Advancement in Mixing Hydrodynamics using Motionless Mixer

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RECEIVED ON 14.04.2014 ACCEPTED ON 17.03.2015

ABSTRACT

A large number of scientists have been conducting research to improve the hydrodynamic characteristics of mixing of fluids. Out of these techniques, static mixing is adopted in this study to improve the mixing of fluids, which has a lead of negligible energy consumption in comparison with dynamic mixers. Air Water system have been cast-off for mixing in which reduction in pressure, energy consumed, bubble diameter and mass transfer rate was mainly taken into account to design the static mixer element. Five different types of elements (Baffle, Plate, Blade, Needle and Wheel) were tested to observe and compare above mentioned hydrodynamic properties. Two point source characteristics i.e. reduction in pressure and bubble size, were carried out using Hg manometer and still photography respectively. Other non-point source characteristics (Energy depletion, rate of mixing) were found to be directly influenced by these point source characteristics. From the experimentations baffle element catches more importance, in terms of less energy depletion, more mixing rate, when compared with the other elements tested. This element becomes also comparable with other elements renowned in literature.

Key Words: Point Source Characteristics, Bubble Size, Reduction in Pressure

1. INTRODUCTION

1.1 General

In the modern era, the purpose of mass transfer/ mixing is fulfilled by static mixers in place of dynamic mixers. The mixing phenomenon is improved by utilizing the kinetic energy of flowing fluid and the mass is transferred by means of stationary elements which forces the stream to change its direction as per design of element. Lesser energy requirements, no stirring parts, long life, lesser seat time are some plus points which boost up the importance of static mixer over dynamic mixers. The adding up of these mixers, into the pipeline of process industries for dispersion, blending purposes, doesn't require complex designing for which these mixers are far more economical to use in place of powered mixers. These mixers are capable of working at elevated temperatures also in which one of the major applications is the homogenization of polymers in which the elimination of radial temperatures is important for spinning and extruding, so the fluids are homogenized by using these mixers.

Static mixers are also used for the throttling of super-heated steam at precise temperature and pressure. They can be used as the catalyst support and the pressure reducing devices in the reactors. From the above brief list of applications of static mixers it is evident that these mixers can handle fluids with wide properties range.

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1.2 Scope of the Investigation

2. EXPERIMENTAL SETUP

For the inspection of mixing hydrodynamics, an experimental arrangement was made, presented in Fig. 2. This arrangement includes an 80 mm diameter pipe of Perspex factual in which mixing is done by means of stationary elements. An Hg manometer is attached between 1st and 3rd element in order to determine the reduction in pressure due to these stationary elements. For the determination of proper bubble diameter, a capturing device is connected after 3rd element which depicts the mixing rate. A pumping device was used to pressurize the water in order to be used in cycle. Rotameter and air manometer was used in order to determine the flow rates of these fluids.

Compressed air was injected into the main tube of static mixer in the form of bubbles. These bubbles get mixed with water by means of stationary elements and hence the reduction in bubble size occurs. This rate of reduction in bubble diameter depicts the mixing rate or DO (Dissolved Oxygen) content. Water Rotameter ranges the water from 1000-4400 gal/hr whereas the air manometer ranges from 5-20 lit/min.

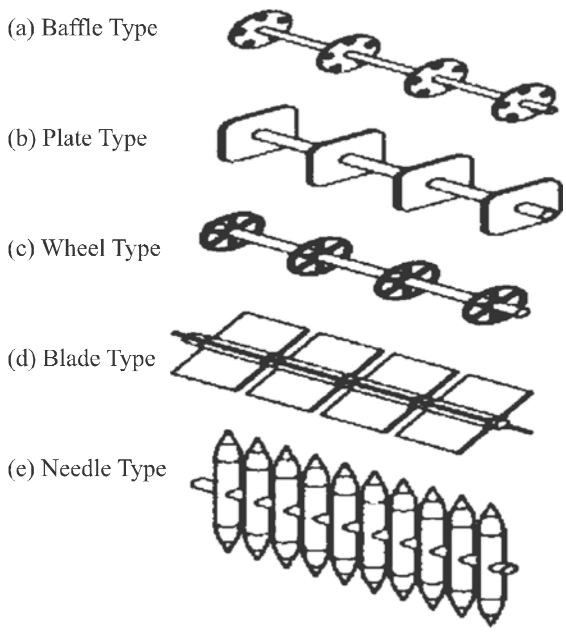


FIG. 1. STATIONARY/STATIC ELEMENTS USED IN STUDY

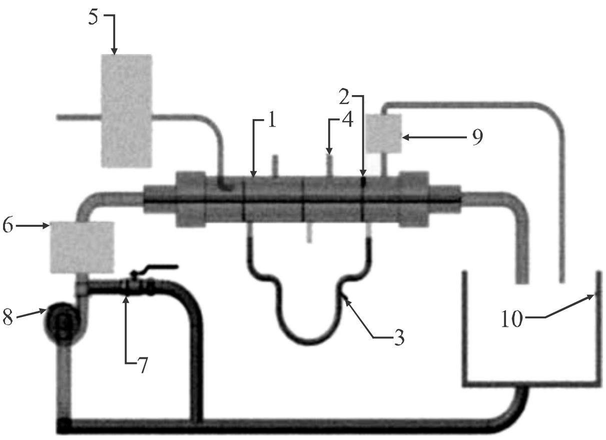
3. RESULTS AND DISCUSSION

3.1 Reduction in Pressure

The most important point source hydrodynamic characteristic is the reduction in pressure which directly affects other mixing characteristics. AHg manometer was connected between three elements in order to investigate the drop on pressure as shown in Fig. 2. From the data set collected it was evident that liquid flow rate directly affects the reduction in pressure. Fig. 3 shows the Hg's height difference in manometer for all elements tested in which baffle type came out with the more pressure drop with the variation in volumetric flow rate of water due to more area available for mass transfer/mixing. Fig. 4 shows the comparison of pressure drop between baffle stationary elements with other geometrical elements having different configurations of Lightnin mixer [1-3]. Results presented in Fig. 4 shows that baffle type element gives more pressure drop due to symmetrical design which causes mass transfer to be occurs on both sides of element. While the values for the comparison of pressure drop are shown in Table 1.

3.2 Bubble/Drop Size Approximation

The rate of decrease in bubble diameter using stationary elements signifies the amount mixing hydrodynamic which ultimately depict the mass transfer promptness. A bubble collecting device was attached with the data



(1) STATIC MIXER MAIN PIPE, (2) STATIC ELEMENT, (3) HG MANOMETER, (4) SAMPLING POINTS, (5) AIR FLOW METER, (6) WATER ROTAMETER, (7) PUMP BY PASS, (8) CENTRIFUGAL PUMP, (9)BUBBLE CAPTURING CELL, (10) STORAGE TANK

FIG. 2. EXPERIMENTAL SETUP

gathering points in order to collect and approximate the diameter of drop by means of digital camera. After the approximation of size it was concluded that drop size decreases as the flow rate of water increases. Using the basic technique of dimensional analysis considering the possible variables which may affect the bubble size in terms of two Non-dimensional numbers as given in Equation (1) as per technique elaborated by Legrand, et. al. [4]. Experimental data collected in this study was employed to determine the values of the coefficients (K, a, b). The model equation for drop size was concluded as expressed in Equation (2).

$$d_b/d_s = K \;\; x \;\; N_{We}^{\;a} \;\; x \;\; N_{Re}^{\;b} \qquad (1)$$

$$d_b/d_s = 1.15 * 10^{-36} \;\; x \;\; N_{We}^{\;-4.775} \;\; x \;\; N_{Re}^{\;10} \qquad (2)$$

Equation (2) represents effect of Weber number and Reynolds number on the bubble diameter.

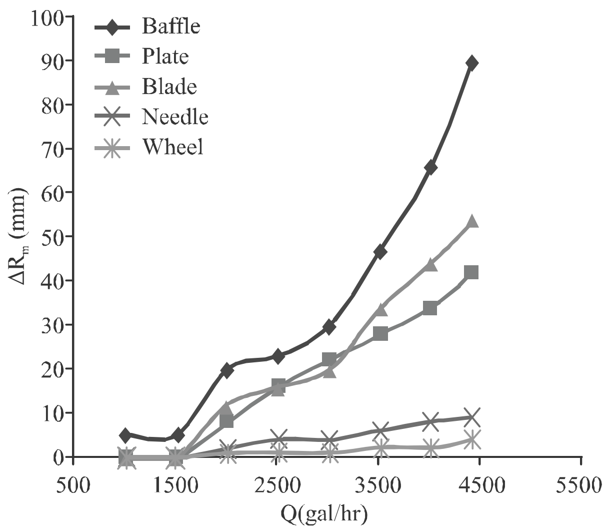


FIG. 3. COMPARISON OF “ R_M OF DIFFERENT ELEMENTS USED

Fig. 5 depicts the comparison of bubble size collected experimentally, by using baffle element, with that of Heyouni, et. al. [1]. Smaller bubble size is evident from Fig. 5 due to the more mixing rate and more shear force by using baffle element. Fig. 6 shows the bubble size/ diameter at different flow rates of water.

3.3 Dissolved Oxygen Content

The extent of DO (Dissolved Oxygen) in water represents the rate of mass transferred from air into water. Bubble breakage phenomenon depends upon the geometry of the element on which bubbles strike, faster the bubble breaks more mass is transferred between fluids. The method to determine of concentration of dissolved oxygen reported by Turunen, et. al. [5]. In the experimental rig used in the study, 3 sampling points were provided at different locations. Samples were collected and concentration of dissolved oxygen was measured using chemical analysis technique.

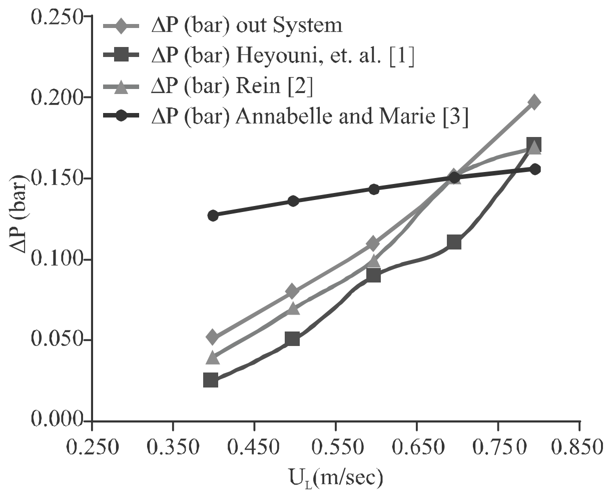


FIG. 4. PRESSURE DROP COMPARISON WITH THAT OF IN LITERATURE

TABLE 1. COMPARISON OF PRESSURE DROP OF BAFFLE ELEMENT WITH OTHER RENOWNED ELEMENTS IN LITERATURE

V_L (m/sec)	ΔP (bar) (Our System)	ΔP (bar) Heyouni, et. al. [1]	ΔP (bar) Rein [2]	ΔP (bar) Annabelle and Marie [3]
0.398	0.051	0.025	0.04	0.128
0.498	0.080	0.05	0.07	0.136
0.598	0.110	0.09	0.1	0.144
0.697	0.151	0.11	0.15	0.150
0.797	0.198	0.17	0.17	0.156

Baffle type static element came out with the highest DO content because of the fact that this element breaks the bubble speedily as its geometry gives symmetrical formation on its both sides, so phenomenon of mass transfer occurs on both sides of element. As shown in Fig. 1 this element consists of 5 holes equally spaced on 360^o circle, so the phenomenon of bubble rupture takes place on every hole which ultimately enhance the oxygen content to be dissolved in water. After this blade type stationary element has highest mixing rate due to the same symmetrical geometry but the mixing content is less than baffle element because of its small contact area.

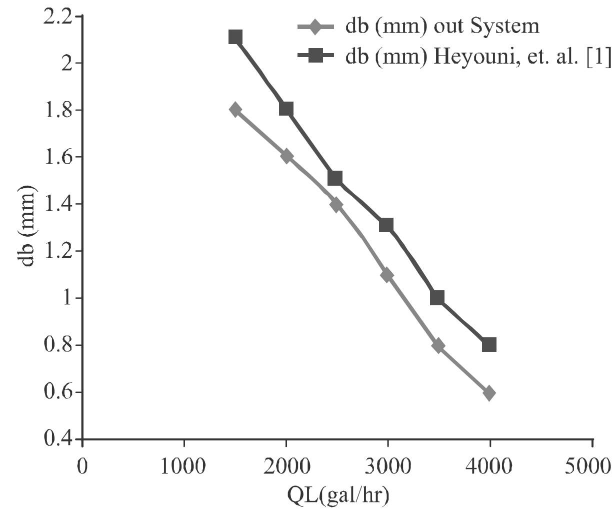


FIG. 5. BUBBLE SIZE COMPARISON WITH THAT OF HEYOUNI, ET. AL. [1]

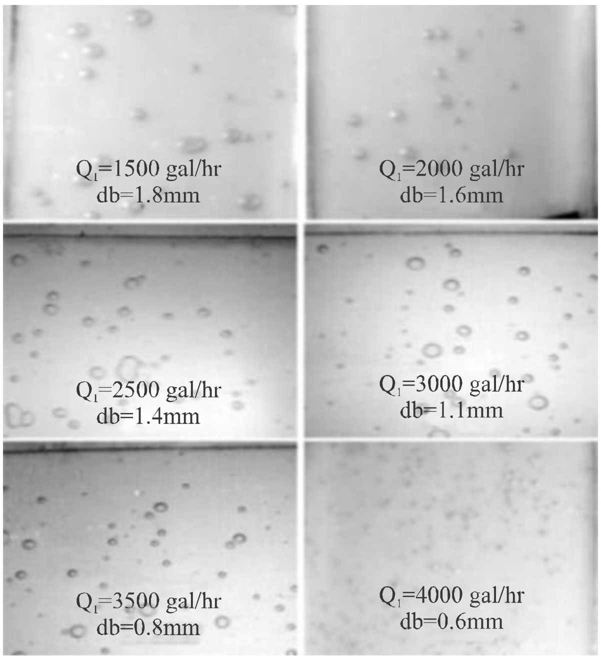


FIG. 6. AVERAGE BUBBLE SIZE/DIAMETER AT DIFFERENT FLOW RATES OF WATER

While doing experimentations on wheel type stationary element it was revealed that by solving one problem in using this element i.e. sticking of bubbles in the wheel, we can attain DO content almost equal to baffle element. The minimum DO content was observed in using Needle element due to its least contacting area with the upcoming bubbles in the stream. Fig. 7 shows the comparison of amount of DO in water by all five elements used in our system.

Table 2 shows the optimal values of DO for each element corresponding to prime values of both fluids' flow rates in which baffle element came out with the uppermost value of 4.65 mg/lit due to the advantages discussed above.

3.4 Coefficient of Mass Transfer ($K_L a$)

The intensity of mixing of two fluids is scaled by the coefficient of mass transfer $K_L a$. The method adopted to

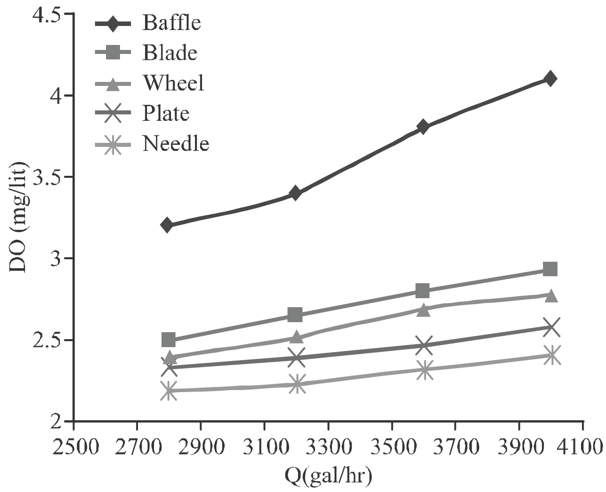


FIG. 7. DISSOLVED OXYGEN CONTENT COMPARISON OF 5 ELEMENTS USED

calculate K_La was used by Turunen, et. al. [5] for finding out the mixing intent of nitrogen with water.

As discussed before the mixing intensity can be formulated by observing the decrease in drop size, more the decrease in diameter more would be the mass transferred from air to water.

$$K_La = K \ x \ V_L^{\,a} \ x \ V_G^{\,b} \quad (3)$$

$$K_La = 12.20*10^{-4} \ x \ V_L^{\,1.51} \ x \ V_G^{\,-0.26} \quad (4)$$

While manipulating the data it was found that water's velocity directly affects the coefficient of mass transfer and when this data was compared with that of Heyouni, et. al. [1], it was found to be more as presented in Fig. 8.

3.5 Power Consumption (W/kg)

The most important parameter by which static mixer leads up with the dynamic stirrer is its less power consumption. The power dissipated (Watt) per unit of mass of fluids (kg) was premeditated through following Equation (5) as per procedure used by Heyouni, et. al. [1]:

$$(P/M) = Q_L * \Delta P / \{\rho * F_{SM} * (1-G_H) * V_{MS}\} \quad (5)$$

As the pressure drop directly affects the power dissipation, so by employing the data, the water velocity was found to be the controlling parameter of power depletion.

While using baffle type stationary element, the comparison of system's power consumption was came out to be comparable less than of Heyouni, et. al. [1], presented in Fig. 9.

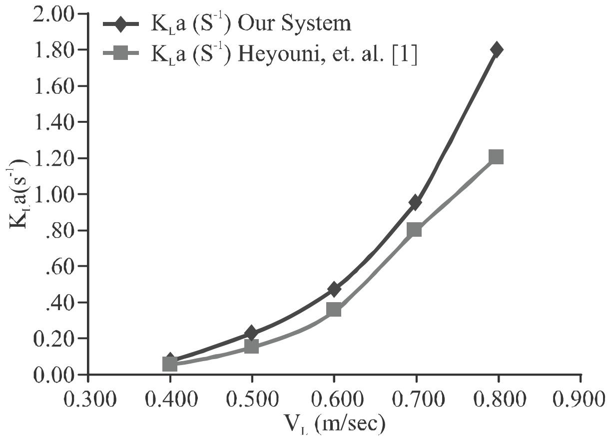


FIG. 8. K_LA COMPARISON WITH THAT OF HEYOUNI, ET. AL. [1]

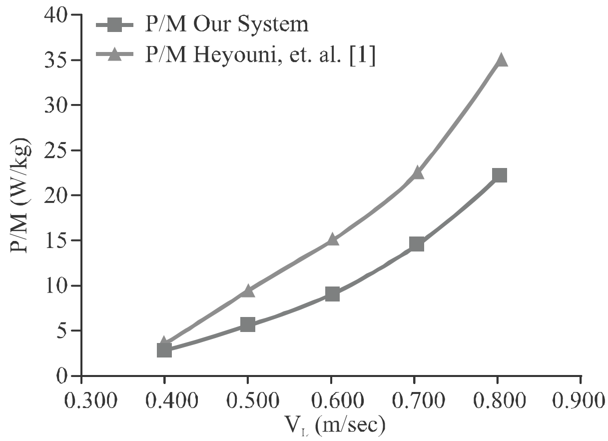


FIG. 9.P/M COMPARISON WITH THAT OF HEYOUNI, ET. AL. [1]

TABLE 2. COMPARISON OF DISSOLVED OXYGEN CONTENTS OF BAFFLE ELEMENT WITH OTHER ELEMENTS

Type of Element	Dissolved Oxygen (mg/lit)	Suitable Combination of Flow Rates	
		Water (gal/hr)	Air (lit/min)
Baffle	4.65	3600	20
Needle	1.67	3200	29
Plate	1.8575	3600	22
Wheel	2.416	3600	20
Blade	2.6025	4000	15

4. CONCLUSIONS

The aims of this study was to give advancement in hydrodynamic characteristics of mixing such as designing of static/stationary element, rapid decrease in drop size, decrease in power dissipation, obtaining higher coefficient of mass transfer, so following results were concluded from this study:

(i) Drop in pressure is directly affected by water's velocity. Baffle type stationary element came up with new concept having equivalent pressure drop with existing elements in literature.

(ii) The Lightnin static mixer which consists of 42 elements. The regular assembly of seven elements that produced a helix, while in the present study case static mixer consists of 3 baffle elements of symmetrical geometric configurations were used. It is evident from the experimental data, 3 baffle elements are more efficient as compared 42 elements.

(iii) Rapid decrease in drop size depicts the extent of mixing between the fluids, and the breakage of bubble is controlled by design of stationary element and liquid's flow rate.

(iv) Baffle type stationary element was found to give higher mixing rate due to its symmetrical design that extents the area of mixing on its both faces, which ultimately enhances the DO content of the system.

(v) Power expended by the baffle type element was taken out to be far less than existing elements in literature and was found to be directly proportioned to drop in pressure and water's flow rate.

5. NOTATIONS

ΔP = Pressure Drop, (bar)

ΔR_m = Hg's Height Diff. in Manometer, (mm)

N_{Re} = Reynolds Number = $\{(d_s * V_L * \rho)/\mu\}$

N_{We} = Weber Number = $\{(\rho * V_L^2 * L)/\sigma\}$

DO = Dissolved Oxygen (mg/lit)

V_L = Velocity of Water(m/sec)

Q_L = Flow Rate of Water (gal/hr)

V_{MS} = Volume of Static Mixer, (m^3)

V_G = Velocity of Air(m/sec)

d_b = Bubble Diameter, (m)

d_s = Main Pipe Diameter, (m)

G_h = Gas Holdup

K_La = Mass Transfer Coefficient, (s^{-1})

P/M = Power Per Unit Mass Consumed (W/kg)

ρ = Density of Water, (kg/m^3)

μ = Dynamic Viscosity of Water ($N.s/m^2$)

σ = Surface Tension (N/m)

L = Length of Static Mixer, (m)

F_{SM} = Void Fraction of Static Mixer

ACKNOWLEDGEMENTS

Authors would like to precise his gratefulness towards the Chairman, Department of Chemical Engineering, University of Engineering & Technology, Lahore, Pakistan, for his kind cooperation and reinforcement which help him in accomplishment of this project. Authors would also like to prompt my special thanks to the honorable Vice-Chancellor, University of Engineering & Technology, Lahore, Pakistan, for believing funding to first author, for this research project.

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