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A Critical Review on Hydrodynamic Study of Sparged -Split- Stirred Multiphase Reactor

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***Abstract*:- Multiphase reactors include a large variety of reactors reacting with three phases of gas-liquid-solid in homogenous and heterogenous reactions with and without catalyst and efficiently working on number of applications of chemical, biotechnology, petrochemical and number of industrial fields with modifications starting from various types of reactors, reactor components, installation positions of the impellers, spargers, baffles. Air lift reactors is a multiphase, sparged reactor with splits inside the reactor playing a major role in biotechnology fields, chemical and petrochemical industries and in waste water treatment plants with its advantageous simple design.no moving parts and less power consumption. Flow characteristics inside the reactors are studied by the hydrodynamic parameters mainly of gas holdup, mixing time and liquid gas velocities. In this review we study all the modified designs in the airlift reactors and suggest the installation of stirrers in the downcomer zone in airlift reactors to improve the hydrodynamic parameters and mass transfer coefficients. Studies are minimum with stirrers in the modified designs of airlift reactors. To improve the performance of airlift reactors stirrers of various geometry and types can be setup and the enhanced properties can be researched.**

Key Words:- HYDRODYNAMICS, MULTIPHASE FLOW, AIRLIFT REACTORS, GAS HOLDUP, SUPERFICIAL GAS VELOCITY

1.INTRODUCTION

Reactors ,reactions ,reactants plays a major role in motivating the researchers to reduce cost and waste to the minimum in redesigning reactors of multiple phases , multiple designs and combining various alternative reactions with number of combinations of reactants to attain our requirement in this competitive globe .Stirred tank reactors is oldest of all the complex equipment which dates back to 1940 ‘s for the production of antibiotic penicillin[1].Recent researchers worked on pneumatic designs of bubbling gas agitation[1].It is further modified to our requirements and needs .The modes of operation may be of batch, semi batch or continuous operations. Stirred tank reactors were redesigned with multiple designs of impellers with radial and axial flow types and also with multiple impeller systems and self - inducing impeller types with spargers of various designs with and without baffles. [2] Bubble column designs were not widely used even if it has its long history. [1] Air lift reactors came into effect with lot of modifications and types like internal loop airlifts and external loop airlifts. They are further classified into internal airlifts which comes under split-cylinder type and another having concentric draught-tube modifications with spargers [1].Airlift reactors comes in various designs of cylindrical[3],square[4] ,rectangular[5] ,helix[3] shapes .Fixed bed reactors ,packed bed reactors with different packing materials also plays an unavoidable role in all industries .Novel bubble -induced flow designs, monolith reactors, miniaturized reactors like micro and nano reactors are also designed and modified according to the industrial problems [2].Number of designs are modified and the research is being continued due to complexity in reaction conditions and unavailability of standard data hand books. Airlift reactors modified by split, sparger and stirrer and hydrodynamic properties variations are studied in this article. Modified design concepts are reviewed in the types of reactors, reactants and reaction conditions. Researches have been done on sparged[6] and split reactors[7] and few researches are available with stirrers[8]. Review concentrates on split sparged designs[9] and suggests to modify the reactors with stirrers according to the required conditions.

Gas ,liquid and solid phases are considered in multiphase reactors were arises the complexity in flow regimes inside the reactors and researches are still continued to standardise the designs by modelling[10] the measurement methods and flow dynamics of the airlift reactor .To optimize and scale up, distributions of bubble size and hydrodynamics knowledge is necessary to establish mass transfer in two phase(G-L) reactors [11].To scale up homogenous reactions in multiphase reactors is simple [12].Risky uncertainties ends up while multi -scaling of multiphase reactors[13].Dispersion phases and their interactions during scaling up is a challenge in understanding the spatial distributions of the phases [14].Probing the hydrodynamics of turbulent phases in various zones are important and it is a challenge. Measuring methods followed are indirect and signals should be followed to infer hydrodynamics .Image based methods record the multiphase flows[11].Intrusive image -based methods are followed to probe the hydrodynamics and local bubble size distributions in multiphase reactors[11].Airlift reactors are easy to scaleup[11].Four point optical probe technique is followed in investigating local gas holdup and to measure the bubble dynamics in a split-cylinder airlift reactor [7].Gas holdup, liquid holdup, mixing time, liquid velocity[6], power consumption ,pressure drop are the hydrodynamic parameters to be understood for scaling up the airlift reactors. Two-stage and multi stage internal loop airlift reactor were designed and bubble dynamics and hydrodynamics were investigated and proved that the multistage internal loop airlift reactors have higher efficiency, gas holdup[15]and mass transfer rates[16].In a two stage internal loop airlift reactor screens of different mesh sizes were installed and the hydrodynamics was studied and found that the screens broke the bubbles and the radial velocity distribution of bubbles were uniform and larger gas holdup can be obtained if a suitable screen can be selected[17].In gas-liquid-solid systems hydrodynamic characteristics are complicated due to the intricate effect of the particles. Bubble dynamics were measured with superficial gas velocities and different solid loadings and found that there is no significant effects on solid loading[18].Bubble pressure oscillation and force variation during collisions were measured to explain bubble particle collision and results showed that bubble breakage occurs at high solid loading[19].PBM(population balance method) characterize the bubble behaviour and CFD simulations were done for lab-scale internal loop airlift reactor and they provided an effective method for scale up[20].The effects of different spargers also have been modified and hydrodynamic characteristics were researched and found that the gas holdup, volumetric oxygen transfer coefficient and liquid velocity depend on the structure of the sparger[21]. In the past decades abundant studies have been carried out on flow dynamic characteristics ,geometry optimization and modelling due to numerous airlift reactors applications [10].Even after a lot of researches ,complete knowledge about airlift reactors with geometries and different scales is not up to the required extent due to lack of orderly set of descriptions of flow dynamics and flow structure .To design various airlift reactors accurately flow dynamics knowledge should be gained to scaleup for various applications. Operational parameters should also be understood along with geometry of reactors. With multiphase flows of complex interphase interactions sub models are not available for simulating with CFD. The aim of this review is to briefly describe the researches done in all industrial applications of the airlift reactors of various modifications in geometry and in operating conditions are reviewed. Impellers of numerous modified designs and position of impellers and multiple impeller designs will be summarised. Hydrodynamic parameters were analysed for all the modified designs. The airlift reactors are analysed with various sparger designs, position of the spargers, split designs, and with various operating superficial velocities. To increase the hydrodynamic parameters and mass transfer rates stirrers are suggested in the downcomer region. Reactors with stirrers give high shear rate .For more oxygen rates required systems airlift reactors with stirrers are advisable[22]. Minimum research work is done with stirrers[8].Suitable designs can be suggested for airlift reactors with stirrers by backtracking all the researches to give maximum gas holdup, liquid holdup , minimum bubble diameter ,shear rate ,liquid circulation velocity ,mass transfer coefficient, minimum mixing time and power consumption for the industrial applications .

2. AIRLIFT REACTOR

2.1 GENERAL CONCEPTS

Airlift reactors (ALR) are pneumatic agitated reactors. They are effective in liquid back-mixing reduction rates. It is a multiphase reactor and efficient contactor on gas-liquid-solid system .Origin is from bubble column reactors (BCR)which has a cylindrical vessel along with a gas distributer at the bottom[23].The flow is random in BCR and in ALR it is a defined cycle[24].It is suitable for shear -sensitive processes since the ALR is having defined cycle flow it reduces dead volume and increases the random turbulence .Compared to other BCR and mechanically stirred reactors they have good mixing, simple design, low shear force low energy requirement ,requires no moving parts and it occupies minimum area[25]. ALR's are very popular in the research of bio process and development ranging from biochemicals production for wastewater to treatment of the waste water due to its hydrodynamic characteristics. ALR 's are playing an important and unavoidable role in all the fermentation processes, chemical engineering, waste water treatment and metallurgy .In china due to stringent standards many waste water treatment plants were not to the emission standards and ALR's efficiency made technical modifications in the biological reactors for treating waste water[26].Due to ALR's convolution of multiphase flow structure it is more complex in spite of its simple design .Hence it leads to studies of world-span research[27-29].ALR's can be studied by concentrating on hydrodynamics and mass transfer and another methodology is based on its applications in various industry processes .

2.2 BASIC DESIGN

In ALR's liquid area is divided into two and one of them alone is gas sparged. Two different bulk densities are caused by differing gas holdups in gassed and un gassed areas[1]. It causes fluid circulation by gas-lift action in the reactor. Riser is the area where it has gas-liquid flowing upwards and downcomer is the area of fluid downflowing[1],gas separator at the top were gas gets separated from the liquid phase [2] and the down comer[30].Riser and downcomer are joined at the top and bottom and they are parallel to each other .Since it's a pneumatically operating reactor sparger is mounted at the riser bottom .They are divided into up and downflow depending on the sparger position[31].The gas is introduced at the bottom in up flow. In the aerated and unaerated area due to density difference the flow occurs by gravity effects. There are two types depending on liquid and gas up and downflows, where the liquid inflows from top by a liquid jet and gas is sparged from the upper part in the downflow ALR's[32].ALR's of up flow are divided into two based on downcomer separation from main reactor. In the internal loop ALR's (IL-ALR) the riser and downcomer or nearer and in the external loop ALR(EL-ALR) the riser and downcomer are separated by a distance. In this complete degassing is achieved[33]due to longer travel of bubbles up to the entrance of the downcomer. It is commonly selected for improved mixing, complete degassing and for the liquid circulation to the maximum[34].Since it has no restrictions on the area ratio of the riser and downcomer it operates on wide flow velocity conditions. The IL-ALR have further classifications based on baffle in between the riser and down comer, a draught tube which is continuous is kept in between the riser and downcomer and draught tube which is sectional is kept in between riser and down come. Up and down flowing regions is connected by additional piping in EL-ALR. There are variety of modified ALR's for specific applications. Flow status will be homogenous for coaxial pipe IL-ALR and has more volume utilized, But in split plate the velocity profile is in homogeneous. To overcome this multiple risers and downcomers were modified in IL-ALR and this gave uniform velocity profile and stable flow in channels. Groveled ALR's are designed to work on wastewater treatment in which they have low aspect ratio compared to conventional ALR which cannot be operated above the output pressure of 98kPa[33].In the G-ALR the riser and downcomer width is small and it makes minimum internal recirculation in riser and dead volume in downcomer and velocity is uniform.

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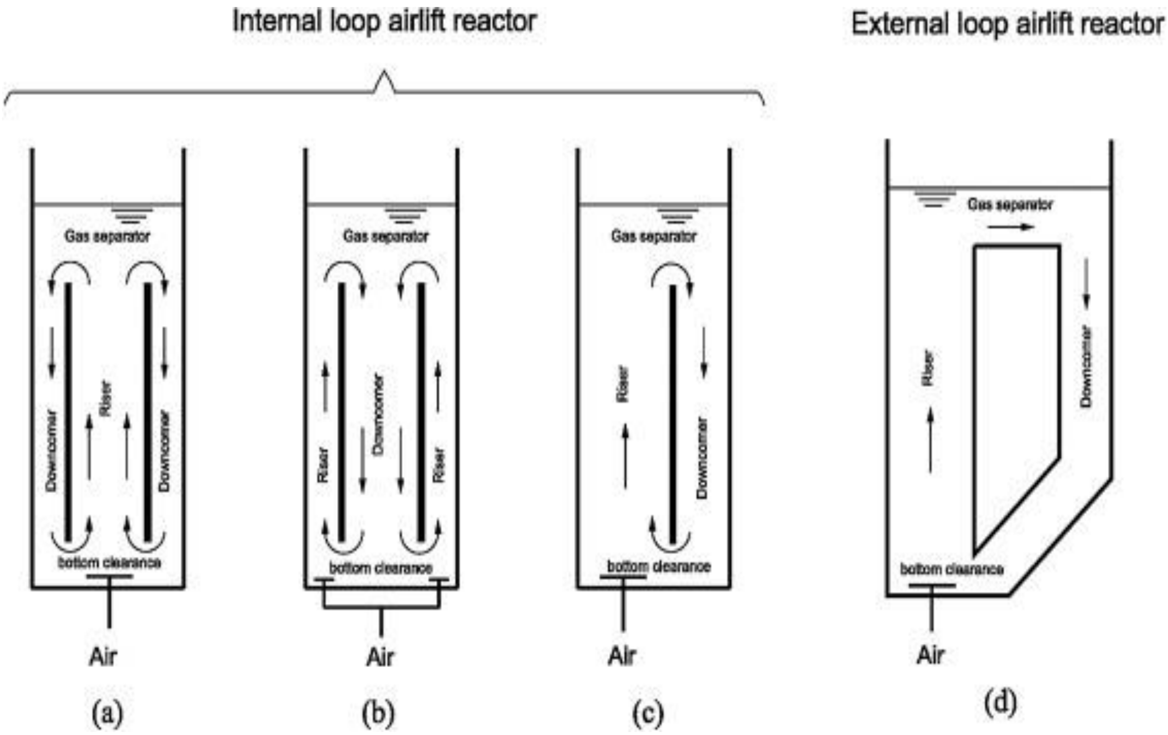

Fig. 1. Classification of Internal and External loop airlift reactor (a) Internal ALR ,(b) Inverse internal loop ALR ,(c) Internal loop ALR with split ,(d) External loop ALR [10]

2.3 MODIFIED DESIGNS OF ALR

In ALR there are numerous modified designs to improve the performance. The modifications make changes in hydrodynamic improvements improve mixing and it also increased mass and heat transfer rates .Funnel shaped designs [35] at the top of the risers guided the flow of rising fluid in the reverse direction of the downcomer and the gas bubble retention time was extended. It also enhanced gas holdup and kinetic energy dissipation was decreased. Trumpet [36]modified design of riser increased oxygen transfer and gas holdup. More gas bubbles in the downcomer changes the gas ratios in the riser to the downcomer and it ends up in the reduction of liquid circulation velocity and it leads to the total holdup increase in the ALR .And thus mass transfer rates are increased[37].Static mixers and wire meshes are modified designs in the riser to enhance mixing, to create disturbances in fluid and to increase the rates of dispersion[4]. ALR 's with annulus sparging types are included with sieve plates in the axial direction at different heights in the modified designs of risers and thus it improves volumetric mass transfer coefficients and the gas holdup. Large bubbles are reduced to smaller bubbles by the sieve meshes. Breaking of bubbles is done by sieves which are included in the modified designs in the riser. To increase the efficiency small bubbles coalescence are reduced by additives of electrolytes [38].Addition of different hole sized and varying hole numbers in perforated plates are also found to reduce the G-L mass transfer coefficient [39] and also they increased the G-L interfacial area .Rectangular wire mesh draft tube modification was also redesigned and it made changes in bubble coalescence and in liquid mixing [40].Gas holdup was also found to be enhanced and mixing time was found to be reduced. Static mixers were also introduced in the draught tube into concentric tube ALR riser and it increased the production rate [41] .Helical flow promoter [42] increased the fluidization capacity when the modified designs were included in the downcomer .The modified design gave enhancement in radial mixing and increased the solid liquid mass transfer coefficients. But it was found to be difficult in scaling up. Design modifications at the bottom by keeping a cross shaped design gives an improved liquid circulation velocity[43] and installation is by changing supporting beams of the riser by the elements of cross shaped. On concluding, the design modifications are not efficient on full scale operations and they limit their usage within the smallscale operations. Flow characteristics gets changed by the above modified designs and to enhance the performance of the reactors with flow patterns some modified designs of ALR's have been tried. In chemical and biological processes for increasing the contact surface some packed materials were used inside the flow channels. Ceramic pall rings packing gave improved gas-liquid mass transfer in split-cylinder ALR also it increased gas holdup and increased the bubble retention time. Oxygen mass transfer coefficients also found to rise to a large difference on the packing inside the split cylinderALR[44].On packing with stainless steel holders in the EL-ALR's with minimum resistance at the top and large cross section in the bottom zone and found that there was no gas bubbles in the region of the downcomer. The gas holdup was found to be increased and the liquid circulation velocity along with bubble size was found to be reduced[45]. Bubble distribution is not even due to backflows and flowing of liquid internally and to avoid and to reduce the rate of backflows the large dimensional riser was kept with small dimensional risers to form a multiple riser design modification .Hydrodynamic parameters were studied with different configurations of ALR's with different draft tubes and found that the ALR with four draft was more efficient in the hydrodynamic parameters compared to the other configurations[46].For increasing the gas holdups and mixing in the downcomer region different modified design of multistage riser with triplet loop ALR was designed and found the hydrodynamic parameters enhanced comparing with single

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stage ALR[47] .Modified designs gave less mixing time, increased volumetric oxygen mass transfer coefficient and reduced liquid circulation velocity with increased gas holdup. Concentric draft tubes were divided into three parts in the riser and they were positioned at a distance with sieve plates kept at the partitions and found that the bubbles broke during travelling upwards in the riser due to sieve plates and found sauter diameter of bubbles get reduced[48].Enhanced hydrodynamic parameters arose when risers were made with permeable walls along with the downcomer. When hydrodynamic parameters were compared with multistage ,perforated permeable and ordinary tube riser the performance was best in permeable riser[49].Draft tubes were replaced of variable cross sections and hydrodynamic parameters were compared and found that there was better performance in the cross section draft tubes of variable modifications .In EL-ALR the riser cross section was modified and hydrodynamic parameters found to be increased on the modified design of the riser[50].Lot of modifications and comparative study emerges day to day having history of decades due to the increased requirements in industries but many modified designs cannot be scaleup due to increased expenses in energy and complex constructional operating procedures ,clog formation and maintenance problems.

2.4 SPARGER DESIGNS

In industrial ALR designs gas is sparged into the reactor at the bottom and flows upwards in the riser. Usual spargers are ring type distributors, single orifice nozzle and perforated plates .Ring type spargers cannot produce small bubbles[51] but they can produce uniform flow. In modified designs according to the industrial requirement spargers of different cross- sections and types are redesigned and also the position of the sparger in the reactor is studied by varying the installation positions to get efficient gas holdup and superficial gas velocity. Gas sparger was fixed in the middle in an EL-ALR combined fluidized bed reactor and it eliminated high shear stress areas [52].In some modified designs it is kept in the draft tube middle[53]It is designed to reduce the shear stress on solid particles formed by bubbles. Vertical EL-ALR with a triangular shape was designed with two operating spargers. Minimum gas flow rate sparger is fixed at the bottom of the downcomer and the maximum flow rate sparger is kept at the bottom of the riser. The modified design gave increased mass transfer rates and mixing was enhanced and reduced the consumption of energy[54].In research work sparger effects are minimum considered since the reactor operates on different velocity ranges with complex fluids[55].Spargers were selected based on the operational limitations[1].Gas holdup will be high if spargers produce small diameter bubbles in the transition zones and homogenous fluids[1]. Sparger types does not have effects but the sparger position should be optimized. Positioning the sparger at the bottom leads to coalescence and gas accumulation. If positioned within the riser then there will be no dead zone. The sparger position should also not to be kept near the surface which cause high gas separation and leads to recirculation which is not acceptable for the reactor performance.

3. FLOW DYNAMIC CHARACTERISTICS

3.1 FLOW REGIMES

Hydrodynamics controls the bulk transport phenomena, interphase and heat transfer of the fluid walls. Gas is passed into the reactor and if the flow of the gas is increased different flow regimes can be seen. When gas flow rate is minimum, bubbles rise straight and interactions will be minimum. This is called homogenous and unhindered flow of the bubbles. When flow of gas is increased it leads to coalesced bubble flow regime due to interaction of bubbles. It will not be constant and on further increase in gas flow it leads to churn turbulent flow. The shape of the bubbles will not be constant due to high turbulence. When the gas flows are increased then the bubbles get the shape of the tube from which they flow and this is called as slug flow regime.

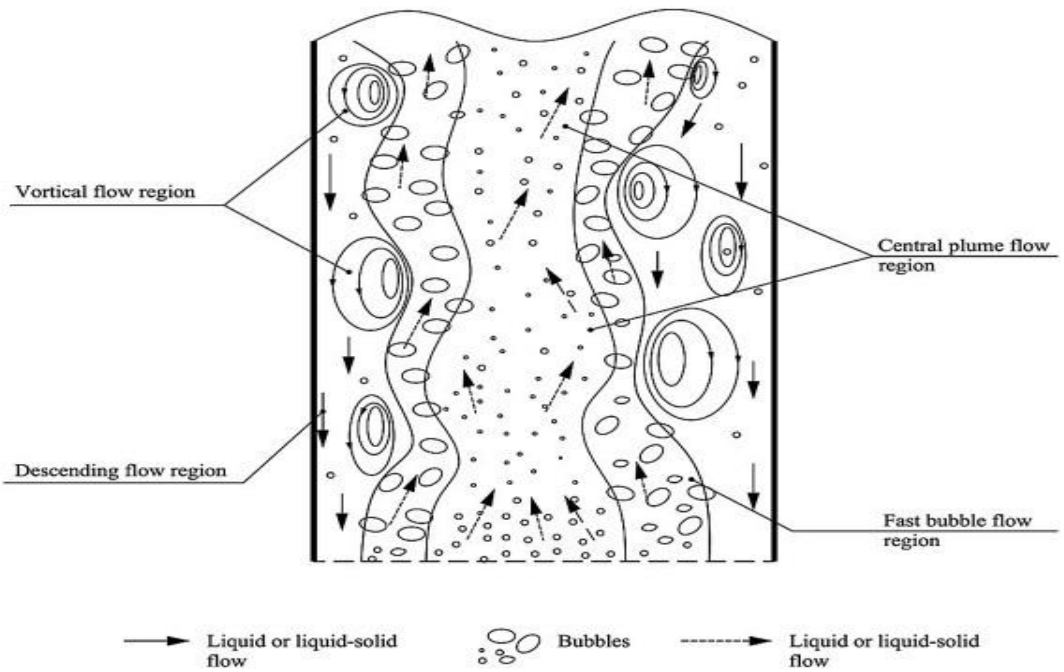

Fig .2. Typical flow characteristics in ALR[56]

3.2 FLOW CHARACTERISTICS

Riser area has large holdup for gas phase. From the sparger at the bottom bubbles rises to the riser area according to its design position where it is fixed in the reactor. When they operate on other regimes recirculation liquid may also enter into the riser from the downcomer and it increases the gas flow rate higher than it is supplied in the riser .In EL-ALR this kind of recirculation is avoided .Usually it occurs when the bubble velocity sparged in the riser is less compared to downcomer recirculating fluid velocity[57].Drag force in the downcomer is more so it carries the entrained small bubbles to the riser and recirculation occurs and by this gas- liquid mass transfer will be increased. Gas li quid moves in a co-current pattern[58].The pattern of fluid flow will be in axis in riser and it will be near the wall during recirculation[59].The stable flow and the improved mixing gives flow uniformity in risers. To increase the mixing rates and to improve the mass transfer coefficient without head loss new modification of convergence-divergence riser was researched [60].To get the velocity of the fluid higher and to make the flow stable a modified design of fixing a cross shaped design is installed at the bottom [61].According to our needs the designing can be made to improve the parameters for the performance efficiency of the reactor .Downcomer usually have liquid or liquid mixed with gas bubbles entered in the downcomer from the riser and it is usually of the plug flow type reactor[62]and researched that when the velocities are negligible it is dominated by plug flow designing an optical system. During this experiment flow was homogenous at minimum gas flow rates with no recirculation of gas bubbles. Calorimetric tracing methodology was designed for the ALR’s having high holdup and found to behave like continuous stirred tank reactor in the top portion and at the bottom it behaved as plug flow[63]. The variation would have occurred due to the bulk shock of water from the riser. Bubble breaking and coalescence are monitored in the top and the bottom of the downcomer zones in the split ALR[64].The liquid recirculation velocity determines the flow characteristics of the downcomer. In designing the modifications of the flows advantageous effects of ALR should not get affected. Effective degassing reduces the bubbles entering the downcomer and reduces recirculation and give high liquid velocities .Gas separator geometry and clearance at the top determines the degassing performance[65].Risers and downcomers are connected by the bottom clearance. This plays an important role in large scale operations. The complete idea about all the characteristics is not known by the researchers and due to this condition optimization is not up to the level of expectations.

4.HYDRODYNAMIC PARAMETERS MEASUREMENT

4.1 BUBBLE SIZE

Gas holdup, bubble size, mixing time, liquid circulation velocity are the essential parameters to measure the hydrodynamic characteristics. There are many methods for measuring these parameters in the history of decades. All parameters are interrelated and it leads to complexity to characterize the flow in ALR ‘S. Liquid circulation and gas holdup are measured by local and global values. For global values the whole reactors average parameters are considered. Instant value at specific points gives the local values. Bubbles sizes was studied by number of authors. Photographic technic was used by many researchers, Two hundred bubbles were photographed at differing heights by a digital video camera and the equivalent bubbles were denoted by spherical equivalent diameters[66] .Dense bubbly flows were measured by image analysis and bubble clusters that were overlapping were researched[67]. Sequenced photographs were used to measure the overlaid bubbles by digital image analysis[68].Optical fiber probes were also used to find the bubble sizes by automatic microprobes techniques and two and four point probes were studied and found four point probing was used in detecting bubbles at high flow rates and two point probing was limited to low gas flow rates.

4.2 GAS HOLDUP

Gas holdup determines the performance of the reactor and the flow characteristics. It calculates the mass transfer rates and evaluates the driving force of flows caused by the density differences in the riser and downcomer. It is defined as the volumetric fraction of gas phase in total volume for the considered space(eq.1):

$$\varepsilon_G = V_G/V_t \quad (1)$$

V indicates the phase volume and Ɛ indicates the phase holdup and total and gas phase volumes are denoted by subscripts G and t. In industrial applications this is the basic parameter for measuring gas holdup. For the measurement of total gas holdup the volume expansion method is followed[69].To calculate total gas holdup the expansion height of liquid level before and after aeration are determined (eq:2):

$$\varepsilon_{Gt} = \frac{Ha - Hs}{Ha} \quad (2)$$

In static and aerated states the Hs and Ha are the corresponding heights[70].The liquid levels was easy to measure at low gas velocities and was difficult during high gas velocities and the average was considered for calculations[71].Pressure difference relative to level of the bottom was used to find the gas holdup[72].(eq:3):

$$\varepsilon_{Gt} = 1 - \Delta P / \rho_L g Ha \quad (3)$$

g is the acceleration due to gravity, ΔP indicates the pressure difference, ρ_L indicates the density of the liquid phase. Even if it receives automatic pressure signals it requires the aerated liquid level for measurements. Riser and downcomer gas holdups are considered as local gas holdups. Two static pressure probes were connected to a U-tube manometer and the riser and downcomer average gas holdups was calculated[73] (eq:4):

$\varepsilon_{Gi=}\ \rho_m - \rho_L / \rho_L * \Delta z / L$ (4)

Δz indicates the differences in height in the manometer, i is the section of riser and downcomer considered, m is the barrier fluid in the manometer and L is the two pressure sampling ports difference. Inverted u tube manometers were used to measure the gas holdups in riser and downcomer[74].Due to the pressure sensors development the gas hold up calculations are modified and it replaced u tube manometers.(eq:5)

$\varepsilon_{Gi\ =\ 1} - \Delta P / \rho_L\ GL$ (5)

For three phase gas liquid solid systems differential pressure methods were used. At the time of degassing and aeration the readings were noted in u tube differential pressure manometer. Solid holdup at complete degassing also was determined when there is no solids in pulse tubes and the following equation gives average gas holdup [75].

$\varepsilon_{Gi} = (\rho s - \rho L)\ \varphi s + (\rho L \Delta h/z) / (\rho s - \rho L) + (\rho L - \rho g)$ (6)

Δh indicates the manometer value at the aeration and φs denotes the solid holdup. The gas holdups are measured by many methods and studies are continued for efficient values.

4.3 MIXING TIME

Mixing ensures the performance of the reactor and it is done by impellers, stirrers, recirculated mixing and pneumatic stirring. In the airlift reactors the mixing occurs pneumatically and by recirculating downcomer fluids. It depends on liquid velocity and gas holdup and of complex to measure. Mixing time is the time taken to attain homogeneity. Tracer method is followed for understanding the performance of the good mixing. Conductivity, light absorption methods are used to monitor the tracer concentration at various points. Concentration inhomogeneity is calculated (eq 7):

$i = \ C(t) - C(\infty) / C(\infty) = Cr - 1$ (7)

Mixing is an essential parameter to know about the reactor performance but it is a complex parameter and depends on liquid velocity and gas holdup. Studies are still continued to find an efficient methodology to calculate proper mixing globally in the reactor.

4.3 LIQUID VELOCITY

Liquid velocity determines the mass transfer characteristics, gas-liquid-solid holdups and mixing. Increased liquid velocity results in good and effective mixing and distributes the solid particles homogeneously. Many methods are followed to measure the velocity and largely neutrally buoyant particles and pulse tracer response are utilized a lot for measurement. A magnetic tracer method was also researched [76]. Neutrally buoyant particle method has its limitations of radial movement. With low cost, tracer pulse measures the liquid velocity. Internal back flows, secondary flows, swirls should be known to understand the velocity profile. Optimization and scaleup will not be possible without understanding of the local velocities. If the measurements are under estimated then it leads to downgrading of reactor efficiency performance. The local liquid velocities are measured by particle image velocimetry, hot film anemometry, laser doppler anemometry. Many inventive methodologies should be researched to optimize and scaleup with models to get accuracy to increase the ALR'S performance on a large scale [10]..

Table 1
LITERATURE REVIEW ON MODIFIED DESIGN OF REACTORS

RESEARCHER	REACTOR	PARAMETERS	REMARKS
M. Yianneskis et al.,[77]	Stirred, Baffled Six bladed impeller	Flow characteristics	Power number increases with Impeller diameter
M. Chisti et al.,[1]	Airlift reactor	Hydrodynamics	Comparison of Reactors (BC&ALR)
M. Chisti et al., [27]	Airlift reactors IL-ALR&EL-ALR	Liquid circulation velocity	Increases with Square root of Reactor height
Y. Chisti et al., [78]	Airlift reactors	Liquid circulation velocity	Induced liquid Circulation
M. Bouaifi et al., [79]	Dual-impeller Agitated reactor	Bubble size & mass transfer Coefficient	Comparison with correlations done
G. A. Hughmark et al., [80]	Agitator, flat blade Turbine impeller	Power requirement, Interfacial area	Correlations for power &int. area
X. Lu et al., [4]	Square ALR-Round ALR	Hydrodynamic parameters	comparison of square ALR with ALR, Mass transfer are better in Square-ALR
J. M. Vasconcelos et al., [81]		Hydrodynamic parameters	Rushton turbine

	Blade shape, six bladed turbine impellers		Retrofitting with Streamlined impellers
T. Moucha et al., [82]	Multiple impellers, triple impeller vessel	Hydrodynamics, power number	Low power number-high dispersion mixing intensities High power number-Better
P. M. Kilonzo et al., [5]	Two riser rectangular ALR-inverse internal loop Expanded G-L separator	Design -baffle clearance	Influenced liquid circulation velocity
W. Yu et al., [16]	Multistage internal -loop ALR	Operating regimes	High operation flexibility
RESEARCHER	REACTOR	PARAMETERS	REMARKS
E. Kadic et al., [2]	Bio reactors	G-L mass transfer	Comparative study of all reactors, ALR best performed
T. Wang et al., [83]	Stirred tank-dual impeller	Hydrodynamic parameters	Axial impeller-less energy Radial-more energy, correlations made, mixing time for double impeller-short, if pitched blade turbine installed lower-best for solids
L. Luo et al., [21]	IL-ALR with different spargers	Hydrodynamic parameters, mass transfer	4-orifice nozzle best
J. C. Gabelle et al., [84]	Stirred reactors	Hydrodynamic parameters, mass transfer	Power consumption, mixing best in rheological behaviour
S. S. de Jesus et al., [22]	ALR, STR, SBR, BC	Hydrodynamic parameter, mass transfer	STR-mass transfer high, ALR-low shear &power requirement Stirred -ALR-Suitable for high oxygen rates
V. Cappello et al., [85]	Stirred reactor	Bubble size ,liquid mass transfer coefficient	Correlations were made New technology-to measure bubble Sauter diameter
M. H. Xie et al., [86]	Stirred reactor, Ellipse gate impeller	Hydrodynamic parameters	High mixing efficiency in transition and turbulent flows
J. Zhang et al., [87]	Stirred reactor, triple impeller	Hydrodynamic parameters	Comparative study of five-triple impeller combinations
M. Räsänen et al., [3]	Helix ALR	Hydrodynamic parameters	Energy efficient Correlations for gas holdup, mass transfer derived
T. Ziegenhein et al., [68]	ALR-Rectangular	Hydrodynamic parameters	Parameters measured at different positions of riser and downcomer
T. Zhang et al .,[33]	ALR	Hydrodynamic parameters	Optimized to scale up with modified designs
A. Ojha et al., [7]	Split -cylinder ALR Four-point probe method	Hydrodynamic parameters	Correlations for gas holdup were derived
D. Li, et al ., [6]	IL-ALR-Two stage	Hydrodynamic parameters, bubble behaviour	Correlations for gas holdup, liquid velocity. Bubble sizes in downcomer decrease with solid particles
N. Kuma et al ., [88]	IL-ALR	Shear rate, mass transfer coefficient	Increase in superficial gas velocity increases average shear rate and volumetric mass transfer coefficient Correlations derived for volumetric mass transfer coefficient
T. Zhang et al.,[10]	ALR	Hydrodynamic parameters	Flow characteristics studied, parameters measured, CFD model designed
P. Ramesh et al., [8]	Packed bed split cylinder reactor	Hydrodynamic parameters ,mass transfer coefficient	Correlations for mixing time and mass transport was developed.
Y. Xiao et al., [11]	Stirred reactor	Hydrodynamic parameters	Intrusive image-based method is used to measure local gas hydrodynamics parameters and bubble size
T. B. Arasi et al., [9]	Split cylinder reactor	Hydrodynamic parameters	Mass transfer coefficient increases with superficial gas velocity and stirrer speed and gas holdup increases with superficial gas velocity

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Table 2 REACTOR COMPARISON

S.NO	REACTOR	DESCRIPTION	REMARKS
1	BUBBLE COLUMN(BC)	It's a column reactor, gas enters at the bottom	Too much back mixing, lack of control Cheaper in cost High shear, Hard to scaleup
2	AIRLIFT REACTOR (ALR)	Modified BC. It has up and down flow zone. density difference is the driving force	Has more control than BC, fluid level Minimum, modifications are possible
3	INTERNAL LOOP AIRLIFT REACTOR (ILALR)	It has internal flow separator for up and down flows	Limited control of flow, better hydrodynamic properties
4	EXTERNAL LOOP AIRLIFT REACTOR (ELALR)	It has a separate loop for fluid flow and they are connected to base &gas separator sections	Have more control, flexibility in design, hydrodynamic properties are best
5	STIRRED TANK REACTOR(STR)	Agitated and mixed with various impeller designs, power consumption high	Efficient in producing small bubbles, cost is too high, power cost too high, impeller scaling occurs
6	PACKED BED REACTOR	Liquid flows through different types of solid materials which is packed. Solid materials will not move	Maintenance cost is high, number of units are possible, flooding occurs due to countercurrent operation,
7	TRICKLE BED REACTOR	Product removed at the bottom where liquid is sprayed over the packing material.	Used in processing plants
8	PACKED BUBBLE COLUMN(PBC)	It's a packed bubble column reactor with different packing materials	Negligible liquid flow
9	SLURRY BUBBLE COLUMN(SBC)	Three phase or gas-solid bubble column	Gas-solid SBC has similar hydrodynamics as gas-solid bubbling fluidized bed reactor
10	FLUIDISED BED REACTOR(FBR)	Solid phase suspends in medium, it's a g-s system	Number of types are possible

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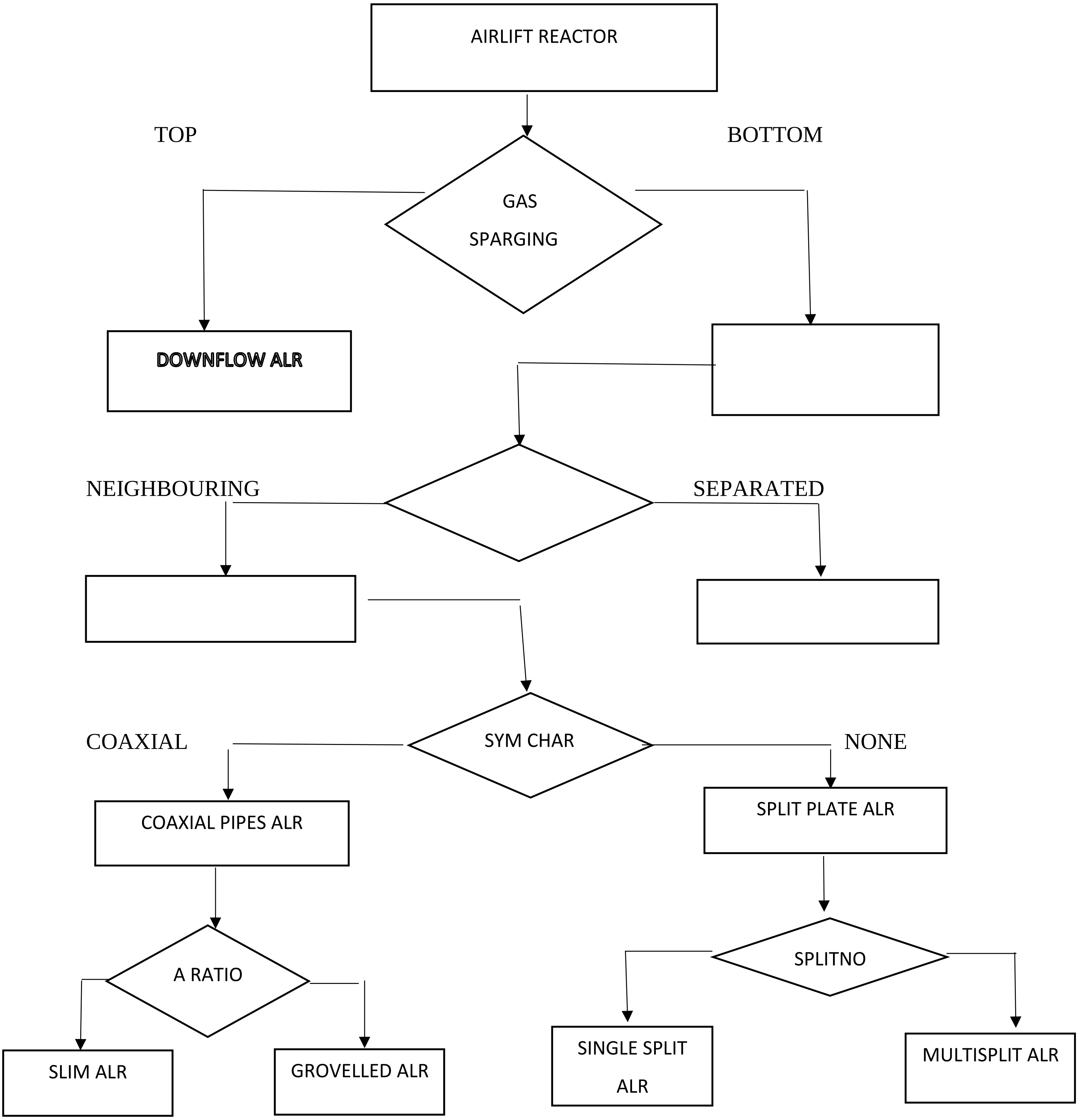

Fig .3.ALR'S CLASSIFICATION [33]

5. CONCLUSIONS

Designing is an art which should be done with research interest in innovating and inventing new ideas and satisfying the requirements of an efficient reactor performance. In this review the performance of sparged, split reactors with various sparger designs and its positions were studied and the hydrodynamic parameters measurement were also reviewed. To increase the flow characteristics the modified designs of the split cylinder-ALR and the various designs of impellers were compared and the suitable required designs for the problems are suggested. Many correlations have been researched by researchers for better performance calculations and for measurements. Only few works have been done with stirrers. Sparged split cylinder ALR with packing on the riser area gives good hydrodynamic parameter performances and increases the mass transfer coefficients and it increases the reactor performance. Research can be done trying with various packing materials on the riser area and with modified design of high performance characteristics stirrers can be installed in different positions suitable in the downcomer area and better efficient performances can be tried by varying superficial gas velocities with multiphases and bubble flow characteristics can be recorded and research can be continued further with stirrers and packing materials in the sparged split cylinder airlift reactor to further increase the ALR'S performance in all industrial application

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