DEBOTTLENECKING OPTIONS AND OPTIMIZATION

by

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Introduction

World Petroleum demand has steadily increased since its most recent nadir in 1983 (Figure 1). Economic growth since that low point has resulted in analogous, increasing Petroleum consumption. Opportunities generated by expanding demand challenge operating personnel, design engineers, and management.

Increasing production from facilities to accommodate product needs can be accomplished by building new units or by debottlenecking existing capacity. Even when new plant construction is the ultimate answer, debottlenecking of existing facilities is usually examined as an option, or implemented in some fashion to supplement new facilities. Often an existing plant can be modified more quickly than a grass roots unit can be started up. In the time required to fund, permit, design, build, and startup a new plant, the undulations of Figure 1 may render the project unprofitable. Existing facility debottlenecking is an attractive method for increasing production with a minimum of risk.

Debottlenecking

Incremental facility debottlenecking often begins even before a new unit's initial startup is completed and usually continues throughout its lifetime. Debottlenecking typically begins with the desire to achieve plant performance that a unit is deemed incapable of in its current configuration. Throughput increases, yield alterations, and specification modifications are typical debottlenecking goals. Debottlenecking may take the form of reliability improvements intended to up the plant's stream factor. A plant may be capable of meeting its production targets if only it can stay on line.

Debottlenecking objectives often are not firmly established initially because the ultimate plant capability and the cost to achieve it are unknown. It may be desirable to increase production of a product, but under study by-product production or utility limitations appear which restrict output. The question, "Well, in that case, how much *can* we get?" is a common refrain.

Once a general goal is set, a thorough review of the plant, its equipment, and its limits is undertaken. In forming the project foundation, this review is critical to maximizing profitability through informed decisions. Upstream and downstream equipment and facilities, transportation systems, utilities, environmental constraints, manpower impacts, etc. must all be considered in addition to the unit's operating equipment. Generating appropriate options and optimizing their implementation requires a big-picture overview. A broad perspective taken while revamping an existing plant helps avoid improving plant performance through mitigating constraints only to be limited by an unforeseen bottleneck elsewhere.

The product of a debottlenecking study is a selection of viable options with varied costs and benefits. Spirited debate is then applied to evaluate the most profitable course of action. Intangible factors such as operational familiarity, technology and equipment preferences, and acceptable risk become important as the final decision is made.

Design

Ironically, one of the best opportunities to reduce future debottlenecking costs is during the design of a new facility. Many of the future debottlenecking benefits that can be accrued through judicious original design cost very little if implemented before equipment is purchased.

A facility may begin life on the design board knowing that future capacity increases are already planned. Initial plant investment may be constrained by capital budgets with expansions to be funded by profits from operation of the plant under design. Or the construction may be producing a new product or entering a new market. In these cases the initial investment risk is reduced by limiting capital outlays and by including expansion capability in the initial concept.

One of the most important areas defined during design is equipment design conditions. Design pressure, and to a lesser degree design temperature, constraints often hamstring debottlenecking efforts. Be sure to consider the impact of higher head pumps that might be used in debottlenecking scenarios. In order to reduce capital costs, equipment downstream of a pump is often intended to operate only with the original equipment pump - even if that pump has the capability for a larger impeller! Original design conditions which allow room to grow are often a sound investment.

After a unit is in operation, equipment rerating may be possible. To rerate equipment, the original design drawings and information, along with inspection reports are gathered for review. The maximum allowable design temperature and pressure are assessed based on the actual design and on the necessary corrosion allowance. During construction, materials in excess of those required to meet the specified design conditions may have been used. This happens due to fabrication limits and component availability that makes it more economical to build a piece of equipment more rugged than required. Additionally, after several inspections in the operating environment, the original corrosion allowance may be shrunk allowing the excessed metal to be included in design condition calculations. Although these methods are available to assist debottlenecking efforts, they can be involved and should supplement other options.

Since higher head pumps often ease debottlenecking, original pump installations should specify the use of impellers that are not the maximum size for the selected pump case. Future pump capacity increases are then inexpensive and straightforward. For a new pump installation, specifying an impeller smaller than the maximum provides for facile corrective action in the event that the new equipment is delivering insufficient head. A larger impeller can be swapped for the original to meet the need quicker, and at a lower cost than replacing the pump. Also, consider purchasing a pump driver sized to accommodate maximum impeller horsepower if additional production demands are likely.

One of the potentially costliest and restrictive limits to debottlenecking can be electrical capacity. If possible, initial construction should deliver sufficient electrical trunk line and substation capability for reasonably foreseeable future work. The smallest equipment change might require a new substation, the cost of which dwarfs any potential profit from the improvement. This situation can exist for years in a facility before a large project comes along capable of absorbing the electrical system cost. Electrical system limits can stymie incremental production and profitability improvements to the long term detriment of the facility.

Heat exchanger train pressure drop increases with the square of the charge-rate and therefore can quickly restrict throughput. If higher head pumps are not an option, system pressure drop reduction may be required. Depassing of heat exchangers can significantly reduce their pressure drop, at the cost of reduced heat recovery. Figure 2 illustrates depassing. During heat exchanger design, particular tube pass configurations can be specified, or tube sheet pathways can be left open to accommodate future depassing. Without these provisions, complete bundle replacement might be necessary. Additionally, configuring exchanger process design and layout in the initial design so that series exchangers may be switched to parallel operation can ease the hydraulic constraints of future higher charge rates.

Supplying connections for future tie-ins can reduce direct debottlenecking cost and can limit lost production due to outages required to install equipment. If the purpose of a project is capacity increase, the profit lost due to project related down-time which reduces production may be substantial. Candidates for future connections include: pumps (perhaps a third pump to up capacity), compressors, reactors (parallel train), and distillation column overhead condensers as well as other exchangers.

During design, there are often hurdle rates (rate of return or payout requirements) that determine the acceptability of expenditures. These hurdle rates should be reviewed to ensure they account for all costs. For example, new construction energy-efficiency hurdle rates may not be taking into account the cost of environmental and other permitting. The total costs of obtaining environmental permits, and possibly construction permits, for initial construction or future debottlenecking should be factored into hurdle rates and into permitting plans so that some debottlenecking can be accommodated without permitting revision.

Recently one refiner in planning to build a new grass-roots crude unit chose major existing equipment changes and new design equipment investments to avoid an onerous Prevention of Significant Deterioration (PSD) permitting procedure which would have increased costs, delayed project execution by at least a year, and left permit approval uncertain. Existing facility furnaces were converted to ultra low NOx burners, liquid fuels were replaced by vaporized fuels, and exchanger surface area beyond previous practice was specified to limit new source emissions.

New equipment design can also prepare units for future debottlenecking by what is *left out of* the design. Use of high capacity technologies for initial designs means these options will not be available when increased capacity is desired. High capacity trays and low-fin heat exchanger tubes should be avoided in initial design if possible so they can be used in the future. Typically the use of high capacity technologies is justified by the reduced equipment capital cost they make possible. For example, high capacity fractionation internals can shrink column diameters thereby lowering their cost. Extended surface exchangers require smaller bare surface areas reducing cost. The initial construction capital requirement reductions afforded by high capacity equipment may mean higher revamp costs and restricted debottlenecking options in the future.

Heat Transfer

Unit heat integration often becomes an issue in debottlenecking. This is especially true in Crude units and Hydroprocessing units such as Hydrotreaters or Hydrocrackers. Often heat transfer debottlenecking issues manifest themselves as a need for additional heat input, e.g. furnace duty, or as a need for additional cooling utility, e.g. cooling water, or both.

Heat transfer issues can creep up as the unit is incrementally debottlenecked over time. A unit that is designed for 100,000 bpsd, and through skilled operation is running 20% over design, requires 20% more heat transfer surface area to maintain the design energy efficiency. Often what appears as a utility limit, not enough furnace for example, may be mitigated through increased heat transfer surface area. Additional exchangers may cost less than added furnace capacity, and do not require fuel gas and an environmental permit to operate.

Figure 3 illustrates the composite curves of a pinch analysis for a Crude Atmospheric Distillation Unit. This particular unit was limited by furnace capacity and cooling capacity. The unit was already operating at over twice its design rate. A pinch analysis is a tool which can provide an insight to heat transfer efficiency, exchanger requirements, and utility utilization. Pinch examinations are used in new unit design, and are powerful tools in existing facility review. Figure 3 depicts the relationship between the streams being heated and the streams being cooled in the Crude Unit under study. Ideally, the unit streams being cooled should transfer their energy to those streams being heated to the greatest degree possible in order to minimize required hot (e.g. furnace) and cold (e.g. cooling water) utilities. Of course, maximizing this transfer between process streams requires increasing amounts of exchanger surface area as the 'ideal' of complete transfer is approached. There is a natural trade-off between reduced energy consumption and equipment capital cost. This simple relationship is complicated in cases where utility generation (e.g. steam) is desirable. However, that is not the case here. From Figure 3, it can be seen that over the years the increasing charge rates have caused the percentage of the total heat duty required that is supplied by the hot process streams to decrease. This is illustrated by the diminished overlap of the hot and cold stream lines in current operation versus the original design. Additional process stream heat exchange surface area might be cost effective. Added area would unload the furnace and cooling systems by allowing already hot streams to heat cool ones. Similar situations also occur in other units and are common where incremental throughput increases have occurred over time.

In some cases heat transfer improvement requirements can be met using technologies such as extended surface (low-fin tubes) or tubulators. Low-fin tubes increase the tube outer surface area and can improve heat transfer where the shell-side transfer coefficient is limiting (and where shell-side fouling is not a concern). Condensers are candidates for extended surface technologies especially when cooling water is on the tube side. Cooling water heat transfer coefficients are typically very high resulting in heat transfer that is limited by the opposing fluid's transfer value. Tubulators raise the tube-side transfer coefficient by generating turbulence at the cost of increased pressure drop. High viscosity materials such as lube oil might benefit from tubulators. Fouling services also may justify tube material upgrades. Stainless steel tubes are typically less susceptible to surface fouling when compared to carbon steel due to their smoother finish. For example reboilers in olefinic service, which often foul with polymer, might benefit from replacement of carbon steel tubes with stainless. Treatments exist for smoothing tube surfaces and should be investigated if fouling is reducing run-length or energy efficiency. Exchanger fouling due to thermal degradation can be especially insidious in the case of exchangers that are heated with steam that is throttled on the exchanger inlet. As the exchanger fouls, the steam inlet valve opens wider in an attempt to transfer additional heat. This increases the steam pressure in the exchanger leading to higher steam temperatures. The higher temperatures increase the rate of thermal degradation - leading to greater fouling. Once established, this loop can feed on itself resulting in accelerated exchanger performance degradation.

Hydraulics

Pushing more through the pipes is often a debottlenecking goal. A number of items may be reviewed to overcome hydraulic limits.

Often a larger hammer is the only solution to achieve higher production; Pump or compressor sizes may need to be increased. Perhaps only the impeller need be changed. However, note that design pressure limits may require pressure relief additions that can greatly complicate a simple impeller or pump replacement project. Parallel or double pumping might be practical if pump curves are such that pumping in parallel does not lead to the pumps fighting each other resulting in reliability problems. Booster pumps may be useful. However, be sure to check that equipment downstream of a booster pump is protected against the case where the booster pump is deadheaded with its suction pressure at the deadhead pressure of the original pump. Throw in the case where the upstream pump suction is at relieving conditions and adding a booster pump will tax most original design conditions - leading to relief system modifications. Flow inducers which allow pumps to operate at reduced Net Positive Suction Heads can sometimes be used to stretch the capacity of highly loaded systems which would otherwise result in cavitation.

Control valves often begin to exhibit substantial pressure drops as plant charge rates rise. Besides affecting the system pressure loss, large drops in liquid service may lead to undesirable vaporization. Larger control valves may up rates by shrinking pressure losses, but may reduce control as the control valve becomes a smaller percentage of the system loss.

Pipe line size and layout can pose a significant hydraulic constraint. Given the same volumetric flow conditions, pipe pressure drop varies with the inverse ratio of the pipe diameters to the fifth power. Over time, it is not unusual for portions of a pipe run to be replaced with larger pipe while part of the smaller original pipe remains. A recent hydrotreater study revealed that 17% of the hydrogen loop piping which was one size smaller than the rest was taking 44% of the system pressure drop! Compressor horsepower savings alone justified replacing the smaller line portions. Where varying line sizes are not an issue, parallel pipe runs might be feasible. There may be out-of-service line running along the system under review that can be put into parallel operation. Runs to storage are often good candidates for this type of debottlenecking.

Feed tanks might be run at higher levels and product tanks at lower levels thereby increasing the apparent unit pressure driving force. While this strategy sounds marginal, surprising results can be had for no cost.

Feed flash drums, sometimes called preflash drums, can be used to improve unit hydraulic performance. Crude units often benefit from their use. Figure 4 illustrates different configurations. By flashing an intermediate stream in the unit feed train, several hydraulic advantages may be gained. The flashed vapor is separated from the liquid and sent directly to the distillation tower at the feed train terminus. This reduces the hydraulic load on the remainder of the feed train - including the furnace - and reduces vapor loading on the portion of the fractionation column below the flashed vapor inlet. If necessary, the flashed vapor may be rectified in a column before entering the main tower thereby providing improved separation and reducing the likelihood of heavy components entering light product fractionation zones. Moving an existing flash drum earlier in the feed train may increase its contribution to unit capacity through bypassing greater amounts of equipment. Flash drum benefits are highly dependent on unit configuration and product slate. However, throughput increases of 20 to 50 % are not uncommon with the addition of a flash drum. One misconception surrounding flash drums is that their installation increases the energy efficiency of a unit. While some slight adjustment in energy consumption may arise from flash drum implementation, they afford no major energy use benefit.

Distillation

Increasing fractionation tower capacity is one debottlenecking area that has received significant attention. Because distillation operation can often significantly benefit from specialized modifications, numerous vendors provide equipment solutions. Various mechanical options are available to add tower capacity. These include high capacity trays, packing, and multiple pass trays. Installing high capacity contacting devices typically increases a column's capacity by 10 to 20%, though greater improvements are from time-to-time purported, and are sometimes achieved.

Internals layout modifications, such as reducing reboiler recirculation, may also lead to substantial improvements. Reboiler feed internals may not be suited for operation at current conditions. Ensuring that the reboiler feed temperature is minimized through efficient recirculation can increase column capacity significantly. In one recent case, the column bottom reboiler inlet temperature was actually, hotter than the column bottoms product! This was caused by unusually deleterious reboiler feed and return internals design. Column capacity was reduced by approximately 30% simply by the arrangement of sheet metal and metal plate.

Distillation throughput is often a function of heat transfer limits. Column performance may be improved by altering feed preheat conditions or adding overhead condensing and/or reboil capacity. If the column is flooding below the feed, higher feed preheat may alleviate the problem. If the column is flooding above the feed, reduced feed preheat may be beneficial. Intermediate reboilers can be added which up reboiler capacity and provide an opportunity for energy efficiency increase through use of a lower temperature source for reboil.

Operating conditions significantly affect fractionation capability. Adjusting the tower pressure or product specification targets may garner substantial benefits. High column pressures may ease column flooding and overhead condenser restrictions, but at the cost of higher bottoms or feed heat input. For example, increasing a Crude column's operating pressure from 20 to 25 psig reduces its internal vapor volumetric flow approximately 10%!

An engineering and operating review of a column's performance may turn up unexpectedly simple upgrade opportunities requiring little capital. Such a review almost always turf's up design or operating information that benefits profitability.

Reactors

Reactor debottlenecking is more problematic than overcoming other limits. Catalyst modification and parallel train operation are two of the primary methods for increasing reactor capacity. FCC units continue to benefit from riser and feed-nozzle technology improvements which up feed-rates and yields. For fixed bed reactors such as hydrotreaters or reformers, dense catalyst loading and heightened catalyst activities may be used to meet debottlenecking goals. Alkylation plants may have reaction sections that are conservatively designed so that throughput increases have little impact on product octane.

Reactor capacity may also be linked to other unit constraints such as hydraulic or heat transfer limits. Careful reactor performance examination is recommended as these restrictions may be masked by the concern for apparent reactor capacity boundaries.

Advanced Control & On-line Optimization

Implementing advanced control strategies and on-line optimization can have significant operating benefits. Simply studying the possibility of implementing these technologies may return handsome rewards through increased understanding and constraint identification. Advanced control, such as advanced level control or multivariable dynamic matrix control, might be able to provide much smoother operation than standard methods reducing product variance, and may allow operation closer to specification reducing giveaway. Optimization systems can provide a tool for maximizing profitability on a continuous basis even under varied operation.

Perhaps the largest bonus returned from these types of systems is the information and information management capability they provide. The data gathering and historical archiving these technologies deliver yield the tools for improved understanding of unit performance and potential.

Out-of-Service Equipment (*The Bone Pile*)

Although management of change restrictions have eliminated, or at least hampered, mid-night requisitions that previously led to low-cost unit modifications, out-of-service hardware continues to provide a profitable source of equipment for unit upgrades.

Proper mothballing of decommissioned equipment is very important in preserving operability. Much sturdy equipment has been rendered worthless by the elements even after withstanding seemingly harsher environments while in operation.

Tracking out-of-service equipment and maintaining records makes assessments of its potential use much easier.

Purchasing an entire plant, moving it, and restarting it is frequently accomplished at significant savings compared with new design and construction.

Duplicate

Stretching the definition of debottlenecking, plant duplication might be considered. A step increase too large for an existing plant debottlenecking project may call for new construction. Duplication of existing facilities can reduce costs and risk. An existing plant in operation probably has many of the kinks worked out and is a known quantity. Equipment procurement, construction, and detailed design costs are reduced through use of previous design information. Incremental improvements over the existing facility or desired new additions can be made as augmentations of the current design instead of starting from scratch.

Summary

Extracting increased existing unit capacity continues to be profitable. Debottlenecking can provide a cost effective means for upgrading capacity. Beginning with the firm underpinning of a well designed existing unit, thorough unit review and proper planning are the two most powerful tools available to achieve existing plant debottlenecking. With the definition of available options and their profitability, courses of action can be reviewed. Ultimately, debottlenecking may or may not be selected as the proper choice. However, the information collected during a debottlenecking study will almost certainly identify previously unknown low-cost improvement opportunities.

Author Biography:

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Figure 1 - World Oil Consumption

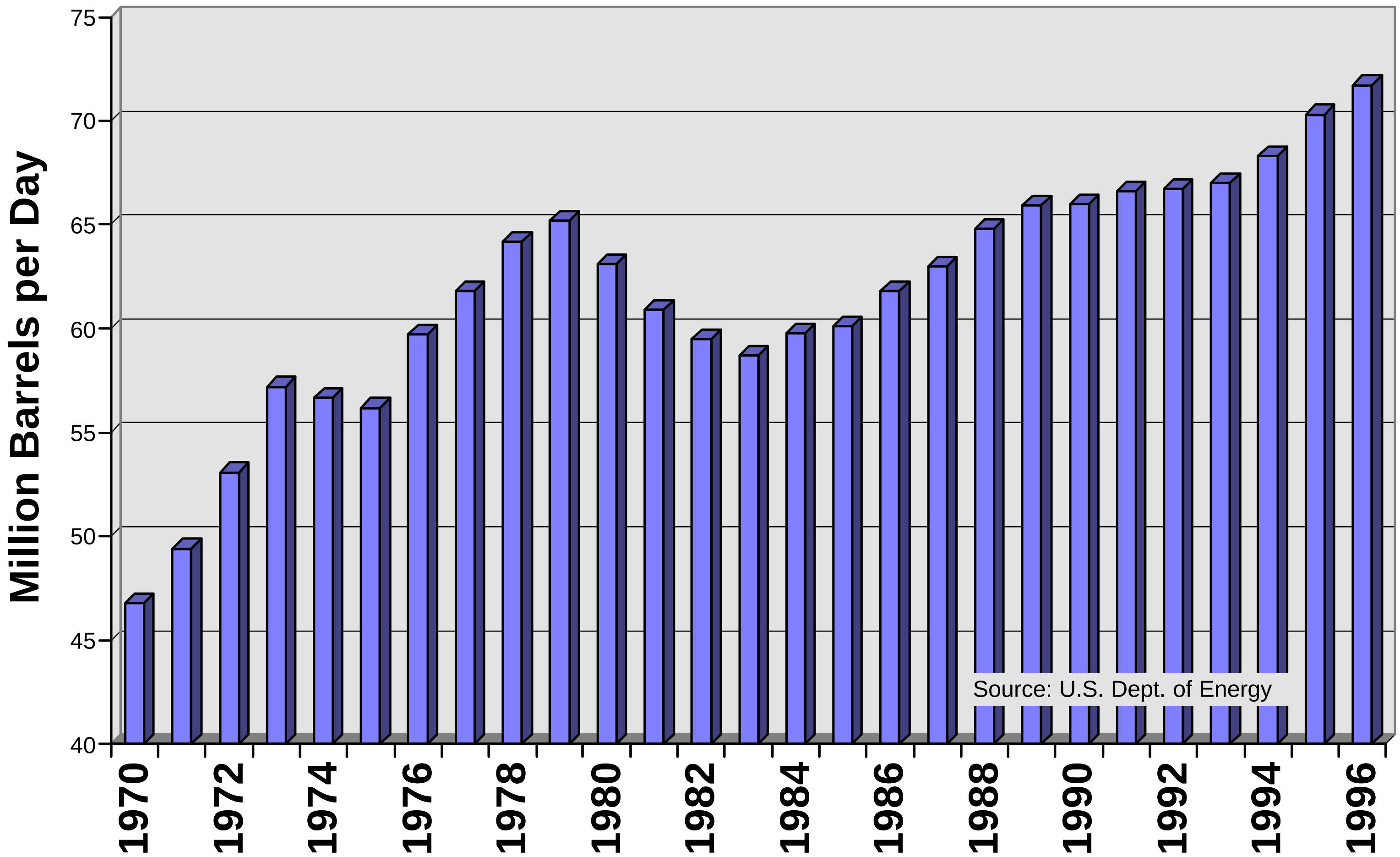


Figure 2 - Heat Exchanger Depassing

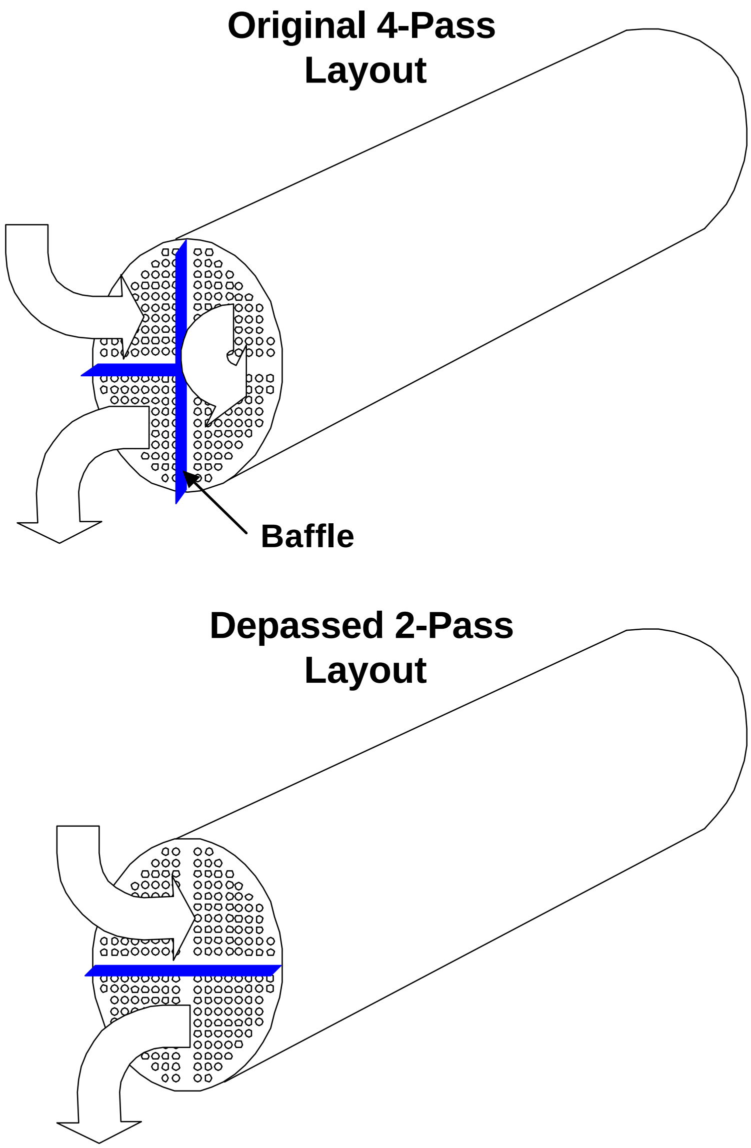


Fig. 3 - Pinch Composite Curves

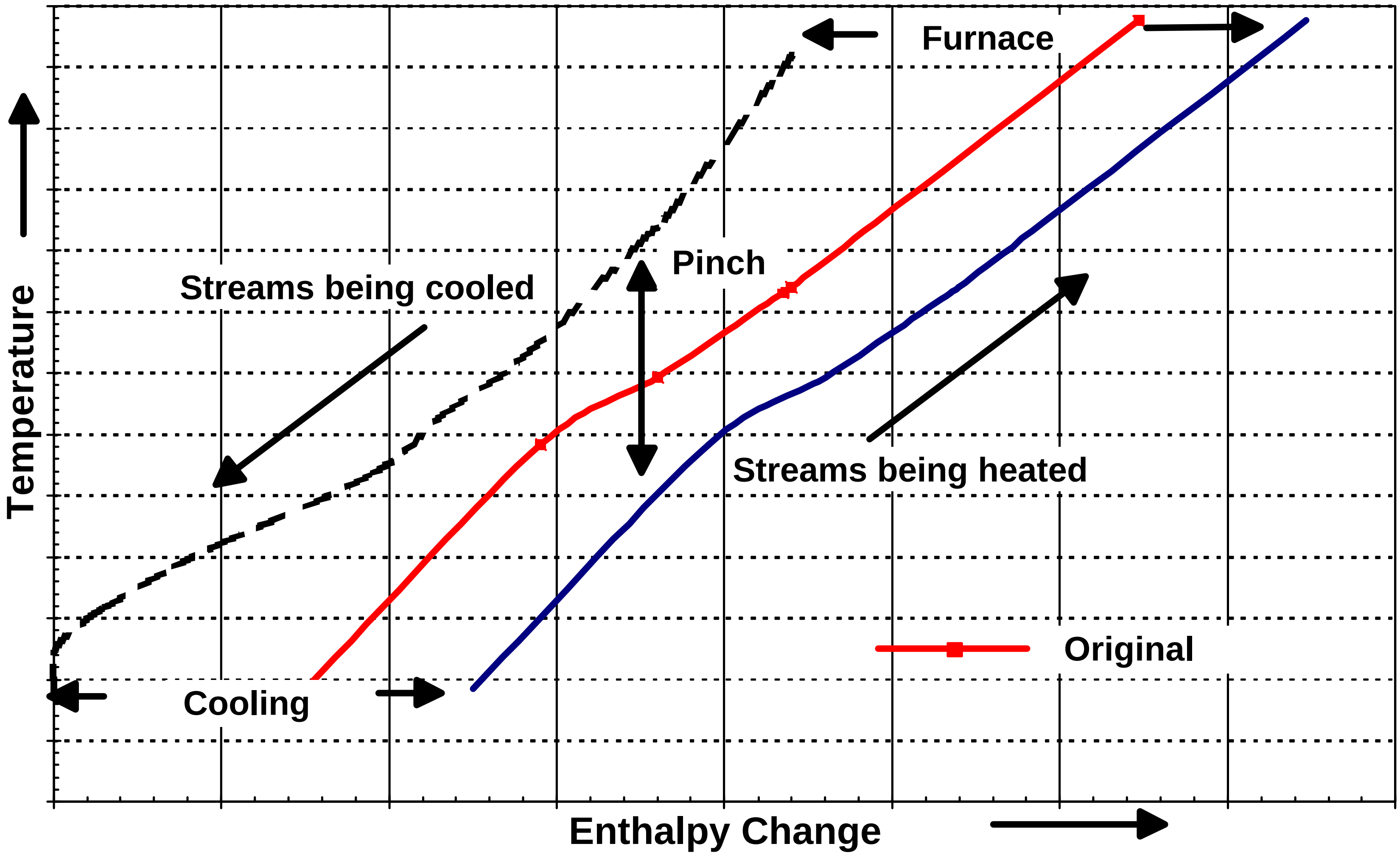
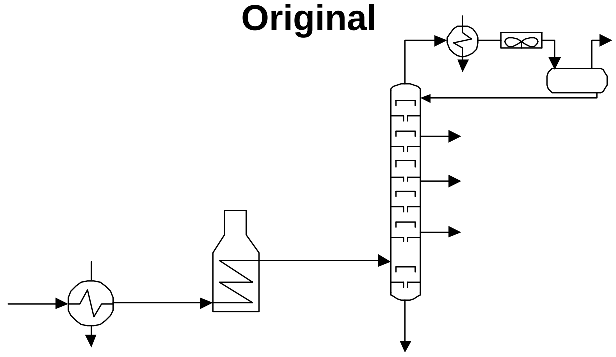
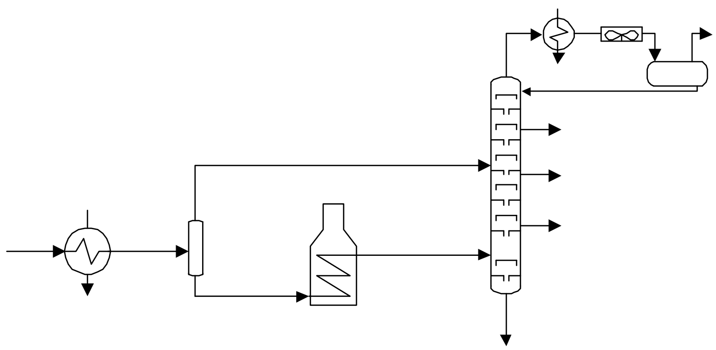


Figure 4 - Flash Drum Configurations

Original



With Flash Drum



With Flash Rectification