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Investigation of Scale-Up Strategies for an Aerated Bioreactor Comprised of a Coaxial Mixer with Yield-Pseudoplastic Fluid

P. L. Barros, F. Ein-Mozaffari, A. Lohi

Toronto Metropolitan University, 350 Victoria Street, Toronto, Canada M5B 2K3

INTRODUCTION & AIM

Defining bioreactor scale-up strategies is a complex task aimed at establishing a framework for achieving equal mixing and mass transfer quality at large scales when compared to smaller scales. A primary concern in developing these strategies is ensuring the applicability of empirical correlations derived from small-scale equipment to the large-scale counterpart. The present study aims to propose and evaluate scale-up frameworks based on empirical estimations of volumetric mass transfer coefficients obtained from a small-scale vessel, as detailed in Figure 1.

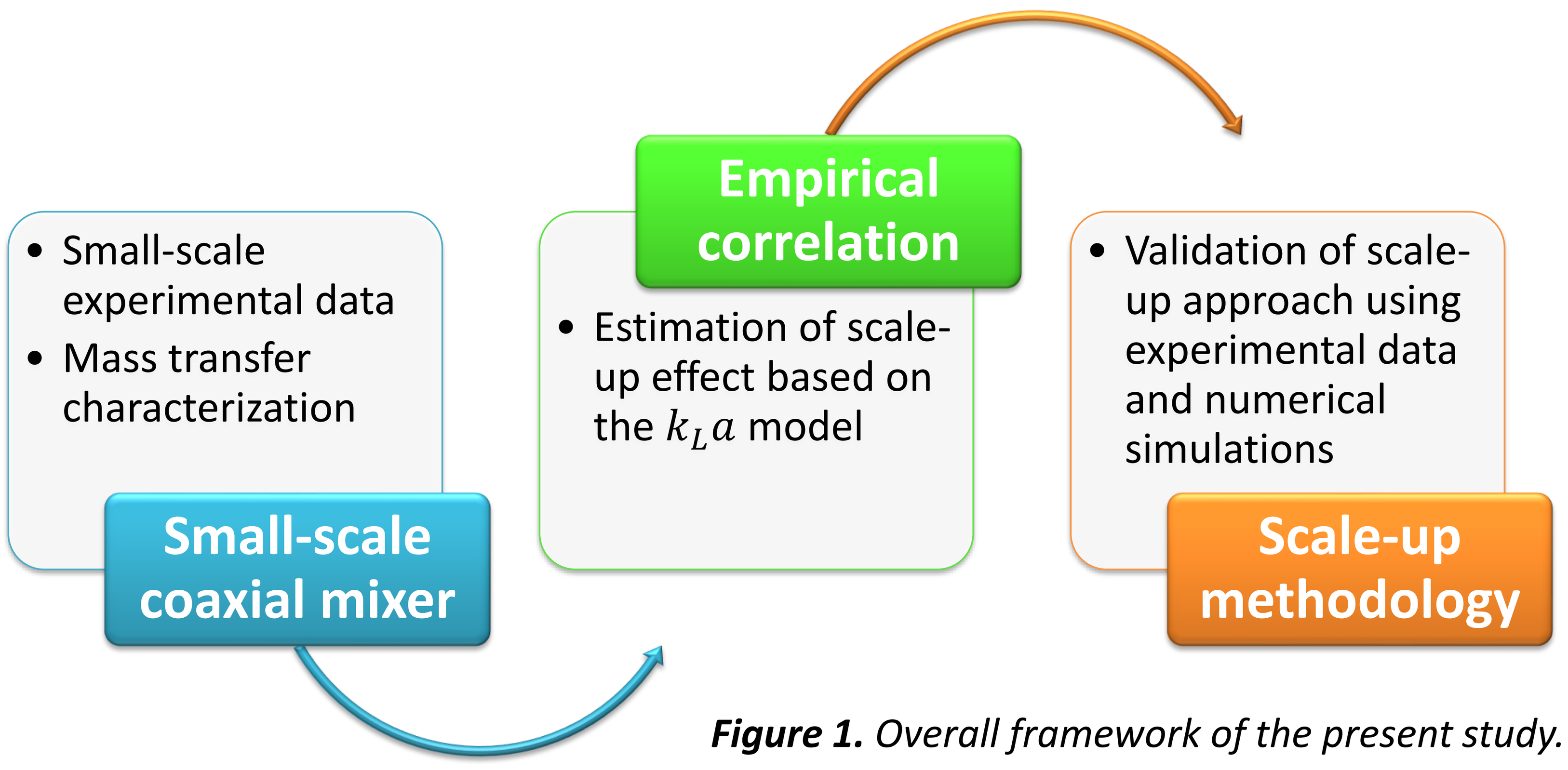
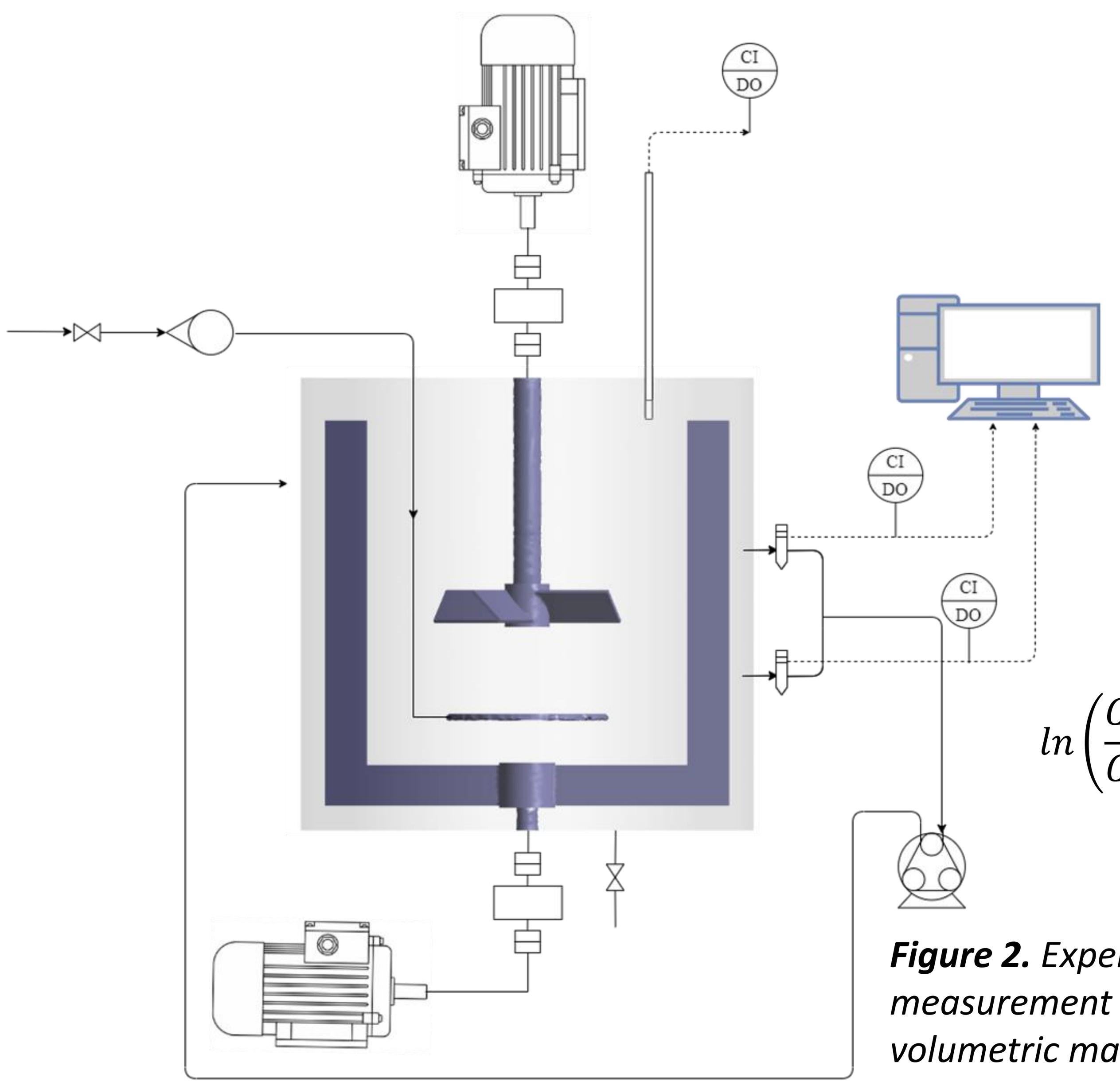


Figure 1. *Overall framework of the present study.*

METHOD



Performance parameters:

- Volumetric mass transfer coefficient (k_La)
- Power consumption

Torque measurement:

$$P_g = 2\pi N_c M_c + 2\pi N_a M_a$$

Dynamic measurement of the dissolved oxygen concentration:

$$ln\left(\frac{C_{sat} - C_2}{C_{sat} - C_1}\right) = -k_La(t_2 - t_1)$$

Figure 2. *Experimental setup for the measurement of power consumption and volumetric mass transfer coefficient.*

Table 1. *Range of operating conditions for obtaining the empirical model.*

Process variable	Range
Aeration rate (vvm)	0.4−0.8
Central impeller speed (rpm)	350−500
Anchor impeller speed (rpm)	20−40
Xanthan gum concentration ($wt\%$)	1.0−1.4

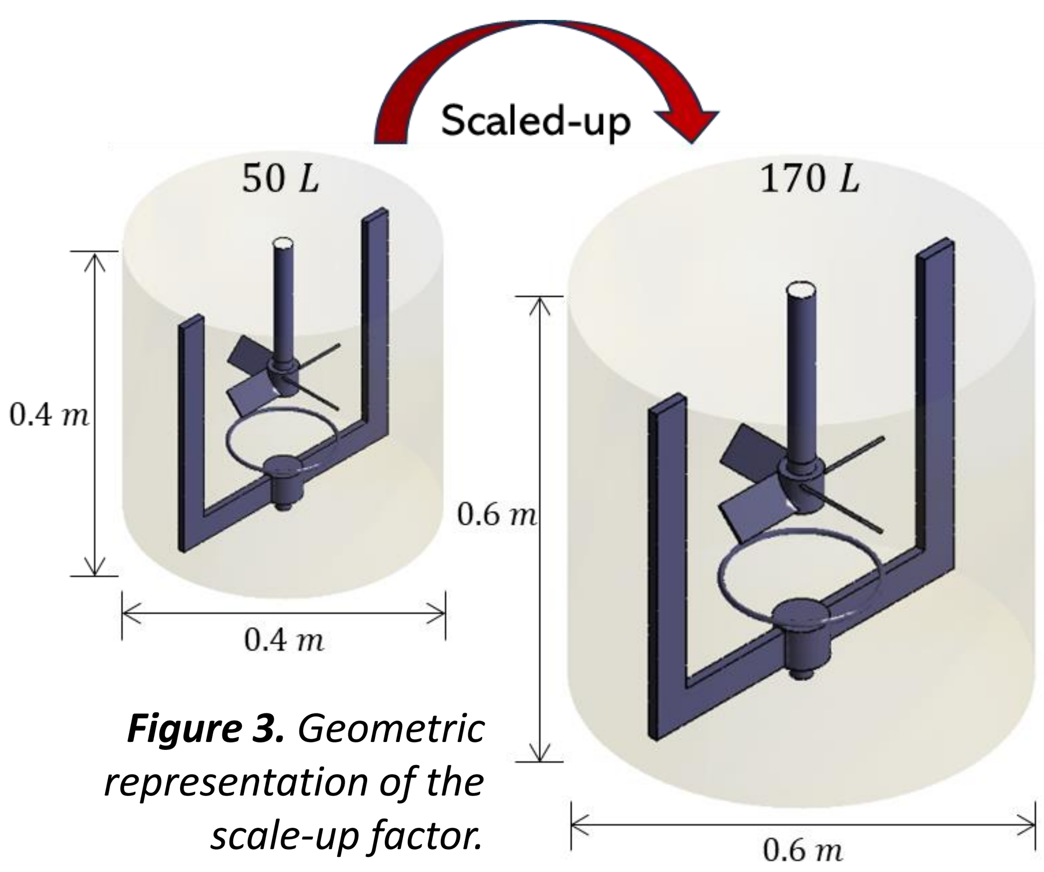


Figure 3. *Geometric representation of the scale-up factor.*

RESULTS & DISCUSSION

$$\frac{k_LaD_C^2}{D_L} = 15.03Re^{1.14}Fl_G^{0.21}$$

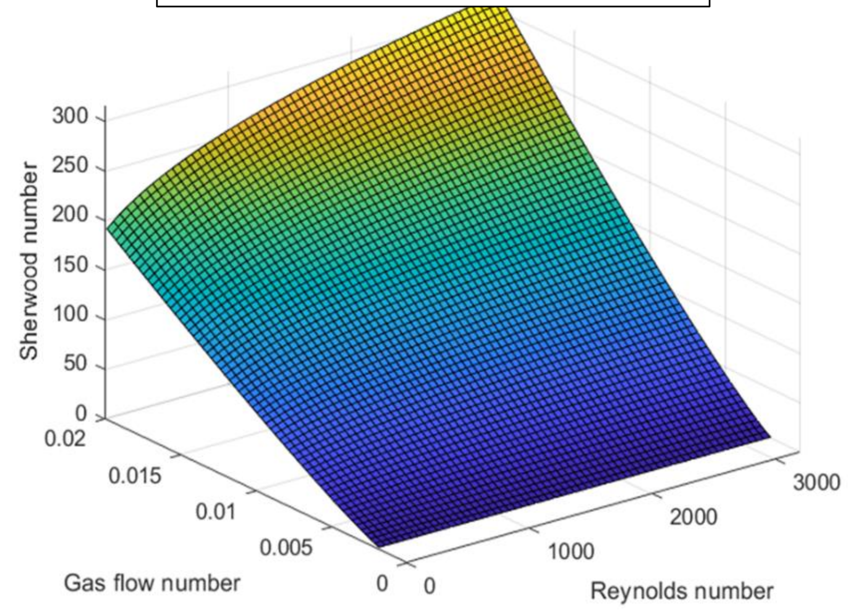


Figure 4. *Estimated effect of gas flow number and Reynolds number on the dimensionless volumetric mass transfer coefficient.*

Table 2: Expected scale-up effect for geometrical factor of 1.5.

Large/Small Scale Variable	Equal N_c, N_a, and vvm	Equal P_g/V, N_r, and vvm
N_{eq}	1	$(1.5)^{-1/6}$
N_a	1	$(1.5)^{-1/6}$
N_c	1	$(1.5)^{-1/6}$
D_{eq}	1.5	1.5
Re	$(1.5)^2$	$(1.5)^{11/6}$
P_g/V	$(1.5)^2$	1
Fl_G	1	$(1.5)^{1/6}$
Q_g	$(1.5)^3$	$(1.5)^3$
vvm	1	1
v_s	1.5	1.5
k_La	$(1.5)^{1.3}$	1.5

Table 3. *Experimental data for validation of the scale-up strategy.*

Mixing Scale	N_c (rpm)	N_a (rpm)	Q_g (L/min)	Estimated k_La (s^{-1})	Experimental k_La (s^{-1})	Relative Error (%)
Small-Scale	300	20	20	0.00083	0.00088	5.41
	350	20	20	0.00110	0.00130	15.70
	400	20	20	0.00139	0.00155	10.15
Large-Scale Equal N_c, N_a, and vvm	300	20	68	0.00139	0.00123	12.95
	350	20	68	0.00184	0.00173	6.41
	400	20	68	0.00234	0.00228	2.66
Large-Scale Equal P_g/V, N_r, and vvm	280.4	18.7	68	0.00124	0.00074	67.73
	327.1	18.7	68	0.00164	0.00134	22.87
	373.7	18.7	68	0.00209	0.00233	10.38

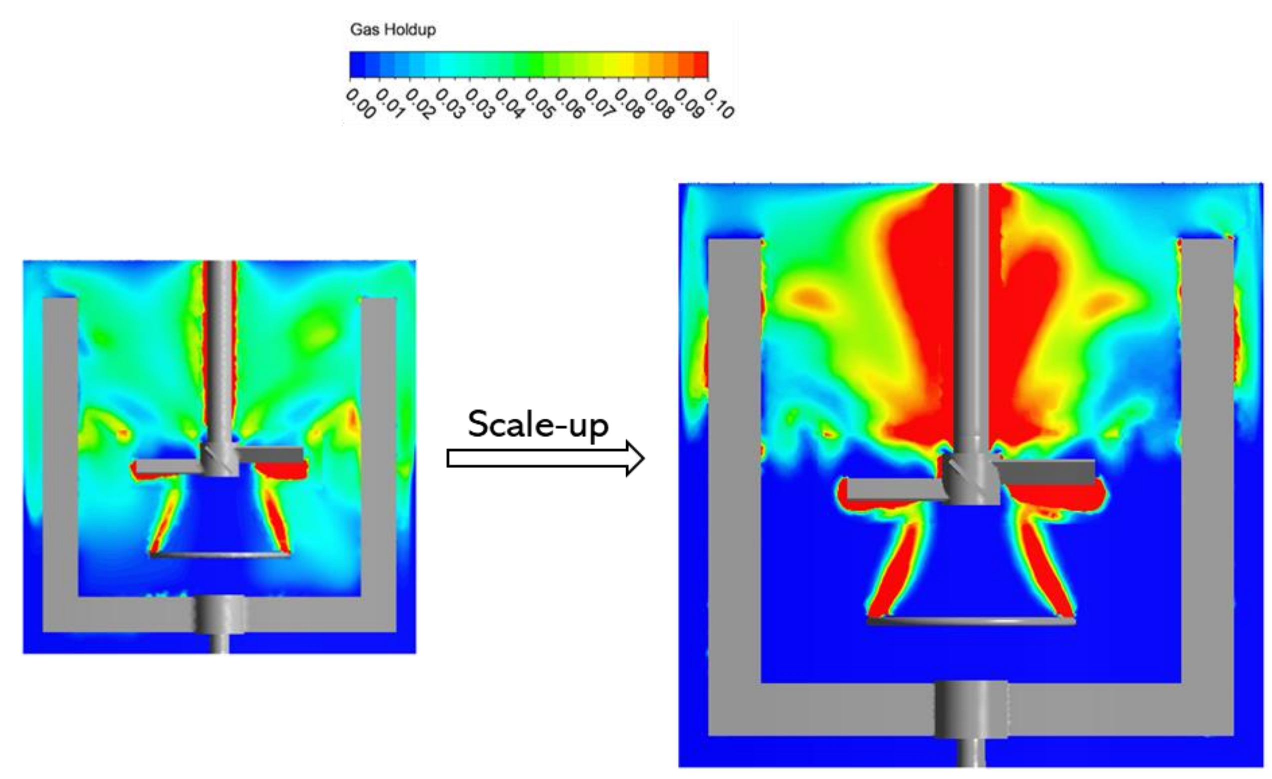


Figure 5. *Variation in flow regime upon scale-up that originated the large error in the scale-up validation data ($N_c = 280.4\ rpm$; $N_a = 18.7\ rpm$, and $Q_g = 68\ L/\text{min}$).*

CONCLUSION

Volumetric Mass Transfer Coefficient Analysis: A proposed dimensionless empirical correlation demonstrated a correlation coefficient of 0.904, accurately predicting 77% of the data within ±15% of the ideal prediction.

Scale-Up Framework: The most efficient strategy consisted in maintaining specific power consumption, speed ratio, and volumetric gas flow rate per volume of liquid constant.

Validity of Scale-Up Strategy: The proposed scale-up strategy remains valid as long as the gas-liquid flow regime remains consistent across different scales.

CFD Modelling Approach: It allows for the prototyping of mixer designs at manufacturing scale.

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