Understanding Process and Design Interactions

The key to efficiency improvements and low cost revamps in ethylene plants

Ethylene plants are now considered to be a mature technology. However, energy reduction and capacity revamp studies can show opportunities for significant cost effective energy and capacity improvements.

The integrated design of the process and its utility systems results in significant interactions. Often small design or operating changes can result in either large capital savings and energy improvements or conversely incur energy and capacity penalties. To understand these interactions a detailed process model can provide the basis for process integration analysis (such as pinch analysis, column targeting and exergy analysis) and also for equipment rating. This analysis provides a fundamental understanding of design opportunities and enables assessment of the potential for trade-offs of capital cost, energy and capacity. This approach allows more rapid development and definition of the most cost effective revamp (design and operational) changes.This paper [1] demonstrates the economic benefits of such an approach by presenting the results from a real case study.

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introduction

Applications of process integration techniques (pinch analysis and column targeting) together with process simulation, detailed equipment rating and plant operation knowledge have resulted in significant investment cost savings in the revamp of ethylene plants[2].

The investment cost reduction has also been accompanied by a reduction in specific energy consumption. As a result, revamp economics have been more attractive than previously thought. This has in turn improved the likelihood of the project being approved and avoided delay or shelving due to poor economics.

This integrated revamp approach has been applied to old plants as well as to new state of the art designs, at the feasibility stage of revamp projects. The results have been equally impressive and have helped confidently define the scope of the revamp (capacity, investment cost and design changes). As a result, the outcome of the feasibility study has been the basis for the decision making process.

One key to the success of the integrated approach is the identification of non-traditional revamp alternatives (operating and process design changes) that make it possible to shift plant bottlenecks from expensive to cheaper equipment items to minimize the overall new capital investment. This involves understanding heat exchanger network interactions that in the case of ethylene plants are highly complex.

revamping ethylene plants

Traditionally, revamp feasibility studies are generally performed for single point solutions and may be based on design data to determine equipment capacity and hence to define equipment bottlenecks. Each bottlenecked equipment item is tackled one-by-one. The bottlenecked equipment is modified, additional equipment added in parallel or the items replaced by larger equipment. Generally, little attempt is made to include process design changes, with the exception of 'leap' revamps where new process technology[5] may be implemented as part of the revamp package. In either case process integration inefficiencies are usually not known or understood and are therefore accepted and carried forward (scaled up!). Heat integration inefficiencies result in higher utility usage and therefore potential investment in larger utility equipment items including refrigerant compressors and their associated turbines and condensers.

Current plant operating data is not often used to define actual equipment performance and to quantify major plant bottlenecks. This approach may not reflect the true equipment capacity limit and can also result in higher investment costs due to equipment over sizing and design conservatism.

The integrated approach, as presented below, has been developed to capture these missed opportunities for investment and operating cost reduction. It employs the use of various complementary techniques including pinch and process synthesis technologies to gain a better understanding of the unit-wide interactions and to use this understanding to develop alternative debottlenecking approaches.

understanding equipment interactions and revamp trade-offs

A major challenge driving the selection of a minimum capital cost process revamp scheme is the identification of design and operating changes that will help shift plant bottlenecks from expensive to cheaper equipment items to minimize overall investment.

Ethylene plant designs are highly integrated, particularly in the cold end separation section of the plant, where process streams, distillation columns and refrigeration systems are heat integrated. Design features can include for example, distillation column side exchangers and reboilers, recuperating or sub-cooling refrigerant. There may also be process-to-process heat recovery to reduce refrigeration usage and the provision of adiabatic or mechanical expansion to generate low temperatures for product recovery.

This level of integration results in complex interactions within the process, between the process and the utility system, and with the refrigeration systems. Column operating pressure affects separation performance, column hydraulics, compressor performance and condenser / reboiler required heat transfer area. The choice of refrigerant level for sub-cooling and recuperation affects compressor performance, capacity and required heat exchanger size. Compressor suction pressure affects compressor capacity and the pressure profile over the stages and influences required heat transfer area. These are a few examples of such interactions and highlight some of the degrees of freedom available to the designer. As a result, the complexity and number of possible combinations at first sight may appear overwhelming and the task of finding improvements within the limited time available by means of inspection or trial and error daunting and time consuming.

Pinch and column analysis make it easier to understand the design interactions within the process and between the process and the utility systems. These techniques are already well established in the literature for heat exchanger networks, distillation columns and utility systems. In the many publications [3,4,6,7,8] describing the techniques and applications, two main features emerge. Firstly, targeting enables the designer to screen promising projects from marginal ones. Secondly, the techniques have consistently identified schemes not only for improved energy performance but also, and simultaneously, for reduced capital costs.

Pinch and column analysis have some interesting features. An important one is the ability to exploit the fact that the process and the utility systems interact. By capitalizing on these interactions it is possible to more effectively use existing or new equipment. A good example of this is distillation column feed conditioning. Column analysis may find that thermal conditioning of a column feed is beneficial. Feed preheat helps recover refrigeration at a colder level than the reboiler, or conversely, feed cooling helps shift colder utility use from the condenser to a warmer level in the feed chiller. In both cases the addition of a new feed exchanger helps free capacity in the refrigeration compressor, may beneficially reduce the vapor and / or liquid traffic within the column and may unload the condenser and / or reboiler.

Correctly applied pinch projects will reduce sub-ambient utility requirements. This will unload some or all of the stages of the refrigeration compressors. It is normally desirable if possible, to evenly unload each of the stages of the refrigerant compressors. This involves assessing the revised load on the compressors for each pinch project and selecting an optimum combination of projects that will free up most refrigeration and process equipment capacity.

an integrated approach to revamping ethylene plants

The integrated approach includes the following steps:

- collecting a comprehensive and consistent set of actual plant operating data
- developing a detailed, rigorous and predictive simulation model tuned to match actual operating data
- rating of major equipment items based on actual operating data supported by design data where necessary
- defining and quantifying all plant equipment bottlenecks and the excess capacity in major equipment items
- performing pinch and column analysis
- identifying and developing alternative, non-traditional revamp projects for each plant bottleneck
- cost estimation of revamp options for each bottlenecked equipment item
- trade-off between all different revamp alternatives
- final review and selection of projects
- developing a process engineering package for the revamp changes

The integrated approach starts by defining the excess capacity in each major equipment item based on design and operational data. An important aspect of this is the identification of actual, not design, equipment performance. This requires some effort to set up the base case process simulation model against which all improvements are subsequently measured.

The application of distillation column thermal and hydraulic analysis enables identification of potential column modifications to feed arrangements, optimum heat supply and removal, and optimum duty and location of side exchangers. Verification of the scope for these changes has to be coupled to an understanding of the process heat integration developed through the application of pinch analysis.

The application of pinch analysis allows the setting of utility heating and cooling targets. It also allows identification of design inefficiencies that cause actual utility usage to be larger than target. Pinch analysis, coupled with potential thermal changes to distillation columns, therefore provides unique insights into how to implement plant (design and operational) modifications to save energy and to increase capacity. Most of the savings reduce sub-ambient utility requirements. This causes the refrigeration compressors to become unloaded, allowing further capacity increase that would not otherwise be possible without machinery revamps. This reduces expensive investment in the compressors if they are the current or near capacity bottlenecks.

With these insights at hand, revamp alternatives for every bottlenecked major equipment item can be defined, developed, and cost estimated. Some equipment items may have revamp options, as there are often several debottlenecking alternatives on the path to get higher capacities e.g. for a column - operational changes, re-tray, feed change, pre-stripper and then parallel tower. This involves assessment of all options and the selection of a set of revamp projects for lowest investment cost.

Workflow for the integrated approach is summarized in Figure 1 below:

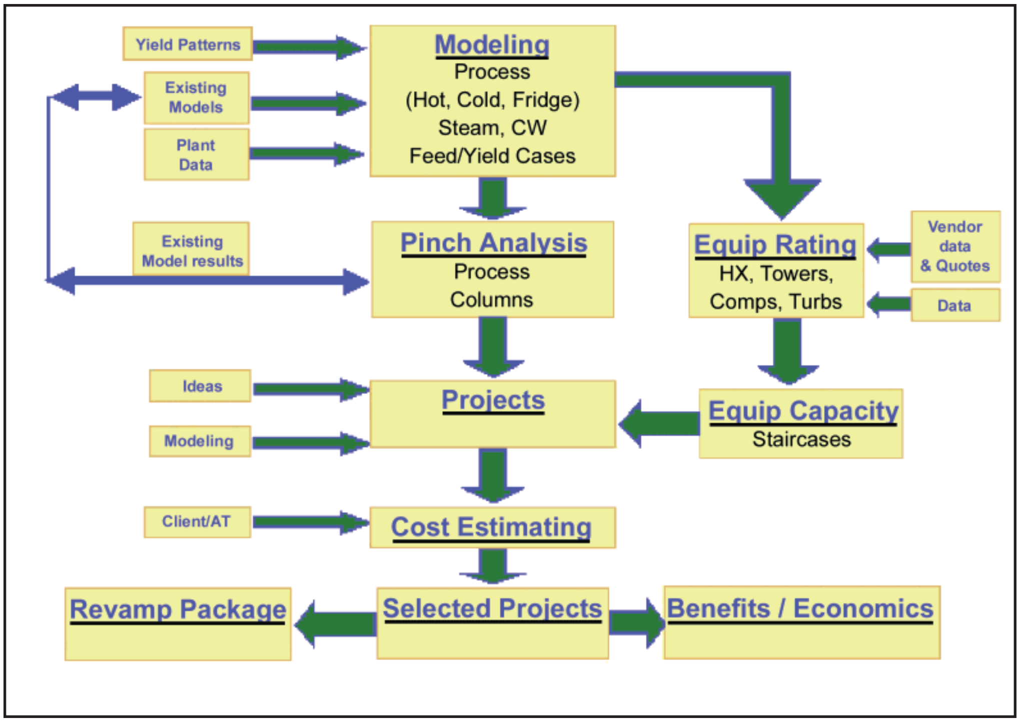

Figure 1. Overview of work flow steps for defining low cost revamp projects

The integrated approach can be easily extended to produce incremental cost capacity curves. This involves assessment of all options at each percentage capacity increase and selection of a set of revamp projects for each point. An illustrative example of a cost capacity curve is shown in Figure 2 below.

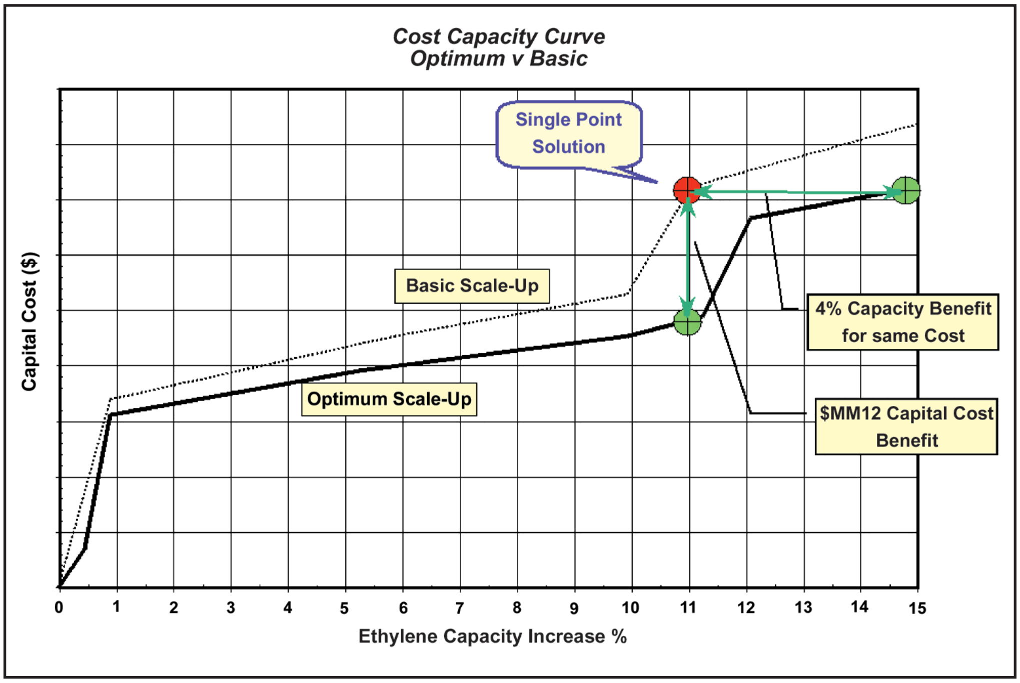

Figure 2. Example of a cost-capacity curve

Basic scale up does not include pinch or process improvement options, optimum scale up does. The make-up of the selected project set for the revamp solution, changes with the magnitude of the capacity increment. This approach provides a complete understanding of all revamp and process performance improvement options for all capacity increments up to the target production rate.

The cost-capacity curve can also be plotted to show the specific revamp investment vs. capacity as shown in Figure 3 below. With this curve it is possible to identify the most economical (cents/lb) revamp capacity.

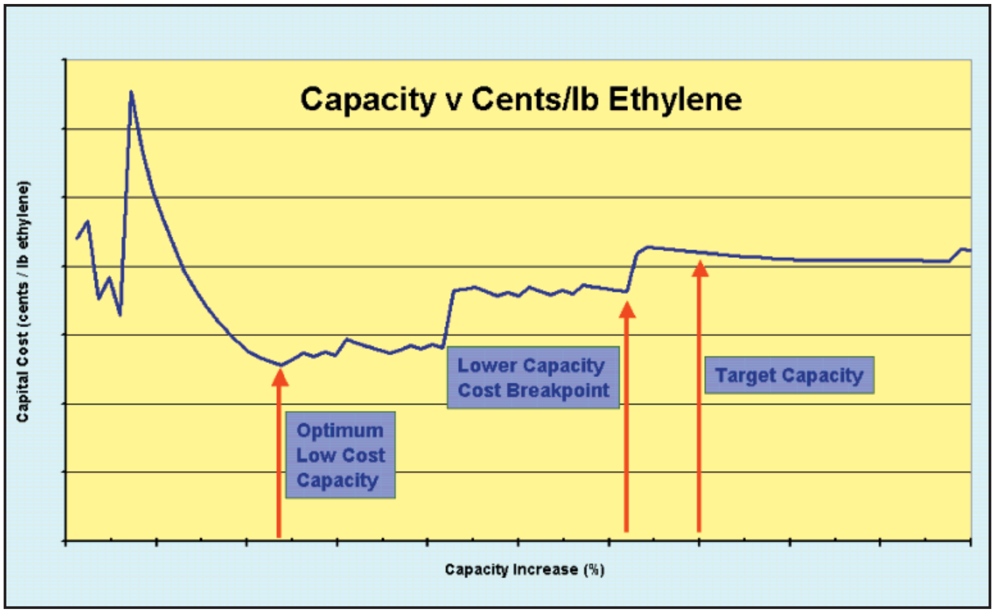

Figure 3. Example of a capacity vs. specific investment cost curve

a recent application

The integrated approach has been applied to more than 30 ethylene revamp projects. A recent application has been to the Yeochun Naphtha Cracking Center (YNNC) No. 2 ethylene unit[2].

YNCC had previously developed a revamp package for the No. 2 plant. That package required a 10 cents/lb investment cost. This option was shelved due to the 1997 Korean economic crisis.

In April 2001, YNCC decided to apply the integrated revamp approach to develop a (two-stage) revamp plan for the No. 2 plant. The Stage-1 objective was to identify the optimum low cost revamp without any modification of the main compressors and steam turbines. The Stage-2 objective was to identify the optimum revamp with low cost modifications to the main compressors and steam turbines.

YNCC implemented the Stage-1 revamp after their summer 2002 plant turnaround.

At the start of the project initial equipment rating showed that the propylene refrigeration compressor was a key bottleneck at the base case capacity, and that a new compressor was needed to achieve higher production rates. There was, however, not enough lead time to order a new machine to meet the 2002 deadline. Application of the integrated approach identified a revamp strategy that avoided changes to this critical machine, and made it possible to meet the 2002 turnaround deadline.

The economic benefits from the application of the integrated approach are:

For the Stage-1 revamp (confirmed following plant startup):

- a 10% capacity increment at a substantially lower capital cost of 5 cents/lb
- a 2.2% improvement in specific energy consumption
- avoidance of propylene compressor replacement through implementation of heat recovery improvement modifications
- pre-investment in alignment with the Stage-2 revamp package
- an extremely attractive revamp proposition resulted, making it possible to meet the 2002 turnaround deadline

For the Stage-2 revamp the benefits are:

- an additional 10% ethylene capacity, which results in a total incremental capacity increase of 20% at an average capital investment cost of 7.1 cents/lb
- a reduction in ethylene loss to tail gas
- improvement to the energy performance of the plant through implementation of heat recovery improvement modifications
- a very attractive revamp proposition that can be implemented as an extension to Stage-1 during a later plant turnaround

conclusions

Heat integration inefficiencies in the design of industrial processes result in higher utility usage and larger utility equipment items. Traditional feasibility studies performed to define the scope of ethylene plant revamps generally do not include design and operating changes that reduce or eliminate those inefficiencies. As a result, revamp costs may be higher than those identified by the application of the integrated approach as described in this paper.

Applications of the integrated approach to the revamp of ethylene plants has been instrumental in:

- defining the optimum capacity, scope, investment cost and design changes
- reducing investment cost ($/lb) and energy use (BTU/lb) relative to a more conventional revamp approach
- improving the likelihood of revamp approval and capital sanction by minimizing the risks and improving the financial justification

The approach is based on a rigorous process simulation tuned to actual plant data, detailed equipment rating, process pinch and column analysis. The selected set of revamp projects (including pinch projects) are all assessed using the simulation model and cost estimated. Therefore, the results from the feasibility study are sound and are based on engineering and economic evidence. This provides confidence in the scope of the revamp as defined by the integrated approach.

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