

## **PERFORMANCE ENHANCEMENT FOR SCALE-UP OF GAS-HYDRATE-FORMING REACTORS USING STIRRED-TANK REACTORS**

Saurabhkumarshishodia  
saurabhshishodia1994@gmail.com  
Vishveshwaryagroup of institutions  
dadri g.bnagar ,UP - 203207

Navinkumar  
navin4240@gmail.com  
Vishveshwaryagroup of institutions  
dadri g.bnagar ,up - 203207

### **ABSTRACT**

An evaluation and analysis method is presented to investigate an approach to scale-up a hydration reactor and to solve some economic problems by looking at the natural gas hydrate storage and transportation process as a whole. This paper presents the stirred tanks used for gas-liquid mixing operations in laboratory setups or industrial processes are various in their design, which may be specified in terms of the tank geometry, the types of impellers for stirring, the types of gas-injection devices, the types of heating/cooling devices. Analyses indicate that the process evaluation parameter is relevant to technology level and resource consumption for a system, which can make it applicable to economic analysis and venture forecasting for optimal capital utilization.

*Keywords: Natural gas hydrates, electrolytes, hydrate inhibitor, stirred-tank reactors etc.*

### **I.INTRODUCTION**

The rate of hydrate formation is identified as one of the critical parameters in design and operation of large-scale hydrate production plants for storage and transport of gas as hydrates. At the Norwegian University of Science and Technology (NTNU), extensive studies of relevant hydrate properties have been carried out (Gudmundsson et al., 2002). In the production process, hydrates are formed in a continuous

water phase at typically 5-15 °C and 50-100 bars. The same conditions are relevant in cold flow technology where oil, gas and water are passed through a subsea unit for flow assurance purposes (Gudmundsson, 2002). In this study, the rate of hydrate formation has been measured in a continuous stirred tank reactor (CSTR) under various pressure, temperature and hydrodynamic conditions. To describe the rate of hydrate formation in a CSTR, a bubble-to-crystal model has been developed.

#### **1.1. Hydrate Formation Studies**

The hydrate formation process has been identified by many researchers as important in understanding the nature of gas hydrates. Vysniauskas and Bishnoi (1983, 1985) initiated a systematic research on hydrate formation kinetics by studying the rate of methane and ethane hydrate formation in a semi-batch stirred reactor. They proposed a semi-empirical model, with pressure, gas-liquid interfacial area and temperature driving force, for the rate of gas consumption, and a mechanism for nucleation and growth.

### **II.PROBLEM STATEMENT**

Characteristic liquid-dispersion-type reactors are composed of high-pressure chambers and water-circulation/cooling assemblies that enable the continuous, downward spraying of pre-cooled

water from a spray nozzle, or nozzles, installed in the top portion of each chamber can be made by simply enlarging the horizontal dimension of the chamber and increasing the number of spray nozzles to be installed in the chamber and the power required for circulating water during the operation of a scaled-up reactor. Hence, we focus our attention hereafter on the issue of the scale-up of two typical reactor designs in the gas-dispersion-type category: one employs gas bubbling into a stirred aqueous-liquid pool filling the lower portion of a cylindrical tank.

### III. SYSTEM MODEL

Stirred-tank fermentors typically follow general guidelines in order to optimize mixing and reduce power requirements. Extensive research has been performed to give guidelines on sizing of stirred tank fermentors and their components. However, none of these guidelines are absolute; rather they are meant to direct the basic geometric design of stirred tank fermentors while other factors are held constant. These guidelines are outlined in the following paragraphs.

*Impellers:* The ratio of the impeller diameter to the diameter of the tank ( $d_i/d_t$ ) should be between 0.3 and 0.5. In the case of using radial flow impellers the ratio should be approximately 0.3. If the impellers are too small they will not generate enough fluid movement, whereas if they are too large they require much more power and become less efficient [15].

*Impeller Spacing:* The spacing between impellers should be  $1.0d_i$  to  $2.0d_i$ , where  $d_i$  is the diameter of the impeller. In addition, the bottom-most impeller should be located  $1.0d_i$  from the bottom of the tank [15, 17]. If the impellers are spaced too close together (less than  $1.0d_i$ ) the power imparted to the fluid can get as low as 80% of that obtained from proper

spacing. On the other hand, if the impellers are spaced too far apart the fluid does not experience adequate mixing [17]. Thus, the number of impellers can be determined from the following equation:

$$\frac{H_L - d_i}{d_i} > n_i > \frac{H_L - 2d_i}{2d_i} \quad (1)$$

where  $H_L$  is the height of liquid in the vessel and  $n_i$  is the number of impellers [17]. However, this is assuming all the impellers are spaced equally between the bottom of the tank and the liquid surface. As stated before, the bottom-most impeller is usually spaced one impeller diameter from the tank bottom, and the upper-most impeller is spaced 1.5 or more impeller diameters from the liquid surface.

*Baffling:* Stirred tank fermentors generally use baffles because of the need to disrupt the bulk fluid flow in the tank. Bioreactors do not need this disruption. In most cases, four flat baffles on 90° centers are used and have a width of  $.08d_t$  to  $.10d_t$ , where  $d_t$  is the diameter of the tank [15]. For low-viscosity flows baffles are attached directly to the wall of the tank, but for moderate to high-viscosity flows baffles are set a small distance away from the wall [18].

*Tank Height:* The height to diameter ratio of the tank is typically between 2.0 and 3.0; however, taller tanks (up to  $H_L/d_t=4.0$ ) have been used to reduce the power requirement of the impellers [20]. Typical tanks also employ a dish-shaped bottom to enhance mixing and prevent dead zones.

### 3.1. Tank Fermentors

Design and scale-up of stirred tank fermentors are largely based on empirical data. Some research suggests that the design of stirred tanks should be based on mixing time, while others claim it should be based on the specific power

input [21]. Others argue it should be based on impeller tip speed [22]. A few researchers have suggested dimensionless number correlations be used for reactor scale-up and design [12].

#### IV. PROPOSED METHOD

The calculation of power requirements for agitation is only a part of the mixer design and the process results are to achieve the optimum mixing and uniform blending. The process results are related to variables characterizing mixing, namely geometric dimensions, stirrer speed (rpm), agitator power, and physical properties of the fluid (e.g., density, viscosity, and surface tension) or their dimensionless combinations. Sometimes, empirical relationships are established to relate process results and agitation parameters. The laboratory system can then be scaled-up to predict the conditions on the larger system.

If geometric similarity is achievable, dynamic and kinematic similarity cannot often be predicted at the same time. For these reasons, experience and judgment are relied on with aspects to scale-up. The main objectives in a fluid agitation process are :

- Equivalent liquid motion (e.g., liquid blending where the liquid motion or corresponding velocities are approximately the same in both cases).
- Equivalent suspension of solids, where the levels of suspension are identical.
- Equivalent rates of mass transfer, where mass transfer is occurring between a liquid and a solid phase, between liquid-liquid phases, or between gas and liquid phases, and the rates are identical.

A scale ratio R is used for scale-up from the standard configuration

1. Determine the scale-up ratio R, assuming that the original vessel is a standard cylinder with  $D_{T1} = H_1$ . The volume  $V_1$  is

$$V_1 = \frac{\pi D_{T1}^2}{4} \cdot H_1 = \frac{\pi D_{T1}^3}{4} \quad (2)$$

The ratio of the volumes is then

$$\frac{V_2}{V_1} = \frac{\pi D_{T2}^3/4}{\pi D_{T1}^3/4} = \frac{D_{T2}^3}{D_{T1}^3} \quad (3)$$

The scale-up ratio R is

$$R = \frac{D_{T2}}{D_{T1}} = \left( \frac{V_{T2}}{V_{T1}} \right)^{\frac{1}{3}} \quad (4)$$

Using the value of R, calculate the new dimensions for all geometric sizes. That is,

$$D_{A2} = R D_{A1}, J_2 = R J_1, W_2 = R W_1$$

$$E_2 = R E_1, L_2 = R L_1, H_2 = R H_1 \quad (5)$$

Or

$$R = \frac{D_{A2}}{D_{A1}} = \frac{D_{T2}}{D_{T1}} = \frac{W_2}{W_1} = \frac{H_2}{H_1} = \frac{J_2}{J_1} = \frac{E_2}{E_1} \quad (6)$$

2. The selected scale-up rule is applied to determine the agitator speed  $N_2$  from the equation:

$$N_2 = N_1 \left( \frac{1}{R} \right)^n = N_1 \left( \frac{D_{T1}}{D_{T2}} \right)^n \quad (7)$$

- Where  $n = 1$  for equal liquid motion
- $n = 3/4$  for equal suspension of solids
- $n = 2/3$  for equal rates of mass transfer (corresponding equivalent power per unit volume, which results in equivalent interfacial area per unit volume)

The value of  $n$  is based on theoretical and empirical considerations and depends on the type of agitation problem.

3. Knowing the value of  $N_2$ , the required power can be determined using Equation (7) and the generalized Power number correlation.

Other possible ways of scaling up are constant tip speed  $uT(\pi NDA)$ , and a constant ratio of circulating capacity to head  $Q/h$ .

Since  $P \propto N^3 D_A^5$  and  $V \propto D_A^3$  then

$$\frac{P}{V} \propto N^3 D_A^2 \quad (8)$$

For scale-up from system 1 to system 2 involving geometrically similar tanks and same liquid properties, the following equations can be applied:

$$N_1 D_{A1} = N_2 D_{A2} \quad (9)$$

For a constant tip speed,

$$\frac{N_2}{N_1} = \frac{D_{A1}}{D_{A2}} \quad (10)$$

For a constant ratio of circulating capacity to head,  $Q/h$ ,

$$N_1^3 D_{A1}^2 = N_2^3 D_{A2}^2 \quad (11)$$

## V.RESULT

The hydrate laboratory consisted of a flow loop with four main units: a reactor, a separator, a heat exchanger and a circulation pump. Each experiment was performed at steady-state conditions. In experiments where stable gas flow rates developed rapidly, the gas injection rate was shifted once and sometimes twice. The recorded data from each experiment were analyzed using MATLAB. Pressures,

temperatures and gas flow rates were plotted against time, and the time interval or intervals with a linear gas bottle pressure drop and a stable gas vent rate were identified. We mention the input parameter in below table.

Table 1: Input parameter

Input parameter	Value
Ambient Temp	3
Heating Element	7
Temp of catalytic converter	8
Concentration of CO	9
Exhaust temperature	10

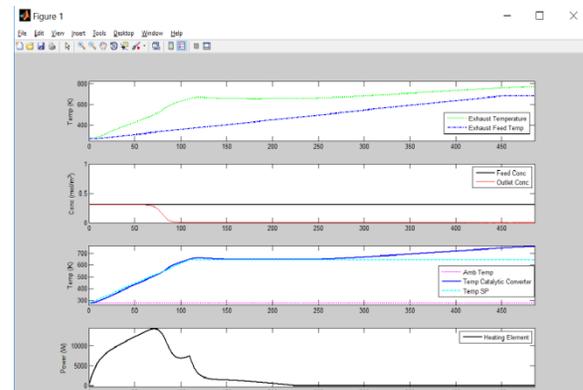


Figure 1: 1a: exhaust temp and exhaust feed temp, 1b: feed conc and outlet conc, 1c: Ambient Temperature and its catalytic, 1d: heating element

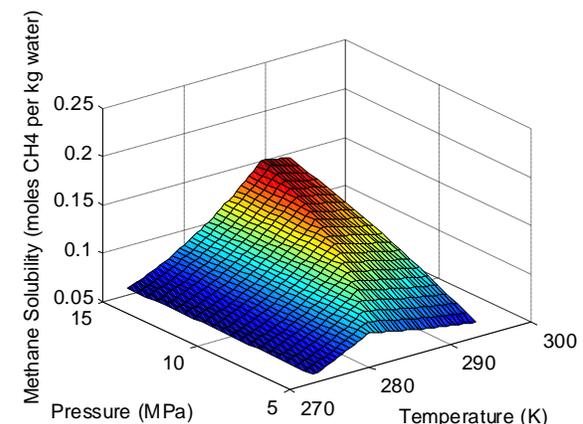


Figure 2: Methane Gas stability and pressure for constant catalyst

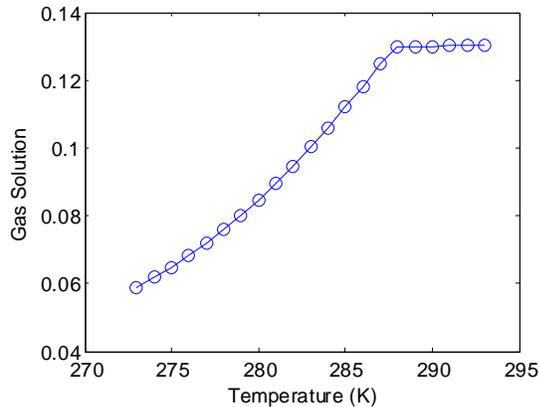


Figure 3: Gas solution performance at temperature raised counter

Temperature	Gas solution
270	--
275	0.062
280	0.075
285	0.105
290	0.125
295	--

Table 2: Comparison between Temperature and Gas solution

## VI. CONCLUSION

Gas hydrates have a large capacity for the storage of gases and are an attractive method for gas filtration and transportation. However, hydrate formation is usually controlled by the rate of crystallization and thus it can be a slow process. A technology that will rapidly and continuously form hydrate is necessary for scale-up. The reactor is stable when it works well, that is, when the organic and inorganic material is being removed from the water.

Through the methane hydration experiment in a spraying reactor and analysis of the result received, the following conclusions were drawn:

1. Liquid spraying hydration experiment with higher pressure and lower temperature enhanced the mass transfer and heat transfer, increasing the hydration rate and reducing the pressure of the gas phase.
2. Process evaluation parameters and integrated process, or better management level could effectively reduce the resource consumption and could further improve the resource output level.

Future work can isolate more specifics of the detailed role of bubbles on electronucleation. It is also useful to compute the fraction of water hydrolyzed over the course of the electronucleation experiment. The current measurement indicates the charge transfer and thus the number of water molecules undergoing hydrolysis over the course of the experiment.

## REFERENCES

- [1] Vysniauskas, A. and Bishnoi, P.J. (1983). A Kinetic Study of Methane Hydrate Formation, *Chemical Engineering Science*, 38, 7, 1061-1072.
- [2] Vysniauskas, A. and Bishnoi, P.J. (1985). Kinetics of Ethane Hydrate Formation, *Chemical Engineering Science*, 40, 2, 299-303.
- [3] Gudmundsson, J.S., Mork, M. and Graff, O.F. (2002). Hydrate Non-Pipeline Technology, 4th International Conference on Gas Hydrates, May 19-23., Yokohama, Japan.
- [4] Englezos, P., Kalogerakis, N., Dholabhai, P.D. and Bishnoi, P.R. (1987). Kinetics of Formation of Methane and Ethane Gas Hydrates, *Chemical Engineering Science*, 42, 11, 2647-2658.
- [5] Herri, J.M., Pic, J.S., Gruy, F. and Counil, M. (1999). Methane Hydrate Crystallization

Mechanism form In-Situ Particle Sizing, *AICHE Journal*, 45, 3.

[6] Monfort, J.P., Jussaume, L., El Hafaia, T. and Canselier, J.P. (2000). Kinetics of Gas Hydrate Formation and Tests of Efficiency of Kinetic Inhibitors, *Experimental and Theoretical Approaches*, *Annals of the New York Academy of Sciences*, 912, 753-765.

[7] Skovborg, P. and Rasmussen, P. (1994). A Mass Transport Limited Model for the Growth of Methane and Ethane Gas Hydrates, *Chemical Engineering Science*, 42, 11, 1131-1143.

[8] Bollavaram, P., Devarakonda, S., Selim, M.S. and Sloan, E.D. (2000). Growth Kinetics of Single Crystal sII Hydrates, Elimination of Mass and Heat Transfer Effects, *Annals of New York Academy of Sciences*, 912, 533-543.

[9] Happel, J., Hnatow, M.A. and Meyer, H. (1994). The Study of Separation of Nitrogen from Methane by Hydrate Formation Using a Novel Apparatus, *Annals of the New York Academy of Sciences*, 715, 412-424.

[10] Wilson, J., and Charles, M., "Fermenter Design," *Encyclopedia of Bioprocess Technology*, John Wiley & Sons, 1999, pp. 1157-1189.

[11] Weetman, R.J., "Development of Transitional Flow Mixing Impeller," *Proceedings of The 7th European Conference on Mixing*, Belgium, 1991.

[12] Cooney, C.L., Demain, A.L., Dunnill, P., Humphrey, A.E., Lilly, M.D., Wang, D.I.C., *Fermentation and Enzyme Technology*, John Wiley & Sons, 1978, pp. 157-192.

[13] Linga P, Daraboina N, Ripmeester JA, Englezos P. Enhanced rate of gas hydrate formation in a fixed bed column filled with sand compared to a stirred vessel. *Chemical Engineering Science*. 2012;68:617–623

[14] Mori Y. Comments on Experimental investigations on scaled-up methane hydrate production with surfactant promotion: *Energy*

considerations. *Journal of Petroleum Science and Engineering*. 2015;134:3

[15] Oldshue, J.Y., *Fermentation and Biochemical Engineering Handbook, 2nd Ed*, William Andrew, 1997, pp. 181-241.

[16] Nauman, E.B., *Chemical Reactor Design, Optimization and Scale-Up*, McGraw Hill, New York, 2002.

[17] Kenty, B.M., Li, Z.J., Lee, S.S., and Xing, Z., "Scale-Up Analysis for a CHO Cell Culture Process in Large-Scale Bioreactors," *Biotechnology and Bioengineering*, vol. 103, no. 4, 2009.

[18] Thornton, E.A., Byron, T.D., and Heubner, K.H., *The Finite Element Method for Engineers*, 3rd ed., John Wiley & Sons, 1995.

[19] Montes, F.J., Galan, M.A., and Martin, M., "On the Contribution of the Scales of Mixing to the Oxygen Transfer in Stirred Tanks," *Chemical Engineering Journal*, vol. 145, 2008, pp. 232-241.

[20] Phillichi, T.L., and Stenstrom, M.K., "Effects of Dissolved Oxygen Probe Lag on Oxygen Transfer Parameter Estimation," *Journal of Water Pollution Control Federation*, vol. 61, no. 1, 1989, pp. 83-86.

[21] Yano, H., Yoshinaga, F., and Kouda, T., "Effect of agitator configuration on bacterial cellulose productivity in aerated and agitated culture," *Journal of Fermentation and Bioengineering*, vol. 38, no. 4, 1997, pp. 371–376.

[22] Doran, P.M., *Bioprocess Engineering Principles*, Sagebrush Education Resources, 1995.