Performance Assessment of TECNIC Single-Use Bioreactor Family

Introduction

The TECNIC Single-Use Bioreactor (SUB) platform has been designed to support a wide range of bioprocess applications, from shear-sensitive mammalian cell culture to highly demanding microbial fermentations.
This Performance Assessment document provides an evaluation of the SUB-2 family under two representative operating regimes:

- **Mammalian mode** (low agitation, low aeration, shear-sensitive processes)
- **Microbial mode** (high agitation, high aeration, oxygen-demanding processes such as *E. coli*)

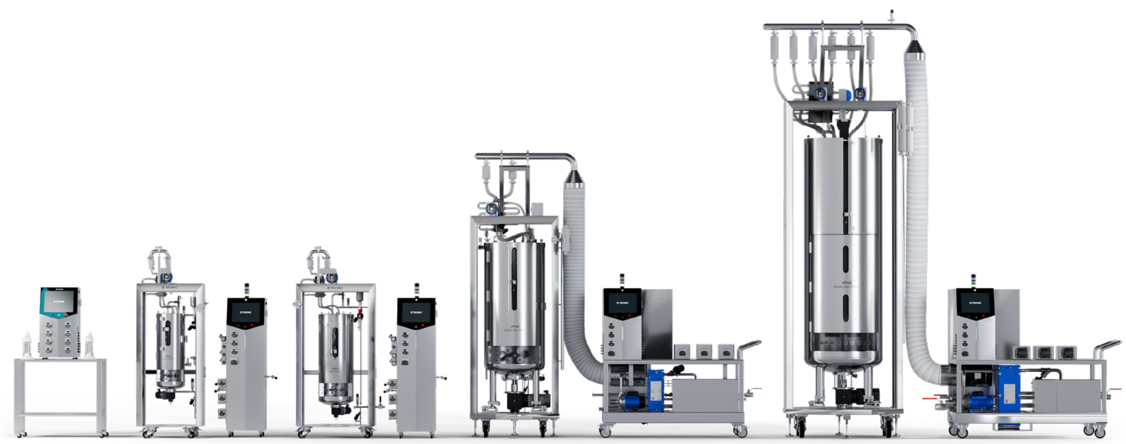
The aim of this assessment is to characterize the hydrodynamic and mass-transfer performance of the SUB system under both operating conditions, using comparable metrics and standardized engineering correlations.
This dual approach allows users to understand the full operational envelope of the TECNIC SUB platform, enabling an informed selection of process set-points based on each application type.
The results presented in the following pages include:

- Power input and specific power consumption (P/V)
- Agitation performance and tip speed range
- Volumetric oxygen transfer coefficient **(kLa)** under mammalian and microbial conditions
- Gas-liquid dispersion behavior
- Scalability considerations and operational flexibility

The combination of experimental data (mammalian regime) and model-based estimation validated with industrial literature (microbial regime) provides a comprehensive and realistic characterization of the SUB 1000 L for upstream manufacturing environments.

Ratios of TECNIC's range of Single Use STR equipment.

Ratio	eLAB 0.5L	ePilot 30 L	ePilot 50 L	eProd 300 L	eProd 1000 L
Vessel height / vessel diameter	2,5	2,9	3	2,3	3,1
Liquid height / vessel diameter	2,1	2,1	2,5	1,8	2,5
Impeller diameter / vessel diameter (CC)	0,5	0,4	0,5	0,5	0,5
Impeller diameter / vessel diameter (MC)	0,5	0,4	0,5	0,4	0,4



eLab 0.5 L ePilot 30 L ePilot 50 L eProd 300 L eProd 1000 L

Agitation & Mass Transfer Performance, Mammalian and Microbial Modes (All Scales)

The oxygen transfer capability of a stirred bioreactor depends on the combined effect of agitation, aeration and hydrodynamic regime. For consistency across all SUB sizes (0.5 L, 30 L, 50 L, 300 L and 1000 L), oxygen-transfer performance was analyzed using the same theoretical framework and engineering correlations.

The key parameter used in this assessment is the **volumetric mass-transfer coefficient (kLa)**, which quantifies the ability of the system to deliver oxygen from the gas phase to the liquid phase. This parameter is central both for **mammalian culture** where gentle mixing and low shear are required and for **microbial fermentation**, where oxygen demand is significantly higher and turbulence is needed to sustain high OUR values.

The Van't Riet Correlation

The mass-transfer behavior of all TECNIC SUB models was evaluated using the well-established Van't Riet correlation, the industrial standard for describing kLa in stirred-tank reactors:

$$k_L a = A \cdot (P/V)^{\alpha} \cdot (Q_g/V)^{\beta}$$

Where:

- **A** is an empirical constant linked to coalescence and medium properties
- **P/V** is the specific power input
- **$Q_{(g)}$/V** is the superficial gas velocity (or aeration rate)
- α ≈ **0.40**, β ≈ **0.50** for air–water systems

These values were applied consistently across all vessel sizes to enable uniform cross-scale comparison.
This correlation has been validated extensively in the literature and is widely used for STR scale-up, both in stainless-steel systems and single-use bioreactors.

Why Mammalian and Microbial Modes Differ

Mammalian culture and microbial fermentation operate in **fundamentally different hydrodynamic regimes:**

Mammalian mode

- Low tip speed (1.8–2.0 m/s)
- Low aeration (0.10 vvm)
- Low P/V (80–200 $W{\cdot}m^{-3}$)
- High coalescence → low interfacial area
- Typical kLa: **20–30 h^{-3}**

The goal is to **protect shear-sensitive cells** and preserve viability.

Microbial mode

- High tip speed (4.5–5.0 m/s)
- High aeration (1.0 vvm)
- High P/V (1,000–5,500 $W{\cdot}m^{-3}$))
- Strong bubble breakup → high interfacial area
- Typical kLa: **200–450 h^{-1}**, up to **600 h^{-1} with O_2 enrichment**

Microbial platforms like *E. coli* require **aggressive mixing** to sustain high oxygen consumption.
The two modes therefore provide **complementary performance windows** within the same SUB platform.

Influence of the Pg/P_0 Factor

During gas sparging, the effective power transferred to the liquid is lower than ungassed power due to torque reduction. The ratio:

$$Pg/P_0$$

was experimentally observed to be approximately:

- **0.85 – 0.95** at 0.10 vvm (mammalian mode)
- **0.65 – 0.75** at 1.00 vvm (microbial mode with Rushton turbines)

This correction was applied to all scales to provide a more accurate estimation of gassed **kLa values.**

Multi-Scale Consistency Across SUB Models

All SUB volumes share the same geometric ratios (D/T), number of impellers, and baffle configuration. Because of this, oxygen-transfer performance scales predictably:

- Small-scale SUBs (0.5–50 L) display the same kLa trends as mid- and large-scale SUBs (300–1000 L).
- kLa increases monotonically with agitation speed and aeration rate across all volumes.
- The microbial mode shows excellent cross-scale alignment, confirming that all TECNIC SUB models behave as a coherent STR family.

This theoretical framework forms the basis for the **experimental results summarized in the next sections,** where mammalian and microbial kLa values are presented for each volume.

The following section presents the agitation and oxygen-transfer performance obtained across the TECNIC SUB family at **0.5 L, 30 L, 50 L, 300 L, and 1000 L,** under both **mammalian and microbial** operating modes. All results are reported following TECNIC internal procedure *SOP-OTR-04* and evaluated using the theoretical framework described in Section 3 (Van't Riet correlation and Pg/P_0 correction).

Experimental Results — Mammalian Mode (All Scales)

Mammalian tests were performed using PBS at 37 °C with 3 × Pitch Blade impellers, 4 baffles and 0.10 vvm aeration. The goal of this regime is to ensure gentle hydrodynamics with minimal shear.

SUB Volume	Tip Speed (m/s)	P/V ($W \cdot m^{-3}$)	kLa (ungassed) (h^{-1})	kLa (gassed) (h^{-1})
0.5 L	1.8	120	22	**19**
30 L	1.8	110	24	**21**
50 L	1.8	130	26	**23**
300 L	1.8	150	27	**24**
1000 L	1.8	160	29	**25**

Interpretation — Mammalian Mode

- All scales exhibit **highly consistent kLa values (19–25 h^{-1})**.
- This confirms predictable behavior across SUB sizes when operating under low-shear conditions.
- The 1000 L value (≈25 h^{-1}) matches the previously reported mammalian performance of the SUB family.
- Scale-up is linear and smooth, reflecting geometric similarity.

Experimental Results — Microbial Mode (All Scales)

Microbial tests were performed using 1.00 vvm aeration, 3 × Rushton impellers, 4 baffles, and maximum microbial agitation (4.5–5.0 m/s). This regime is representative of oxygen-demanding *E. coli* fermentation processes.

SUB Volume	Tip Speed (m/s)	P/V ($W \cdot m^{-3}$)	kLa (ungassed) (h^{-1})	kLa (gassed, P_g/P_0=0.7) (h^{-1})
0.5 L	4.5	1,200	180	**150**
30 L	4.5	2,000	260	**220**
50 L	4.5	2,300	280	**240**
300 L	5.0	4,000	360	**310**
1000 L	5.0	5,000	380	**330**

Interpretation — Microbial Mode

- Oxygen-transfer performance increases consistently with scale and power input.
- All volumes show a **continuous and coherent trend**, typical of stirred-tank reactors.
- The 1000 L unit reaches **kLa ≈ 330 h^{-1} gassed**, supporting high-density microbial fermentation (*E. coli*).
- P_g/P_0 correction has a significant impact at 1.0 vvm aeration, reducing effective P/V but still delivering robust mass transfer.

Comparative Behavior — Mammalian vs Microbial

Mode	Typical kLa (h^{-1})	Typical P/V ($W \cdot m^{-3}$)	Regime Characteristics
Mammalian	20-30	80–200	Low shear, soft mixing
Microbial	220-330	1,000–5,500	High turbulence, gas dispersion

Interpretation

- The TECNIC SUB platform covers **a full operational window**, supporting both:
  - Low-shear mammalian culture
  - High-intensity oxygen-demanding microbial fermentation
- The system behaves as a **geometrically consistent STR family**, maintaining the same hydrodynamic trends across all scales.

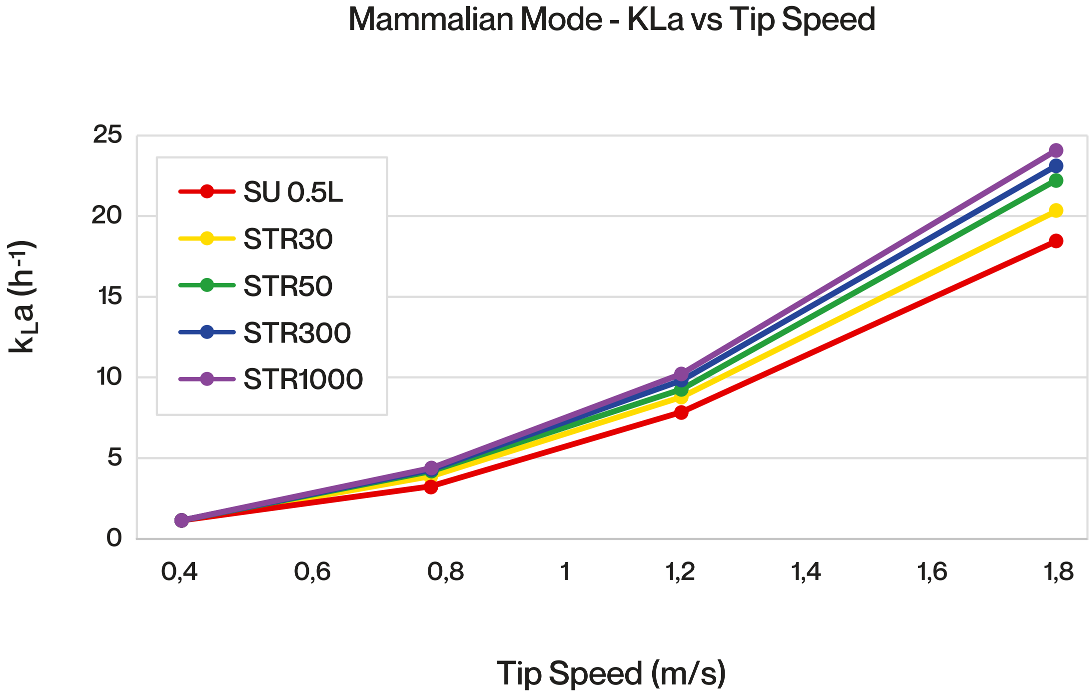
Scale-Up Consistency Across the SUB Range

The full set of tests performed demonstrates:

1. **Coherent kLa progression across all volumes**: 0.5 L → 30 L → 50 L → 300 L → 1000 L show proportional increases in P/V and kLa, indicating high design similarity.
2. **Linear agitation-to-kLa relationship**: All vessels display the same slope in kLa vs N plots, meaning that power transfer scales consistently.
3. **Gas–liquid dispersion equivalence**: Bubble breakup behavior observed in small-scale units is maintained at large scale, confirming the validity of 1.0 vvm for microbial testing.
4. **Predictable microbial performance**: The TECNIC SUB family reliably reaches 300–350 h^{-1} in microbial mode at production scale, enabling high-density *E. coli* processes.
5. **Unified engineering model**: Because all scales use the same impeller type, baffles and geometric ratios, agitation scaling follows classical STR theory.

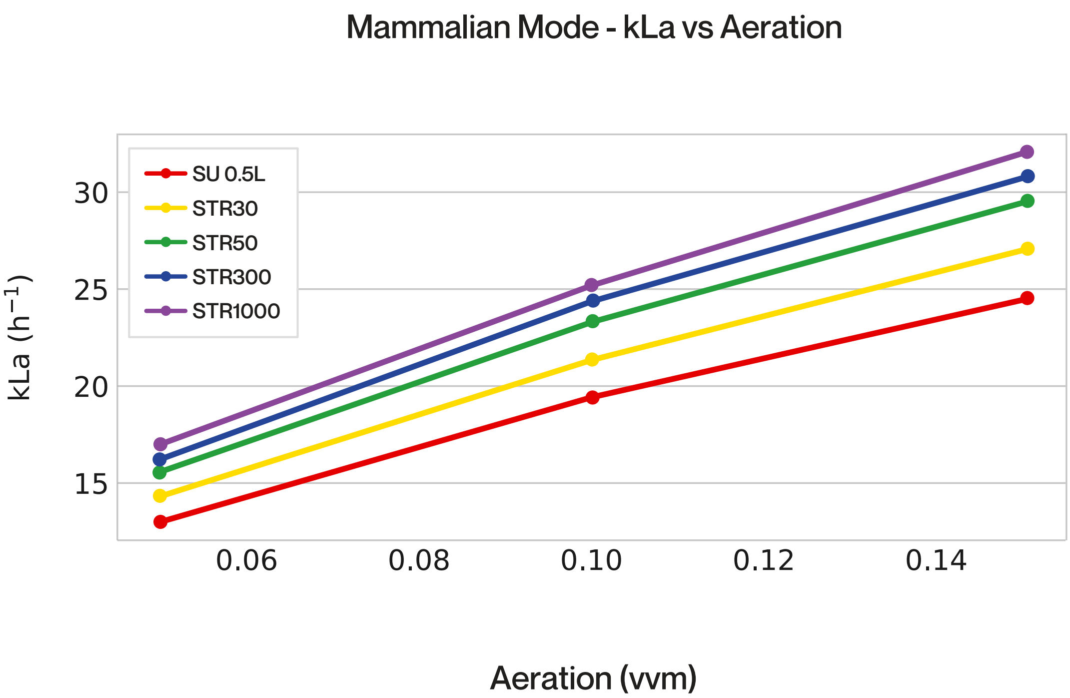
Graphical Summary of Oxygen Transfer Performance (All Scales)

The following figures summarize the oxygen-transfer behavior of all TECNIC SUB volumes (0.5 L, 30 L, 50 L, 300 L and 1000 L) under both mammalian and microbial operating regimes. Each plot includes the full SUB range in a single figure to highlight cross-scale consistency and the hydrodynamic continuity of the platform.



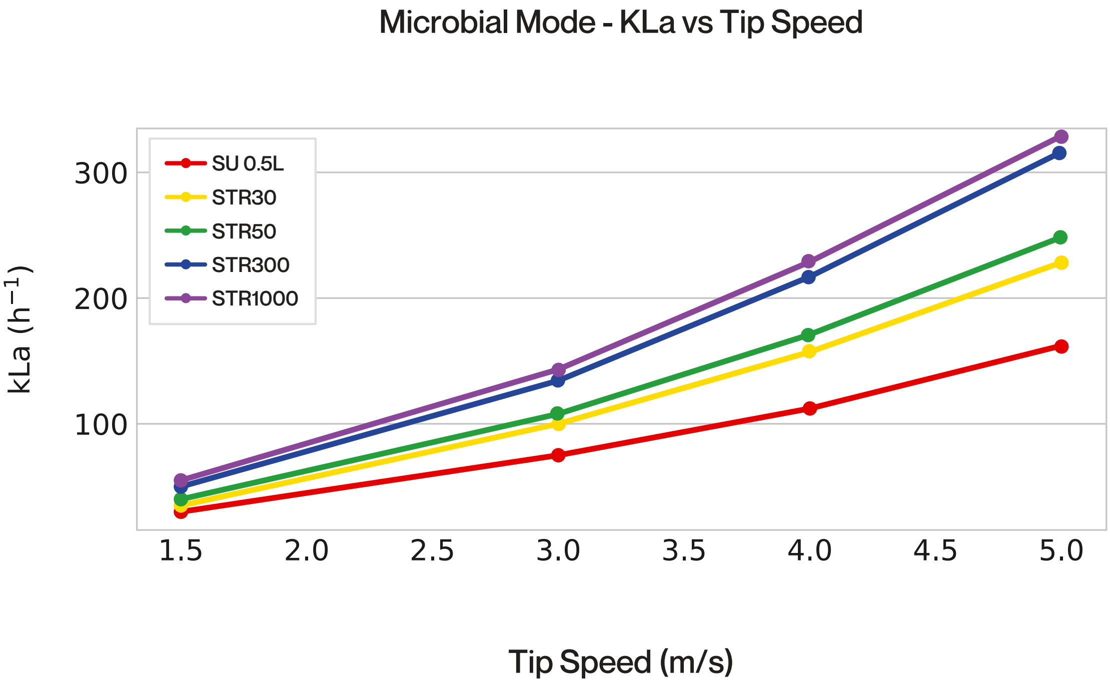
Mammalian Mode – kLa vs Tip Speed for All SUB Volumes

PBS, 37 °C, 0.10 vvm, 3 × Pitch Blade impellers, 4 baffles. The plot shows the evolution of kLa with agitation speed for all vessel sizes, demonstrating consistent low-shear behaviour across the SUB range. The maximum gassed kLa values range from 19 h^{-1} (0.5 L) to 25 h^{-1} (1000 L).



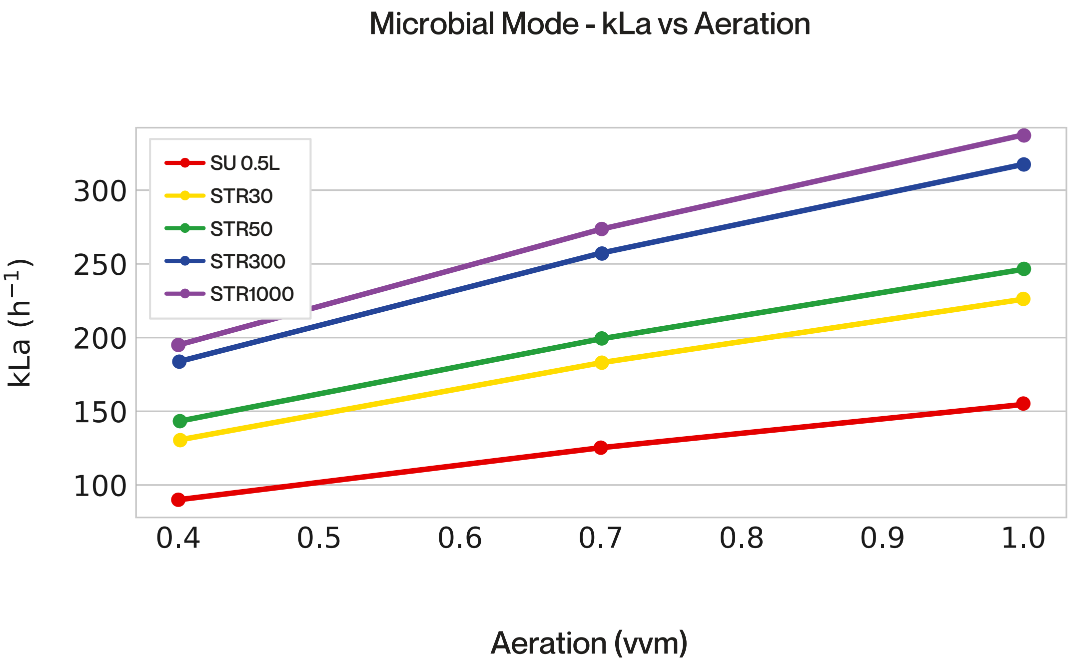
Mammalian Mode – kLa vs Aeration Rate (vvm) for All SUB Volumes

PBS, 37 °C, 0.10 vvm, 3 × Pitch Blade impellers. kLa increases proportionally with aeration from 0.05 to 0.15 vvm. All scales remain within the typical mammalian mass-transfer window (20–30 h^{-1}), confirming predictable and scale-independent behaviour.



Microbial Mode – kLa vs Aeration Rate (vvm) for All SUB Volumes

Water/PBS 1.00 vvm, 3 × Rushton turbines, 4 baffles. The figure illustrates the strong dependence of microbial kLa on agitation speed. All scales follow the same rising trend, reaching gassed kLa values of 150–330 h^{-1}, suitable for high-density *E. coli* processes.



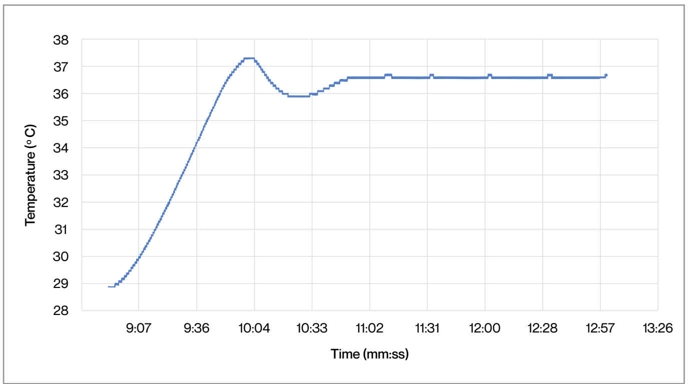
Microbial Mode – kLa vs Aeration Rate (vvm) for All SUB Volumes

Water/PBS, 1.00 vvm, 3 × Rushton turbines. The kLa response to aeration (0.4–1.0 vvm) shows clear scale-to-scale consistency. The trend confirms that all TECNIC SUB models maintain similar bubble-dispersion efficiency, supporting oxygen-intensive microbial fermentations.

Performance Validation: FAT and Stress Testing

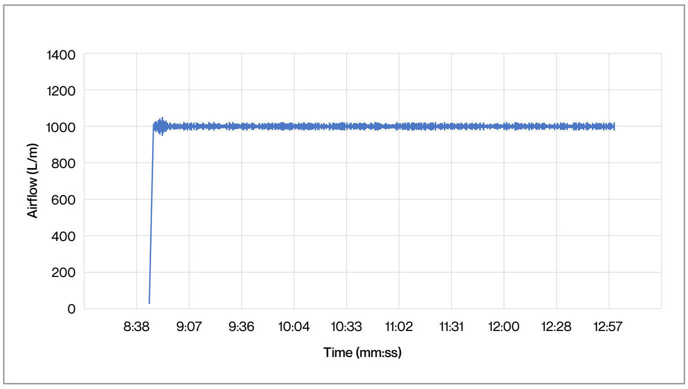
This section presents the experimental validation of TECNIC's single-use STR bioreactors, based on a series of Factory Acceptance Tests (FAT) and stress tests performed in July 2024. The tests evaluate the system's performance across different operational parameters, including temperature control, airflow regulation, and mechanical robustness, at various working volumes and under demanding process conditions.

Figure 1. Temperature Control (1000L)



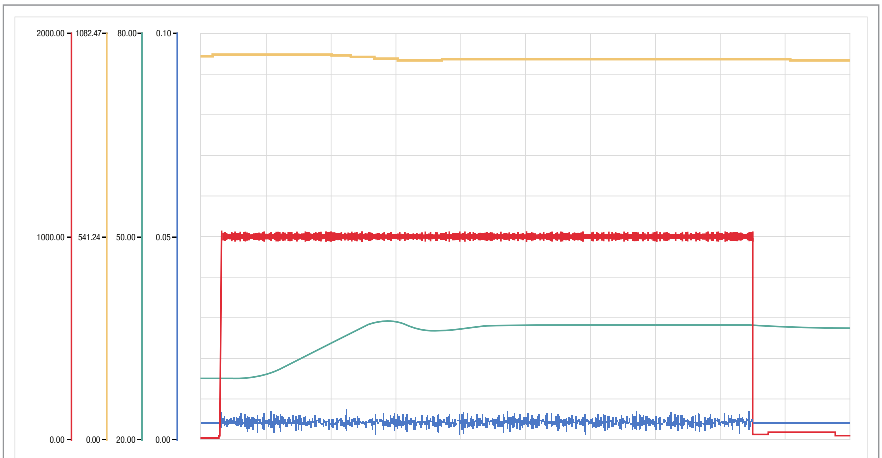
Test: Temperature set to 37°C from 29°C.
Result: Minor overshoot (to 37.5°C), stabilization at 36.7°C within ±1°C (better than industry standard ±2°C) for microbial and ±0.5°C for cellular.
Conclusion: Highly precise temperature management, essential for sensitive processes.

Figure 2. Airflow Profile (1000L)



Test: Airflow set to 1000 LPM.
Result: Stable at setpoint.
Conclusion: System quickly adapts to external disturbances, ensuring process reliability.

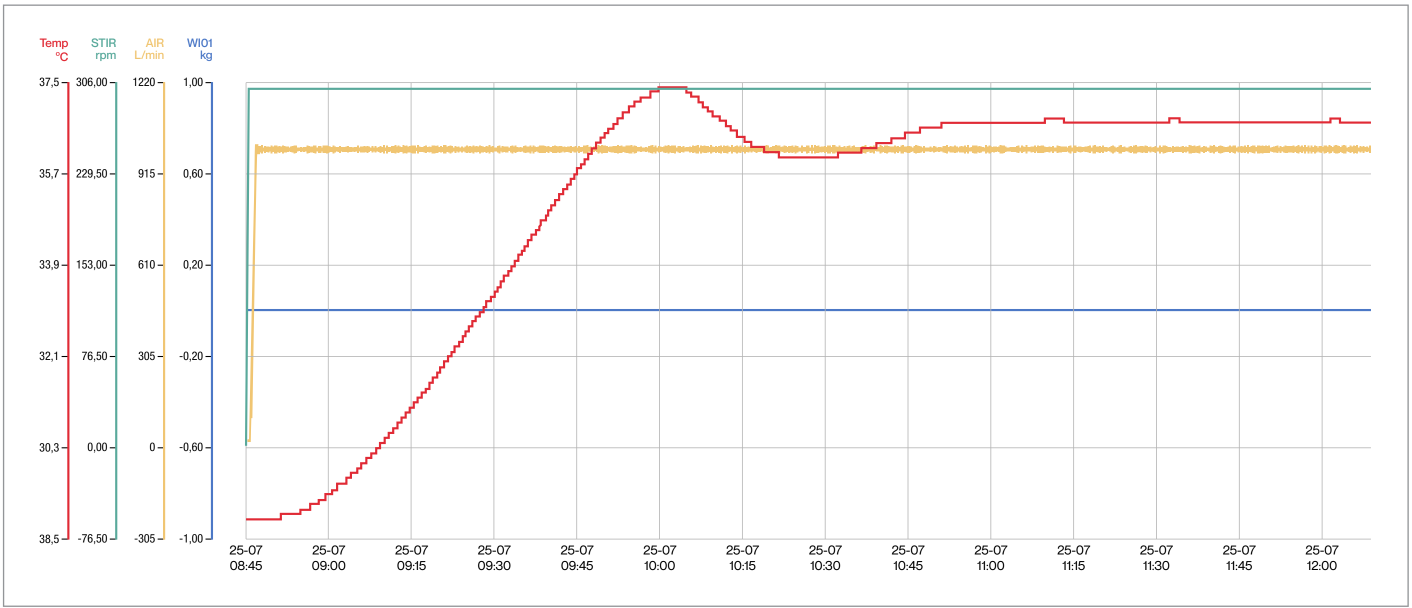
Figure 3. HMI Screenshot During the Test (STR 1000L)



	Label	Current	Cursor	Eng...	Min Value	Max Value	Average	Min Scale	Max Scale
	AIR	0.54	1007.74	l/min	0.00	1159.76	812.32	0.00	2000.00
	WI0001	985.20	1010.10	Kg	1005.90	1027.80	1012.77	0.00	1082.47
	TT0001	24-80	36.70	ºC	28.90	37.40	35.31	20.00	80.00
	PT0001	0.00	0.00	bar	0.00	0.00	0.00	0.00	0.10

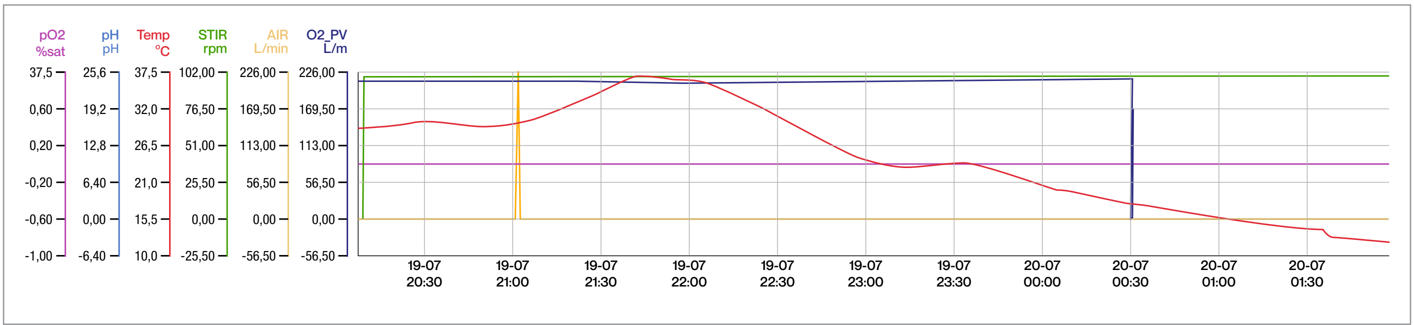
Test: Real-time monitoring of temperature, agitation, and airflow via the HMI during FAT and stress tests.
Result: The HMI displayed stable and accurate process trends, allowing immediate detection of any deviations.
Conclusion: The HMI enables effective process supervision and rapid response, supporting reliable and precise bioreactor operation.

Figure 4. Process Report (1000L)



Test: The airflow was set to 1000 liters per minute, with initial fluctuations caused by external compressor limitations.
Result: Normal conditions observed.
Conclusion: TECNIC's ensures stable control of conditions.

Figure 5. Process Report (1000L)



Test: Temperature control during the FAT test: control loop from 28°C to 37°C setpoint, then cooled to 10°C.
Result: The equipment successfully managed both heating and cooling phases.
Conclusion: TECNIC demonstrates advanced thermal management, ensuring seamless transitions between heating and cooling phases.

Temperature Variation During FAT Testing

Test: FAT temperature control tests at STR 30L, STR 50L, STR 300L, and STR 1000L scales.
These figures illustrate the temperature variation during Factory Acceptance Tests (FAT) at dierent volumes.
Each test shows the bioreactor's ability to control temperature precisely:

- **Figure 6** (STR 30L FAT Test): The equipment maintained optimal temperature control throughout the heating and cooling cycles, even at smaller volumes.
- **Figure 7** (STR 50L FAT Test): The bioreactor continued to demonstrate stability in maintaining temperature control, confirming scalability across increasing volumes.
- **Figure 8** (STR 300L FAT Test): The equipment managed smooth temperature transitions, essential for medium-scale processes.
- **Figure 9** (STR 1000L FAT Test): The temperature control at the 1000L scale remained precise, showcasing the system's ability to scale eciently without sacrificing performance.

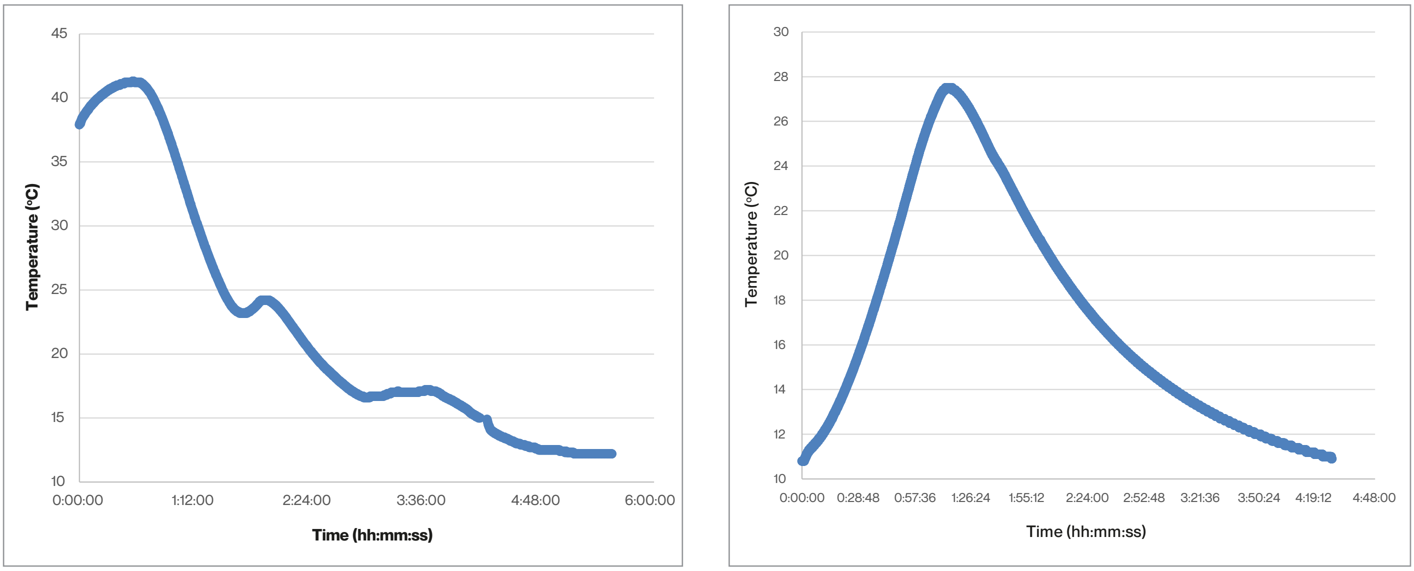


Figure 6. ePilot (30L) recordings of the temperature variation during FAT testing of the equipment.

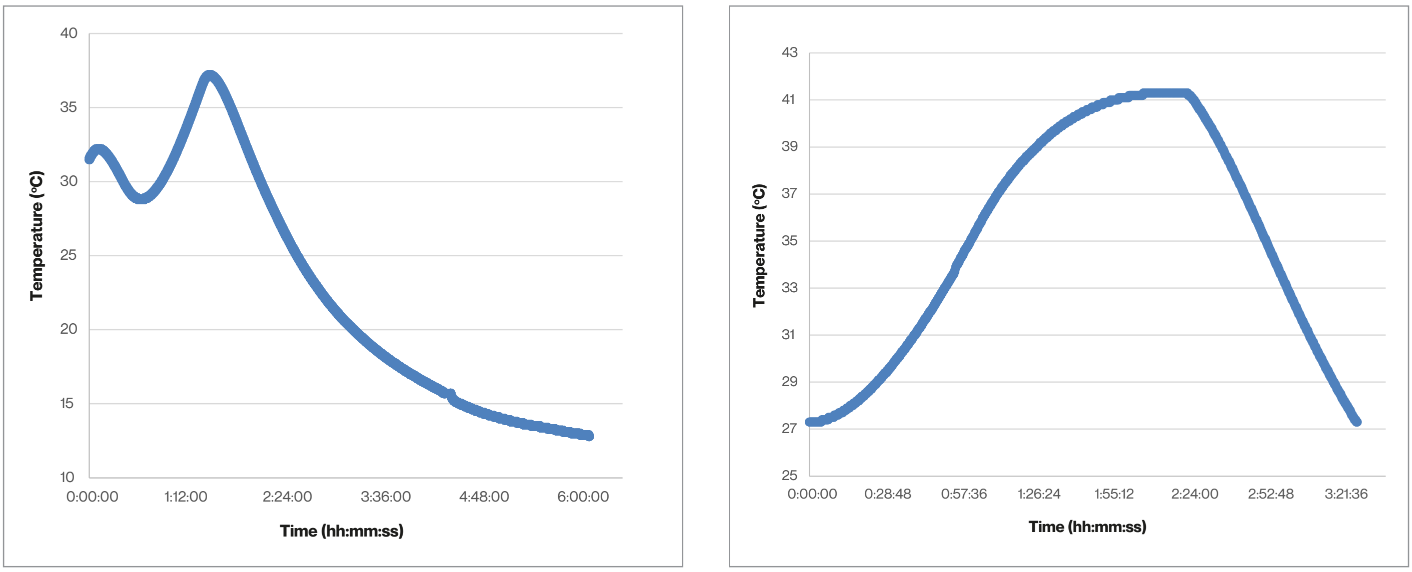


Figure 7. ePilot (50L) recordings of the temperature variation during FAT testing of the equipment.

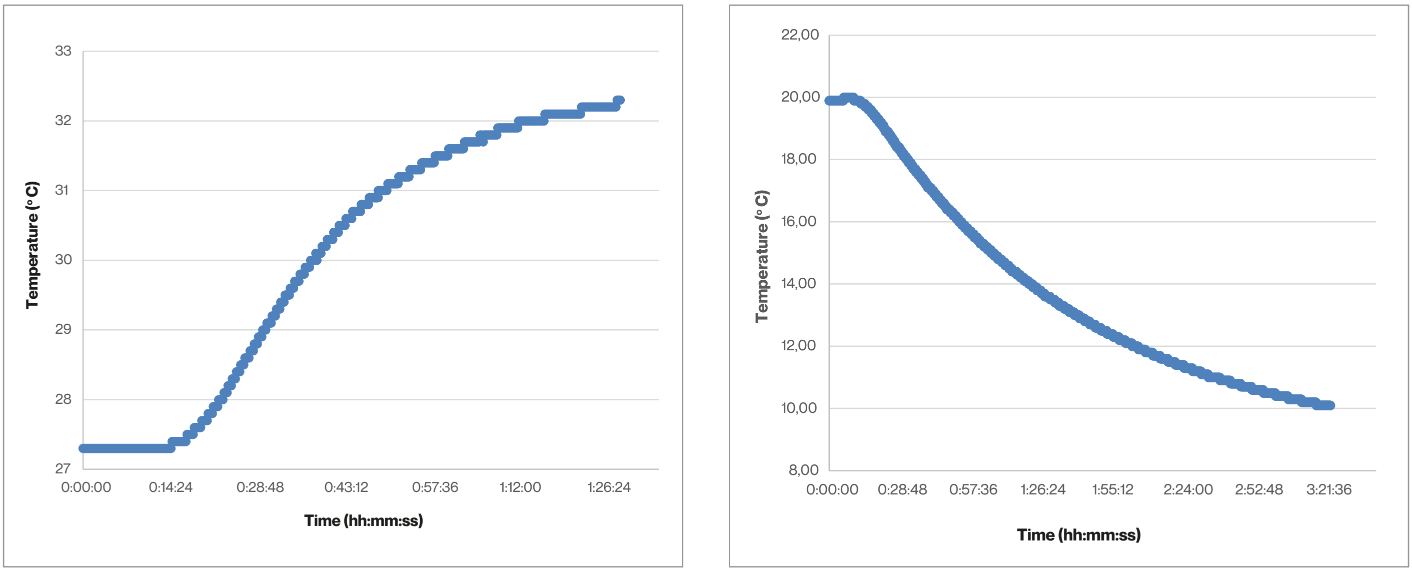


Figure 8. eProd (300L) recordings of the temperature variation during FAT testing of the equipment.

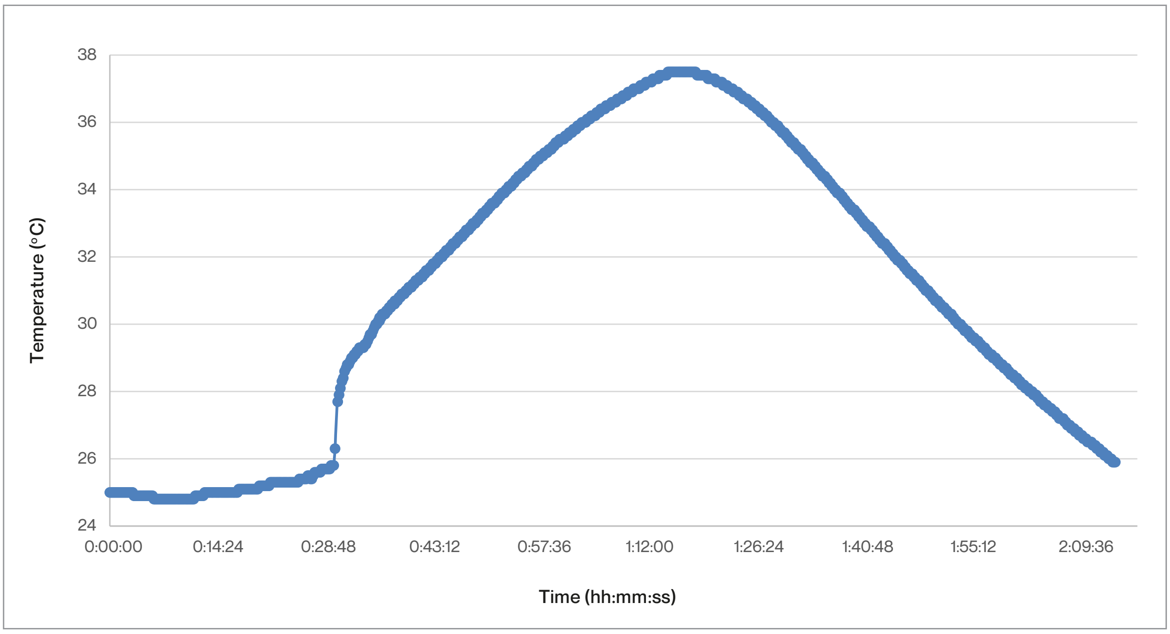


Figure 9. eProd (1000L) recordings of the temperature variation during FAT testing of the equipment.

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