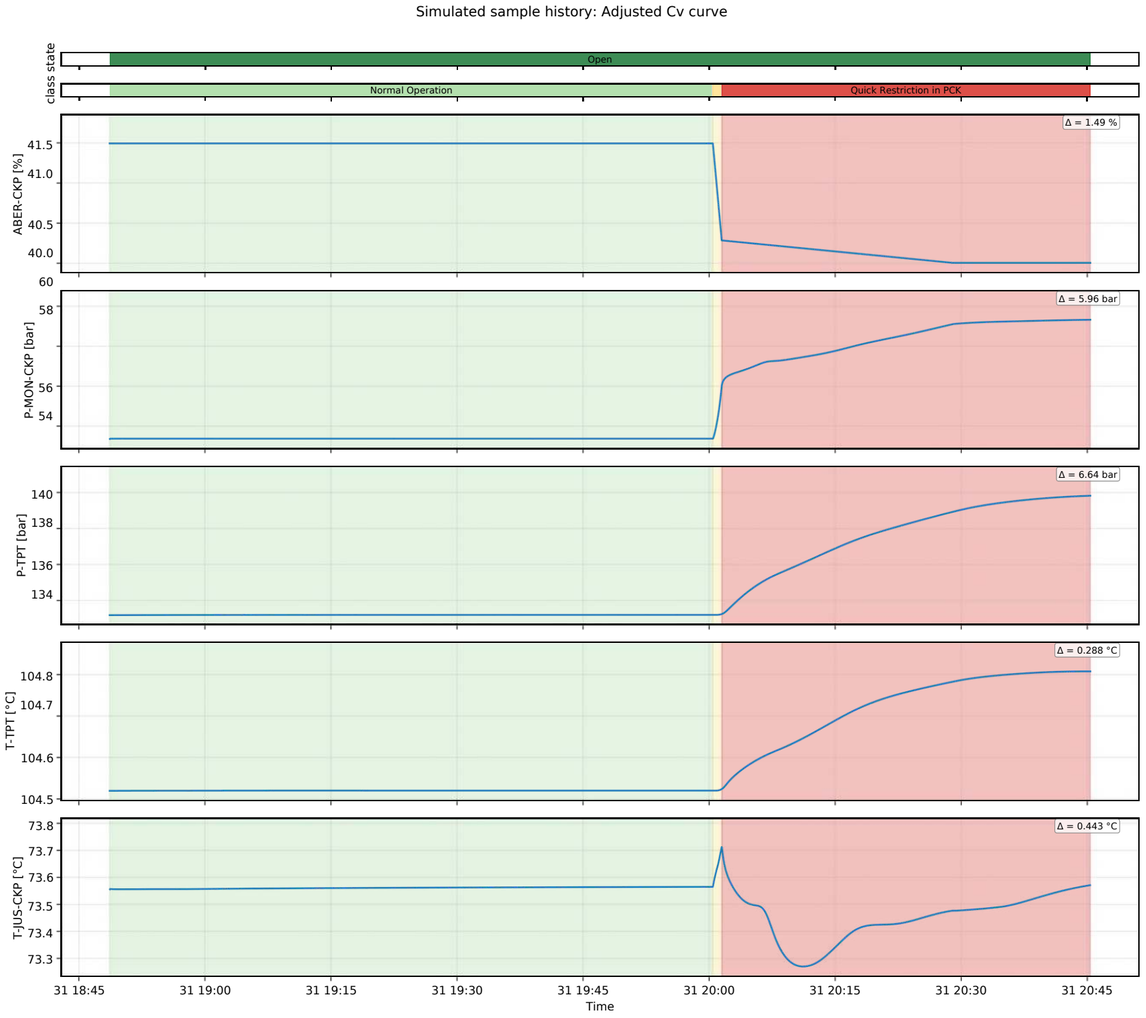
Resultado Simulado



Dado de Campo

Resultados: Avanços Recentes

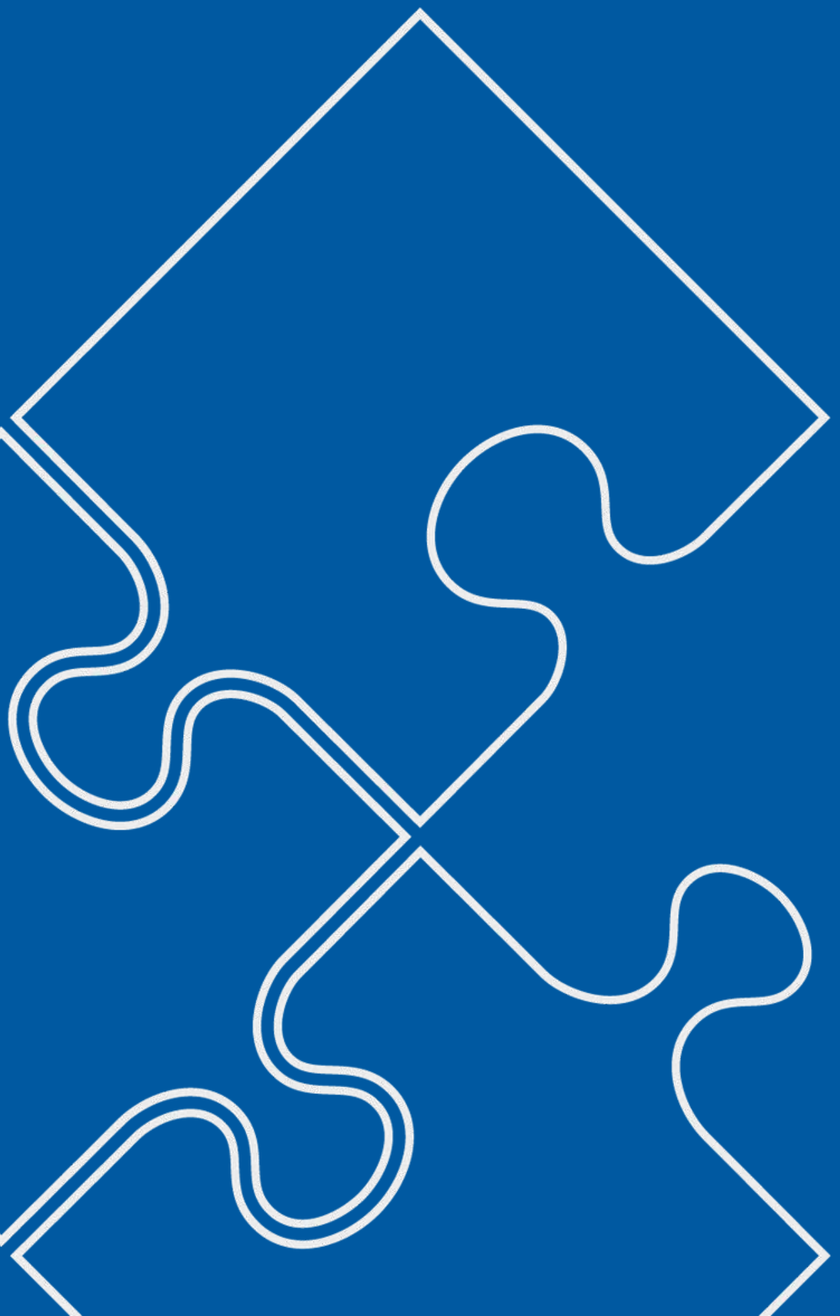




Dados Sintéticos para o Estudo de Anomalias em GARESC

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#4 Conclusões:

- **Framework de Geração, Rotulação e Validação de Dados de Restrição Abrupta da CKP Concluida com Sucesso**
- **Necessária calibração da Tabela PVT**
- **Ajuste fino de Parâmetros como Rugosidade**
- **Obtenção de Dados de Benchmark mais Confiáveis**

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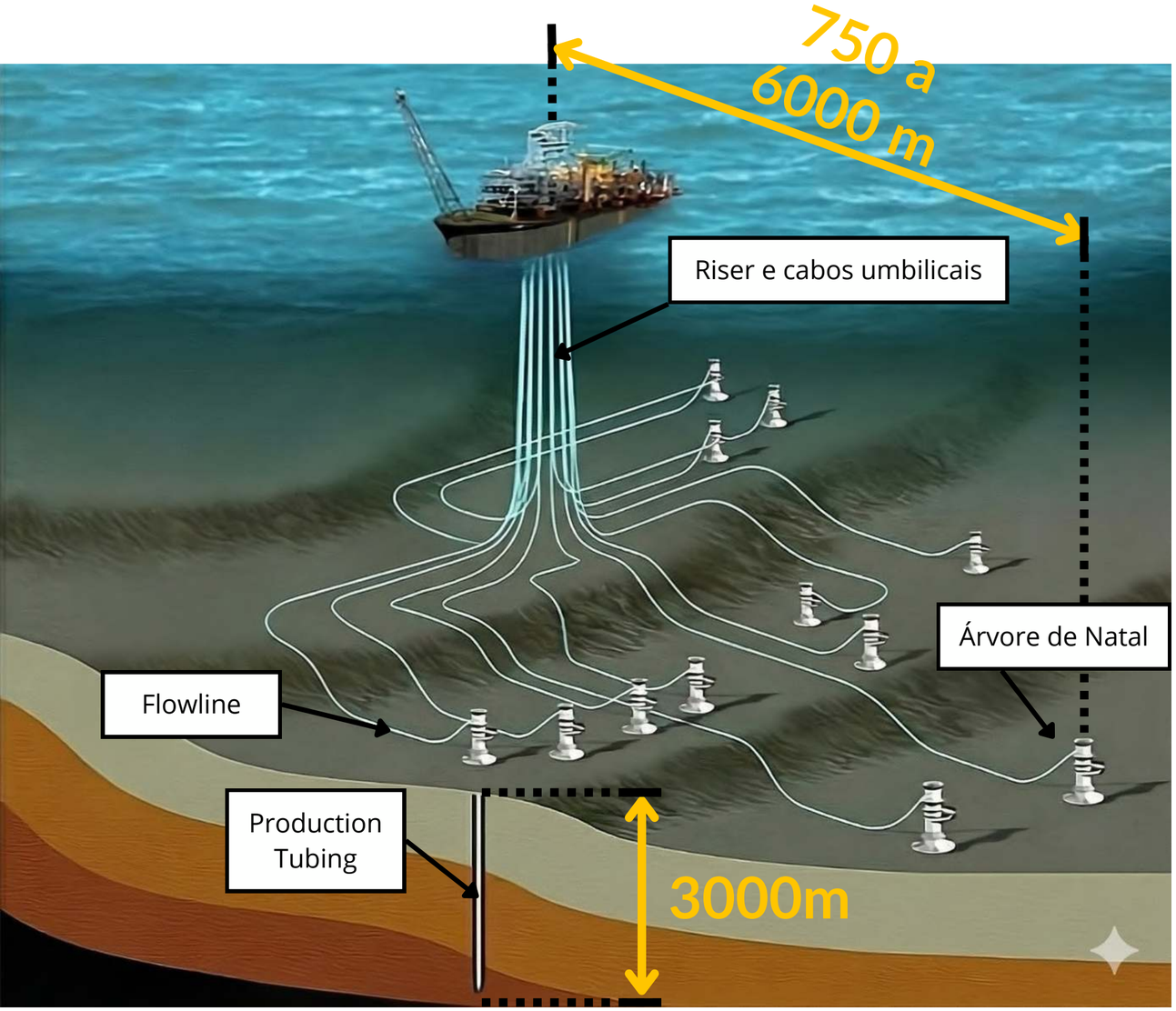
Linkedin

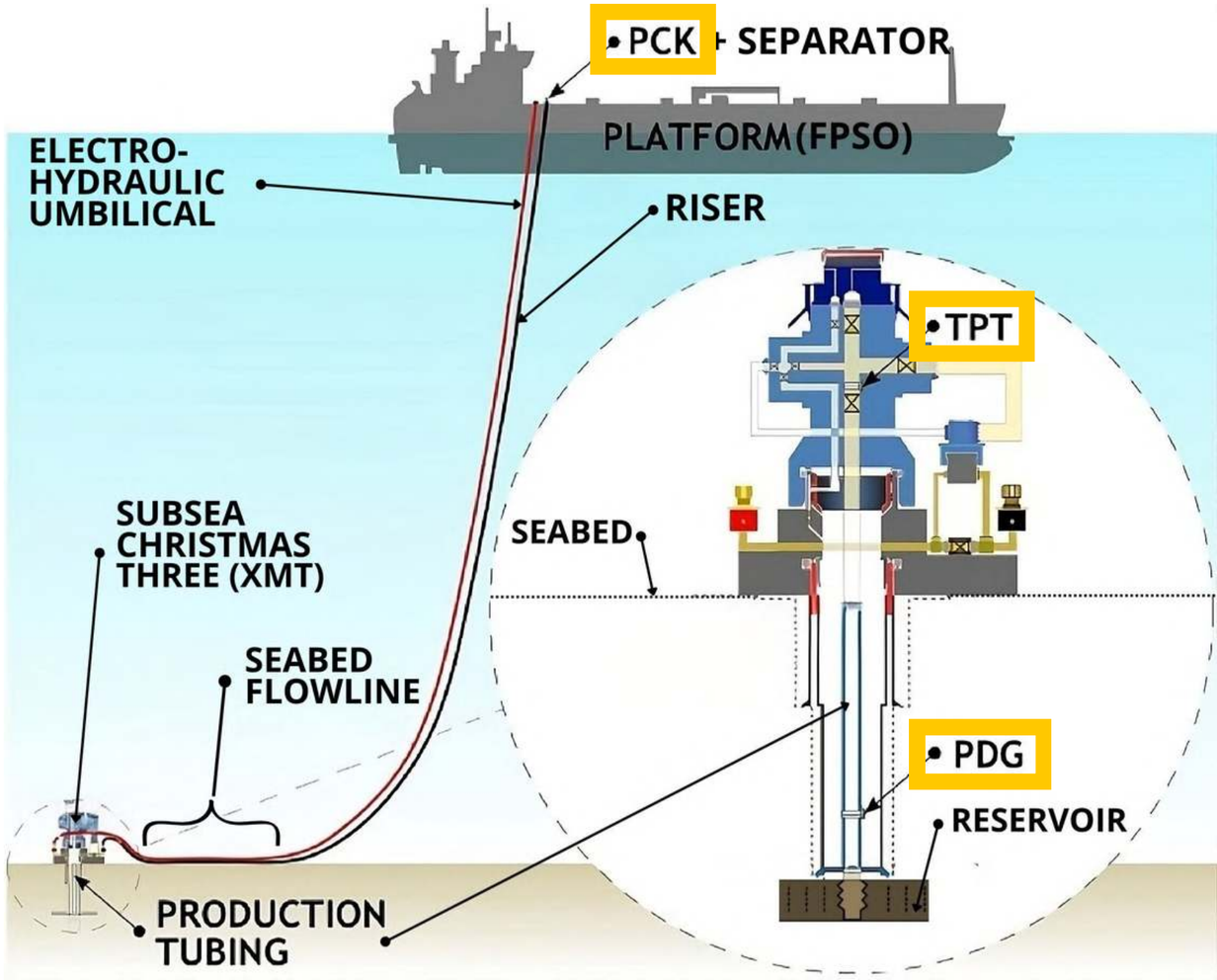


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anp | Gestão: FAPESP

Metodologia e Background





Metodologia e Background

Casos Simulados na primeira etapa

Table 3.2 – Simulation matrix: system segment lengths for all simulated cases.

ID	Production Tubing [m]	Flowline [m]	Riser [m]	Total System Length [m]
Case 1	3000	750	1520	5270
Case 2	3000	1500	1520	6020
Case 3	3000	2250	1520	6770
Case 4	3000	3000	1520	7520
Case 5	3000	3750	1520	8270
Case 6	3000	4500	1520	9020
Case 7	3000	5250	1520	9770
Case 8	3000	6000	1520	10520

- t_final = 6 h
- 2 h < CKP restriction < 3 h

Metodologia

Production tubing
Internal initial conditions:
Inlet: 88.5 [ºC] / 300 [bar]
Outlet: 80 [ºC] / 130 [bar]

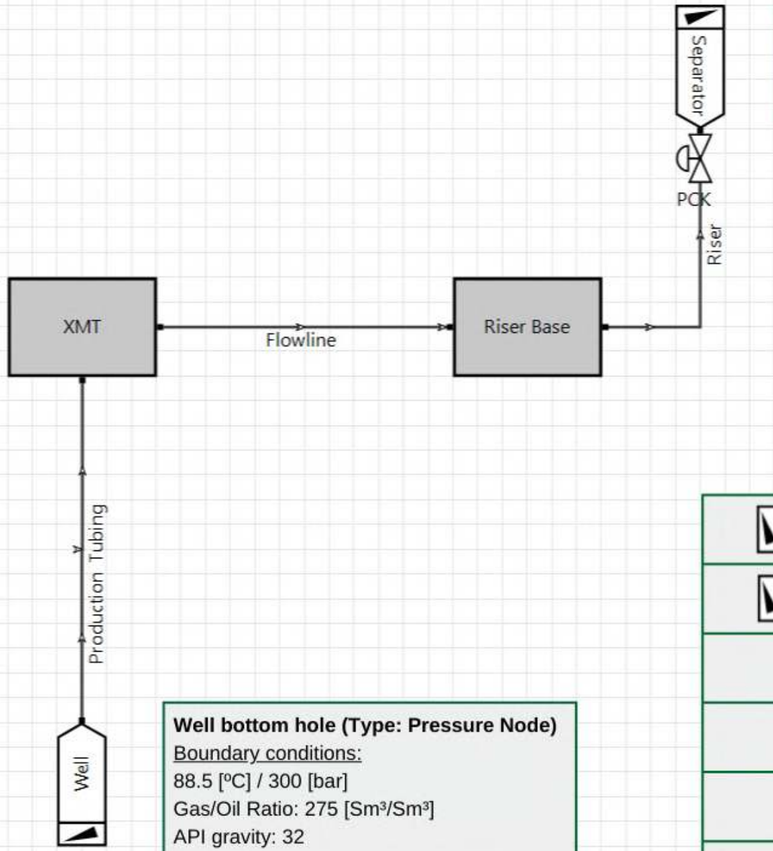
Boundary conditions:
h_amb: 4 [W/m².ºC]
h_internal: 500 [W/m².ºC]
T_amb: interpolated from 88.5 [ºC] to 6 [ºC]

Flowline
Internal initial conditions:
Inlet: 80 [ºC] / 130 [bar]
Outlet: 78 [ºC] / 120 [bar]

Boundary conditions:
h_amb: 8 [W/m².ºC]
h_internal: 500 [W/m².ºC]
T_amb: 4 [ºC]

Riser
Internal initial conditions:
Inlet: 78 [ºC] / 70 [bar]
Outlet: 74 [ºC] / 20 [bar]

Boundary conditions:
h_amb: 8 [W/m².ºC]
h_internal: 500 [W/m².ºC]
T_amb: interpolated from 4 [ºC] to 19 [ºC]



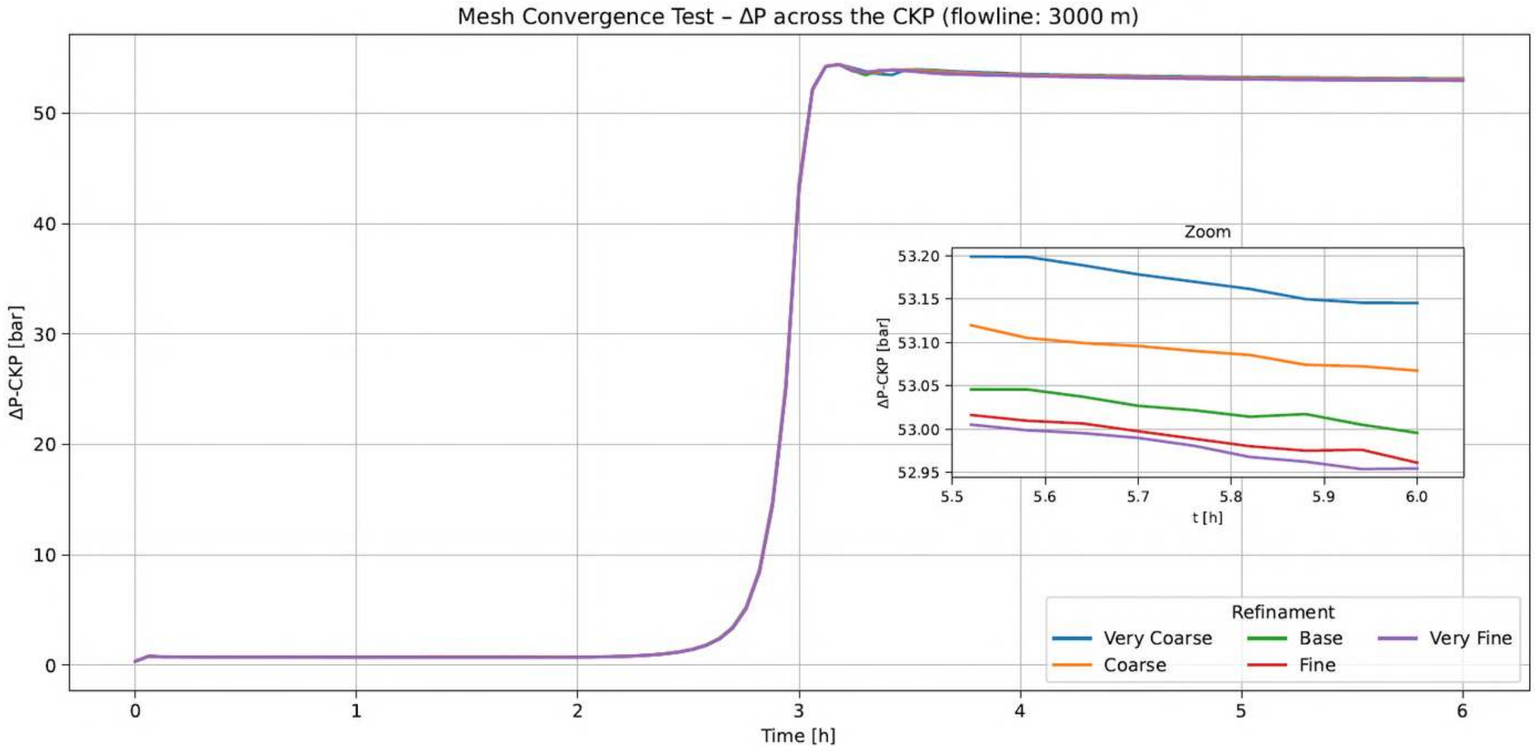
Separator (Type: Pressure Node)
Boundary conditions:
57 [ºC] / 20 [bar]

Well bottom hole (Type: Pressure Node)
Boundary conditions:
88.5 [ºC] / 300 [bar]
Gas/Oil Ratio: 275 [Sm³/Sm³]
API gravity: 32

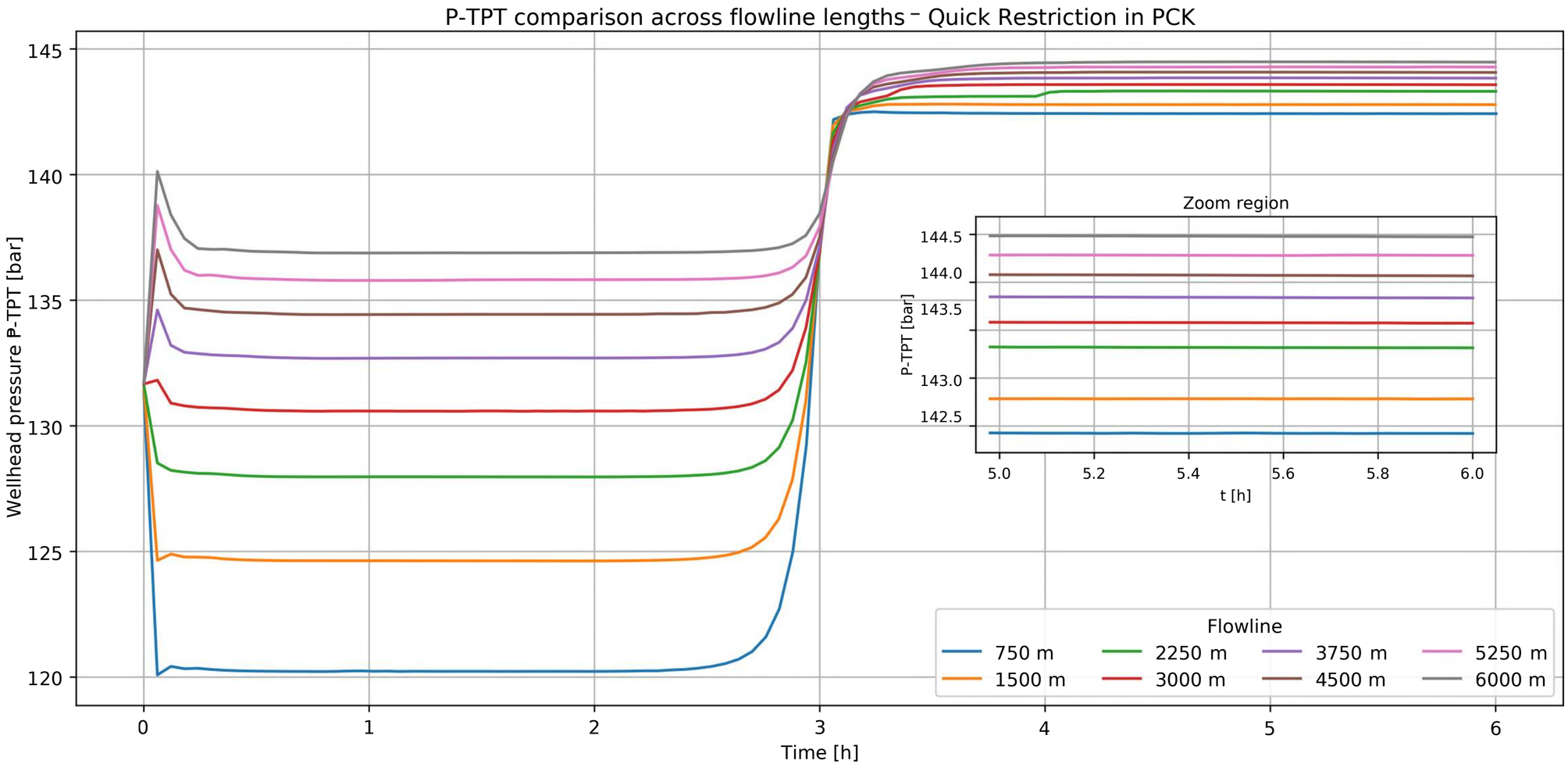
Well	Well bottom hole
Separator	Multiphase separator
XMT	Subsea christmas tree
Riser Base	Riser base
	Pipeline
	Prodution choke valve

Teste de convergência

Mesh ID	Total Elements (CVs)	Δt_{max} [s]
Mesh 1 (Very Coarse)	213	8.75
Mesh 2 (Coarse)	226	7.5
Mesh 3 (Base)	**252**	**5.0**
Mesh 4 (Fine)	278	2.5
Mesh 5 (Very Fine)	304	1.25



Resultados preeliminares



$$\Delta P_{\text{total}} \approx \Delta P_{\text{friction}} + \Delta P_{\text{PCK}} + \Delta P_{\text{gravity}}$$

Pressão na árvore de natal para todos os casos

Equações governantes

3.1.1 Mass Transport Equations

For each mass field m_i (defined as mass per unit pipe volume) traveling with velocity U_i, the conservation of mass is expressed as:

$$\frac{\partial m_i}{\partial t} + \frac{\partial}{\partial z}(m_i U_i) = \sum_j \Psi_{ji} + G_i, \tag{3.1}$$

where Ψ_{ji} represents inter-field mass transfer rates (e.g., entrainment and deposition of droplets) and G_i denotes source/sink terms. This formulation yields five distinct mass equations for: gas phase, oil layer, water layer, oil droplets, and water droplets.

3.1.2 Momentum Balance Equations

For each continuous layer i (gas, oil, water), the momentum balance equation is given by:

$$\frac{\partial(m_i U_i)}{\partial t} + \frac{\partial}{\partial z}(m_i U_i^2) = -\alpha_i \frac{\partial P}{\partial z} - m_i g \sin\varphi - \frac{1}{D_h}\tau_w + \sum_j F_{ji}^I + \sum_j \Psi_{ji} U_j, \tag{3.2}$$

where:

- α_i is the volume fraction of layer i,
- P is the system pressure,
- g is gravitational acceleration and φ is the pipe inclination,
- τ_w represents wall shear stress (friction),
- F_{ji}^I represents interfacial friction forces between layers.

3.1.3 Energy Equation

Assuming thermal equilibrium among phases (a single mixture temperature field), the mixture energy equation is solved:

$$\frac{\partial}{\partial t}\left(\sum_i m_i E_i\right) + \frac{\partial}{\partial z}\left(\sum_i m_i U_i H_i\right) = Q_w + \sum_i S_i, \tag{3.3}$$

where:

- E_i is the specific internal energy,
- H_i is the specific enthalpy ($H_i = E_i + P/\rho_i$),
- Q_w represents heat transfer through the pipe wall to the environment,
- S_i represents enthalpy sources from mass sources.

3.1.4 Volume Constraint and Pressure Closure

To ensure physical consistency, the sum of volume fractions must equal unity:

$$\sum_i \alpha_i = 1. \tag{3.4}$$

The system of equations is closed by relating density, pressure, and temperature through the fluid's Equation of State (EOS) and the volume constraint:

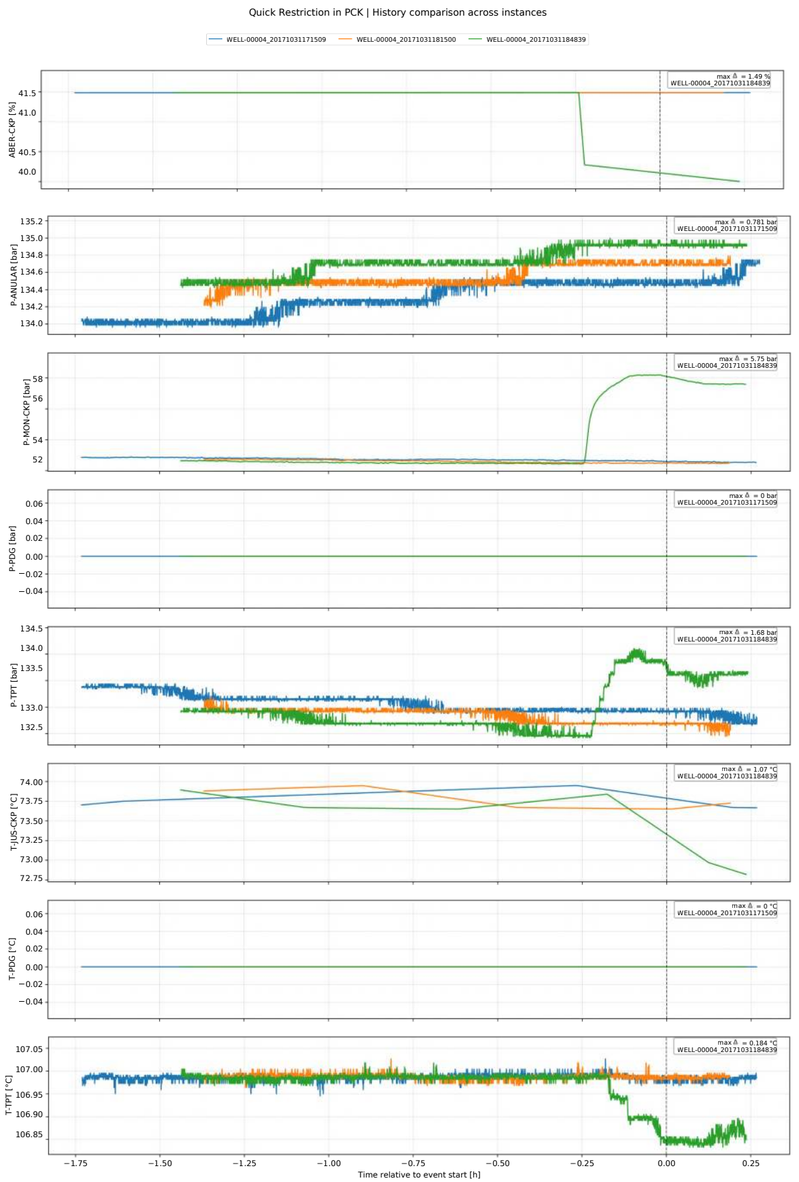
$$\sum_i \frac{m_i}{\rho_i(P,T)} = 1, \tag{3.5}$$

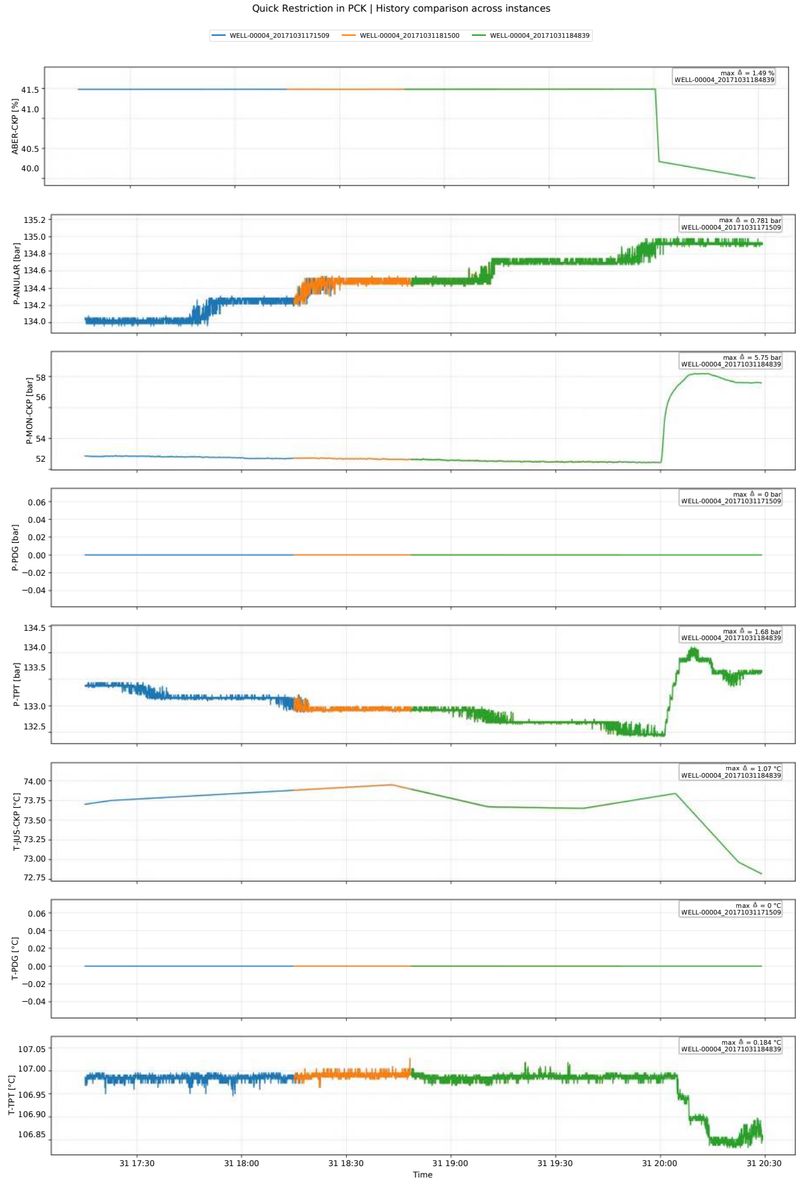
where $\rho_i(P,T)$ is the density of phase i calculated by the PVT package.

Parametros Escolhidos

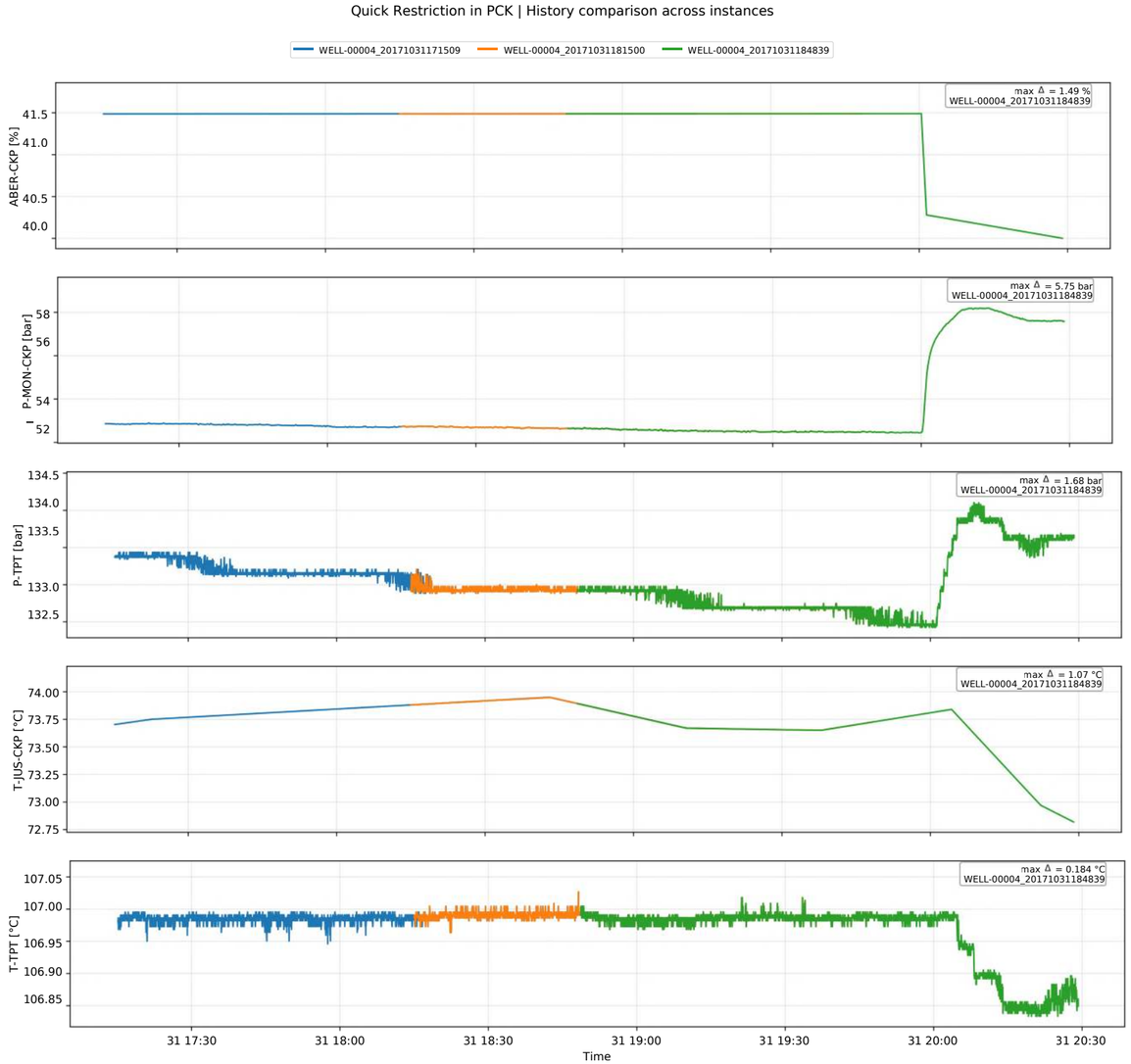
Category	Parameter	Value	Description / Source
Fluid Properties (Black Oil)			
	API Gravity	32°	Typical grade for Brazilian Pre-salt fields. Based on crude oil assay (Annex A) available in (ASA, 2025).
	Gas-Oil Ratio (GOR)	275 Sm^3/Sm^3	Within the typical range for pre-salt fields (200–450 Sm^3/Sm^3) (ANP, 2019).
	Water Cut	0%	Assumption of pure hydrocarbon flow; valid for early-life fields.
Boundary Conditions (Internal Flow)			
	Inlet Pressure	300 bar	Reservoir pressure (Driving force).
	Inlet Temperature	88.5 °C	Estimated at 3000 m depth based on the pre-salt geothermal gradient (2.2–2.9°C/100 m) (Zuo *et al.*, 2023).
	Outlet Pressure	20 bar	Separator backpressure (Topside constraint).
	Outlet Temperature	57 °C	Fluid arrival temperature at the separator.
Geometry			
	Internal Diameter	0.12 m	Constant for Tubing, Flowline, and Riser (Bai; Bai, 2018).
	Roughness	50 μm	Standard roughness for new Carbon Steel pipes (Hussein, 2022).
	Tubing Length	3000 m	Typical for UO-ES offshore wells.
	Riser Length	1520 m	Typical for UO-ES offshore wells.
	Flowline Length	*Variable*	**See Simulation Matrix (Table 3.1).**
Wall Materials & Thermal Properties			
	Wall Layer 1 (Inner)	Steel	15 mm thick (k = 50 W/mK) (Bai; Bai, 2018).
	Wall Layer 2 (Outer)	Polypropylene	60 mm thick (k = 0.22 W/mK); Insulation for subsea sections (Bai; Bai, 2018).
	$h_{internal}$	500 W/m^2K	Inner convective heat transfer coefficient.
Environmental Conditions (External)			
	Seabed Temp.	4 °C	Constant ambient temp. at sea bottom (> 1000 m) (Makogon, 2019).
	Riser Top Temp.	19 °C	Ambient temp. at sea surface (Huang *et al.*, 2024).
	$h_{ambient}$	4 – 8 W/m^2K	External seawater convective heat transfer coefficient.

ANÁLISE E SELEÇÃO DE DADO DE CAMPO NO 3W





ANÁLISE E SELEÇÃO DE DADO DE CAMPO NO 3W



Δ Aber_CKP [%]	Δt
1,21	63 s
0,28	27 min

Table 4.2 – Maximum variations observed in the selected real occurrence.

Variable	Maximum variation
P_{MON_CKP}	5.75 bar
P_{TPT}	1.68 bar
T_{JUS_CKP}	1.07 °C
T_{TPT}	0.184 °C

IDENTIFICAÇÃO DO POÇO E ATRIBUTOS

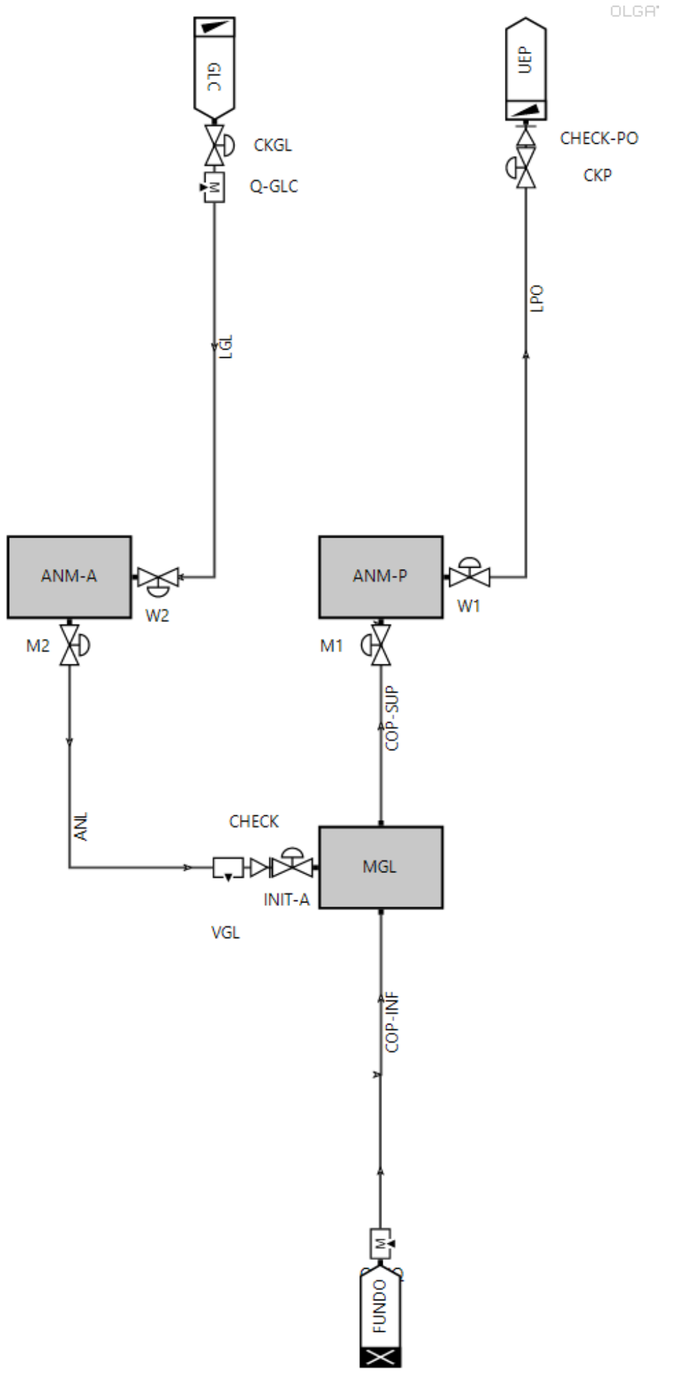
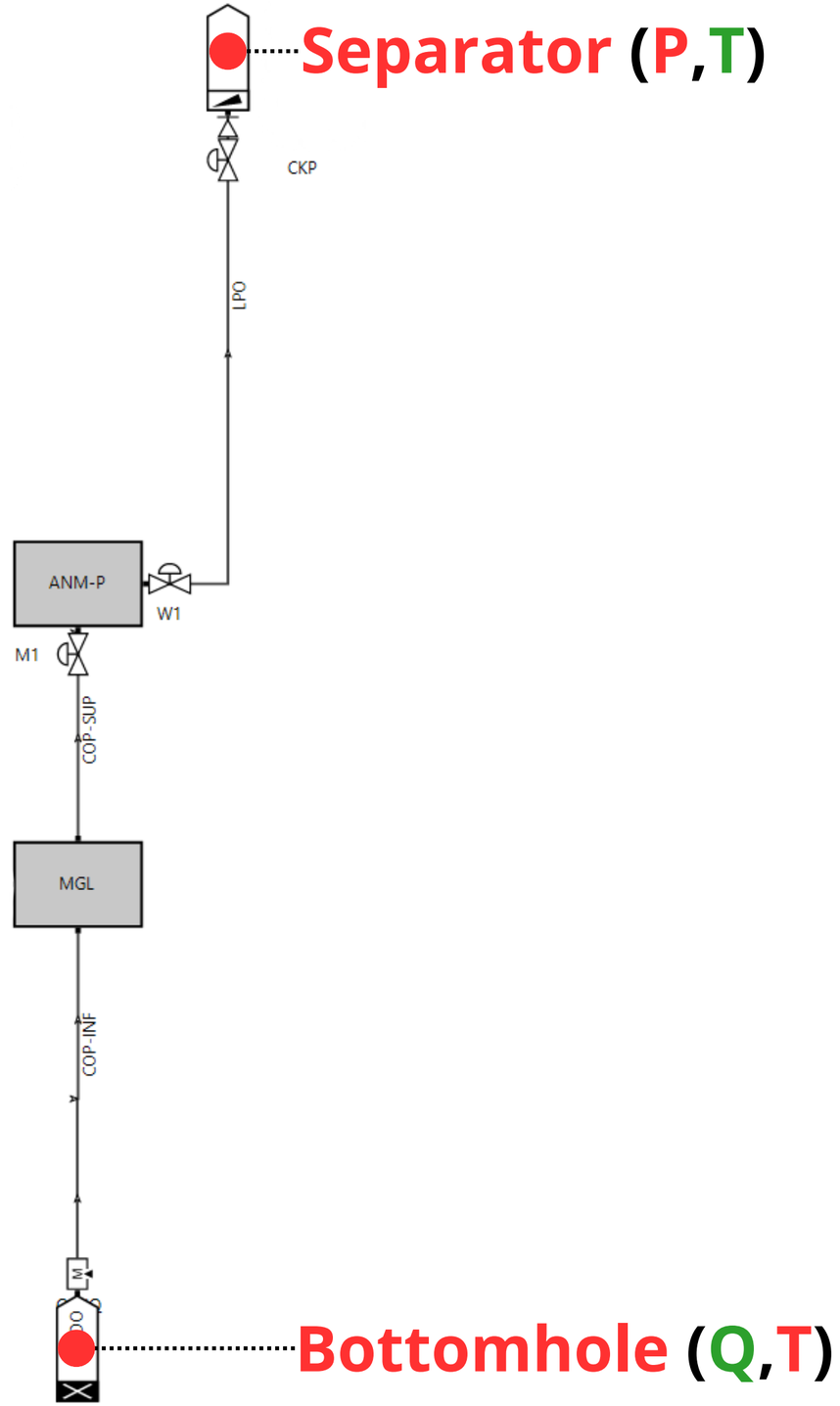


Table 5.7 – Boundary-condition variables and availability for the selected event.

Node	Variable	Unit	Availability
Bottomhole	Oil flow rate	Sm^3/d	Known
Bottomhole	GOR	Sm^3/Sm^3	Known
Bottomhole	Water cut / BSW	%	Known
Bottomhole	Source temperature	°C	Unknown
Separator	Pressure	bar	Unknown
Separator	Temperature	°C	Known

MODELAGEM E CALIBRAÇÃO DA OPERAÇÃO NORMAL



MODELAGEM E CALIBRAÇÃO DA OPERAÇÃO NORMAL

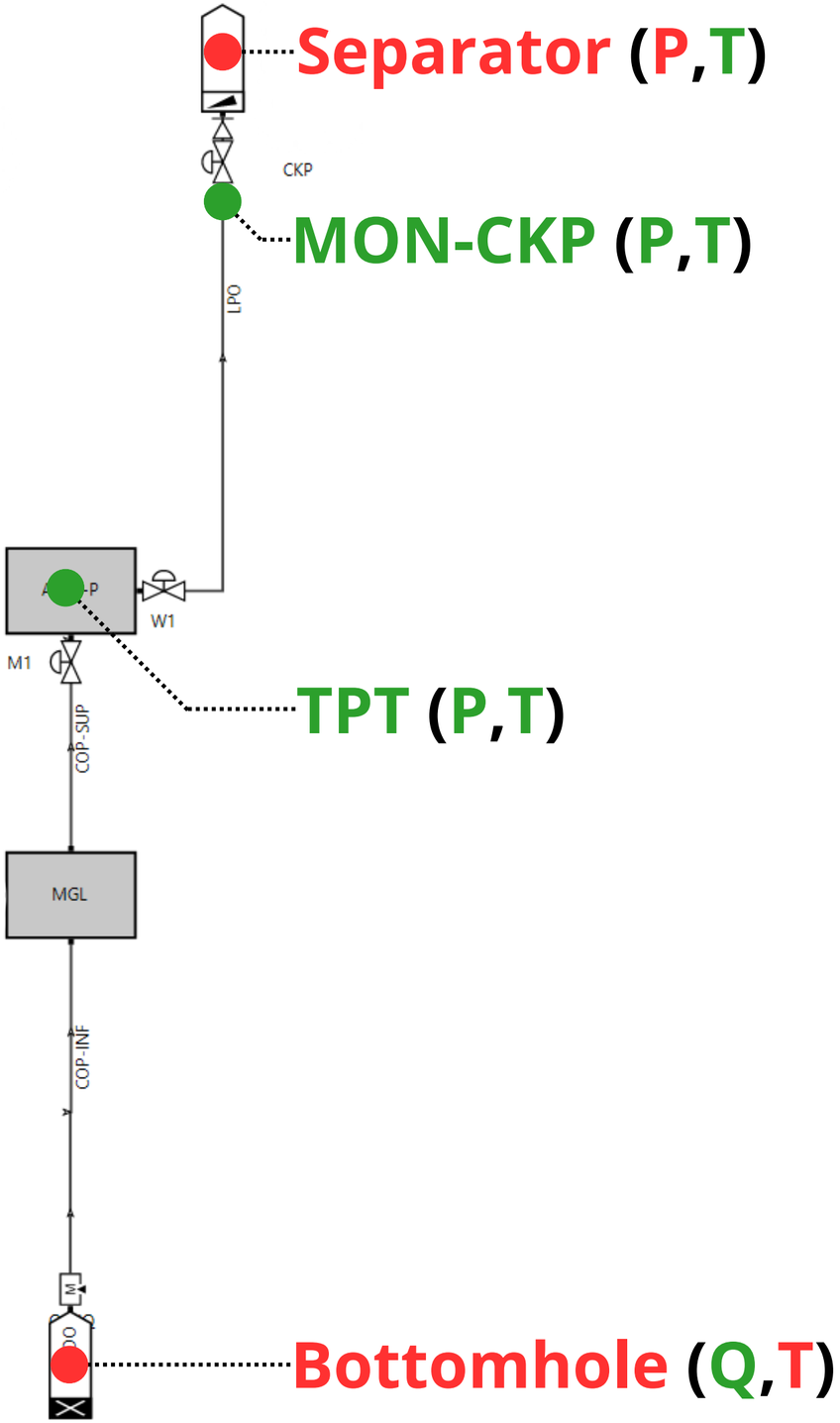


Table 6.1 – Reference values available at internal monitored points.

Point	Pressure [bar]	Temperature [°C]
TPT	134.2	107.0
MON-CKP	53.3	73.8

MODELAGEM E CALIBRAÇÃO DA OPERAÇÃO NORMAL

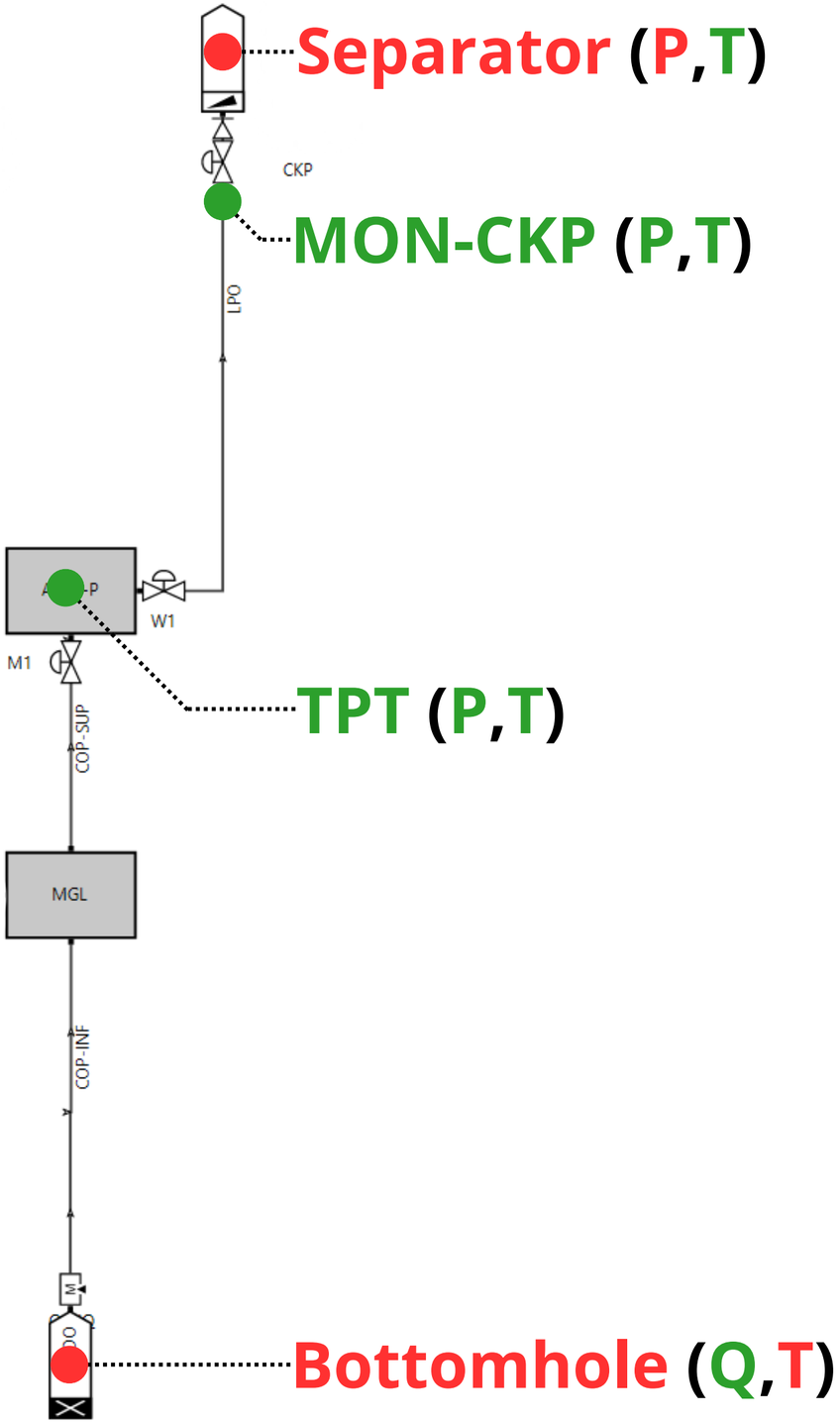


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MODELAGEM E CALIBRAÇÃO DA OPERAÇÃO NORMAL

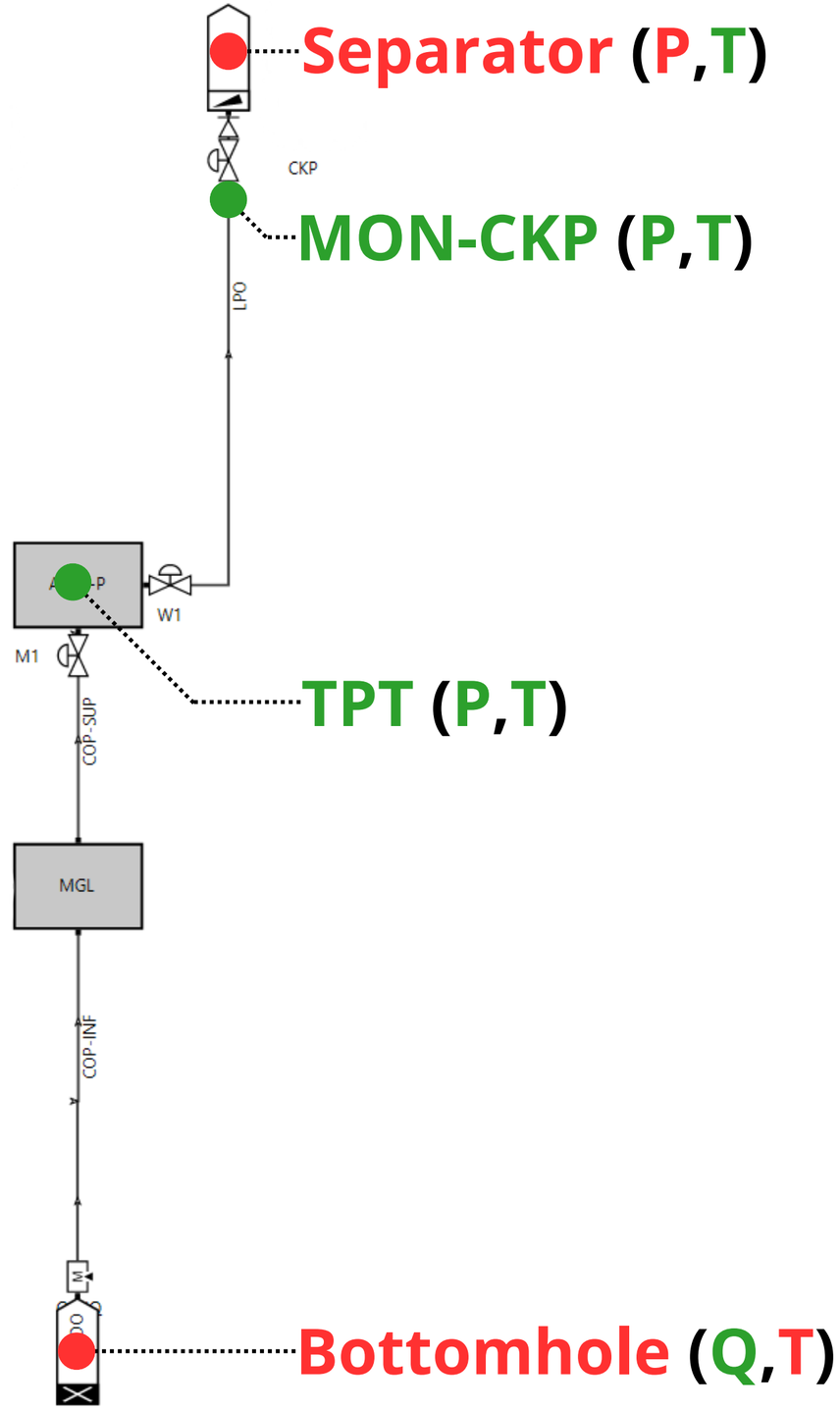


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Point	Pressure [bar]	Temperature [°C]
TPT	134.2	107.0
MON-CKP	53.3	73.8

$$f(x) = y_{\text{sim}}(x) - y_{\text{field}}$$

$$x_{n+1} = x_n - \frac{f(x_n)(x_n - x_{n-1})}{f(x_n) - f(x_{n-1})}$$

$$\epsilon_{\text{rel}} = \left| \frac{y_{\text{sim}} - y_{\text{field}}}{y_{\text{field}}} \right| \times 100$$

MODELAGEM E CALIBRAÇÃO DA OPERAÇÃO NORMAL

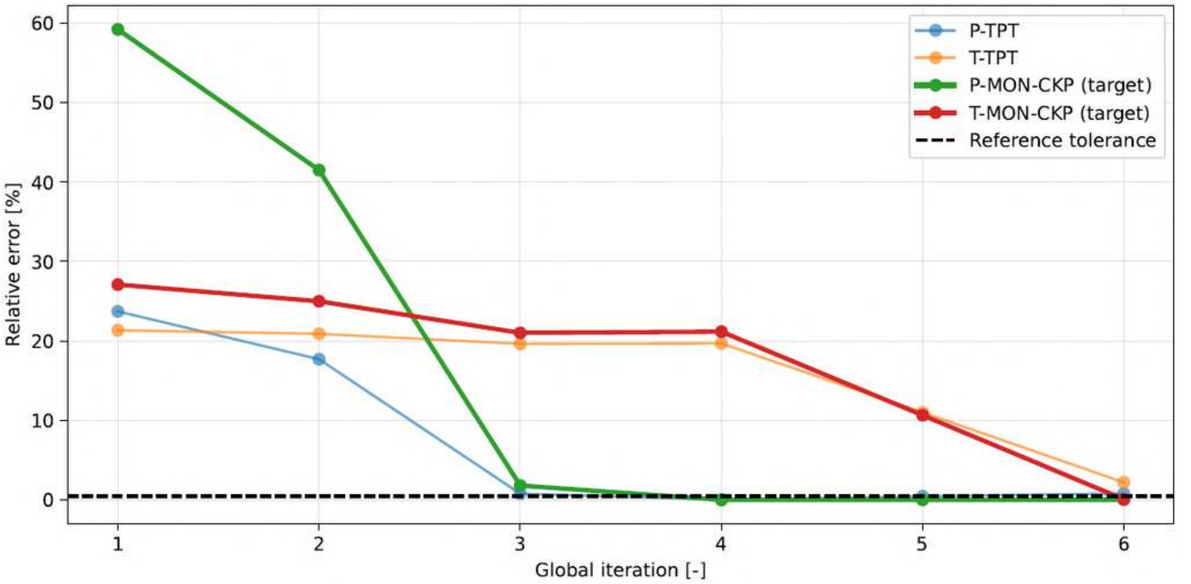


Figure 7.3 – Relative-error diagnostics during the calibration without a C_v curve.

Table 7.3 – Final monitored-point summary for the campaign without a C_v curve.

Point	Role	P_{field} [bar]	P_{sim} [bar]	P error [%]	T_{field} [°C]	T_{sim} [°C]	T error [%]
MON-CKP	Target	53,25	53,27	0,03	73,80	73,86	0,08
TPT	Diagnostic	134,15	133,07	0,81	107,00	104,64	2,20

Table 7.4 – Final calibrated boundary conditions for the campaign without a C_v curve.

$Q_{Bottomhole}$ [Sm^3/d]	$P_{Separator}$ [bar]	$T_{Bottomhole}$ [°C]	Target tolerance [%]	Final iteration
3118,0	52,45	120,14	0,5	6