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(19) (CA) **APPLICATION FOR CANADIAN PATENT** (12)

(54) Rotary Gas Injector

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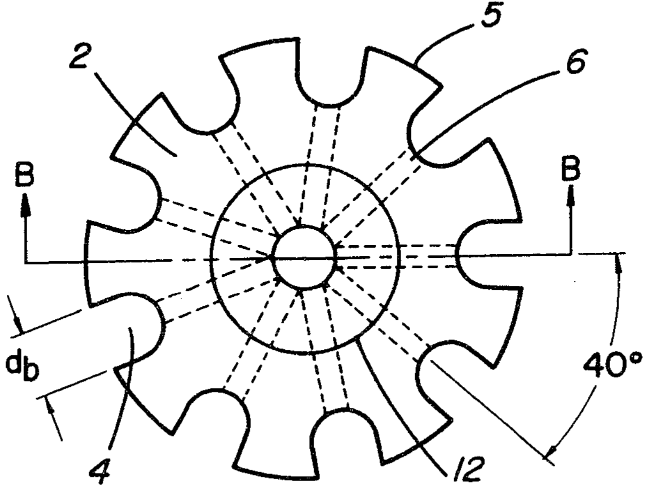
(57) 11 Claims

Notice: The specification contained herein as filed



5
6
2
B
B
40°
d_b
4
12

Abstract of the Disclosure:

A rotary gas injector comprises a graphite impeller attached to the end of a hollow cylindrical graphite shaft having a central bore. The impeller is cylindrical in shape and has a plurality of cuts equally spaced around the circumference thereof to define blades for the impeller, and radial holes are drilled in the centre of the cuts and communicate with the central bore of the shaft, whereby gas injected through the bore in the shaft and the radial holes of the impeller are sheared by the blades to form fine bubbles to enhance mass transfer and chemical reaction in gas-liquid and gas-liquid-solid systems.

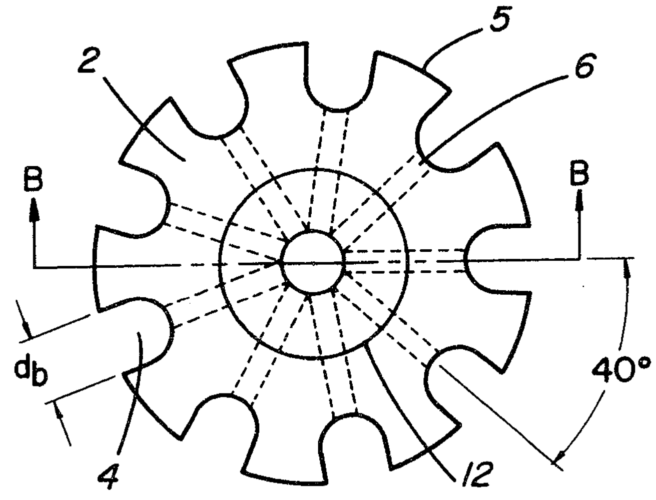
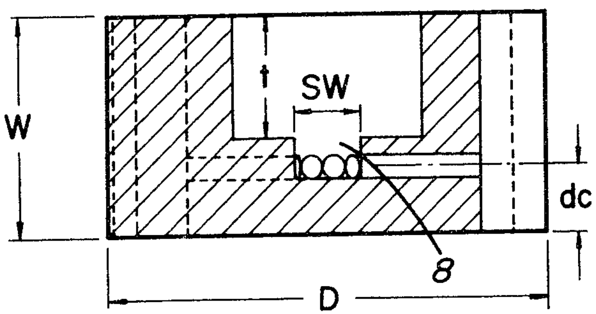


Fig. 1a



Section B-B
Fig. 1b

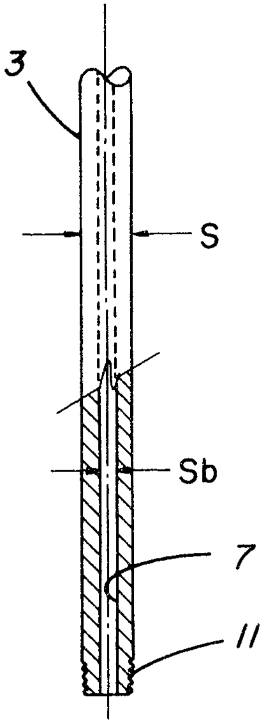


Fig. 2

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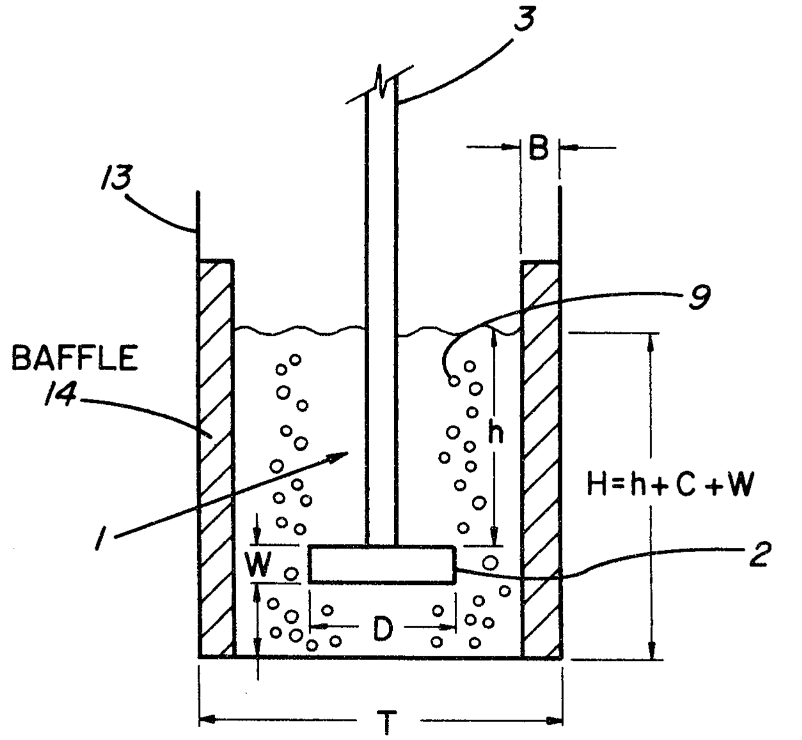

Fig. 3

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Figure: 4 Plot Of Sodium Sulphite Concentration Against Time

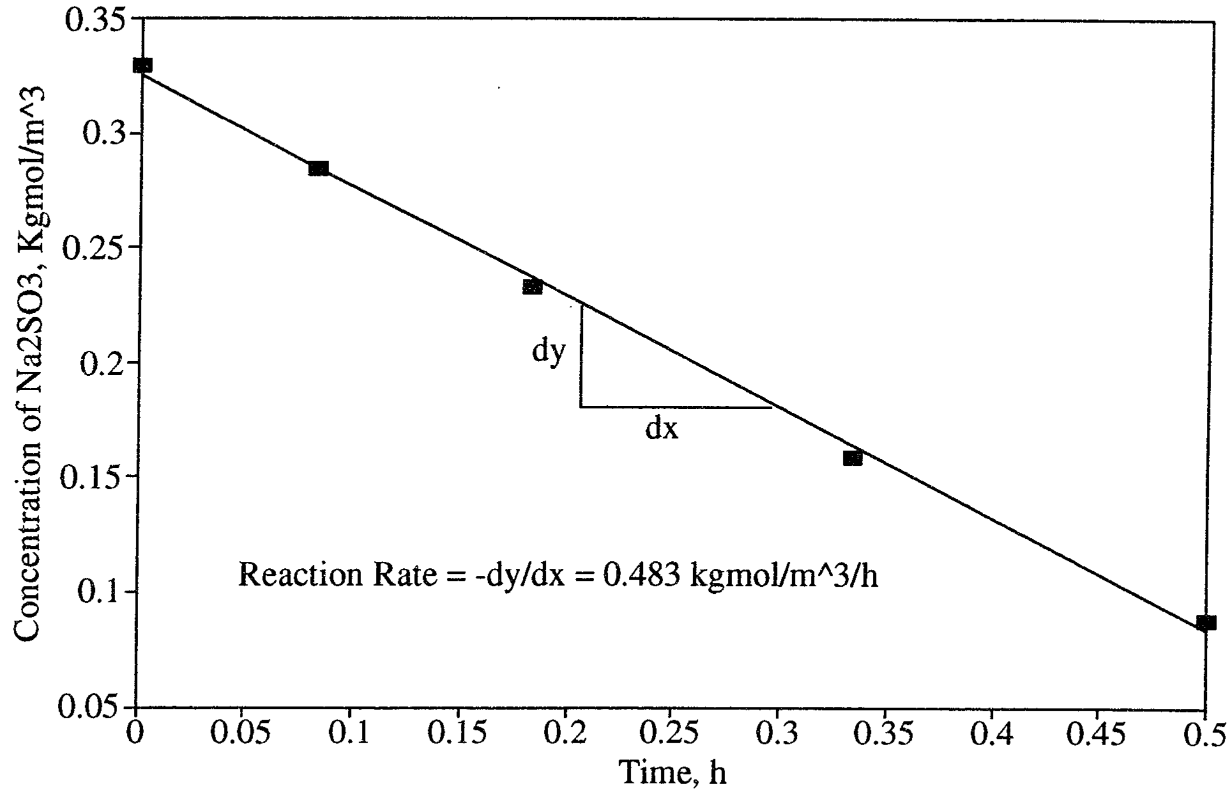

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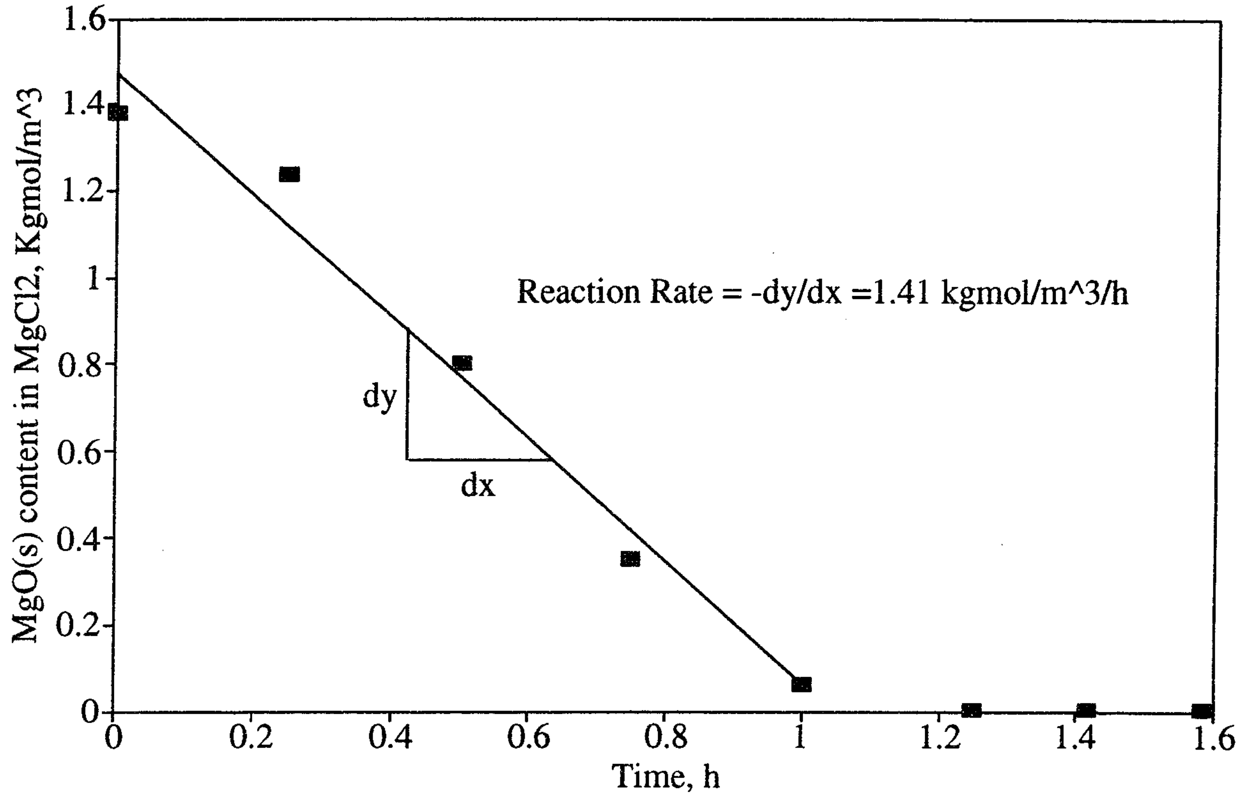
Figure: 5 Plot of MgO(s) Content Against Time



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ROTARY GAS INJECTOR

This invention relates to a rotary gas injector for use in gas-liquid and gas-liquid-solid systems.

Background of the Invention:

For chemical reactions to occur it is necessary to bring the reagents into contact with one another. When the reagents are present in different phases such as oxygen in air and sodium sulphite in water this can be a non-trivial problem. Practical reaction rates are achieved by maximizing the contact area between the different phases. In the case of most gas-liquid and gas-liquid-solid reactions this involves dispersing the gas phase, as small bubbles into the liquid phase. These fine bubbles can be generated by a number of mechanisms such as porous spargers, lances, or rotating impellers. If a rotating impeller is used, fine bubbles are formed by shearing the gas in vortexes created at the trailing edge of the impeller blades. When the impeller is rotated faster, the shear increases, creating larger numbers of smaller bubbles, with higher total gas-liquid surface area per unit gas volume.

In most systems it is possible to fabricate shafts and impellers from a variety of materials. Graphite has been used in some specialized applications, where the gases, liquids or solids present in the system are highly reactive to metals, or the temperature is extremely high. Graphite is a relatively inert and inexpensive material, but it is difficult to manufacture most standard impeller designs from graphite. Many unique impeller designs using graphite have been developed for such uses as aluminum degassing.

In some processes used for hydrogen removal from aluminum, an inert gas is injected using a rotary gas injector consisting of a graphite shaft and impeller. The gas is injected through an internal cavity in the graphite shaft and impeller, exiting either above or below the impeller. For the gas to be sheared into small bubbles the injected gas must be drawn into the low pressure zones created behind the impeller blades (relative to the direction of rotation). Depending on the impeller rotational speed and the gas injection rate, some gas may bypass the impeller and not be sheared and dispersed. This is not an efficient mode of operation.

Summary of the Invention:

The present invention provides an improved design for a rotary gas injector fabricated from graphite. This injector consists of an impeller attached to a hollow cylindrical shaft having a central bore. The impeller is cylindrical in shape and has a plurality of cuts equally spaced around the circumference thereof to define blades for the impeller. Radial holes are drilled in the centre of the cuts and communicate with the central bore of the shaft.

When the shaft is rotated at sufficient speed and gas is injected through the shaft, exiting between the blades of the impeller through the radial holes, fine bubbles are formed by the shearing action of the blades. These fine bubbles serve to enhance gas-liquid mass transfer and chemical reaction in gas-liquid and gas-liquid-solid systems. The performance (total gas-liquid interfacial area per unit liquid volume) of the impeller can be measured as via the total rate of mass transfer or chemical reaction (for mass transfer limited reactions).

Short Description of the Drawings:

The present invention will now be described by way of example, with reference to the accompanying drawings in which:

Figures 1a and 1b are drawings of one embodiment of the impeller of the rotary gas injector of the present invention;

Figure 2 is a drawing of the shaft of the rotary gas injector;

Figure 3 is a schematic drawing of the lay-out of the rotary gas injector;

Figure 4 is a plot of sodium sulphite concentration against time; and

Figure 5 is a plot of solid magnesium oxide content against time.

Detailed Description of the Invention:

Referring to Figures 1 through 3, the rotary gas injector 1 consists of an impeller 2 with diameter D, attached to a hollow cylindrical shaft 3 of diameter S. The impeller of the gas injector is cylindrical in shape, with the thickness W to diameter D ratio typically being between 0.2 and 1.0. In chemical engineering applications for gas dispersion most impellers have a W/D ratio of 0.2 or less. It was found that increasing the impeller thickness to a W/D over 0.2 greatly improved gas dispersion at the expense of higher power consumption for a given impeller speed. A practical limit exists on the thickness of the impeller because of the impeller weight and the strength of the graphite construction material. The impeller is fabricated with a series of U-shaped cuts 4 equally spaced around the circumference thereof, such that the width of the cut opening is equal to twice the radius of the curved end of the U. The width d_b of the U-shaped cuts 4 is between 0.12 and 0.20 of the diameter D of the impeller 2. The number of cuts can vary from 6 to 12 and is typically 9. The curved edges of the impeller remaining between these cuts, act as blades 5 of the impeller 2. Holes 6 with diameter d_o are drilled in the centre of each cut, located at height d_c between 1/4 and 1/2 times the width W of the impeller, and preferably 1/3 the width of the impeller from the bottom of the impeller. The hole diameter d_o should be from 0.05 to 0.03 times the diameter D of the impeller. When the shaft 3 is rotated at sufficient speed and gas is injected through a bore 7 of diameter S_b centrally located in the shaft 3, entering a windbox 8 of diameter S_w, inside the impeller 2, and exiting between the blades of the impeller, through holes 6, fine bubbles 9 are formed by the shearing action of the blades.

The shaft 3 should be constructed of graphite of a grade identical to that used in the fabrication of the impeller. The diameter of the shaft, should be from 0.17 to 0.425 times the impeller diameter, and preferably from 0.300 to 0.375. The shaft length can be determined by the skilled practitioner based on the known properties of graphite and the special requirements of the intended application. The diameter S_b of the centrally located bore 7 can be made of uniform dimension along the length of the shaft or can vary. The maximum bore diameter S_b should not exceed 1/3 of the shaft diameter to insure the mechanical integrity of the shaft. The skilled practitioner can couple the top portion 10 of the shaft 3 to any suitable drive mechanism, insuring that the shaft turns true and that provision for gas injection is given in the drive mechanism. The bottom portion of the shaft should be threaded 11 such that the shaft and impeller can be coupled together. The diameter of the thread 11 should be as standard size and preferably equal to the shaft diameter. The length t of the thread 11 should be between 0.25 and 0.3 of the diameter of the impeller. For a clockwise rotation, the thread 11 should be right hand, while a left hand thread 11 should be used for counterclockwise rotation of the gas injector. The impeller should be equipped with a threaded hole 12 such that the shaft 3 can be coupled to the impeller. The diameter d_c of the hole 12 should be such that a female thread matching the thread 11 on the shaft can be machined into the hole 12. The depth of the hole 12 should be incrementally less than the length t of the threaded portion 11 of the shaft. A hole should be drilled at the bottom of the threaded hole 12 to meet the radial holes 6 at the centre of the impeller, forming the windbox 8. The diameter S_w of the windbox 8 should be from 0.5 to 1.5 times the diameter S_b of the bore 7 in the shaft 3, and preferably of identical diameter.

The performance of the rotary gas injector is maximized when it is used in a vessel 13 of proper dimensions. Best results are obtained when the ratio of the impeller diameter to the characteristic transverse length T of the vessel 13 is between 0.25 and 0.5, and particularly between 0.3 and 0.4. For cylindrical vessels the characteristic length T is the diameter, while for square vessels the characteristic length, is the length of one side. If a rectangular vessel is used both the length l to diameter D and width w to diameter D ratios, should be between 0.25 and 0.5.

The impeller should be centrally located in the vessel, with the height C of the impeller 2 off the bottom of the vessel 13 between 0.125 and 1.0 times the diameter of the impeller for flat bottomed vessels. Best results are obtained when the impeller is between 0.25D and 0.5D from the bottom of the vessel. The liquid height h above the impeller should be between 1.0 and 2.0 times the diameter of the impeller. The total liquid height (H=[h+C+W]), should be from 1.5 to 3.0 times the diameter of the impeller.

Baffles 14 with width B equal to 0.1 to 0.12 times the characteristic length T of the vessel 13 should be used to prevent vortexing of the liquid in the vessel. From 1 to 4 baffles should be used, with maximum performance (and maximum power consumption) being obtained when using 4 baffles. For cylindrical vessels, the baffles should be attached to the wall of the vessel at 90 degree intervals. For square or rectangular vessels the baffles should be positioned in the centre of each wall. For the purposes of determining the baffle width B in rectangular vessels the baffles width should be 0.1 to 0.12 times the smallest of the length l or width w.

The rotary gas injector can be used in vessels, which are neither round, square, or rectangular, without departing from the spirit of this invention. Baffles should be used regardless of the shape of the vessel.

The use of the present invention is described in the following examples. These examples are purely illustrative and should not restrict the applicability of the present invention.

Example 1:

A rotary gas injector was operated in a square plexiglass vessel, containing 141 L of water. Initially, 0.33 Kgmol/m^3 of sodium sulphite (Na_2SO_3) was dissolved in the water. The impeller was located at the centre of the tank, perpendicular to the bottom, and was rotated at 320 revolutions per minute. Air at 25 Deg C was injected at a rate equivalent to 250 L/min at standard temperature and pressure (S.T.P. or 1 atm and 0 Deg C) down the bore in the shaft, passing through the centre of the impeller, and exiting a 15.9 mm diameter hole located in the bottom of the impeller. A small amount (10^{-3} M) of copper sulphate was added to the solution to catalyse the sulphite oxidation reaction which is given below:

$$SO_{3(aq)}^{2-} + 0.5\ O_{2(aq)} = SO_{4(aq)}^{2-} \qquad (1)$$

It is well known as disclosed in the following references:

1) Cooper, C.M., Fernstrom, G.A., Miller, S.A., "Gas-Liquid Contactors,"

Industrial and Engineering Chemistry, Vol. 36, No. 6, p504-509, 1944.

2) Linek, V., Vacek, V., "Chemical Engineering Use of Catalyzed Sulphite Oxidation Kinetics For The Determination of Mass Transfer Characteristics of Gas-Liquid Contactors," Chemical Engineering Science, Vol. 36, No. 11, p1747-1768, Gt. Br., 1981. Example 2:

that the addition of copper sulphate increases the oxidation rate of sulphite, such that the reaction rate becomes limited by the rate of oxygen mass transport into the water. The rate of reaction can then be described by the following equation:

$$\frac{\delta\,(C_{Na_2SO_3})}{\delta t} = -\,k_L\,a\,(C^* - C_b) \qquad \text{(i)}$$

where: k_L is the liquid phase mass transfer coefficient (m/h), a is the gas liquid interfacial area (m^2/m^3), C^* is the solubility of oxygen in water ($Kgmol/m^3$), C_b is the actual bulk concentration of oxygen in the water (negligibly small).

The rate of reaction (1) is therefore independent of the sulphite concentration and linearly dependant on time (for constant gas flow and impeller speed). For a fixed mass transport coefficient, the reaction rate is directly proportional to the gas-liquid interfacial area. The increase in the rate of sulphite oxidation due to agitation, is then directly indicative of the increase in the gas surface area per liquid volume. The dimensions of this system are given in Table 1.

Table 1

Impeller	Parameter Value
diameter, D	229 mm
thickness, W	114 mm
cut size, d_b	42.9 mm
height off bottom, C	114 mm
rotation rate	320 r.p.m.
Shaft	
diameter, S	38.1 mm
bore diameter, S_b	6.4 mm
Vessel	
characteristic dimension, T	521 mm
liquid depth, H	521 mm

The concentration of dissolved sodium sulphite has been plotted as a function of time in Figure 4. The rate of change of the concentration is linear with time, indicating that the reaction rate (slope) is constant at 0.483 Kgmol of Na_2SO_3 reacting per m^3 of water per hour.

Example 2:

In this example, the gas outlet hole in the impeller of example 1 was plugged. New gas outlets with a diameter of 6.4 mm were created between the impeller blades in accordance with the present invention. The procedure used in example 1 was again followed. Air was injected at a rate equivalent to 250 L/min @ S.T.P., and the impeller was rotated at 320 r.p.m.. The initial sulphite concentration was 0.32 Kgmol/m^3. Over 31 minutes, 5.280 Kg of sodium sulphite were reacted. The new sulphite oxidation rate was 0.575 Kgmol/m^3/h, and was 19 percent higher than the oxidation rate in example 1. The only change from example 1 to example 2 was the change in the location of the gas outlet. It can therefore be concluded that gas injection between the impeller blades increases the gas-liquid interfacial area available for mass-transfer.

Example 3:

The effect of impeller thickness to diameter ratio (W/D ratio) is illustrated the following examples. In this example the reaction rate in a gas-liquid-solid system is accelerated using the rotary gas injector of this invention with an impeller W/D ratio of 0.26. A 51:49 mixture of chlorine (Cl_2) and carbon monoxide (CO) was injected using the rotary gas injector at a total gas flow rate equivalent to 57.9 L/min @ S.T.P.. This gas mixture reacted with solid magnesium oxide (MgO) particles of approximately 20 micron size, in a molten bath of magnesium chloride ($MgCl_2$). The products of the reaction where carbon dioxide (CO_2) and $MgCl_2$, as shown below:

$$Cl_{2(g)} + CO_{(g)} + MgO_{(s)} = MgCl_{2(l)} + CO_{2(g)} \qquad (2)$$

Since chlorine is extremely reactive with metals at the temperature of the reaction (820 °C) both the square vessel, and rotary gas injector were fabricated from graphite. The physical parameters describing the present example are given in Table 2.

Table: 2

Impeller	Parameter Value	
diameter, (D)	146	mm
thickness, (W)	38.1	mm
hole size, (d_o)	6.4	mm
cut size, (d_b)	22.2	mm
height from bottom of vessel, (C)	19	mm
rotation rate	551	r.p.m.
Shaft		
diameter, (S)	57	mm
bore diameter, (S_b)	6.4	mm
Vessel		
characteristic dimension, (T)	292	mm
liquid depth, (H)	297	mm
4 baffles, (B)	29.2	mm

Reaction (2) had been found previously to proceed at a negligible rate (<0.1Kgmol/m^3/h) using a lance type injector in the absence of a catalyst. Using the rotary gas injector, the MgO content of the $MgCl_2$ bath was reduced linearly with time from 6.1 weight percent to 0.57 weight percent over 150 minutes. The rate of reaction (2) was then calculated to be 1.09 Kgmol of MgO per m^3 of liquid $MgCl_2$ per hour. The change in the rate of reaction with agitation is due to the increase in gas-liquid area available for mass transfer of the gaseous reagents into the liquid $MgCl_2$.

Example 4:

As in the previous example, a rotary injector fabricated from graphite was used to inject chlorine and carbon monoxide into a molten bath of $MgCl_2$. Initially the bath contained 3.3 weight percent MgO. The injector was rotated at 554 r.p.m. and a 48:52 mixture of chlorine and carbon monoxide was injected at a rate equivalent to 60.8 L/min @ S.T.P.. The impeller had a W/D ratio of 0.52 (twice that of the impeller used in the previous example). All other physical parameters were identical to those given in Table 2. The MgO content of the vessel has been plotted as a function of time in Figure 5. The observed rate of MgO chlorination was 1.44 Kgmol of MgO per m^3 of liquid $MgCl_2$ per hour. Therefore the rate of reaction (2) was increased by 32 percent by increasing the W/D ratio of the impeller from 0.26 to 0.52. As shown in Figure 5 the reaction rate is independent of the MgO content at MgO concentrations above about 0.1 weight percent MgO in the $MgCl_2$.

WHAT IS CLAIMED IS:

1. A rotary gas injector comprising a graphite impeller attached to the end of a hollow cylindrical graphite shaft having a central bore, said impeller being cylindrical in shape and having a plurality of U-shaped cuts equally spaced around the circumference thereof to define blades for the impeller, and radial holes drilled in the centre of the cuts and communicating with the central bore of the shaft, whereby gas may be injected through the bore in the shaft and the radial holes of the impeller and be sheared by the blades to form fine bubbles to enhance gas liquid mass transfer and chemical reaction in gas-liquid and gas-liquid-solid systems.

2. A rotary gas injector according to claim 1, wherein the thickness W to diameter D ratio W/D of the impeller is between 0.2 and 1.0.

3. A rotary gas injector according to claim 1, wherein the width of the cuts is between 0.12 and 0.20 of the diameter of the impeller.

4. A rotary gas injector according to claim 1 or 3, wherein the number of cuts vary from 6 to 12.

5. A rotary gas injector according to claim 4 wherein the number of cuts is 9.

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6. A rotary gas injector according to claim 1 wherein the diameter of the radial holes is from 0.05 to 0.03 times the diameter of the impeller.

7. A rotary gas injector according to claim 1 wherein the injector is centrally located in a vessel which can be of any shape selected from round, square or rectangular.

8. A rotary gas injector according to claim 7, wherein the ratio of the diameter of the impeller to the characteristic transverse length of the vessel is between 0.25 and 0.5.

9. A rotary gas injector according to claim 2, wherein the height of the impeller from the bottom of the vessel is between 0.125 and 1.0 times the diameter of the impeller.

10. A rotary gas injector according to claim 2, wherein the liquid height above the impeller is between 1.0 and 2.0 times diameter of the impeller.

11. A rotary gas injector according to claim 7, wherein vertical baffles are located around the inside wall of the vessel to prevent vortexing of the liquid in the vessel.