

Table 1. SEM model verification parameters.

Parameter	Value	Units
Initial Inlet Pressure (P_z)	3000	kPa
Initial Outlet Pressure (P_L)	$P_z - \frac{fZR T Q Q L}{2DA^2 M_w P_z}$	kPa
Initial Mass Flow (Q)	5	kg/s
Friction (f)	0.4	-
Compressibility (Z)	0.95	-
Gas Constant (R)	8314.47	J/kmolK
Temperature (T)	300	K
Molecular Weight (M_w)	17.2	kg/kmol
Pipe Length (L)	5000	m
Pipe Diameter (D)	0.38	m
Element Length Ratio (r_D)	1	-

Table 2. Model verification results.

n	N	States	Δ MOE (Pa)	Δ States	$(\Delta t \leq)$
1	2	6	-	-	494
2	2	10	851	4	247
2	3	14	33	4	137
3	3	20	18	6	91
3	4	26	15	6	57

Table 3. Model validation parameters.

Header	L_r (m)	L_G (m)	K_G (m^{-1})
A	800	358	9.3×10^5
B	800	384	8.9×10^5
C	4000	3468	9.5×10^5

Table 4. Input and output operating ranges.

Parameter	Operating range size	Unit
Pressures	200	kPa
Flows	20	kg/s
Temperatures	15	K
Molecular Weight	1.5	kg/kmol

Table 5. SEM Simulation tuning parameters per header.

Parameter	Description	Value
n	Number of pipe elements	2
N	Polynomial order	3
r_D	Ratio between element lengths	v_p^{in}/v_p^{out}

Table 6. SEM compared to measured data.

Header	Pearson Correlation	NRMSE
A	0.93	16.3×10^{-5}
B	0.57	7.3×10^{-5}
C	0.94	14.5×10^{-5}

Table 7. SEM compared to the trapezoidal rule.

Header	Pearson Correlation	NRMSE
A	0.99	3.3×10^{-5}
B	0.89	5.4×10^{-5}
C	0.99	3.4×10^{-5}

Table 8. Dynamic simulation model initialisation values.

Parameter	Value	Units
Initial Inlet Pressure (P_z)	3000	kPa
Initial Outlet Pressure (P_L)	$P_z - \frac{fZR}{2DA^2M_w} \frac{TQ Q L}{P_z}$	kPa
Initial Mass Flow (Q)	10	kg/s
Friction (f)	0.2	-
Compressibility (Z)	0.95	-
Gas Constant (R)	8314.47	J/kmolK
Temperature (T)	300	K
Molecular Weight (M_w)	17.2	kg/kmol
Pipe Length (L)	5000	m
Pipe Diameter (D)	0.5	m
Pipe Segments (n)	2	-
Polynomial Order (N)	3	-
Element Length Ratio (r_D)	1	-
Time Step Size (Δt)	1	s

Table 9. Input and output scaling factors.

Parameter	Scaling Value	Unit
Pressure	5000	Pa
Flows	5	kg/s

Table 10. EKF parameters.

Parameter	Value	Unit
\hat{Z}_P	1	kPa
\hat{Z}_Q	0.1	kg/s
\hat{R}_P	3	kPa
\hat{R}_Q	0.2	kg/s
σ_v^2	1	kPa
$\sigma_{w_P}^2$	3	kPa
$\sigma_{w_Q}^2$	0.1	kg/s

Table 11. State estimation errors.

Measurement Location	RMSE (kPa)
P_1	4.9
P_2	2.8
P_3	7.1
P_4	3.9
P_5	7.1
P_6	2.1
P_7	0.6

Table 12. Tuning values.

Parameter	Value	Units
K	140.32	Pa/kg
τ_I	570	s
$K_{c,1}$	0.05×10^{-3}	kg/Pa.s
$K_{c,2}$	0.57×10^{-3}	kg/Pa.s
$\tau_c + \theta$	143	s

Table 13. Performance metrics for the closed loop simulations while the over and under pressure controllers are active (Fig. ??) and disabled (Fig. ??).

Consumer Flow (Q_V) Stability Metric	Active (Fig. ??)	Disabled (Fig. ??)
Sum of Incremental Changes (kg)	277.4	350.3
Absolute Change (kg/s)	7.94	10

Table 14. Cost function weights.

Weight	Value
W_1	3.5
W_2	0.018
W_3	1.1

Table 15. Optimal reference locations for disturbance sizes of $1.25Q_{max}$.

Amplitude (kg/s)	Period (min)	Reference Location (o, p)		
		$J_F + J_S$	J_V	J_T
$1.25Q_{max}$	1	7,7	1,7	7,7
$1.25Q_{max}$	20	7,7	1,7	2,7
$1.25Q_{max}$	60	7,7	2,7	4,4

Table 16. Monte Carlo simulation disturbance parameters and variation ranges.

Parameter	Range	Units
Compressibility (Z)	0.95 - 1	-
Temperature (T)	295-330	K
Molecular Weight (M_w)	17 - 20	kg/kmol
Initialising Inlet Pressure ($P_{z,0}$)	1800 - 3400	kPa
Disturbance Magnitude	2.5 - 7.5	kg/s
Disturbance Sine Wave Period	1 - 60	min

Table 17. Cost of flaring (J_F), supplier use (J_S), and consumer stability (J_V) results across all Monte Carlo simulations. The number of tuning parameters (NTP) and process outputs (NPO) are also shown.

Controller	$J_F + J_S$	J_V	J_T	NTP	NPO
Override Only	100.0	0.0	100.0	2	1
PI (IMC)	7.90	100	107.9	2	1
PI (SIMC)	23.5	82.0	105.5	2	1
Gap	19.7	85.6	105.3	3	1
Range	17.2	81.1	98.2	6	2
Error-Squared	20.0	82.9	102.9	3	1
Polynomial	20.4	83.8	104.2	2	2
Variable SP	22.3	82.9	105.1	3	2
LMPC	16.2	82.0	98.1	7	4
NMPC	15.7	81.1	96.7	7	7
CLMPC	16.0	82.0	97.9	7	7

Table 18. First- and total-order Sobol indices.

Parameter	First-order Effects	Total-order Effects
Z	0.069	0.066
T	0.32	0.33
M_w	0.61	0.63
$P_{z,0}$	0.023	0.0

Table 19. Cost of flaring and consumer stability results.

Parameter	PI	CLMPC	PI/CLMPC
$J_{V,1}$	0.76	0.57	1.3
$J_{V,2}$	0.57	0.073	7.9
$J_{F,1}$	0.0	0.0	-
$J_{F,2}$	8.4	1.6	5.2
J_T	9.7	2.3	4.3

Table 20. Scaling ranges used for the industrial case study.

Parameter	Range	Units
Temperatures	35	K
Molecular Weight	3	kg/kmol
Pressures	60	kPa
Flows	15	kg/s

Table 21. FFT spectral analysis of the first two highest disturbance signals.

Flow	Amplitude (kg/s)	Period (min)
$Q_{z,1}$	1.06	50
$Q_{z,1}$	0.35	25
$Q_{z,2}$	0.96	50
$Q_{z,2}$	0.38	20