Downflow Gas Contactor (DGC): A versatile Gas-Liquid Contactor-Reactor

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BACKGROUND

In last two decades, scientists and engineers have developed/are developing new reactors for improved selectivity/yields, safer operations; converting batch to continuous process and faster reaction/mass transfer rates with objective of sustainable development to reduce the waste generated and higher productivity.

Different designs have emerged and are in commercial use based on various concepts/technologies: static mixer, falling film, rotating packed bed, spinning disk and micro-reactors. New reactor designs are evolving based on emerging technologies: membrane, ultrasonic & hydrodynamic cavitation and microwave irradiation, some of which should be commercialised in coming years.

Each of these reactors have some advantages and limitations. Based on type of reaction, its kinetics, mass transfer requirements, operation parameters etc. specific reactor is selected for use.

Downflow Gas Contactor (DGC) is one such novel reactor for use in a range of gas-liquid & liquid-liquid systems. It works on concept of high mass transfer rates generated by fine gas bubbles with interfacial area up to 6,000-m^2/m^3 and high gas hold-up of 40-50%. DGC was developed at Birmingham University, UK where a team of professors and students worked on chemical reactions & gas absorption in 1990s, and published papers on gas-liquid reactions, viz. oxidation and hydrogenation. In 2001, one of the professors involved in developing DGC applications, Dr. S. Raymahasay started WRK Design and Services Ltd., UK to develop commercial applications of DGC. Over the years WRK has worked on projects for various companies, institutes and Government departments in area of chemical reactions, gas absorption, effluent treatment etc. In last few years WRK has filed patents on CO_2 capture from biogas/flue gas with a novel water-based solvent, and on production of biodiesel using DGC. Currently, WRK has a lab in Birmingham equipped with a couple of skid-mounted DGC units for carrying out initial trials.

Since 2014, STEP Pvt. Ltd. partnered with WRK to market DGC for various applications within India and globally; and to promote the CO_2 capture technology patented by WRK. STEP, in partnership with Snowtech Fabricator Ltd. (Navi Mumbai) have set up a DGC pilot plant unit mainly for initial trials for effluent treatment to reduce COD/BOD, and for chemical reactions like oxidation, amonolysis. STEP is discussing with a company to set up a pilot plant for removal of CO_2 from biogas generated from waste/effluent, to produce bio-methane for use as biofuel.

Introduction to DGC

DGC reactor is one of the most efficient mass transfer devices for contacting liquids and gases. It has evolved from a novel concept of contacting a liquid continuum and a dispersed phase. An intense shearing of the dispersed phase is induced with a minimum expenditure of energy over that required for motive power. Where the dispersed phase is a gas or another liquid, an enormous interfacial area is generated in a small containment volume.

The interface is subjected to rapid surface renewal through repeated rupture and coalescence, resulting in intense mixing and highly efficient mass transfer. High interfacial areas are produced by exploiting a controlled hydrodynamic flow regime and do not require mechanical aids such as stirrers or baffles. In the case of DGC, not only the performance can be improved, but also operational and capital costs can be substantially reduced per kg basis for commercial plants.

Many industries require gas/liquid contacting in a wide range of processes and some typical examples where the DGC can be beneficial are: absorption; stripping; flotation; ozone treatment; micro-bubble generation; oxidation; catalytic oxidation; hydrogenation; heterogeneous reactions; effluent treatment; carbonation; fermentation; oxygenation; mineral separation.

The concept

DGC consists of a column, the dimensions and configuration of which depend on the application and operating conditions. The novel feature of the design is the downward co-current flow of the dispersed and continuous phases through a specially configured nozzle or orifice and entry zone at the top of the column. As the continuous phase expands into the column, part of the kinetic energy imparted to the fluid on its passage through the nozzle is used in the formation of interfacial area. The intense turbulence and shear at the interface results in efficient gas-liquid mixing and allows mass transfer operations to approach equilibrium in very short contact times.

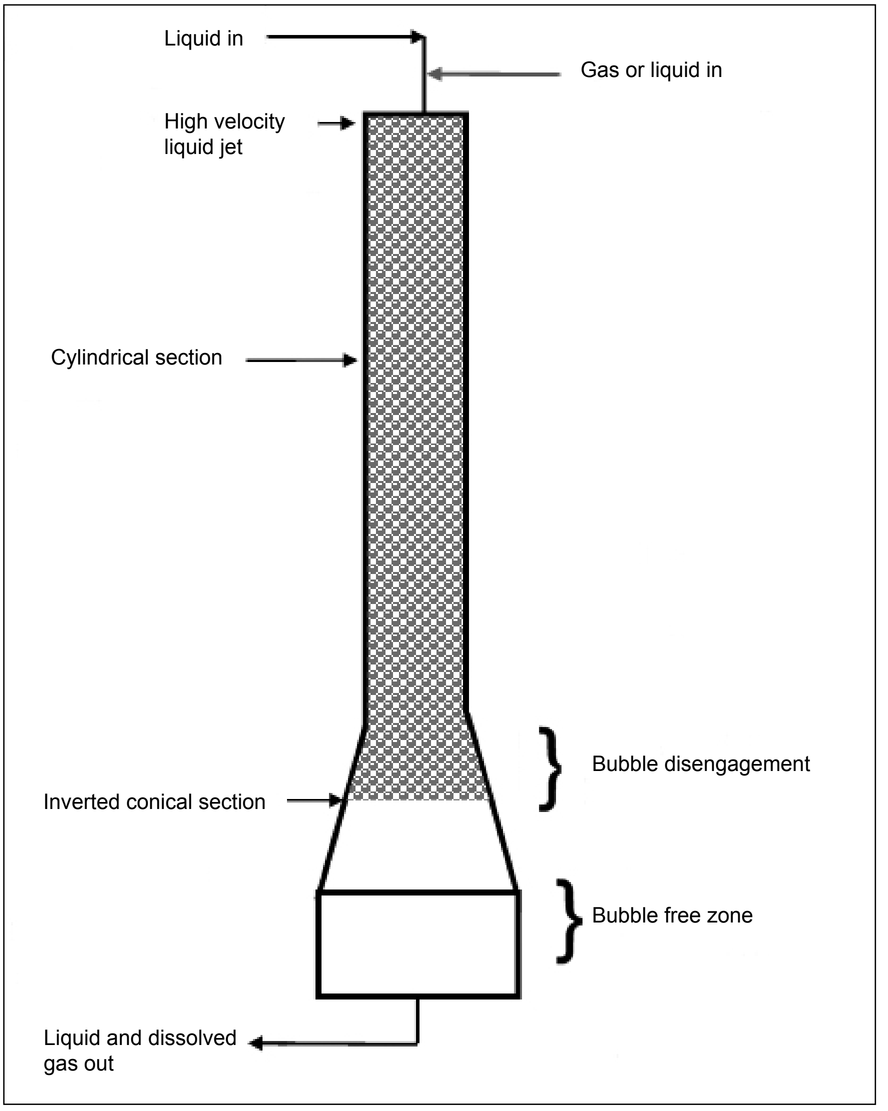
Description of DGC

DGC is a downflow co-current device and consists of a cylindrical section with a specially designed orifice/inlet at its entry section (at the top), allowing both liquid and gas inputs into the reactor. For few specific applications, an additional inverted conical section may be provided after the cylindrical section for improved performance. Liquid enters from top of the column in the form of one or more high velocity liquid streams. Gas may be introduced into the system at any point in the column although the usual method is to feed the gas into the incoming liquid stream immediately prior to the column inlet through the nozzle/orifice concurrently. The high velocity liquid passing through the nozzle/orifice generates intense shear and energy.

The specific shape, dimensions and configuration of the DGC reactor depend on the application and operating conditions required. A model DGC could be designed and operated to take into account all variations of operating conditions and applications. The DGC Reactor system also includes a pump and receiver connected together with necessary piping. Suitable control systems (for heating, cooling, dispersion level, pressure, liquid flowrate control etc.) are included as required.

Mode of operation

The DGC reactor is a mass transfer efficient gas-liquid contacting device, where the gas and liquid stream are introduced co-currently through an orifice and entry zone at the top of a fully flooded column. The high velocity liquid jet inlet stream, generating intense shear and energy, produces a vigorously agitated gas-liquid dispersion in



the upper section of the column. This shear causes break-up of any gas pocket at the inlet and allows the formation of a vigorously agitated gas-liquid dispersion, at the top of the column, with high interfacial area in a small operating volume. It also prevents the formation of a permanent gas space at the top of the column thus maintaining a fully flooded situation.

The high degree of intense shear and turbulence caused by the incoming liquid jet, induces intense mixing and efficient mass transfer as well as constant surface renewal. The downflow liquid velocity in the column is maintained at a value below the rise velocity of the gas bubbles so that there is no tendency for the bubbles to be carried downwards. Hence there is no net movement of the gas phase whilst the liquid phase flows downwards through the inter-bubble spaces.

The gas-liquid bubble dispersion slowly expands down the fully flooded column and the level of dispersion (and thereby volume of the gas-liquid dispersion) can be controlled by control of the operating conditions (liquid and gas flowrates).

In the lower section of the column as the dispersion proceeds downwards, there is a degree of bubble coalescence since it is no longer within the region of direct inlet steam impingement. This coalescence produces larger bubbles, which rise up the column where they are broken up by the shear of the high velocity inlet liquid jet.

Typical bubble dispersion achieved in the DGC is shown above. The picture shows the stable bubble matrix formed, which contains nearly uniform size bubbles and results in a distinct gas-liquid interface, as shown. The gas/liquid mixture is maintained at a desired level within the reactor therefore preventing entrainment of gas bubbles through the outlet of the reactor and ensuring 100% gas utilisation.

Intense turbulence, good mixing and high gas hold-up within the bubble dispersion, would account for efficient mass transfer performance of the DGC The inverted conical lower section, when used, is to protect bubbles from leaving the DGC as an added insurance to 100% gas utilisation.

Advantages

The inherent simple design and operation of the DGC offers specific advantages over other conventional contactors/reactors:

- Lower power consumption.
- Smaller operating volume – can be used as a variable volume reactor.
- No foaming possible, as no free gas-liquid interface at the inlet.
- 100% gas utilisation and greater than 95% approach to equilibrium in very short contact time.
- High and good control of interfacial areas (1,000 – 6,000 m^2/m^3 depending on bubble sizes), allows for improved reaction rates and reaction specificity.
- No internal moving parts like stirrer and therefore lower capex and operating costs.
- Higher gas hold-up (40-50%).
- Tolerance to particulates – system allows for high solid content.
- Easy scale-up without loss in efficiency.
- Easy automation and control with safe operating conditions.
- Simple, compact and flexible of design.

Industrial applications

The DGC reactor, with its advantages as specified above is a versatile tool, which can be used for various applications. It can be operated in a batch, semi-continuous or continuous mode.

The main areas of application are:

- Gas absorption
- Effluent treatment
- Chemical reactions

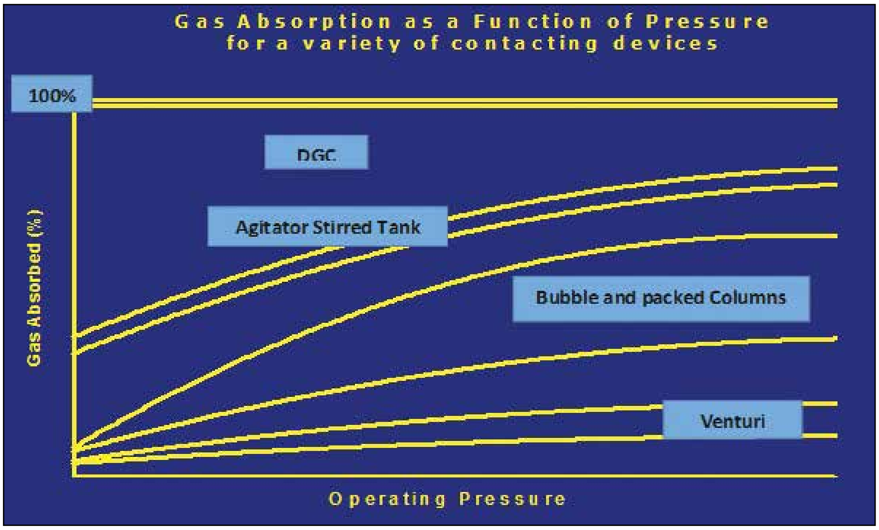
Gas absorption

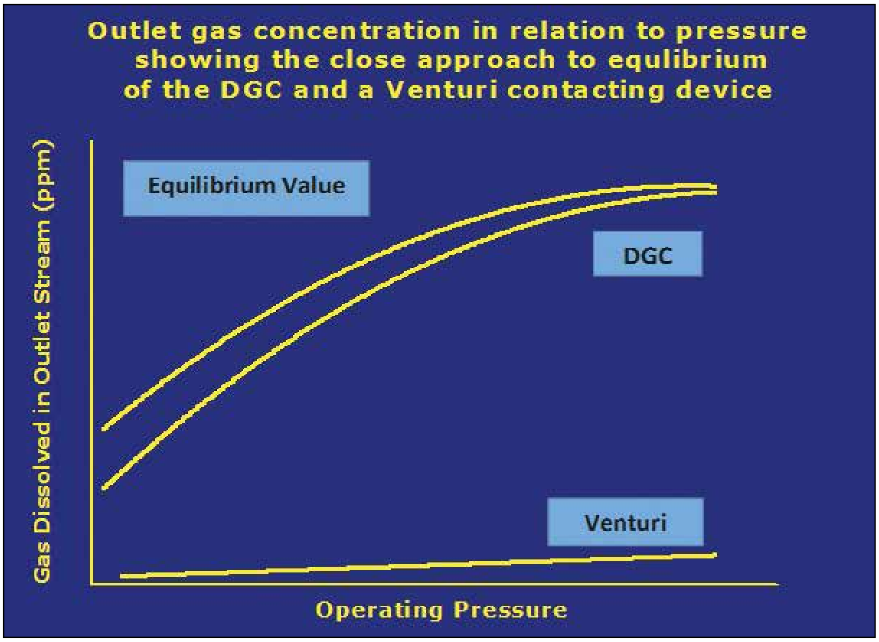
Gas-liquid contacting devices are used widely in the chemical industry for absorbing gases into liquids and solvents. These devices range from stirred vessels to packed beds and bubble columns and are employed for a variety industrial applications. Most applications employ an upflow mode of gas flow with relatively low gas hold- ups (< 20%) along with subsequent gas disengagement with recycling, coalescence and back-mixing problems. Free gas-liquid interfaces with gas pockets are formed in these reactors causing safety problems.

DGC offers significant advantages over more conventional gas-liquid contacting devices and is able to achieve saturation in very short reaction times. Some of the advantages of the DGC when compared with other contacting devices are highlighted in next page:

Effluent treatment

Many industrial applications produce wastewater effluent that is often highly contaminated and detrimental to the environment. This necessitates treatment technologies to decompose toxic industrial effluents to innocuous products and also aim to improve water quality. DGC can be used very efficiently in biological waste and effluent treatment plants where transfer of oxygen to the liquid effluent is one of the most important requirements and





the biological demand of the treatment plant can be easily met.

DGC can also be used in advanced oxidation processes for water and effluent treatment. It can be easily operated with oxygen or ozone, and as a photocatalytic reactor with an UV lamp with/without titanium dioxide or other photocatalysts. This offers an innovative energy efficient and cost-effective technology for treatment of difficult wastes. The application of an intensively mixed bubble column reactor together with the combination of different process alternatives, results in near total degradation of polluted water and effluents (both industrial and domestic) and complete mineralisation of toxic organic compounds.

Photocatalytic DGC reactor makes use of oxygen based oxidants, viz. oxygen, ozone or hydrogen peroxide, to produce the oxidising species, the hydroxyl radical, which is considered to be the principle oxidising species for organic substances. DGC reactor system allows for elimination of saturated and chloro-hydrocarbons, solvents, pesticides, aromatics, and reduction of COD /BOD levels. It can be easily integrated into existing water treatment and effluent plants or as a separate plant.

Chemical reactions

DGC has been successfully used in lab as a three phase chemical reactor for a number of different industrial applications. Results have shown that it is a very efficient gas-liquid-solid contacting device providing a high degree of mass transfer with chemical reaction that is almost entirely reaction rate controlled. Due to the intense level of mixing achieved in the DGC, all reactions are completed in much shorter reaction times and generally with better selectivity and higher yields.

Due to its high and efficient mass transfer capabilities along with its tolerance for high solid contents and particulates, DGC reactor can be used with catalysts for various types of chemical reactions like hydrogenation, oxidation, carbonylation, hydroformylation etc. Catalysts can be used in different forms like slurry, on packed beds, or on monoliths.

Major projects completed

Major projects completed using the DGC include:

1. Selective capture of CO_2 from air.
2. Upgrading of biogas by removal of CO_2 and hydrogen sulphide.
3. CO_2 absorption into digestate food waste.
4. CO_2 and oxygen transfer to liquids
5. Growth of algae and biodiesel production from algal oil.
6. Biodiesel production using edible & non-edible oils (sunflower, rapeseed, waste oil).
7. Oxygen transfer for *thiobacillus*

DGC set-up in Navi Mumbai

ferrooxidans in river sludge for gold extraction .

8. Vegetable oil (rapeseed, soyabean) and ozonized rapeseed oil hydrogenation.
9. Catalytic hydrogenation reactions of itaconic acid, crotonaldehyde, cinnamaldehyde, glucose, benzaldehyde in both slurry and packed bed form.
10. Catalytic oxidation reaction of p-cresol.
11. Treatment of industrial effluent wastes (phenols, chlorophenols, methanol, propylene glycol, cyclohexadecane) with reduction in COD levels using a DGC photocatalytic reactor.
12. Treatment of landfill leachates – reduction in COD levels using a DGC/UV reactor.
13. Reduction of COD levels of orange waste; beverage waste, milk waste and 1,3-cyclohexanedione effluents.
14. Photocatalytic degradation of chlorine and chloroamines in swimming pool water.
15. Treatment and breakdown of endocrine disruptors in sewage water.
16. Treatment & bio-reduction of COD levels of whey waste effluent.
17. Biochemical enhancement of ammonium fertiliser production from farm slurry – stripping of ammonia and conversion to liquid fertiliser.
18. CO_2 capture with client's own proprietary absorbent salt.
19. Design of wet air oxidation pilot plant for sludge destruction & resource recovery.
20. Design of a DGC ammonia absorption unit for ammonia recovery from waste slurry.