Al-Khwarizmi Engineering Journal

Al-Khwarizmi Engineering Journal, Vol. 4, No. 4, PP 1-8 (2008)

Performance of Gas Induction in a Dual – Impeller Agitated Bioreactor

Alaa K. Mohammed, Hassanin Ali Hussen and Safa Abid Al-Rassul
Genetic Engineering and Biotechnology/ Institute for Postgraduate Studies / University of Baghdad

(Received 14 January 2008; accepted 11 Seotermber 2008)

Abstract

The rate of gas induction was measured in gas-inducing type mechanically agitated contactors provided with two impellers. A reactor of 0.5 m i.d. was used with a working capacity of 60 liters of liquid. Tap water was used as the liquid phase, and air was used as the gas phase. The bioreactor mixing system consists of two equal diameter stirrers; the top impeller is shrouded-disk/curved-blade turbine with six evacuated bending blades, while the bottom impeller was disk turbine. The impeller speed was varied in the range of 50 to 800 rpm. The ratio of impeller diameter to tank diameter (D/T) and the submergence (S) of upper impeller from the top were varied. The effects of clearance of lower impeller from the tank bottom (C_2) and the impeller spacing (C_3**,** distance between the two impellers) were also varied over a wide range. Rate of gas induction (Q) was measured for all these combinations. It was found that the rate of gas induction increases with both decreasing in submergence and increasing in the stirrer diameter. While it decreases with both increasing the impeller spacing and the clearance from the bottom.

Keywords: Bioreactor, Dual-impeller, Suction- type impeller, fermentor)**.**

1. Introduction:

In many gas-liquid reacting systems, the recirculation of gas from the head space back into liquid is desired. This can be achieved by using different reactor designs such as sparged loop reactors, surface aerators, and gas-inducing-type mechanically agitated contactors (GIMAC). The comparison of GIMAC with other reactors has been reported by Saravanan et al. (1994). These reactors are useful for unit processes such as alkylation, ozonolysis, and hydrochlorination where it is desirable to have complete utilization of the solute gas. It is particularly useful for situations where the gas is available at relatively low pressure and the gas is introduced in the contactor by generating a low-pressure region in the vicinity of impeller. Many designs of gas inducing impellers have been reported in the published literature (Zlokamik and Judat, 1967; Joshi and Sharma, 1977; Zundelevich, 1979; Joshi, 1980; Raidoo., 1987, Mundale and Joshi, 1995; Swapnil et al. 2003; Swapnil et al. 2004). These designs include the pipe impeller consisting of a hollow shaft and hollow impeller, the flattened cylindrical impeller, the turbo aerator, the shrouded-disk curved-blade turbine, and the pitched-blade down flow turbine. Swapnil and Joshi (2004) have examined the different impeller designs and have shown the pitched-blade down flow turbine (PBTD) to be the most energy efficient.

However, these reactors having only one impeller need further improvements. The rate of gas induction decreases with an increase in the impeller submergence from the top. Therefore, the gas-inducing impeller needs to be as close to the surface as possible. On the other hand, the dispersion ability of the impeller decreases as the impeller is brought closer to the liquid surface. In addition, it is also known that the suspension ability of the gas-inducing impeller is very poor. These limitations of the single-impeller system can be overcome by using a double-impeller system. The top impeller acts as a gas-inducing impeller, and the second impeller distributes the gas bubbles throughout the vessel. Thus the functions of gas introduction and gas dispersion are assigned to two different impellers. There is yet another advantage of the second impeller. The second impeller is closer to the bottom and it is more effective for the purpose of solid suspension. Thus, the induction, the dispersion, and the suspension ability of the two-impeller system are far superior to those of the single-impeller system. Therefore, it was thought desirable to undertake a systematic investigation to optimize the impeller combination.

2. Materials and Methods:

Investigations were carried out in 0.5 m i.d. gas-inducing type of mechanically agitated reactors (GIMAC) of 60 liter capacity. The schematic diagrams of the GIMAC and the experimental setup are shown in Figure 1. The design details of vessels are given in Table 1. The prime mover was a DC motor, driven by a thyristor-controlled power source. The speed of rotation of the shaft was controlled by regulating the voltage applied to the armature of the motor by a ten-turn potentiometer. Fixed pulleys and twin C section were used to connect the agitator shaft to the motor. The entire device was able to control the speed. The bioreactor mixing system consists of two equal diameter stirrers; the top one is shrouded-disk/curved-blade turbine with six evacuated bending blades as shown in Figure 2., while the bottom impeller was disk turbine. The reactor tank, the central draft tube, the aeration wheel disk and hub were made of stainless steel. The air ducts were also stainless steel tubes, which were welded to the disk. The assembly was tinned and the hub was turned to fit a vulcanite sleeve in the bottom guide bearing. The shaft was made of ¾ inch stainless steel pipe. The cap for the introduction of air was bored to a tight running fit.

The impeller speed was varied in the range of 50 – 800 rpm. The ratio of impeller diameter to vessel diameter (D/T) was varied from 0.15 to 0.35 .The lower impeller clearance from the tank bottom (C1) was also varied over a wide range (C1 =T/4 to T/8). The effect of top impeller submergence (s) was studied in the range of 0.5D – 1.5D. The distance between the impellers (C3) varied in the range of 0.5D - 2D. The variables ranges were chosen such that it include the optimum values for the operation of single impeller system(Swapnil et al.2003) and this will permit to compare the results of this study with that of single impeller system. All these details are summarized in Table 1. Rate of gas induction (Q) was measured for all these combinations.

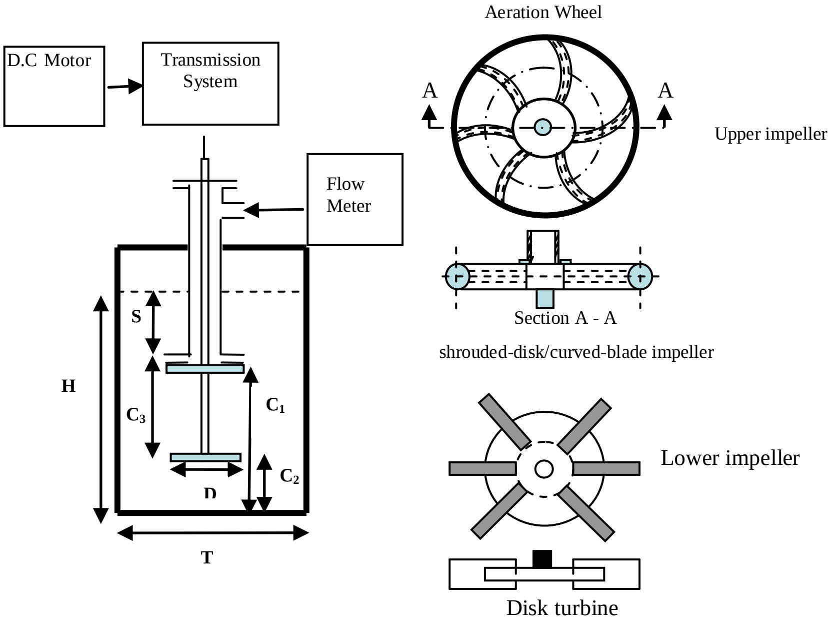

Fig. 1. Schematic Diagram of the Experimental Diagram.

Table 1.
Design Details of Gas- Inducing Mechanically Agitated Contactor.

Diameter of vessel, T	0.5 m
Impeller Diameter, D	0.15T, 0.25T, 0.35T
Baffle width	10% of vessel diameter.
Number of baffles	4
Construction material	Stainless steel.
Geometry	Cylindrical with flat bottom
Lower impeller clearance from bottom C1	T/8, T/6, T/4 T = 0.5m
Submergence of upper impeller from the top liquid surface, S	0.5 D, 1D, 1.5D D = 0.15m
Impeller Spacing, C_3	0.5D, 1.5D, 2D D = 0.15m

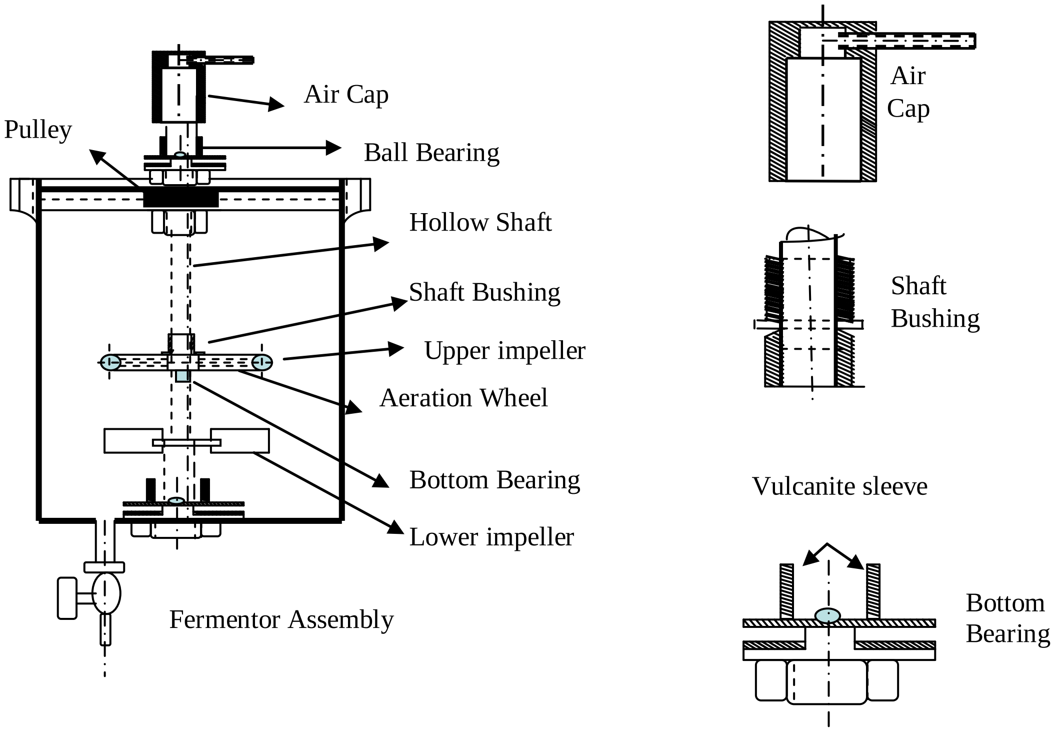

Fig. 2. Laboratory Experimental Fermentor with Mechanical Aerator.

3. Results and Discussion:

3.1. Effect of Impeller Diameter:

The effect of impeller diameter on the rate of gas induction was studied. The impeller diameter was varied from 0.15T – 3.5 T .The results are shown in Figure 3. It can be seen that the rate of gas induction increases with an increase in the impeller diameter. It may be emphasized that the pumping effectiveness increases with an increase in the impeller diameter and hence larger inertia force generating at the edge of impeller which causing higher vacuum at the impeller tip and hence increasing the rate of gas induction. Also it was noticed that larger impeller diameter show greater formation of bubbles (number), the size of bubbles is very fine, and the distribution of bubbles is uniform. However, on the other hand, it is very difficult to bubble the liquid when the impeller diameter is reduced to T/8. Hence a decrease in the induction rate was observed.

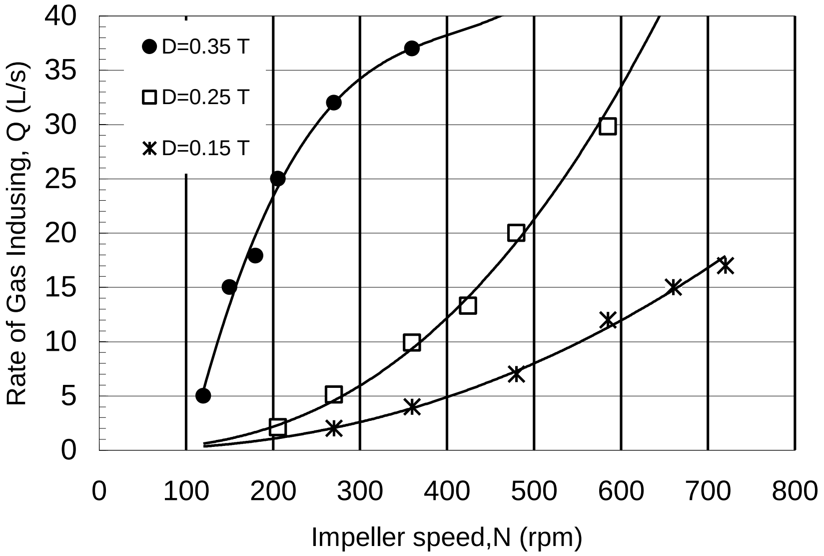

Fig. 3. Effect of Impeller Diameter and Impeller Speed on Rate of Gas Induction (T=0.5 m, C_1=1.5T, S=1.5 D, C_3=2 D).

3.2. Effect of Submergence:

This is a major parameter which affects the rate of gas induction. Submergence is the liquid height above the upper impeller and is measured from the static liquid surface to the center line of the upper impeller. Generally, it is known that the rate of gas induction decreases as the liquid submergence increases. Experiments were carried out with submergence of the upper impeller was varied from 0.5D – 1.5D. The results are shown in Figure 4. As pointed out earlier by Saravanan *et al.* (1994), the critical impeller speed for gas induction increases with an increase in the liquid submergence. Therefore, for the same rate of gas induction, a higher impeller speed is needed at a higher liquid submergence. It may be emphasized that increasing submergence (i.e the liquid height above the upper impeller) will led to increase the static liquid head at the impeller tip, the point which cause higher resistance for bubbles to liberate from impeller edge. There fore higher agitation speed is needed to react this effect and generating higher inertia force which assist the bubble to liberate from impeller edge.

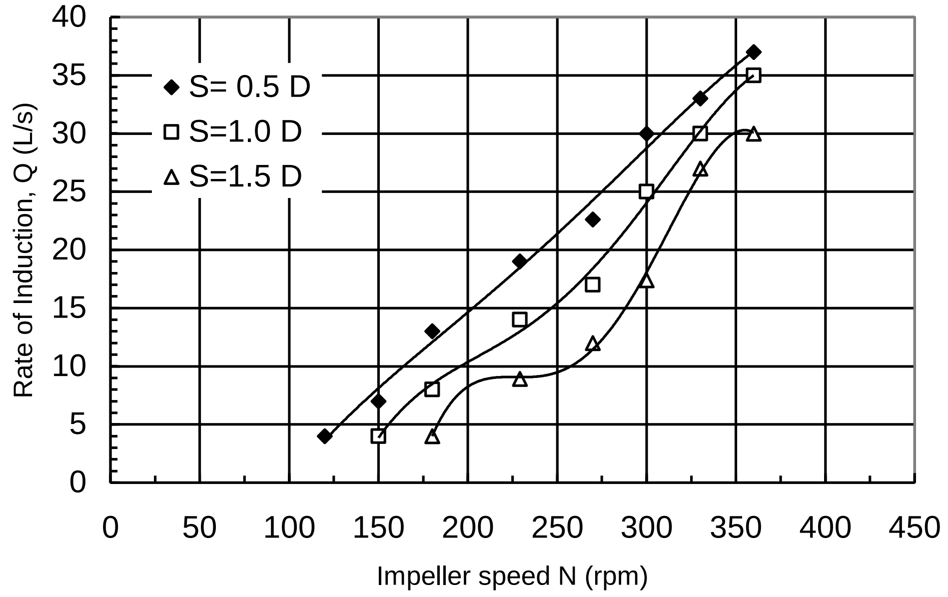

Fig. 4. Effect of Submergence and Impeller Speed on Rate of Gas Induction. (T=0.5 T, D=0.25 m, C_1=1.5 T, C_3=2D).

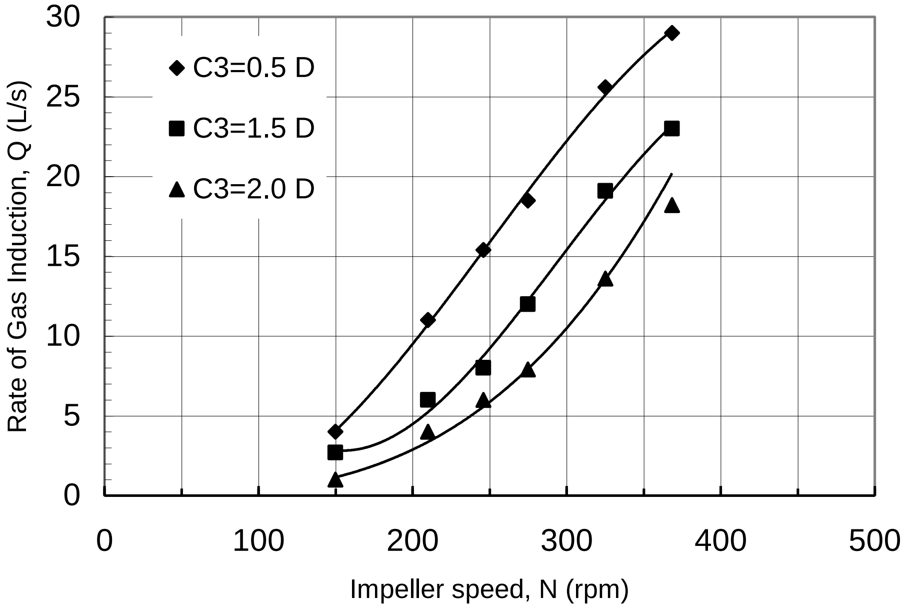

Fig. 5. Effect of Impeller Spacing (C_3) on Rate of Gas Induction. (T=0.5, D=0.15 m, C_1=T/4, S=1.5 D).

3.3. Effect of Impeller Spacing (Impeller Clearance):

It is believed that the distance between the two impellers plays an important role in the gas induction process. Spacing between the two impellers (C3) is measured between the two impeller center planes. Effect of impeller spacing was extensively studied in a mechanically agitated contactor by Zundelevich (1979) and Joshi (1980) for two-turbine impellers. They have varied the impeller spacing over a wide range from 0.2D to 4D. In the present investigation, the distance between the two impellers was varied in the range of 0.5D-2D. The results are shown in Figure 5. It was observed that the rate of gas induction increases with a decrease in the impeller clearances. It may be emphasized that decreasing the distance between the impellers will led to generate a high agitation region near the suction impeller and hence causing higher vacuum which led to higher rate of gas induction.

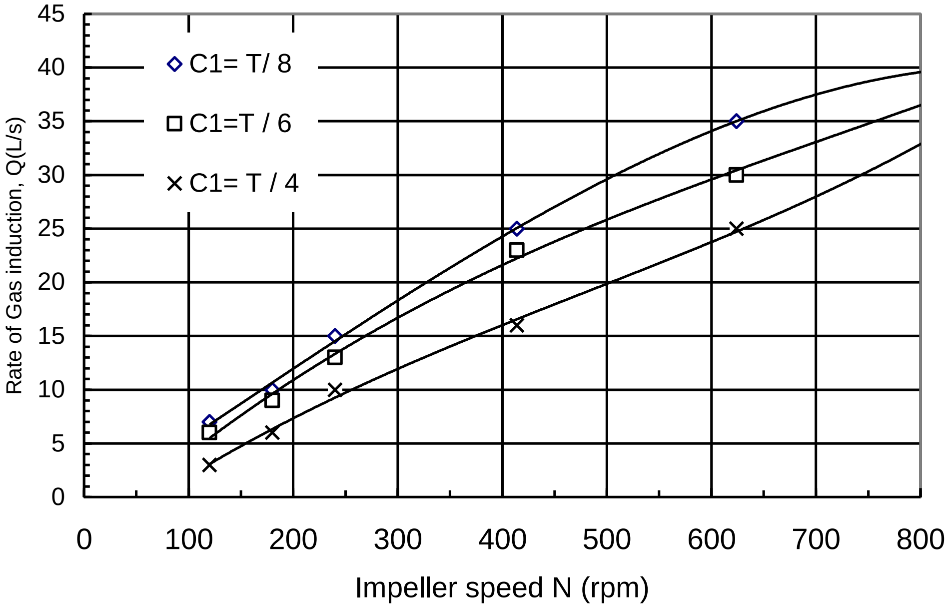

Fig.6. Effect of Impeller Bottom Clearance on Rate of Gas Induction. (T=0.5m, D=0.15m, S=1.5 D, C3=1.5 D).

3.4. Effect of Impeller Bottom Clearance:

Impeller off-bottom clearance C_1 is measured between the lower impeller center plane and the tank bottom. The clearance of an impeller from tank base was varied from T/8 to T/4. The results are shown in Figure 6**.** It was found that the rate of gas induction decreases with an increase in the clearance from bottom. It may be emphasized that decreasing the bottom clearance will cut the bubbles profile in the region between the tank bottom and the lower impeller that will led to increase the momentum of eddies near the surface impeller and hence increasing the vacuum near the impeller tip so higher gas rate induction is obtained. This finding is in agreement with that found with for simple impeller system (Swapnil and Joshi 2004). On the other hand very low clearance results in higher resistance for the flow, and hence a lower rate of gas induction is obtained that is because of higher friction between the motive fluid and the bottom of the tank which will generate higher resistance for liberation of bubbles from the impeller tip.

4. Conclusions:

1. The rate of gas induction in the multiple-impeller system was found to be greater than that for the single impeller system.
2. Also in the single-impeller system, the induced gas is not distributed throughout the vessel, but it takes only an upward path as soon as it is induced from the stator impeller region. This limitation is eliminated by using a dual-impeller system in which the induced gas (in the form of bubbles) is distributed throughout the vessel.
3. The submergence of the upper impeller was found to have a strong influence on the rate of gas induction. The rate of gas induction increased with a decrease in the submergence.
4. The rate of gas induction gas holdup decreased with an increase in the impeller spacing.
5. The rate of gas induction decreased with an increase in the clearance from the bottom.
6. For the same impeller type, the rate of gas induction increases with an increase in the stirrer diameter.

5. Nomenclature:

C1	Upper impeller clearance form tank bottom (m).
C2	Lower impeller clearance from tank bottom (m).
C3	Impeller clearance (m), (center to center distance between two impellers).
D	Impeller diameter (m).
GIMAC	Gas-inducing mechanically agitated contactor.
H	Height of liquid in vessel (m).
N	Impeller rotational speed (rpm).
Q	Gas-induction rate (l/s).
S	Submergence of upper impeller in clear liquid.
T	Vessel diameter (m).

6. References:

[1] Swapnil, S.P.; Deshmukh , N.A. and Joshi, J.B.(2004)."Mass- transfer characteristics of surface Aerators and Gas – Inducing impellers". Ind. Eng.Chem.Res. 43, 2765-2774.

[2] Shulka, V.B. and Pandit, A.B. (2001). "Scale- up of biotransformation process in stirred tank reactor using dual impeller bioreactor". Biochemical Engineering Journal. 8, 19-20

[3] Swapnil S.p.; Patil and Joshi J.B.(2003). "Optimum Design of Multiple–Impeller Self-Inducing System". Ind. Eng. Chem Res. 42, 1261-1265.

[4] Mishra, V. P.; Joshi, J. B. (1993). Flow Generated by a Disc Turbine: Part III: Effect of Impeller Diameter, Impeller Location and Comparison with Other Radial and Flow Turbines. Chem. Eng. Res. Des., 71, 563-570.

[5] Mundale, V. D.; Joshi, J. B. (1995). Optimization of Impeller Design for Gas Inducing Type of Agitated Contactor. Can. J. Chem. Eng., 73, 6-17.

[6] Joshi, J. B. (1980). Modifications in the Design of Gas inducing Impellers. Chem. Eng. Commun., 5, 1 09-114.

[7] Joshi, J.B.; Sharma, M. M. (1977). Mass Transfer and Hydrodynamic Characteristics of Gas inducing Type of Agitated Contactors. Can. J. Chem. Eng., 65, 683-695.

[8] Raidoo, A. D.; RaghavRao, K. S. M. S.; Sawant, S. B.; Joshi, J. B. (1987). Improvements in Gas Inducing Impeller Design. Chem. Eng. Commun., 54, 241-264.

[9] Saravanan, K.; Mundale, V. D.; Joshi, J. B. (1994). Gas Inducing Type

[10] Mechanically Agitated Contactors. Ind. Eng. Chem. Res., 33, 2226- 2241

[11] Zlokarnik, M.; Judat, H. (1967). Tube and Disk Stirrers - Two Efficient Stirrers for the Gassing of Liquids. Chem. Ing. Tech., 39, 1163-1168.

[12] Zundelevich, V. (1979). Power Consumption and Gas Capacity of Self Inducing Turbo Aerations. AIChE J., 25, 763-773.

اداء المفاعلات الحيوية ذات الخلاطات المزدوجة الساحبة للهواء

علاء كريم محمد حسنين علي حسين صفاء عبد الرسول
معهد الهندسة الوراثية والتقنيات الاحيائية للدراسات العليا/ جامعة بغداد

الخلاصة

تم قياس معدل سحب الهواء في المفاعلات الحيوية ذات الخلاطات المزدوجة الساحبة للهواء. استخدم مفاعل ذو قطر 0.5 م وسعة 60 لتر. استخدم الماء كوسط سائل والهواء كوسط غاز. يتكون نظام الخلط في المفاعل من خلاطين متساويين في القطر: الخلاط الاعلى من نوع الريش الانبوبية الساحبة للهواء (shrouded disk/curved-blade turbine) والخلاط الاسفل من نوع القرص التوربيني(disk turbine). المتغيرات التي تم دراستها في هذا البحث هي :سرعة دوران الخلاط بحدود 500 – 800 دورة/دقيقة ، نسبة قطر الخلاط الى قطر المفاعل ، عمق الخلاط الاعلى عن سطح السائل (submergence)، المسافة بين الخلاطين (Clearance) ، بعد الخلاط الاسفل عن قعر المفاعل.

وجد ان معدل سحب الهواء يزداد بزيادة قطر الخلاط ونقصان عمق الخلاط عن السطح العلوي للسائل، بينما يقل معدل السحب بزيادة المسافة بين الخلاطين وزيادة المسافة بين قعر المفاعل والخلاط السفلي.