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Beijing, P. R. China

Organized by
Institute of Chemical Engineering, China
University of Petroleum
Tsinghua University

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Preface

This proceeding of 1996 Asian-Pacific Chemical Reaction Engineering Forum ('96 APCRE) Changping, Beijing, China are the collections of 116 contributions, (3 plenary, 95 oral lectures and 18 posters) in the fields of catalysis and kinetics, applications of CRE in biotechnology, advanced materials and energy development and utilization, methodologies for reactor R & D and novel reactors, environmental protection, experimental techniques and instrumentation, mathematical modeling, transient behavior of reactor operation and controlling. Colleagues mainly from the Asian-Pacific region and some cooperative efforts with colleagues outside this region.

The participation and contributions from quite a number of reknow scientists of chemical reaction engineering, to mention a few: S. H. E. H. E. Elnashaie from Saudi Arabia, Kenji Hashimoto from Japan and Mooson Kwauk, Weikang Yuan from China have elevated the academic prestige of the forum hence the quality of the proceedings. Their contributions are therefore cordially appreciated.

Asia-Pacific region is a region with wonderful peculiarities. First it is a coupling of the oldest civilization with the fastest developing modern economy. Second it is a region embracing of very highly developed country like Japan and largest developing country like China and countries of south, middle and south eastern Asia of varies degrees of developing. Third it is a region that the task in activating its tremendernous human and material resource to solve its problems in development, in utilization and conservation of energy, in environmental protection, in modernizing its agriculture and population control is so overwhelming that a cooperative and concerted efforts in the region scale is extremely necessary.

In talking such a task, the challenges and opportunities in the field of chemistry, biochemistry and chemical engineering in which chemical reaction engineering constitutes an important part, are very fascinating. Standing on the threshold between centuries, I must say the '96 APCRE Forum is a very good beginning for us all. This regional activity may expand or must expand to involve our colleagues from America and Europe to participate with the common objective of rising the academic as well as technological level of chemical reaction engineering in this area and motivated to the holly desire of coprosperity.

(Yang Guanghua)

15/06/96

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Novel reactors and experimental technique

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PROCESS INTENSIFICATION: THE EXPLOITATION OF CENTRIFUGAL FIELDS

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1. INTRODUCTION

Process Intensification (PI) is a term used to describe the strategy of making dramatic reductions in the size of a chemical plant in order to reach a given production objective. The concept was pioneered in ICI during the late 70s, when the primary goal was to reduce the capital cost of a production system. The virtue of the PI approach will be recognised when it is appreciated that the Main Plant Items involved in the process (i.e. reactors, heat exchangers, separators etc.) only contribute around 20% of the cost of a given plant. The balance is incurred by installation costs which involve pipework, structural support, civil engineering and so on. While cost reduction was the original target for PI, it quickly became apparent that there were other important benefits, particularly in respect of improved intrinsic safety, reduced environmental impact and energy consumption. Given the anticipated plant volume reductions, the toxic and flammable inventories of intensified plant are correspondingly reduced, thereby making a major contribution to intrinsic safety.

The use of centrifugal fields to enhance the performance of many unit operations, including separations, reactions and heat and mass transfer, is a very powerful technique for process intensification. Some opportunities in these areas will now be discussed.

2. BACKGROUND TO "HIGEE"

The fluid dynamic behaviour of multiphase systems is controlled by the interphase buoyancy term $\Delta\rho g$. If this term is large, then the system has a strong tendency to stratify and the interphase slip velocity will be high. On the other hand, with small buoyancy forces the slip velocity is modest and interphase dispersion is easy, even at low fluid velocities and shear stresses.

In the limit, where $\Delta\rho g = 0$ (e.g. in deep space) a multiphase operation at very low contacting velocities will be controlled by capillary forces. Thus, a distillation experiment under these conditions will result in coalesced liquid at one end of the column complemented by a vapour space at the other. Little interfacial contact will develop and there will be negligible separation of the feed. Conversely, at high levels of applied acceleration, the enhanced slip velocity boosts the system's flooding performance and the interfacial shear stress, thereby improving the mass transfer coefficients.

Flooding behaviour in packed beds is conveniently correlated by the Sherwood plot shown in Fig.1. For a given system and imposed values of the superficial liquid and gas mass flows (L, G, respectively) the abscissa defines the critical value of the ordinate which will just give rise to flooding - i.e. when liquid will be carried out of the unit with the gas. For the chosen system, this defines the value of the term u_g^2a/gE^3, where

u_g = vapour superficial velocity
a = bed specific interfacial area
E = bed voidage
g = applied acceleration

The enhanced acceleration permits either the gas flow or the packing specific area to be increased. This results in either a large hydraulic capacity or more mass transfer area (and hence lower stage heights). As pointed out by Pratt [1] the separative power of any device or process is proportional to the product of its hydraulic capacity and the number of mass transfer stages. The reasoning described above suggests that if multiphase equipment is designed to exploit high accelerations, its operating intensity (or space-time performance) is potentially very high. Similar reasoning can be applied to the remaining operations listed in Table 1, and shows that they all may be intensified in high acceleration environments - which are henceforward presumed to be generated by centrifugal fields.

Table 1

Duty	Operation
Separation	Distillation
	Absorption/stripping
	Extraction
	Phase disengagement
Heat transfer	Boiling/evaporation
	Condensation
General	Electrolysis/fuel cells
	Crystallisation/precipitation
	Gas liquid reactors

3. SEPARATION

In order that fluid separation involving many stages can be accomplished efficiently, it is imperative that the contacting phases move in counter-current flow. This need is simply achieved in a centrifugal acceleration field, provided there is a reasonable interfacial density difference, as pointed out above. In addition, the highest possible mass transfer coefficients and area densities are desirable in order to minimise the stage heights. In this context, it is worth noting that immersed bodies or channels which have a small characteristic dimension are intrinsically superior in performing heat or mass transfer operations. Thus, the Nusselt number for heat transfer from cylinders and filaments is given by:

$$Nu = \frac{hd}{k} = 0.32 + 0.43\left(\frac{\rho ud}{\mu}\right)^{0.52}$$

for $\rho ud/\mu$ in the range 0.1-1000.

For a given stream velocity (u) it can be seen that small diameters (d) favour high values of the film coefficient (h). A matrix of fine filaments will therefore create a unit having a high specific surface area and a large mass transfer capacity - provided all the surface area can be exploited. At low or terrestrial accelerations, the area of the envisaged matrices tends to be occluded by liquid and is therefore inaccessible for the mass transfer process. However, as pointed out above, consideration of the flooding behaviour at enhanced accelerations shows that the area of dense matrices can be made available for the mass transfer process.

A number of investigators have explored the mass transfer performance of rotating beds of packing or plates. Pilo and Dahlbeck [2] tested various types of "filler bodies" and plates in his rotor for scrubbing benzene from town gas and the selective removal of H_2S from coke oven gas. No performance details are given but it was claimed that the low residence times in the rotor were conducive to a high absorption of H_2S relative to that for CO_2. Although Pilo claims that his unit could cope with liquid-liquid systems, it appears that his experimental work was restricted to gas-liquid contacting. Apart from a demonstration unit which was installed at the Stockholm gas works there is no indication that the equipment was ever commercialised.

As part of ICI's intensification studies, Ramshaw and co-workers [3] explored the mass transfer behaviour of an irrigated rotating torus comprising reticulated metal foam or a wound filamentary matrix. The studies covered both distillation and gas film limited absorption operations, giving equivalent plate heights of 1-2 cm for the former and similar values for the Height of a Transfer Unit (HTU) for the latter. The work culminated in the building of a "Higee" (Fig.2) full scale distillation unit for demonstration purposes having a reflux capacity of about 10 ton h^{-1}. Earlier laboratory results were vindicated once some initial distribution problems were resolved. Eventually over 20 theoretical plates were achieved in a rotor having internal/external diameters of 200/800 mm respectively, using the isopropyl alcohol-ethanol system. The pressure drop per plate corresponded to the values expected in a plate column rather than a packed column.

Higee technology (continuous gas phase) in its present state of development is probably best exploited where the following situations prevail or the characteristics below are highly prized:-

(1) small size/low weight;
(2) low inventory;
(3) short residence time/rapid response;

Further Higee experiments are being performed at Newcastle University. They involve the air stripping of ethylene dichloride from water (a liquid film-limited system) and have given HTU's down to 5 cms.

4. FLUID MALDISTRIBUTION

Although the measured mass transfer in a Higee rotor is high, it is significantly poorer than that predicted on the assumption that all the packing is effective. A photographic study by Burns [4] of the liquid flow within the packing, revealed pronounced channelling Fig.3 as the liquid proceeded from the inner cylindrical surface of the packing to the periphery. Clearly all the installed area does not contribute to the rotor performance. These studies are continuing and could indicate an optimum packing density which minimises the gas pressure drop for a given mass transfer duty. It appears that, as for packed towers, fluid maldistribution is an intrinsic characteristic of the gas-liquid system. An innovative approach is needed to overcome the performance penalty incurred.

5. CONCLUSION

Process intensification is a very fertile though challenging basis for designing future chemical plant. The exploitation of centrifugal fields is a powerful technique for achieving a given intensification objective.

Notation

a	specific interfacial area
d	diameter
E	voidage fraction
G	gas mass flux
g	applied acceleration
h	heat transfer coefficient
k	thermal conductivity
L	liquid mass flux
u_g	gas velocity
μ	viscosity
ρ	density

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