Overcoming barriers to the application of process synthesis techniques in industry

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Introduction

Process synthesis is a systematic approach to designing chemical processes, as compared with the traditional evolutionary intuition and experienced based approach to process development. A large number of techniques feature under this umbrella, some wide-ranging in scope while others are narrow in their scope. Of these techniques, pinch technology for the design of heat exchanger networks has been most widely applied in industry.

Linnhoff & Turner (1981) illustrated that the conventional belief of a trade-off between capital cost and heat recovery does not always hold: “In most cases, design changes have been found that are less expensive in both energy and capital.” The impact of this effect can be increased significantly if timing of the process synthesis reviews and projects is well synchronized with the evolution of the site configuration.

Process synthesis began to emerge in the early 1970’s and by the early 1980’s these techniques seemed to be making great headway, offering the promise of a reduction in environmental impact and energy consumption together with a significant reduction in capital costs. “Pinch analysis has evolved during the last decade from a specialized tool for heat recovery into a broad based methodology for reducing capital costs, emissions, and energy consumption, spanning process design and total site planning” (Linnhoff, 1994). Over the past three decades there has been a substantial body of published work and significant progress has been made in process synthesis methodology, expanded application thereof and development of tools to ease application. One example of the extent of progress in this field is the Jacaranda system from University College of London. “Jacaranda is a system for process synthesis, or automated process design, intended for conceptual or early stage design. It aims to provide the support necessary for creative and exploratory design, helping the engineer identify the important issues and constraints for a given design problem.” (Fraga, 2003).

Despite these developments, the use of these techniques in industry has been less widespread than might have been expected. There has been steady progress in improving processes due to evolutionary design improvements, but few step changes due to the use of process synthesis techniques. Johns (2001) concludes that over the next ten years use of process synthesis techniques will substantially increase due to pressures for improved processes and improved process synthesis algorithms.

However, in our view, the use of process synthesis techniques is mainly limited by human and organizational factors that present significant barriers to their widespread and effective use. In reviewing some of these factors, we draw conclusions that may seem to be quite elementary, but few companies have addressed these issues effectively. Modern process designs tend to be more cost-effective than older designs and most of the latest tools for process design are well used, but many opportunities to improve efficiency and reduce capital cost are still overlooked. Effective use of process synthesis techniques in a systematic way supported by appropriate organizational, management and work processes would significantly improve the process design of many units.

Historical problems with Process Synthesis

In the early 1980's some proponents of process synthesis techniques gave the impression that they were easy to apply and would give rise to an optimal design without the need for the input of skilled and experienced engineers. Perhaps this lies in the future, but with the current state of the art, the opposite is true. Almost all of the techniques take great skill to apply effectively, and require experience and insight to develop a design that is safe, environmentally responsible, operable, and has low capital and operating cost. Many attempts to use these techniques by engineers with inadequate experience and training have resulted in failure. A common example of this is for an inexperienced engineer to set up a pinch study in a way that constrains the solution to the existing design, leaving the impression that the technique is of interest in academia, but of no value to the practicing engineer.

Rapid changes in site configuration and use of outdated information can cause the outcomes of retrofit process synthesis study projects to be useless soon after completion, and this contributes to the notion that these studies end up gathering dust on engineers' shelves rather than being implemented. It is effective to set up a work process to keep an ongoing and up to date understanding of the site using process synthesis tools and trigger a review when significant site changes occur.

Control problems have in some instances been associated with processes designed using narrowly focused process synthesis techniques. Consideration of process dynamics and use of appropriate techniques will ensure that the design will be controllable and operable, and may reduce the cost of instrumentation and control systems by improving the inherent control response of the process and inherent safety.

Formulation of process design problems

Formulation of the design objectives, scope, constraints, improvement requirements and related attributes of the design naturally creates the playfield and boundaries for the design process and therefore strongly influences the design. A general problem with grass roots plants as well as retrofit improvement and expansion projects is that the project is constrained (sometimes unknowingly) through people's comfort zones and the known operating space.

The opportunity to improve the system is then lost due to over constraining the opportunity space. A notion of "anything goes to improve the system provided nothing changes" is often found, and obviously leaves no room to improve. While this seems obvious, it is not that obvious when it happens in practice since no one talks about limiting changes. After all, keeping requirements and boundary conditions to the known area appears to minimize risk and protect process integrity. One knows that this problem is present when all significant proposed changes are labeled as impractical etc. based on experience and no clear basis for this is forthcoming. Systems are typically complex and relationships of constraints, degrees of freedom and other variables are not always clear – especially if several plant units are involved. This creates both the opportunity to find improvements in many process design projects and equally the opportunity to oppose change.

A classic example of this problem was experienced during a process synthesis project effort with the objective of increasing plant capacity by 30-40% with little energy consumption increase. Initial indications from the analysis indicated that the objective was reasonably achievable, but that it would require some significant changes in operating philosophy as well as challenging plant boundary specifications. The participants were very excited with the potential of the project, but failed to cross the comfort gap to allow the flexibility in the system to accommodate the changes. The result was that in each iteration of the project, constraints were further tightened to the known inter-plant boundary conditions with the eventual result that the options were tightly tied to the current operation. All improvement opportunity was lost and the current practice became the only allowable solution.

To overcome this problem, it is important that the typical initial spirit of challenging the status quo and current practices be realistically grounded at the beginning of a conceptual design effort, and maintained in the team and stakeholders in a consistent manner throughout the effort. The effort must be managed in a manner that ensures that the comfort based constraints of team members are handled appropriately, being brought out into open discussion and resolved, and that the objectives and constraints of the project are used as the real basis for decision making. The concerns of experienced team members provides valuable input for the design effort, saving time and money by avoiding known pitfalls, but must not be allowed to prevent exploring unknown areas..

To overcome these problems, it is important to include people well versed and experienced in using the selected process synthesis techniques in the team, and it is important to ensure basic understanding of the approach and objectives by everyone on the team. The team must be managed in a way that encourages team members to challenge the design objectives, scope, requirements and approach early on and to limit constraints to those that are really valid..

Industrial practices for conceptual process design

The design work process for conceptual design of chemical companies varies to some extent, but most companies follow the same basic approach. A team of process engineers, perhaps with a few members from other disciplines, is assembled and given the task of conceptual design and then basic engineering starting with the flowsheet of the previous or existing plant. The team usually includes process engineers who are experienced in the process technology. These individuals typically were members of the project team for the previous project using the same process, and participated in the studies and decisions that resulted in the final process design, in commissioning and problem solving on the plant. Their experience leaves them with an emotional attachment to the current design.

A second influential role on many teams is that of the plant production engineer, brought in to ensure that the perspective of the people who are going to run the plant is brought in from the beginning. The typical inherent bias of these production engineers is to design a plant like the previous one, but with a list of problems fixed, (better pump, stainless steel heat exchanger, etc.) and with improvements based on practical experience and personal insight. The remainder of the team is usually less influential than these key roles, and young engineers quickly learn to align their values to agree with those of the technology and production engineers.

The work process for conceptual process design may be formalized, with a clear set of procedures, or more informal, relying on the experience of the team members and managers to know the steps that must be completed to produce an acceptable design. There are typically a large number of steps to go through, including a number of safety and environmental reviews. Sometimes, pinch analysis (or another process synthesis technique) is tacked on as a mandatory step. In most cases the analysis is undertaken by an "expert" from outside the core project team and many times too late in the process when changes to the design become costly. Many experienced process technology engineers believe that they can determine the best heat exchanger network by inspection, coupled with their expertise in the particular process technology. Subconsciously their bias is to look for ways to discredit improvements suggested by the external "expert". Improvements in heat integration or other changes that don't affect the core process too much are sometimes welcomed by the team, but substantial changes to the process are too often rejected out of hand. Pinch analysis performed by the core team may be much more effective, provided that the team members have the skills and experience required.

Focus: site, process and equipment

On the typical project, at the start of conceptual design, the team jumps right into reviewing the design of the previous project and making changes, including changes appropriate for the site. The focus quickly becomes scale up of equipment and resolving equipment problems. Opportunities to take advantage of less obvious site-specific opportunities or to resolve site problems are missed in this way.

A team using a systematic process synthesis approach will look at the overall site early in the process. This clearly does not need to be repeated for each project on a site if an overall site strategy is maintained. An understanding of the overall site heat flow in the major processes in normal and upset operation can bring significant advantage. For example with this knowledge it may be obvious that addition of a new local intermediate pressure steam header would allow beneficial transfer of heat from one process to another. Similarly, an understanding of the site water flows may uncover significant opportunities.

The next level, and the main focus using a process synthesis approach is the process. A significant part of the benefits of using process synthesis techniques is due to the inherent shift in focus from equipment to overall process. Attention to how the process works in normal operation as well as startup, shutdown, etc. can lead to improved operability as well as insights leading to reduction in capital and operating cost.

Plant evolution – the lost opportunity

Plant evolution is a continuous process that happens in all but the most stagnant plants. As plants are modified for various reasons (maintenance, capacity improvement, product slate or specification changes, diversification, safety improvement or failure repairs), the modification process invariably presents some opportunities for improvement. For example, justifying a project to save energy is much easier when you have to replace a furnace for maintenance or environmental reasons, compared to having to replace it only for the sake of improved energy efficiency. Opportunities are missed because the people closely involved either do not realize that the potential for improvement exists (equipment focus rather than process and site focus), or preparation has not been done and there is no time to take advantage of the opportunities that present themselves.

On a complex site, activities that are not well coordinated can easily result in “conflicting” projects, and invalid constraints being imposed on systems resulting in the opportunities being locked out and thus lost. Controlling the process of continuous improvement on a site is an ongoing and difficult challenge, and failure to address the issue inevitably leads to substantial lost potential. Conversely, substantial value can be generated by developing and maintaining a site energy strategy using process synthesis tools and an appropriate work process.

Managing Process Risk

There is always some process risk in building a new chemical facility or revamping an existing unit. In principle, as one deviates from a previous design, the risk increases. The consequence may be lost production when the plant starts up, additional capital to resolve problems, operability problems and in there is the possibility that an unsafe design may be implemented. Some changes are almost always introduced, and failure to think these through may well cause problems on a plant even with minimal changes. In designing a plant for reduced capital and operating cost, it is essential that process risk be properly taken into account and managed.

A well thought out process synthesis approach will include a structured approach to process risk. In many cases where a unit is being scaled up, significant changes to the process in some areas do not significantly increase the process risk. For example in many cases there is sufficient knowledge to change the distillation sequence and distillation column pressures with little risk. When departing from an existing design it may be prudent to look for a low cost risk mitigation strategy by providing the flexibility to operate either in the desired efficient configuration, or to operate in an alternative configuration that is less efficient, but similar to the existing design.

A team that takes a well reasoned proactive approach to management of process risk is more likely to gain acceptance for an innovative cost-effective process design. Early involvement of the business manager in this process is very helpful in striving to reach a balanced process design efficiently, to help the team to make the many design decisions with a realistic understanding of the risk profile acceptable to the ultimate decision makers. If a decision is made by business managers to accept a degree of process risk, and the decision is passed to a conceptual design team through a formal process, this decision tends to be disregarded in many companies. In these companies, engineers have learned that taking well considered risks is praised in generalities, but punished in specifics. When a business manager participates in thinking through risk issues rationally, the culture of an overly conservative team can change very quickly.

The Process Design Professional and The Team

As discussed previously, a balanced project team will include process design professionals who have experience in a number of different process technologies and a range of process design techniques, and are also likely to have experience working on plants so that they have a sense as to what can be made to work in practice. They are unlikely to be knowledgeable in the full range of available process synthesis techniques, but must have a mind-set and experience that allows them to work effectively with experts in the techniques chosen for the project. Process synthesis techniques used will not be merely added to the normal conceptual design work process, but will be at the core of the way the design is approached.

Success requires more than powerful techniques and design professionals with the appropriate knowledge and experience. . A team that works effectively together to achieve a common goal is a key requirement. The team must be focused and motivated and must have guiding work processes in place. Engineers are often more comfortable dealing with technology issues, and fail to adequately address underlying human issues, although most of us recognize that success in creating innovative process designs is as much dependant on addressing the human issues as technology issues. By contrast NASA for example, has achieved success on many missions requiring tremendous technological innovation only by focusing on human issues as well as technology issues. Sloppy, incompetent or half-hearted use of techniques to address human issues in a team environment leads to failure just as surely as sloppy, incompetent or half-hearted use of process synthesis techniques. It is worth noting that in most cases of failure, it is not the technology that fails but the human systems that are supposed to harness it. It is these other soft dimensions that we need to become serious about if we want to see these fabulous technological advances turning into the great impacts they potentially can be.

A good basis for helping teams to operate effectively in a commitment paradigm (as opposed to a control paradigm) can be found in the large body of work on high-performance work systems, and also in the work tailored for the organization by Fisher (1996) and others. Kumar (2000) analyzed the application of high performance work systems and concluded that “the lack of a supportive and committed organizational environment continues to be the most important barrier to a wider diffusion of high-performance practices.” In our opinion, this organizational barrier is also one of the more important barriers in the successful application of process synthesis techniques. The survey that formed the basis for that work (done for Canada but also indicative of trends in the USA) also “found a very low incidence of high performance work practices overall”. This illustrates that the personnel, team, environment and organizational dimensions of an integrated approach tends to lag far behind the technological dimension.

A good systems approach to organizing teams as well as systems and processes is the Viable Systems Methodology (Topp, 1997). The Explorer Methodology (Kritzinger, 1997) is suggested as a framework that can be used to achieve this “total system” approach. Companies that actively develop well rounded process design professionals, as well as specific technology engineers and production engineers, and assemble them in high performance work teams are in a good position to design plants with significantly improved performance.

The Effective Project Sponsor

The relationship of the process design team with business management is interesting. Business managers have the incentive to support improved design practices leading to lower capital and operating costs. High level business executives are usually deeply involved in the management of the sales and production aspects of their businesses, but take a hands-off approach to process design. Decisions taken in the early stages of a project have much greater impact on financial performance than those taken later on. None the less, business executives usually limit themselves to the commercial aspects of projects in conceptual design, and abdicate their responsibility for management of the conceptual process design effort. Although this seems to be irrational, there are psychological forces that make this a stable arrangement. The business executive doesn't have to move outside his or her comfort zone. Production engineers are able to get a plant similar to the one that they have experience of. Engineering management and the project team don't have to deal with interference from business management, and get to make the key decisions with a large impact on the future performance of the business, and their experience is held as being the key to a successful project.

In the experience of the authors, projects that have been successful in achieving a substantial improvement in capital and operating cost over the previous generation, have two key characteristics in the conceptual design stage: a powerful project sponsor in the business organization and a conceptual design team that includes influential team members who are process design professionals, knowledgeable in process design techniques and in many different processes.

The role of the business sponsor is to clearly articulate the business perspective to the design team and ensure that they are selected and managed to achieve business goals. This does not mean excessive interference, but rather indirect management of the group to create team membership and motivation that support the business. The project sponsor will ensure that several significant members of the conceptual design team are chosen based on their ability to produce a process design significantly better than the previous generation, and will ensure that team members perceive that their career aspirations are likely to be supported by working to achieve innovative designs in which capital cost, operating cost and process risk are well managed to achieve business goals. In a well balanced team, access to the business sponsor gives innovative team members sufficient influence to counterbalance the bias of technology and production engineers wanting to keep the design unchanged. The result is a team that has some internal conflict, but is well able to balance risk and reward.

Expenditure of a moderate amount of time and effort by a business executive in acting as sponsor of projects in the conceptual design phase, can in the long term make a real difference to the return on investment achieved by a business, and is an effective use of the executive's time. Several companies have appointed project sponsors at the start of conceptual design work, recognizing the importance of this role. A sponsor must be the executive responsible for the business, and their seniority needs to be appropriate to the size of the project. A sponsor with insufficient organizational influence will clearly fail to achieve the desired effect. If an executive sets up a conceptual design team with a goal to design a plant that is significantly more cost-effective than the current technology, he or she must be willing and able to protect innovative engineers against the inherent bias of most engineering organizations to conservative, tried-and-trusted designs and work processes

Conclusion

Process synthesis techniques have been widely available in the chemical industry for more than three decades. Powerful tools have been developed to help engineers design improved processes effectively, and there is a large body of published work in this area. However, these tools and techniques have not been widely and effectively used in industry despite their potential to substantially reduce capital and operating costs.

Human and organizational factors make it very difficult for a specialist group within a chemical company to effectively use process synthesis techniques to make a step change in plant costs. In many organizations such specialist groups achieved initial success, but have failed to achieve the widespread success initially expected. The barriers to success are largely human and organizational.

The recommended first step towards effective use of process synthesis tools and techniques is to sell the concept to business managers. They are the real customers who need better process designs from an environmental and cost perspective. When a business executive understands the potential for design of improved processes, he or she can play a key role in managing resources to achieve a successful outcome, and is then in a position to act effectively as a project sponsor. The executive will also play a key role in creating a conducive organizational climate and culture, will manage the process of setting and communicating business goals and constraints, and will ensure that the team is led to value productive innovation.

The effective conceptual design team will include process design professionals with the knowledge and experience to produce innovative process designs. The team will use the knowledge and experience of technology and production engineers without being bound by the bias against change usually implicit in these roles. The ability of the participants to manage process risk effectively is also an important factor in achieving success.

The work process used by the team will be substantially different from that commonly used in industry today, being designed around the systematic development of the process design using process synthesis techniques. The approach will be firstly to focus on the site, so that the process can be designed to take advantage of the unique characteristics of each site, then on the process, and finally on equipment. Process dynamics and process safety will be fully considered in design of the process to ensure a safe and operable process, and to reduce the cost of process control and safety equipment.

To significantly enhance the probability for success in the execution of process synthesis projects, we encourage the adoption of a holistic, multi-dimensional, total systems approach that integrates the technology, tools, process constraints, risk management, organizational structure and culture, work processes, management style, communications, personnel development and team dynamics into a coherent focus on the mission goals.

Key words:

Process synthesis, industry, barrier, management, organization, design, process improvement

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