ABSTRACT

In today’s world, chemical industries have to compete not only with themselves but also with other sectors like software and hardware industries. To meet the market demand, the chemical industry should respond to the changing needs of the chemical process industry. Thus to adapt to today’s business world, the only way to improve performance, lower cost products and obtain smaller and compact plant is process intensification (PI). Process intensification is a revolutionary approach to process and plant design, development and implementation. A range of PI technologies and methodologies are available, the correct application of which can bring a substantial business benefits. In the present paper methodologies of process intensification are presented, taking a business/ process driven route, on the different existing industrial processes, which matches the precise requirement of the process and meets the business needs. The decisive characteristic of this approach is the combination of all main items of equipment in one unit, with lot of advantages compared to the conventional established unit. Case studies of hydrogen peroxide distillation have been taken to explain the methodology and validation of process intensification technology.

Key words: process intensification, methodology, case studies

1. INTRODUCTION

Competition among different industrial sectors is very strong and for chemical industry to survive it, the only way is to produce low cost and high quality products that meet the needs of clients. Chemical industries should prove to the shareholders that the profits, which they obtain from them, are as good as what they obtain from other sectors (software and servicing). Industries needs manufacturing processes which are cheaper to construct and more economic and flexible to operate so as to remain competitive in the global trade. For this an integrated system approach of complex multidisciplinary, non linear, non equilibrium process occurring on different lengths and time scale is required, which can be obtained by molecular modeling, instrumentation and powerful computational tools (CFD etc.). The solution of the problems, like large amount of utilities, large working capital, higher capital investment, long gestation period and high cost of utility, which always surrounds chemical plants, lies in the order of magnitude reduction.

Process intensification is a key strategy that the chemical industry is adopting for increasing energy efficiency and profitability. Process intensification is a revolutionary approach to
process and plant design, development and implementation (BHR Group). Process intensification aims to drastic improvement of performance of a process, by rethinking the process as a whole. Alternative routes may be thought off, which till now have not been employed because of safety and control reasons. Process intensification has come out of the laboratory and is making an impact in the concept and design of process plant for more efficient and cleaner production. Process intensification is simply equivalent to process improvement and is defined by Ramshaw (Ramshaw C 1983) as devising an exceedingly compact plant which reduces both the main plant items and the installation cost. According to Heggs (Heggs 1983), PI is concerned with order of magnitude reduction in both the process plant and equipment. Douglas JM 1988, interpreted Process intensification as the novel equipment, processing techniques and process development methods that compared to the conventional ones, offers a substantial improvements in chemical manufacturing and processing. To sum-up, process intensification is a rapidly developing field inspiring ideas of modeling and new equipment designing and operating modes, which’s potential are still to be explored. Figure 1 and 2 shows the various process intensification equipments and methods employed in chemical industries.

The current worldwide market of the chemicals is estimate to be 1.6 trillion dollars annually. This includes commodity chemicals (56%) and specialty chemicals (44%). Specialty chemicals include pharmaceuticals, agro chemicals, performance chemicals, which includes water treatment chemicals, catalysts, textile auxiliaries etc. Indian contribution to world chemical industry is only 1.75%, which is indeed small. Nevertheless there are sectors in chemical industries such as fine and specialty chemicals including bulk drugs and dyes, where Indian share of world market of 8.5 and 6% respectively, which is 4 – 6 times the average of 1.75% share of the overall world chemical market. The difference in contribution of India to the bulk and specialty is the matter to look for.

The reason of the difference lies in the scale of operation. The specialty chemicals are mostly produced on small/medium scale and the ingenuity and brilliance of the individual/group of individuals is the reason of the success. Large pool of scientifically trained people experiments on small and medium scale, optimize the process, develop new chemistry routes and implement it to benefit the productivity and profitability of these small and medium scale industries. On the contrary in the bulk chemical industries, the source and cost of finance for such mega-structures coupled with the inadequate infrastructure have coupled the problem for chemical industries producing them.

To solve the problem the trial and error procedure cannot be employed in mega scale industries. Even the problem of outdated technologies and poor infrastructures cannot be solved overnight. So the only cheaper alternative is process intensification i.e. getting more from the existing.

Judicious application of process intensification in the operating plants can result into enhancement in the capacities ranging from 20 to 100% with simultaneous improvement in the selectivity’s. (Joshi 2001) Improvement in an operating plant can be realized through various stages of implementation.
In the present paper, the methodology for the application of process intensification into a chemical plant is described. The step by step procedure is adopted to make a remarkable improvement in the existing plant. Case studies of aldehyde oxidation, in detail, and hydrogen peroxide distillation is described. Results show that process intensification is a vital tool to realize an improved plant.

2. METHODOLOGY

Before process intensification be introduced into a process, it is important to know the phase the process is in, on which intensification is required. The phases of a process are defined as

New idea → optimizing process chemistry → pilot plant → plant design → plant start up → debottle necking.

On the first two phases, it is easier and economical to apply process intensification, these being the initial stages (Bakker et al. 2001). Here the intrinsically optimal route and optimal kinetics can be found with ease. However, except for plant startup, on which there is no application of process intensification, on all other the application of process intensification leads to expenditure, which increases as we go along the line and in some case it may become necessary to repeat the earlier steps and the cost and time spent in the previous phases are lost. The step by step implication of process intensification constitutes a number of steps (Figure.1):

The first step is understanding the whole process including its chemistry and unit operations and appreciating how each aspect affects the other. The chemistry should explain the synthesis route and catalyst/solvent choice. The potential of alternative solvents/catalysts are also looked. The knowledge of kinetics of reaction is gathered. Generally fast reactions are desirable. Lab scale experiments are conducted to get the information about chemistry. Process performance in measure of yield, selectivity or other measurable factors is related to product quality. In the next stage, the existing plant is examined to determine the operating capabilities of each unit. Mass and heat transfer capabilities and the reason of the choice of particular equipment are discussed. The process flow diagram is an essential tool. Update and accurate process flow diagrams are must. It is important that the process flow diagram reflect actual plant operating conditions and material and energy balances to ensure a valid basis for the effort.

In the second stage the drivers are considered. The first and most important step in any process improvement effort is to identify the area of the process that really should get attention. Most processes contain numerous shortcomings; therefore, many options exist for the improvement effort. It is crucial, however to focus on the most significant enhancement-the one that will brings the greatest rewards to your business. The drivers are mainly business drivers, which are economic and social considerations relating to profitability and process drivers, which involves optimizing factors such as heat transfer and mass transfer within the system. The proper driver’s selections would improve plant performance and reduce costs.

In the third stage, from the analysis of equipment and chemistry, the rate limiting step is identified. The kinetics of synthesis and the capabilities of plant are compared and the plot of
working condition in the process performance and mixing effectiveness is made to generate conditions for improved plant.

In the next stage, ideas are collected to intensify the process within the boundaries of goal of the study. Well balanced team of engineers, R&D, process technologist and chemical experts undergo a brainstorming session to suggest an optimal operating condition. The database of various process intensification equipments is made and a design of a draft of new process alternatives is made by drawing a flow sheet. The idea behind the choice of database is to fit the requirement of process and drivers. There are certain keywords on which the session is based upon like intensify, segment, use of different aid, change conditions, combine, fix, add or remove, periodic actions etc.

In stage five, based on the results of analysis, most suitable equipment for the task is selected. If a particular approach cannot be decide upon, options were made. The choices available are compared in detailed construction and costing.

In stage six, to justify the choice, the selected equipment/s is/are compared with the conventional and concern is mainly made of performance and economics. This also includes safety and environmental factors. Finally with open mind process intensification is introduced in the plant.

3. CASE STUDY-

Hydrogen peroxide distillation:

Distillation is the most widely used separation technology in the chemical and petrochemical industry. The successful design of the distillation system requires high safety and reliability as well as extreme flexibility in operation. Case study of hydrogen peroxide distillation is taken with the aim to provide a compact plant with very little pressure drop and small product holdup (Meili 1997).

Overview whole process:

Chemistry:

\[
\text{OH} + \text{O}_2 \xrightarrow{\text{Catalyst}} \text{H}_2\text{O}_2 + \text{OH}
\]

Crude hydrogen peroxide with a concentration of 25 to 40 % wt H$_2$O$_2$ is essentially produced.

Equipment:

Conventional distillation plant consists of steam heated evaporator(1), separator(2), tray column(3), water cooled shell and tube heat exchanger(4), vacuum pump(5) and the necessary piping (Figure.2).

Drivers
The business drivers for the process are i) Lowest possible operating temperature ii) Improved safety and iii) Minimal product hold up. Process drivers are listed below

- Hydrogen peroxide tends to decompose.
- Under certain operating conditions there is a risk of explosive mixtures being formed
- Concentrated hydrogen peroxide can cause spontaneous combustion if it comes into contact with flammable materials

**Identify Rate Limiting Steps**

Impurities in the crude feed, considerable pressure drop in each equipment, elevation of the temperature in the bottom of reboiler and high product holdup are the steps that limit the process.

**Generate Design Concepts:**

A brain storming session was conducted to identify the causes of limitation. All the possible root causes of limitation are listed and based on that the following are the conclusions made by the team:

- Pressure drop should be minimal
- Yield should be high
- Total product hold up should be low
- Packing that has minimal hold up and that provides high turn down ratio with excellent separation and energy efficiency should be chosen.

**Analyze the Design Concepts**

By deeply analyzing the limitation sources, a design was made (Figure 3). The decisive characteristics of this design is the combination of all main items of equipment in one unit with very little pressure drop and small product holdup. The design constitute a climbing film evaporator(1) with low liquid hold-up is directly mounted to the bottom of the column which contains the lamella type separator(2) with extremely low pressure drop. The column (3) is equipped with structured packing which are known for minimal hold up and negligible pressure drop. A direct condenser (4) which allows a temperature difference of only 2-3 °C between all these main items. The vacuum pump (5) is connected to the condenser. To increase the safety, a flooding tank (6) is mounted on top of the unit.

**Comparison with conventional process and making final decision**

Safety in operation is drastically improved by using the intensified process with low operating temperature, minimal product holdup in the system, reliable safety devices and proper selection and treatment of the materials of construction. Further there is little impact on environment as there are practically no losses.

A structure packing employed provides high turn down ratio with excellent separation and energy efficiency. It provides higher capacity and smaller column diameter than conventional trays. (Table 1)

Thus the improved plant is compact, safer and energy efficient than the conventional and can be introduced.
The previous case study shows how process intensification can reduce the risk of chemical processing, increases yield; lower the energy demand and waste production. The main contributions to the growth of process intensification were the business, legislative and environment aspects which are influencing the chemical plant in terms of energy, space, emissions, cost, waste and recyclability.

4. CONCLUSION

The world economy is growing and globalizing. To sustain a position in the market, one needs to provide the product at low cost and acceptable quality and sufficient quantity eg. in the case of pharmaceutical industries, producers can supply its product from any part of the world since transportation cost is only a small part of the production cost. So process intensification is the need of the hour in the large scale chemical industries, fine chemicals and pharmaceutical industries, focusing on the material, energy, labor, efficiency and number of steps etc.

Process intensification can be considered as a design philosophy aimed to match the business and process drivers. It involves one or more of the three imperatives- make it small (micro reactors, compact heat exchangers etc.), combine (reactive separation, reactive distillation etc.) or intensify the driving force (centrifugal force, microwave, electric fields etc.). The present paper presented a methodology for improving existing process that focuses on gaining a fundamental understanding of the current process. The case study is an example of how process intensification could be applied to an industrial process, showing the benefits in using novel equipment, process technology etc. The process intensification is introduced step by step on the main cost contributors of the process and results in lowering the overall cost of the process. When practiced correctly, the approach has the potential to identify previously unrecognized process limitations and flaws. The resulting solution often is obvious and simple-clearly the best solution given today’s limited capital availability.

REFERENCES
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Table 1. Comparison of structures column packing with the conventional trays in the hydrogen peroxide distillation of 40000 t/yr capacity, and feed and product of 37% wt and 70% wt respectively.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Conventional Trays</th>
<th>Mallepak</th>
<th>Optiflow</th>
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<tr>
<td>Column Dia., m</td>
<td>3.5</td>
<td>2.5</td>
<td>2.0</td>
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<tr>
<td>Column Ht., m</td>
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<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Specific capacity, %</td>
<td>100</td>
<td>200</td>
<td>300</td>
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Figure 1. Steps in process intensification methodology
Figure 2. Conventional distillation plant for hydrogen peroxide

Figure 3. Intensified plant for distillation of hydrogen peroxide