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Effect of Fractional Gas hold-up (ε_G) on Volumetric Mass Transfer Co-efficient (KLa) in Modified Airlift Contactor

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Abstract

Effect of fractional gas hold-up ε_G on volumetric mass transfer coefficient KLa were studied for two different type of airlift contactors conventional and modified. KLa was directly proportional to gas hold-up within bubbly flow regime (UG < 0.075 m/s) in conventional one but reverse trend (inversely proportional) was reported in modified airlift contactor. Mathematical relation between KLa and gas hold-up were developed for both the reactors with the help of experimental data.

Symbols:

ALC	Airlift contactor
UT-ALC	Uniform tube airlift contractor
CDT-ALC	Converging diverging tube airlift contactor
K_La	Volumetric mass transfer coefficient (1/hr.)
ε_r	Fractional gas hold-up in the riser

1. Introduction

Airlift contactors are a special class of pneumatic contactors which are receiving much attention for potential application as a bioreactor. Their self-generated liquid circulation has been shown to give them added advantages such as improved heat transfer, mass transfer and mixing characteristics.

The gas-liquid volumetric mass transfer coefficient (KLa) depends on gas hold-up in gas-sparged, non-agitated fermenter [1,2,3]. An extensive study of gas-liquid mass transfer in external-loop airlift contactors were presented by Bellow [1]. Bellow and co-workers inferred from their result that negligible mass transfer occur in the down-comer and suggested that this was due to a negligibly small slip velocity in this region. Depletion of oxygen in the bubble in the down-comer (because of their long residence time), reduces the mass transfer rate. If the hold-up in the down-comer is assumed not to contribute to mass transfer, the volumetric mass transfer coefficient should depend only on the active gas hold-up in the riser (ε_r).

$$\varepsilon_r = [VDr - Vr] / Vr \quad (1)$$

ε_r is the gas hold-up in the riser.

VDr is the dispersed liquid volume in the riser

V is the initial liquid volume in the riser

Ar area of riser in m3

For the external loop airlift contactor dispersed liquid height in the riser is hD and initial liquid height in the riser is hi. So, VDr = hD Ar .

Initial liquid volume in the riser Vr = hi Ar

$$\varepsilon_r = [h_D - hr] / hi \quad (2)$$

The relation between (KLa)r and ε_r in bubble column is given below

$$(KLa)r = C \ \varepsilon_r n \quad (3)$$

(KLa)r is the volumetric mass transfer coefficient in riser.

Bellow and co-worker reported that negligible mass transfer occurred in the down-comer.

We may write

$$KLa = C \ \varepsilon_r n \quad (4)$$

Where KLa is the over all volumetric mass transfer coefficient

This relation is assumed to be valid for external loop airlift contactor

So, $$KLa = C \ \varepsilon_r n \quad (5)$$

In this study the gas hold-up in the riser was measured according to the equation 2. Overall volumetric mass transfer coefficient was determined by sulphite oxidation method for both the reactors (UT-ALC and CDT-ALC) under identical operating condition for a fixed Ad / Ar ratio = 1.7

Literature review reported lot of study with Ad /Ar less than 1.0. Reports with Ad /Ar more than 1.0 is rarely available.

Ad = Area of down-comer

Ar = Area of riser

2. Experimental

The riser tube of conventional external loop Uniform Tube airlift contactor (UT-ALC) was replaced by a converging-diverging tube. The modified airlift reactor system is called CDT-ALC (Converging diverging tube airlift contactor)
The airlift contactors (ALC) used in this study are shown in fig.1 (UT-ALC) and fig.2 (CDT-ATC) with dimension given in table 1. Volumetric mass transfer coefficient K_La were determined experimentally for both the reactors (contactors) under identical operating conditions by sulphite oxidation method. Gas hold-up was measured from dispersed height for riser part only.

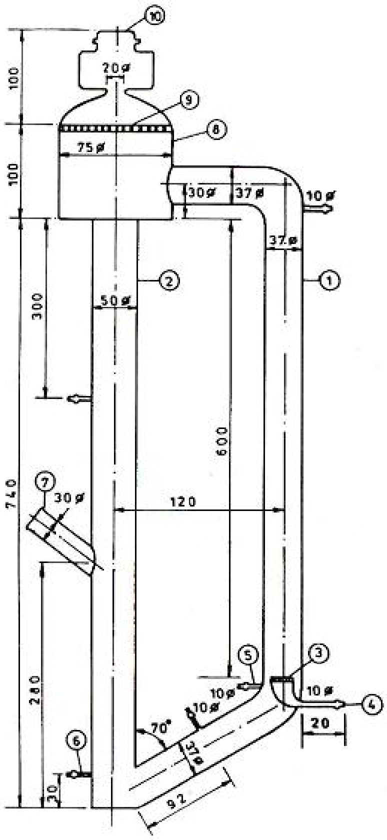

Figure 1. Conventional External Loop Uniform Tube Air-Lift Contractor (UT-ALC)

1. Riser 2.Down-comer 3.Gas sparger with 25ϕ sintered glass 4. Gas inlet 5. Sampling port 6. Drain 7. Probe point 8. Gas liquid separator 9. Perforated plate 3ϕ on 10 mm pitch 10. Gas outlet. All dimensions are in mm.

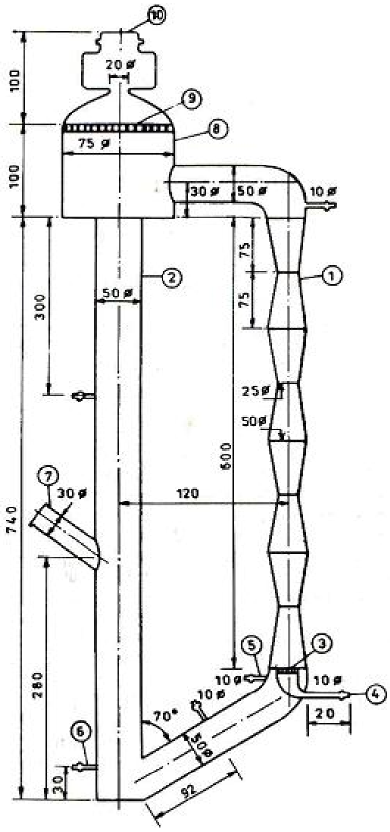

Figure 2. External Loop Converging-Diverging Tube Air-Lift Contractor (CDT-ALC)

1. Riser 2. Down-comer 3.Gas sparger with 25ϕ sintered glass 4. Gas inlet 5. Sampling port 6. Drain 7. Probe point 8. Gas liquid separator 9. Perforated plate 3ϕ on 10 mm pitch 10. Gas outlet
All dimensions are in mm.

Table 1. Details of Air-lift contactor (ALC) used

Material of construction : Borosil glass, All dimensions are in meter

	UT-ALC	CDT-ALC
1. Riser height	0.6000	0.600.0
2. Down comer height	0.7400	0.740.0
3. Riser diameter		
For CDT-ALC		
Dmax		0.050.0
Dmin		0.025.0
For UT-ALC		

Dave	0.0375	
4. Down comer diameter	0.0500	0.050.0
5. Distance between riser and downcomer	0.1200	120.0
6. Diameter of top connector	0.050.0	0.050.0
7. Diameter of bottom connector	0.050.0	0.050.0
8. Diameter of gas-liquid separator	0.075.0	0.075.0
9. Height of gas-liquid separator	0.200.0	0.200.0
10 Diameter of sintered glass sparger	0.025.0	0.02.0
11.Volume of the fermenter (m^3)	0.0020	0.0020

4. Results

Results depicted in fig 3 illustrates that K_La is directly proportional to fractional gas hold-up within a range of U_G less than 0.075 m/s. U_G more than 0.075 m/s , K_La goes down drastically. From hydrodynamic point of view the bubbly flow was maintained up to U_G = 0.075 m/s. Above that transition region starts. A complete reverse trend was reported in CDT-ALC (fig 4). In CDT volumetric mass transfer coefficient K_La is inversely proportional to fractional gas hold-up. In both the reactors K_La is inversely proportional to initial liquid height hi. At any operating condition, CDT reported much higher KLa compared to UT-ALC. CDT-ALC reported 140 % higher KLa at the lowest initial liquid height of hi= 0.50 m.

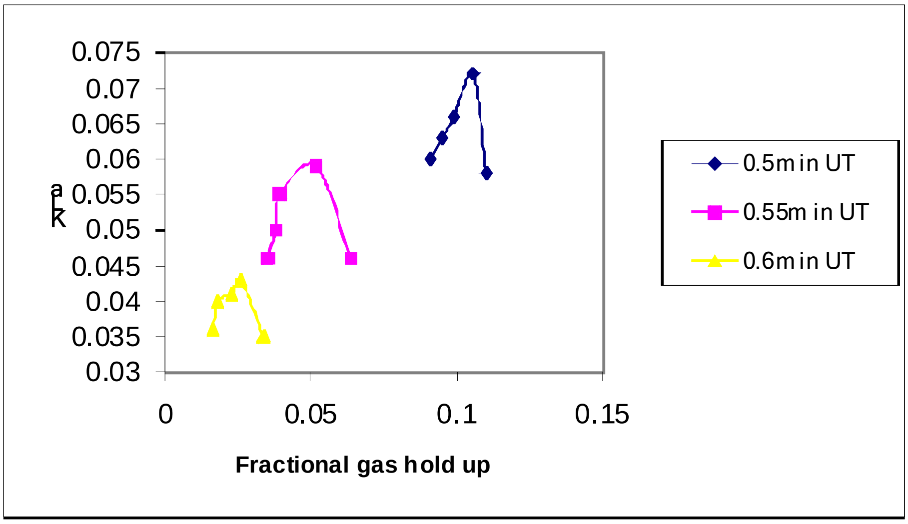

Figure 3. Effect of fractional gas hold-up on volumetric mass transfer coefficient KLa for different initial liquid height (hi) in UT - ALF.

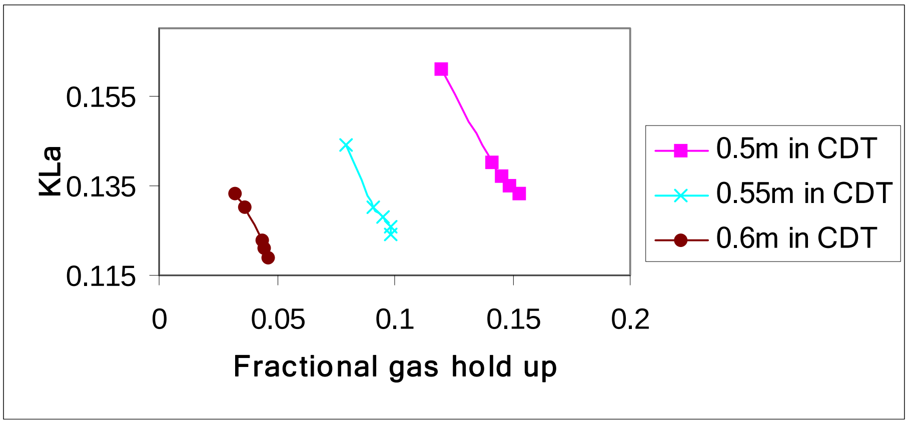

Fig 4. Effect of fractional gas hold-up on volumetric mass transfer coefficient KLa for different initial liquid height (hi) in CDT - ALF.

Determination of proportionality constant (n and C) of equation (5)

Fig 5 illustrates the result of log-log plot of fractional gas hold-up and K_La. The result is linear only up to U_G is less than 0.075 m/s

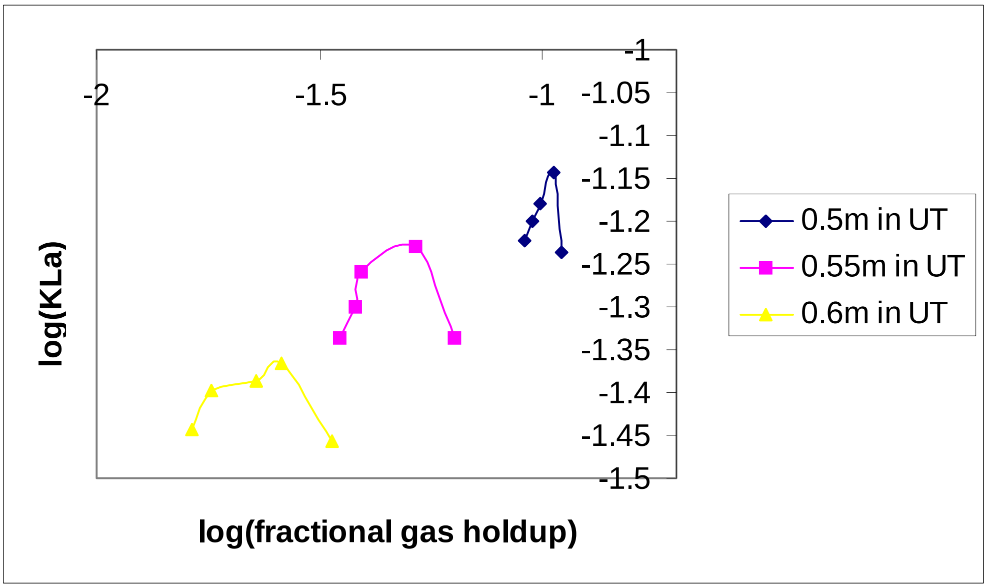

Figure 5. Relation between fractional gas hold-up and KLa in log-log scale for different hi

Log – Log plot of the experimental data of KLa and gas hold-up is presented in fig 6 within the range of linearity (UT-ALC)

Fig 6 represents only the linear relation between the two in UT-ALC. The relations are given below.

Y = 1.231 X + 3.6 for hi = 0.50 m

Y = 0.578 X + 3.1 for hi = 0.55 m

Y = 0.3243 X + 2.7 for hi = 0.60 m

So, average value of 'n' is (1.23 + 0.578 + 0.324)/3 = 0.71
McManamey in his paper [4] reported that for bubble columns, 'n' has been found to be between 0.8 and 1.1. So, approximately, K_La is proportional to ε_G [5,6,7].
So, approximate final relation is given below.

$$K_La \propto \varepsilon_r$$

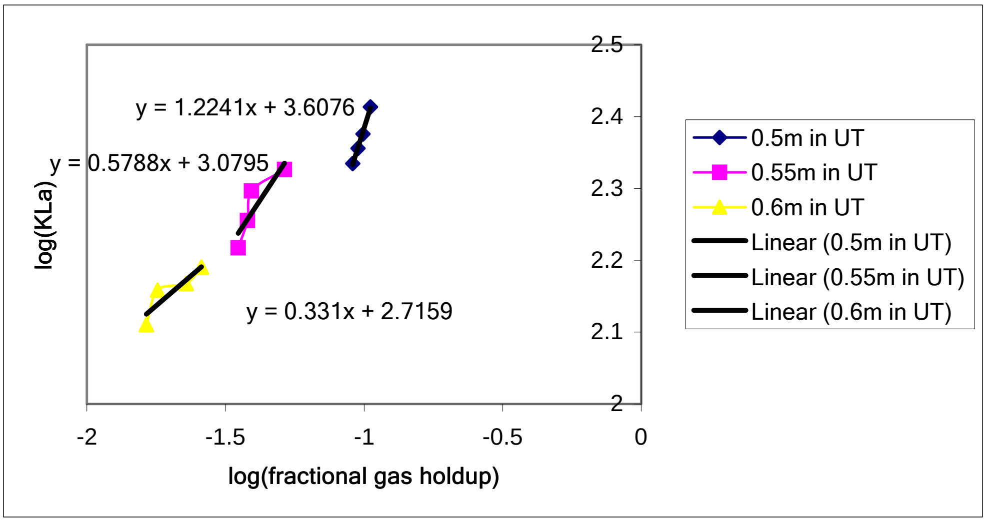

Figure 6. Linear relationship between fractional gas hold-up and KLa in log-log scale for different hi

Results illustrated in fig 7 reported the relationship between fractional gas hold-up and K_La in CDT-ALC. The relations are given below

Y = -0.82 X +2.0 for hi = 0.50 m

Y = -0.66 X + 1.986 for hi = 0.55 m

Y = -0.265 X +2.3 for hi = 0.60 m

So, average value of 'n' is -(0.82 + 0.66 + 0.265) = - 0.58 ,
'n' is negative, approximate relation is given below.

$$K_La \propto [\varepsilon_r]^{-1/2}$$

This is a remarkable result reported in this paper rarely available in the literature.

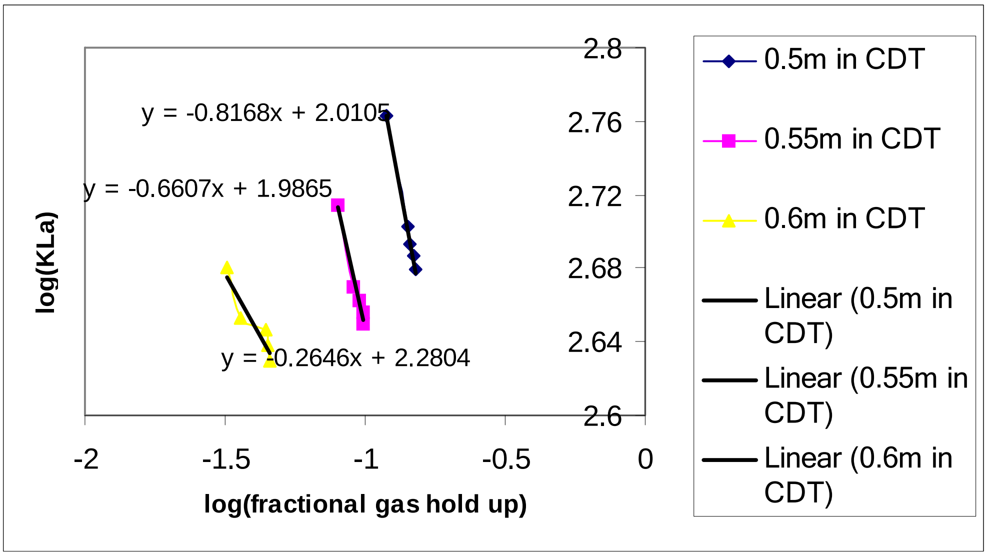

Figure 7. Linear relationship between fractional gas hold-up and K_La in log-log scale for different hi

5. Discussion

Main drawback of ALC is high operating cost. System is unable to provide huge oxygen demand due to microbial growth. To maintain high oxygen transfer rate (high K_La) high air flow is must. High air flow rate not only increase operating cost but also inhibit cell growth due to high share force [8]. So, natural demand is high mass transfer at low air rate. This is impossible to achieve in UT-ALC. To the contrary it is very easy to maintain required environment in CDT-ALC. Results depicted in fig 4 reported that maximum K_La (580 hr.$^{-1}$) is easy to achieve in CDT-ALC at the lowest hold up of ($\varepsilon_r = 0.137$) and corresponding air flow rate was of 2 LPM. Volumetric mass transfer coefficient is directly proportional to gas hold up in UT-ALC but inversely proportional in CDT-ALC. The system always generate mild shear force which is ideal for cell growth. For the above mentioned reasons CDT-ALC may be suitable for cell mass growth in near future.

As the geometry is converging diverging at regular intervals the direction of flow through the system changes periodically from most divergent part to the most convergent part. These affect concentration boundary layer. This may be another reason why CDT-ALC reported much higher K_La compared to UT-ALC at the low superficial gas velocity.

At high superficial gas velocity (above 0.075 m/s) bubbly flow cannot be maintained. Liquid velocity fluctuation due to convergent divergent geometry generates pressure fluctuation.

Liquid velocity oscillates with varying amplitude which generates pulsation effect in the system. This may be another reason for high Kla in CDT-ALC. At high air rate bubbly flow regime cannot be maintained. Liquid velocity fluctuation also not prominent As a result low Kla was reported at higher superficial gas velocity.

Most experiment in screening and process development are performed in shaken bioreactor. Today airlift contactors are gaining popularity because airlift system can generate uniform and mild shear stress. According to the results depicted in fig. 4, CDT-ALF reported highest KLa (volumetric oxygen transfer coefficient) (0.162 1/sec or 580 1/hr.) at the minimum air rate of 2 LPM corresponding to a gas hold-up of 14 %. This is the unique characteristics of CDT. High volumetric oxygen transfer is possible at the minimum shear rate. In any reactor system cell growth is very sensitive to shear force. As a result CDT-ALF system may be used for cell culture [9,10]

In the above mentioned investigation it was reported that performance of CDT - ALF was far better compared to UT-ALF at the lowest air rate (2 LPM).

Hydrodynamic conditions have a significant impact on cell mass growth and its life cycle [11]. CDT may be used for animal cell culture as it generates low shear stress. The effect of hydrodynamic forces on animal cell cultures, were extensively studied, still lacks significant, fundamental understanding [12]. Hong Sun reported that shear rate have a significant negative impact on growth rate [13]

Volumetric oxygen transfer coefficient (KLa) is one of the most common scale-up parameter. KLa which essentially is a measure of how much oxygen can be supplied to cells growing in a bioreactor. Oxygen is typically the limiting substrate due to its poor aqueous solubility. B. Bandyopadhyay et al [14] reported that in general cells grown in two dissimilar bioreactors but operated at equal KLa will show similar growth and product formation kinetics. In cultivation processes the dissolved oxygen (D.O) concentration is generally accepted as critical parameter [15].

6. Conclusion

Modified system (CDT-ALF) reported excellent performance. Maximum KLa was reported at the lowest gas hold-up i e at the lowest air flow rate. As a result operating cost may be minimized to a great extent if commercialized. Elaborate and in-depth study is must to use this as a successful airlift contactor.

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