Deep Cut Vacuum Tower Incentives for Various Crudes

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Introduction

Vacuum towers are one of the simpler refinery units since they are not a conversion unit like a hydrocracker or FCCU. However, vacuum units are very important because along with crude units they process all of a refinery's incoming crude. Crude and vacuum unit performance affects all downstream operations. Figure 1 illustrates part of a high conversion capacity refinery layout.

Vacuum units have improved over the years. Originally, many vacuum units had trays for mass transfer. In fuels type vacuum towers where low pressures improve HVGO recovery and profitability, trays gradually were replaced with random packings. The packings had lower pressure drops than trays reducing flash zone pressures and overall column pressure drop. In the 70’s and 80’s, structured packings were successfully installed in many units. Structured packing has even higher capacity than random packings and is now the dominant contacting device in vacuum service.

Improved vacuum tower operation meets the demands of the ever heavier world crude slate. Better technology and operation not only accommodate heavier feed, but make possible yield improvements through upgrading residue to heavy vacuum gas oil (HVGO). Increasing HVGO recovery provides a large economic incentive per barrel, and may reduce the need for capital expenditure. Reducing residue production through Deep Cut vacuum tower operation helps mitigate the effects of heavier crude slates reducing the need for additional residue processing capacity such as coking.

Deep Cut vacuum tower operations can offer significant incentives over existing operations. Defining the exact incentives, capital costs, and payouts requires an engineering study. However, initial project feasibility studies can benefit from simplified analysis. This paper compares deep cut incentives for typical light and heavy crudes, Brent and Arabian Heavy. The resultant yields structures and incentives are compared for the two crudes, and economic calculations presented for various charge rates. This technique is valuable in determining project potential and equipment requirements. Deep Cut concerns are also reviewed so that a structure for benefit *and* risk analysis can be developed.

Deep Cut

Deep Cut operations are characterized by increased gas oil yields and lower column bottoms flow rates. For a vacuum tower, this means a higher residue initial boiling point and greater heavy vacuum gas oil (HVGO) production. Because traditional crude vacuum fractionation columns deliver a HVGO / residue cut point of approximately 1050 °F, Deep Cut operation is considered to commence when higher cut points are implemented. However, many vacuum columns operate at cut points below 1050 °F. These units may benefit greatly from higher cut points. Cutting deeper into the bottoms to recover desirable product is not a new strategy for any fractionation system. Increased product recovery has always been beneficial to profit enhancement. However, vacuum column operations present an arduous environment for efficient fractionation which makes upgrading product from bottoms to distillate more difficult than other services.

There are many challenges to atmospheric bottoms vacuum fractionation. High heat removal requirements make pumparounds a necessity. These zones require column height but reduce separation efficiency. Coking and column feed thermal degradation must be managed to ensure efficient and continued equipment operation. Generating and maintaining a vacuum for column operation is often a constant battle.

Even with these problems, cutting deeper into the vacuum bottoms product to recover valuable gas oil product is increasingly practiced. In part this is due to technology development. Vacuum tower fractionation technology has improved with better structured packing options, and more knowledge about their operation and coke formation mitigation. Not only distillation technology has improved. Conversion units such as FCC's are better equipped to handle heavier gas oil feeds. Ways have also been found to debottleneck these units and up their yields increasing the demand for feed. Finally, refinery crude feeds have been getting increasingly heavier over time. This trend raises the importance of distillate production *and* of downstream conversion capacity. These factors combine to focus attention on Deep Cut potential.

Simulation

Today's process simulators are powerful tools for evaluating processes and designing facilities. Many plant revamps and almost all new designs begin with a computer model of the existing or planned process. This model allows the examination of process parameters, what-if scenarios, and equipment requirements. Deep Cut operations are candidates for process modeling like any other system. These models provide for low risk economic and facilities requirement analyses. A technical evaluation of an existing facility being considered for a Deep Cut upgrade should include a process simulation.

The purpose of this paper is not to describe in detail the simulation process. However, one aspect of modeling that is especially pertinent to vacuum system simulation is worth noting; feed heavy component characterization. Typically, the heaviest portion of a crude feed is the least likely to be well understood or accurately represented in a computer simulation. Partially this is due to the difficulty in analyzing heavy materials. High boiling point, high molecular weight hydrocarbons that are messy enough in the refinery, are even less forgiving when introduced into laboratory equipment. Special requests, and justifications, are often needed to obtain desired analyses. Additionally, heavy components are usually not extensively examined because the vacuum bottoms' properties are normally not as critical as those of distillates. The bottom is the bottom - you get what comes out. However, if the goal is upgrading bottoms to gas oil, as it is in a Deep Cut scenario, the importance of representative heavy fraction data increases.

Characterizing the heavy fractions of a Deep Cut candidate feed is very important for a number of reasons. The first Deep Cut question to be asked may be "How much potential gas oil may be recovered from the residue?" Assay data may not be detailed enough to supply accurate yield data. Additional testing will probably be necessary.

After the volume of gas oil potentially available is assessed, the composition of the material should be examined. The material's aromaticity, metals content, sulfur content, and nitrogen content should be evaluated. Again, assay data may not be adequate for the detail required and supplemental tests will probably be necessary. The heavier crude fractions typically contain increasing concentrations of these components. If possible, establishing a boiling point distribution of these and any other important contaminants assists Deep Cut prospect analysis. These data can be inserted into a process model as pseudocomponent properties that are evaluated like any other physical property. This allows design optimization relative to contaminant risks concurrent with yield evaluations.

Within the process simulation, it is important to ensure that there are sufficient pseudo component cuts in the heavy gas oil fraction region. Typical algorithms for separating an assay into pseudo component cuts place decreasing value on increasing boiling point. Ordinarily this strategy speeds computation by reducing the number of components. However, if the assay region under scrutiny is not broken into enough cuts, model output may not accurately represent reality. Figure 2 depicts the results of a computer generated set of crude pseudo components without engineering intervention. Figure 3 illustrates a more desirable Deep Cut pseudo component set.

Another area in which the simulator may require special attention is in hydrocarbon molecular weight estimation. Deep Cut operations often result in a vacuum tower bottoms product that is the equivalent of a bunch of big rocks. The bottoms product molecules are large and bulky. This is especially true of the heavier crudes that are often considered for Deep Cut operation. Accurate molecular weight characterization is critical to reliable equilibrium evaluation. Once again special analyses may be required to gather sufficient data. If an existing plant is being reviewed, a process simulation of current operation may be used to better approximate heavy ends molecular weights. This is done by altering model molecular weight correlations or values until operating parameters, especially vacuum column bottoms temperature, are met. Even if accurate laboratory molecular weight data are obtained, using available existing plant data to confirm and fine-tune the information is recommended. Molecular weight correlations supported by computer simulators vary widely and can change from version to version. In addition, they yield strikingly different results. Figure 4 illustrates molecular weight values using several correlations. There is substantial variation between the methods which suggests review is required in any vacuum column model.

Study

This paper compares deep cut incentives for two major export crudes - Brent and Arabian Heavy. Brent (38.3 °API) is a typical light crude, while Arabian Heavy is a typical heavy crude (27.4 °API). Product yields and properties were approximated using a computer model of a crude and vacuum column. This type of analysis is useful for preliminary examination of project economics. The simulations done for this presentation use assays from the Oil and Gas Journal (Rhodes, 1991, 1995). Figure 5 depicts the simulation layout and product slate. Crude column side products are steam stripped and the vacuum column is operated without steam stripping. Model operating parameters were varied in examination of several operating effects. Results are presented graphically for interpretation.

Vacuum column flash zone pressure and column total pressure drop have significant operating and yields impacts. Figure 6 illustrates the effect of reducing the flash zone pressure at constant flash zone temperature upon residue production for both Brent and Arabian Heavy crudes. Operation at 100 mm Hg flash zone pressure is typical of old, high pressure units. Operation at 15 mm Hg and lower typifies a modern, low pressure deep cut design. Reducing the flash zone pressure from 100 mm Hg to 15 mm Hg reduces the Arabian Heavy residue production from 37 to 25% of the crude charge rate. Brent shows similar residue reductions although Brent contains less residue material than Arabian Heavy. Figure 7 shows the same pressure effect upon the residue cut point again at constant flash zone temperature.

Figure 6 suggests residue make is reduced approximately 5% on crude by moving from a flash zone pressure of 50 mmHg to 20 mmHg. If the crude unit charge rate is 100 MBPSD, the residue rate would drop 5,000 BPSD. Table 1 provides a simplified method for evaluating HVGO production increase payouts. For example, if HVGO is worth $1/bbl more than residue, the 5,000 BPSD of increased HVGO production is worth $1.8 MM/yr. If the revamp costs for the unit in question are less than this $1.8 MM, the project payout is less than a year to reduce the flash zone pressure from 50 to 20 mm Hg.

Figures 8 & 9 illustrate the effects of temperature upon residue production and cut point at constant flash zone pressure and column pressure drop. No surprises here, the higher the flash zone temperature, the lower the residue production. Fuels refiners trying to minimize residue production typically maximize the flash zone temperature up to the temperature limit at which excessive cracking and/or coking occurs in the furnace and column.

Unit design can affect the maximum temperature of the vacuum tower feed before it reaches the flash zone, and the resulting amount of cracking and coking potential. A great deal of focus is commonly placed on vacuum column internals - especially the wash zone. A high level of interest is certainly warranted for this equipment. However, the furnace and its transfer line also plays an important role in vacuum tower operation even without the rigors of Deep Cut performance. The top curve in Figure 10 shows the temperature/pressure profile in a non-optimized vacuum furnace and transfer line design. The vacuum tower feed enters the furnace at the left of the curve at low temperature and high pressure. As the oil flows through the furnace, the oil is heated while two phase flow causes significant pressure to drop. The non-optimized example shown has a furnace outlet temperature of 775°F to achieve a flash zone temperature of 725°F. The pressure drop in the restrictive transfer line piping causes a substantial pressure drop between the furnace outlet and the vacuum tower flash zone. This pressure drop results in transfer line flashing and an accompanying diminishing temperature. The latter portions of the radiant tubes also display high pressure drops causing high temperatures to be maintained throughout much of the heater increasing the fouling susceptibility. There are other potential furnace flow aberrations. Due to the inherently low vacuum column operating pressures which result in low vapor densities, furnace tube flow rates can approach sonic velocities. Sonic discontinuities across the furnace outlet can occur before the furnace outlet laterals, which are typically larger pipe or lead to the large transfer line, are able to provide for reduced velocities. This flow phenomenon results in fluid flow rates insensitive to pressure decreases downstream of the critical flow region. High furnace outlet temperatures and increased thermal degradation and coking are products of this condition. Additionally, the high velocities can lead to erosion as particulates are swept through the furnace. Furnace tube velocities should be kept below 85% of sonic if possible.

The lower curve in Figure 10 presents an optimized furnace and transfer line design. To achieve the same flash zone temperature of 725°F, the furnace outlet temperature is only 750°F. Also, the latter radiant coils are significantly larger reducing the pressure drop in the high temperature section of the heater. The overall benefit of the cooler temperature profile in the optimized design is represented by the difference in area between the two curves. The resulting benefits are reduced thermal degradation and coking.

The advantage of the lower pressure drop design is that the flash zone temperature can be increased with a minimal increase in the cracking/coking tendency of the vacuum tower feed. In the example shown, the flash zone temperature probably could be increased almost 50°F to experience a similar coking tendency as the non-optimized design. Deep Cut profit incentives often must account for furnace modifications as well as tower upgrades.

Deep Cut Concerns

A number of concerns must be kept in mind while Deep Cut profitability benefits are examined. Yield evaluation does not provide a sufficiently broad perspective to determine project viability. The effects of HVGO composition changes on vacuum tower operation and on downstream units can be significant and could substantially erode perceived Deep Cut advantageous.

A primary concern for vacuum column operation under any yield slate is coke formation. Coke forms within vacuum towers resulting from hydrocarbon thermal degradation due to the temperatures and residence times in the furnace, column bottoms, and column flash and wash zones. Simply increasing the severity of operation in an effort to improve gas oil yields may exacerbate coke formation. Column and furnace design along with operating limits must be reviewed for acceptability and required upgrades.

Downstream unit operation can be adversely affected by HVGO quality degradation under Deep Cut scenarios. As the residue initial boiling point is raised, increasing quantities of high molecular weight polycyclic aromatics (PCA) or asphaltenes are drawn into the HVGO. The presence of these compounds can be measured by quantifying the amount of material that is not solubilized by a selected solvent. Heptane is commonly used. The HVGO Heptane Insolubles content of the HVGO could be increased due to flash zone entrainment or ineffective wash zone operation. If the HVGO is fed to a hydrocracker, 100 ppmw max Heptane Insolubles is a typical limit beyond which hydrocracker catalyst deactivation, fouling and plugging is expected. VGO FCC units are less sensitive to higher levels of Heptane Insolubles with concentrations of greater than 2000 ppmw being acceptable.

Deep Cut operation may also increase the metals content of the HVGO. As the residue initial boiling point increases, HVGO metals concentration typically increases as heavier organo-metallic species migrate up the column. Vanadium and Nickel are two primary metal components which may be swept into HVGO under Deep Cut production. FCC units in particular are sensitive to these materials. Vanadium negatively impacts FCC catalyst activity through its destruction of the catalyst zeolite structure, and through its dehydrogenation catalytic capacity which increases FCC coke formation and lowers gasoline and distillate yields through increased off gas production. Nickel catalyzes dehydrogenation reactions to a greater degree than Vanadium. Methods exist for mitigating feed Vanadium and Nickel contamination in FCC units; these costs should be included in Deep Cut analyses where applicable.

HVGO sulfur and nitrogen content may also increase in Deep Cut scenarios. The primary result of these increases is added treating loads; sulfur and H2S removal systems may require review. Increased sulfur and nitrogen composition will also raise hydroprocessing reactor heat release and hydrogen uptake. Basic nitrogen compounds can temporarily poison FCC catalyst through interference with catalytic acid sites. These compounds are rejected as NOx from the regenerator and from the CO boiler.

Residue composition is also affected by Deep Cut operation. Increasing the residue initial boiling point clearly results in a heavier bottoms product with a higher molecular weight. The average concentration of contaminants, such as metals, will likely go up with front end material removal. Conradson Carbon will increase and downstream yields may shift to higher coke production.

Summary

Fully evaluating the benefits of deep cut vacuum tower operation requires an engineering study. The crude type, furnace, tower, exchanger, and vacuum jet equipment all play important roles in the ultimate capacity, low pressure capability, and revamp cost of each specific unit. Specific conclusions cannot be reliably made without studying all of these and other factors. However, scoping economic judgments can be made to determine project feasibilities and potential project payouts. Accurate feed characterization in concert with effective process simulation are key factors in Deep Cut option evaluation.

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Figure 1 - Refinery Layout

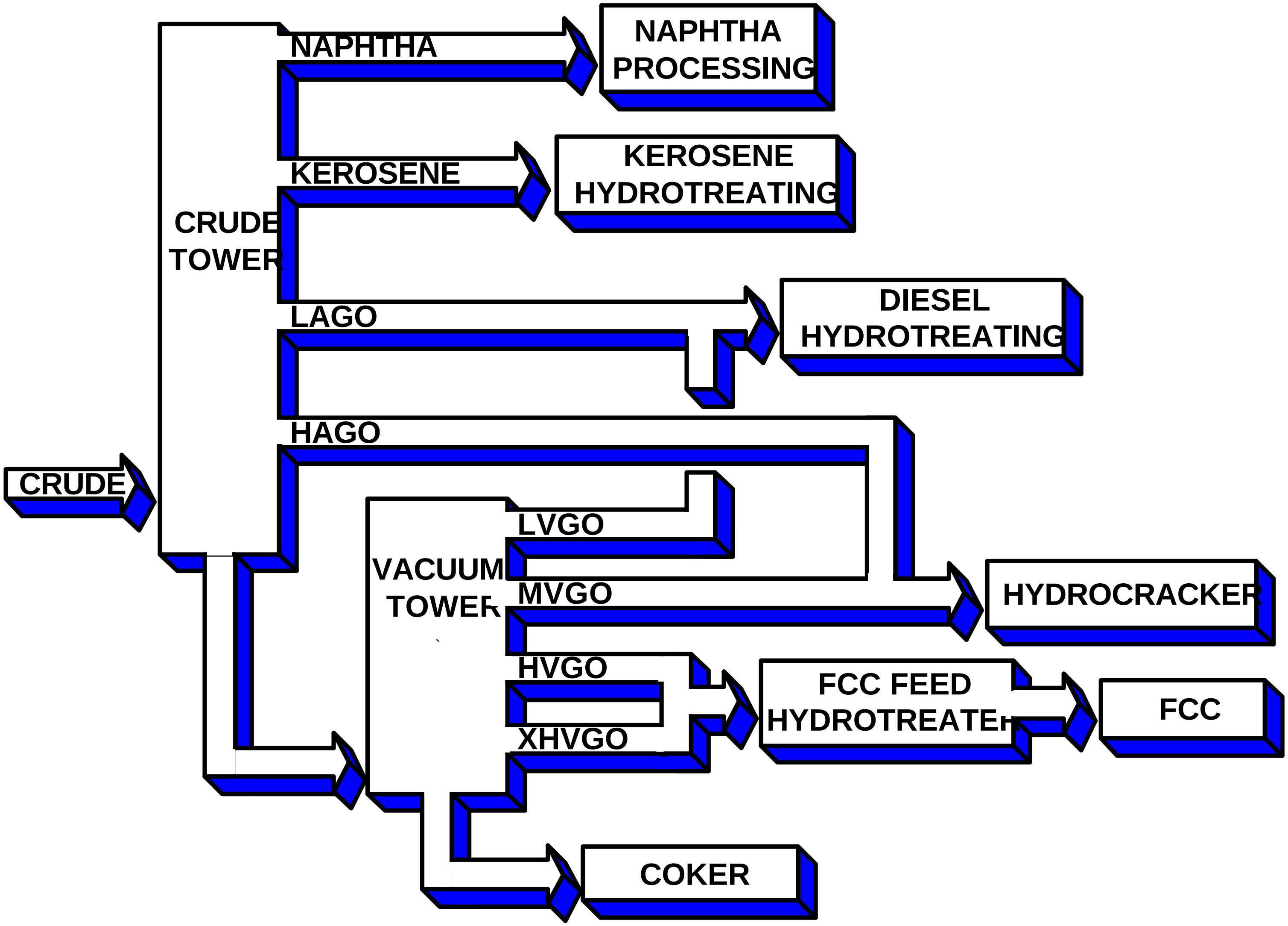

Figure 2 - Typical Assay Cuts

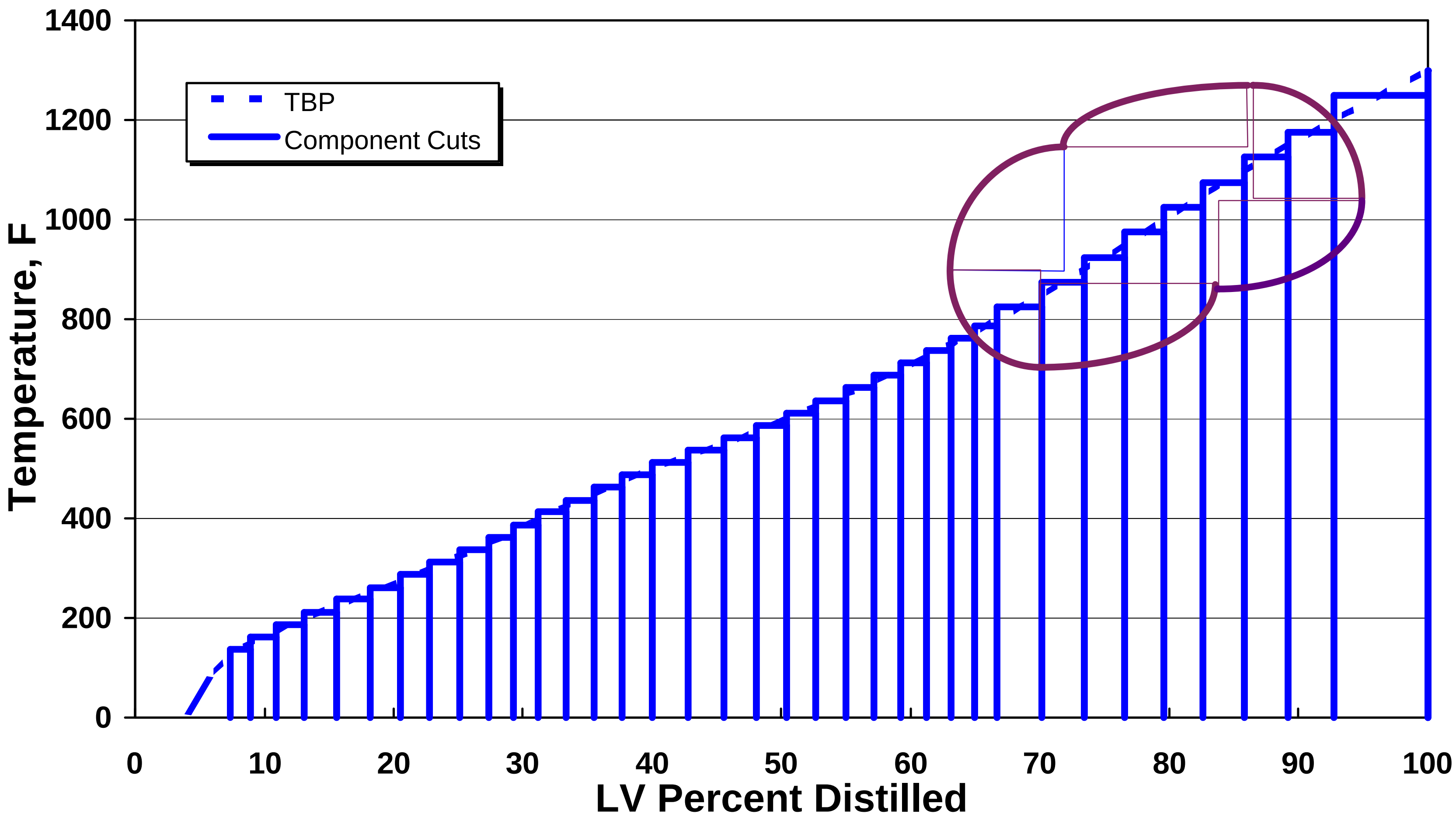

Figure 3 - Improved Assay Cuts

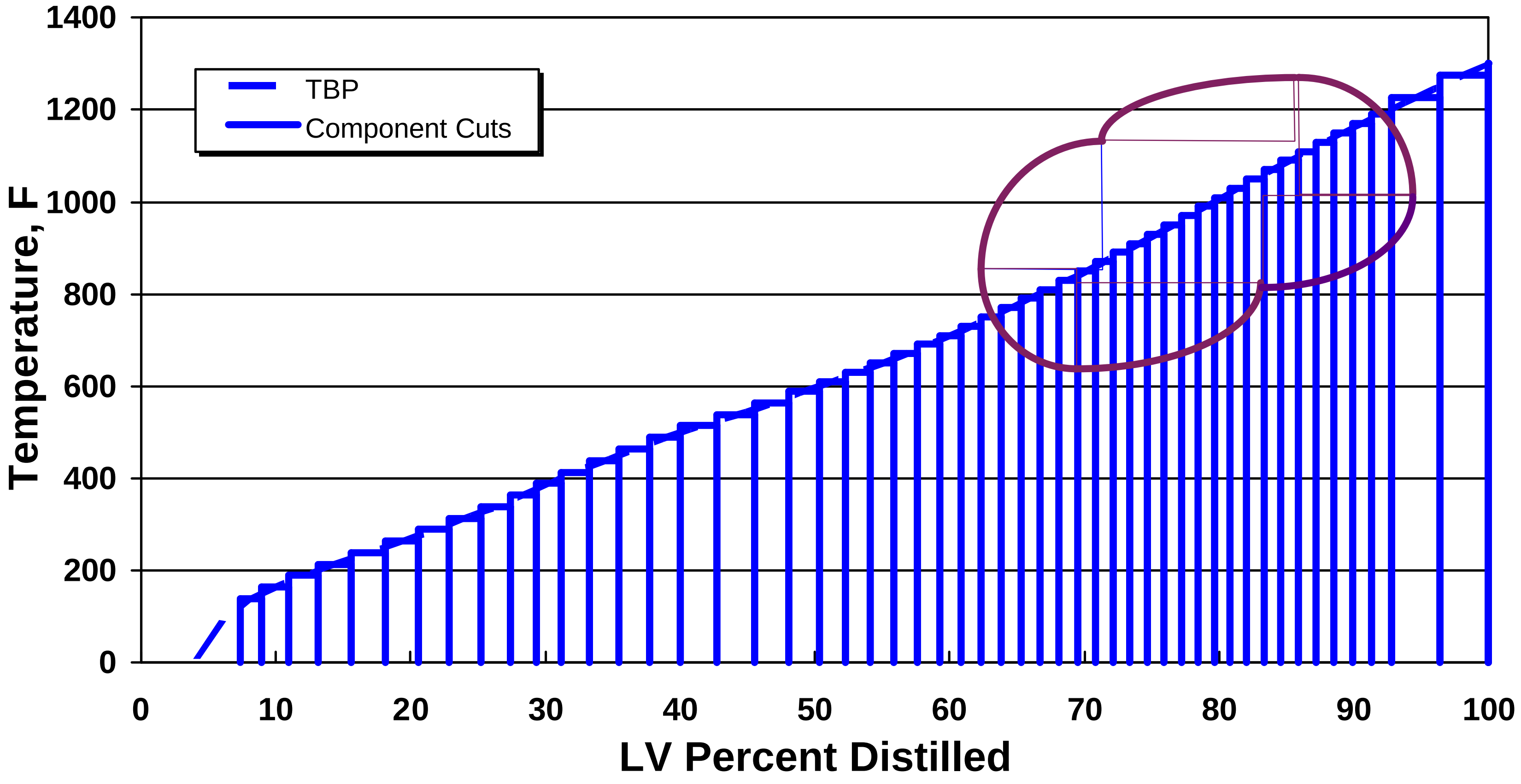

Figure 4 - Crude Molecular Weight

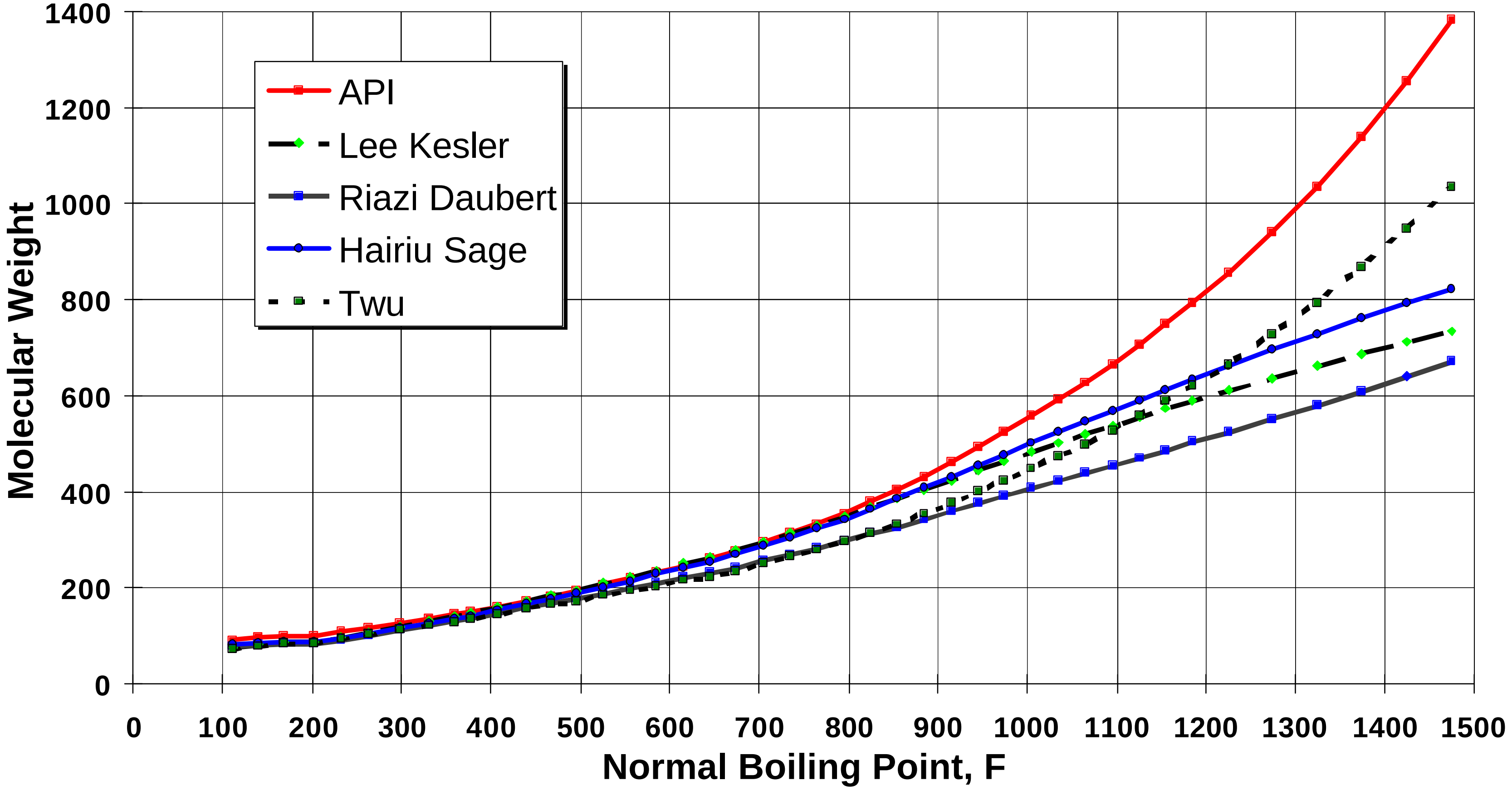

Figure 5 - Simulation Layout

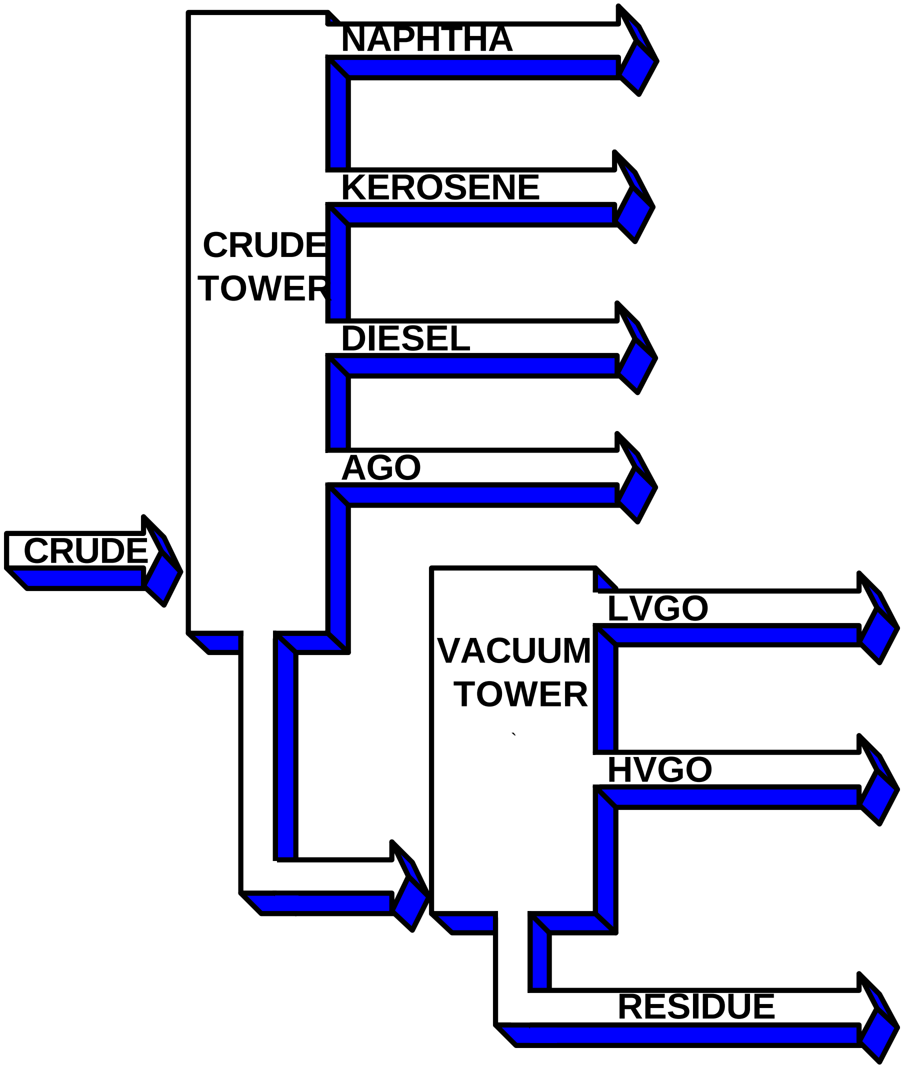

Figure 6 - Effect of Flash Zone Pressure on Residue Production

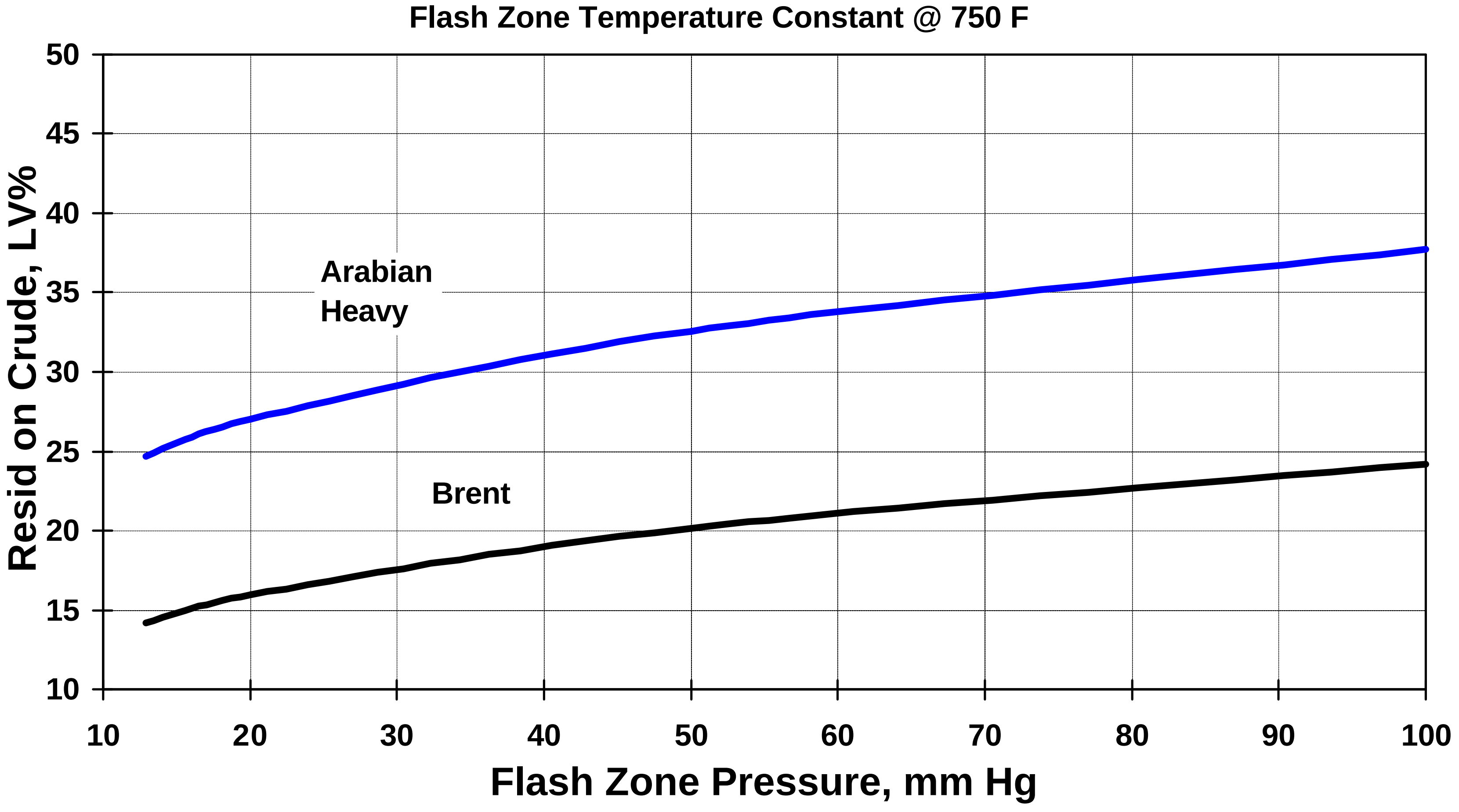

Figure 7 - Effect of Flash Zone Pressure on Residue Cut Point

Flash Zone Temperature Constant @ 750 F

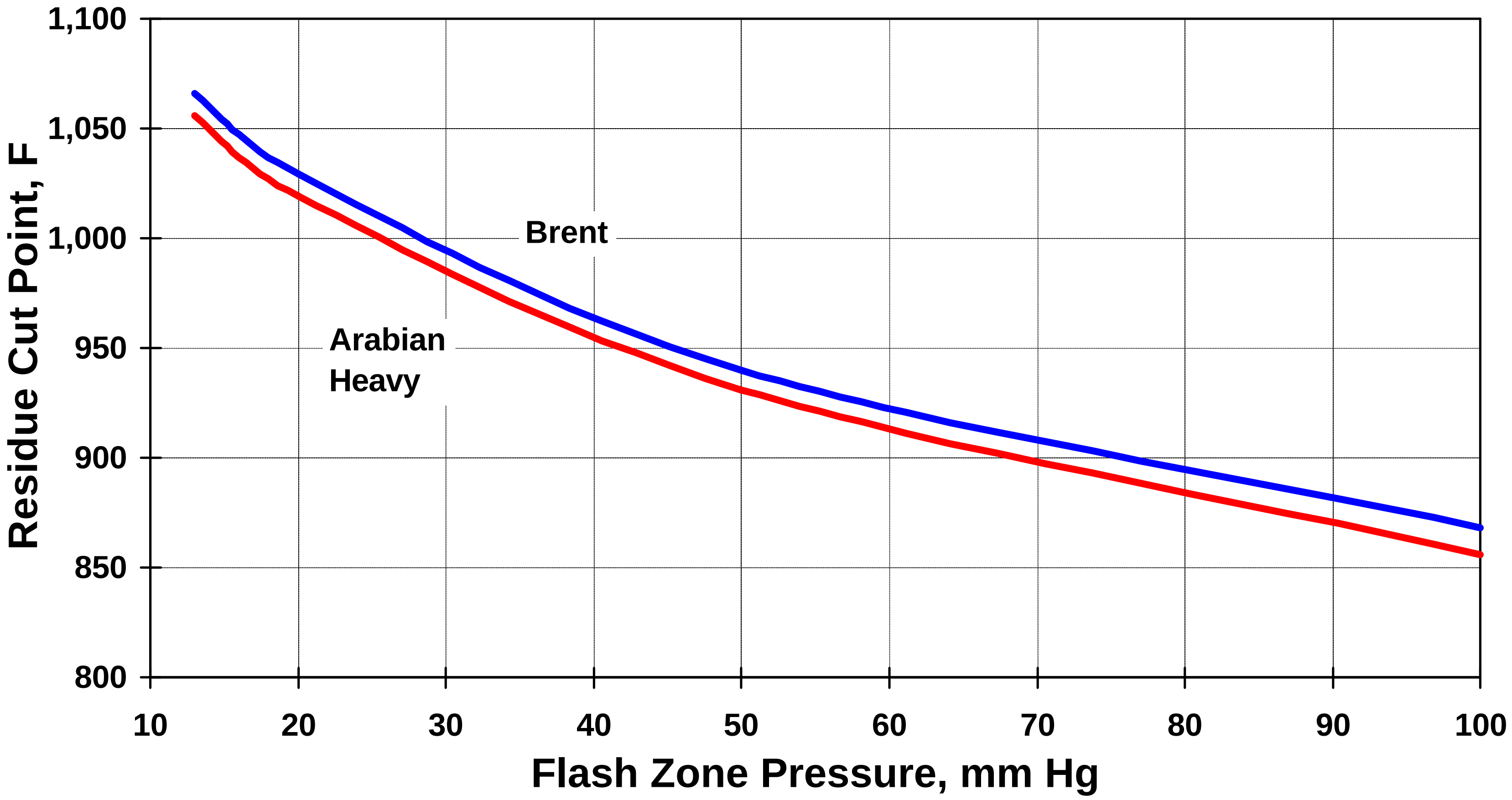

Figure 8 - Effect of Flash Zone Temepratature on Residue Production

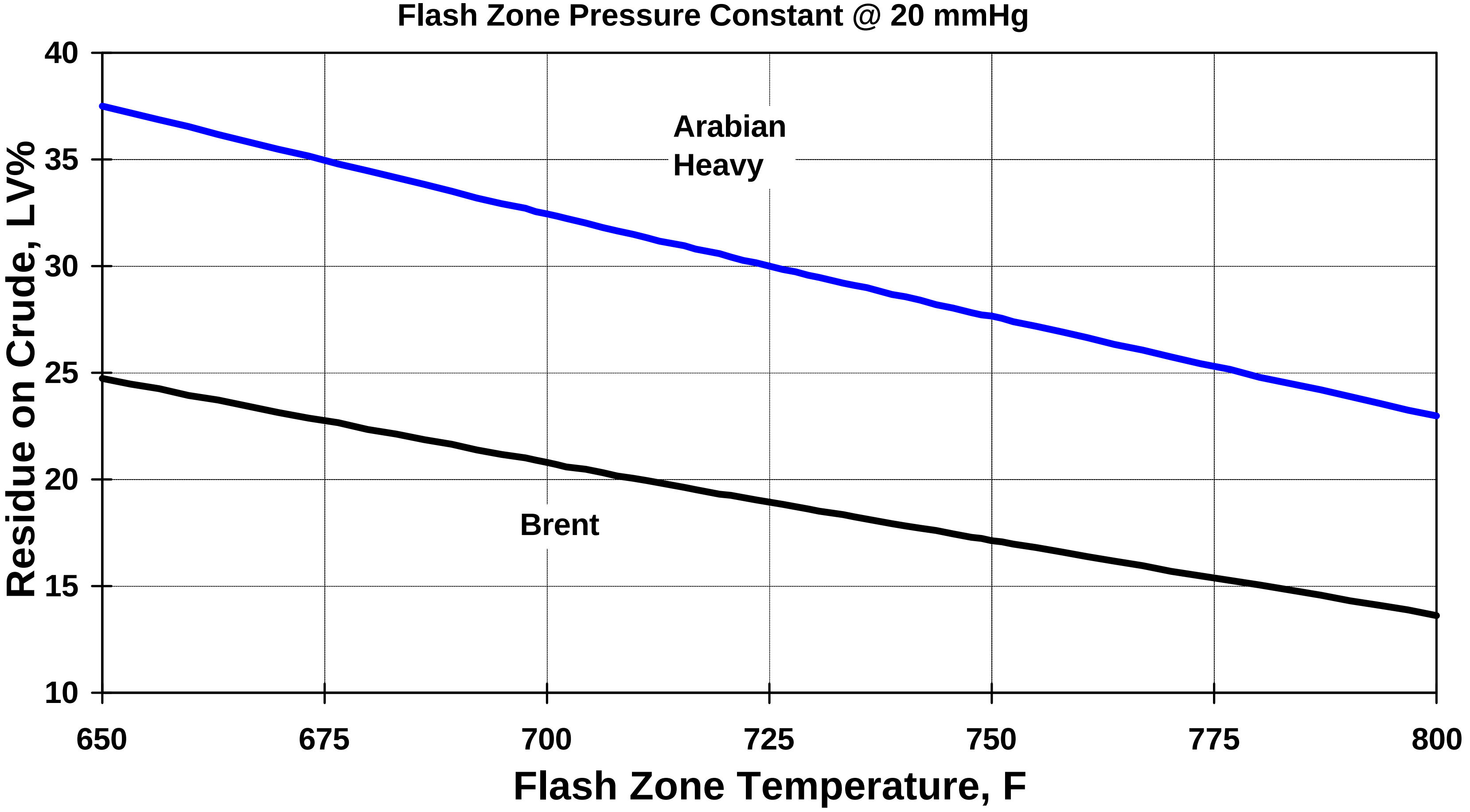

Figure 9 - Effect of Flash Zone Temperature on Residue Cut Point

Flash Zone Pressure Constant @ 20 mmHg

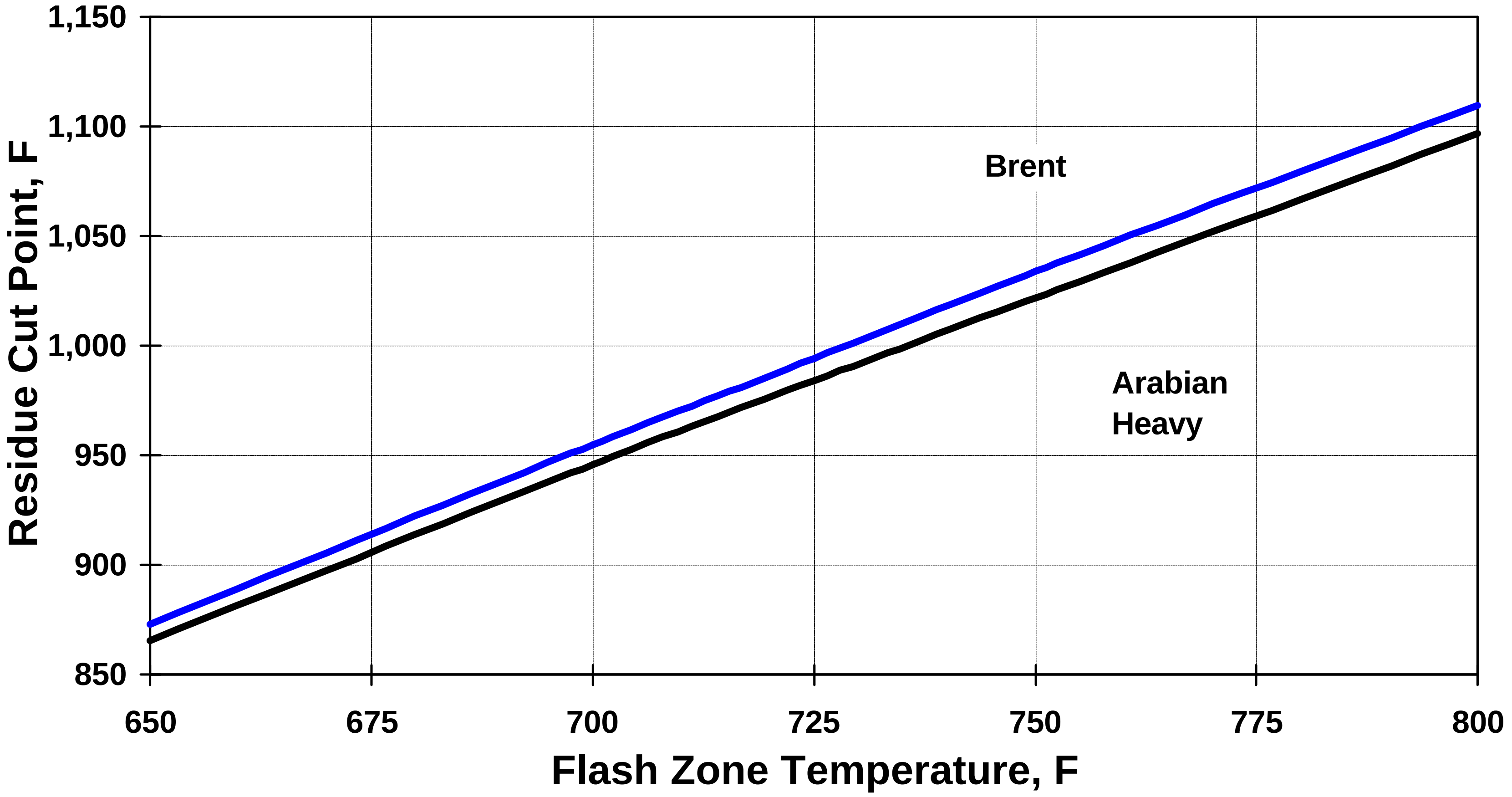

Figure 10 - Vacuum Furnace and Transfer Line Temperature Profiles

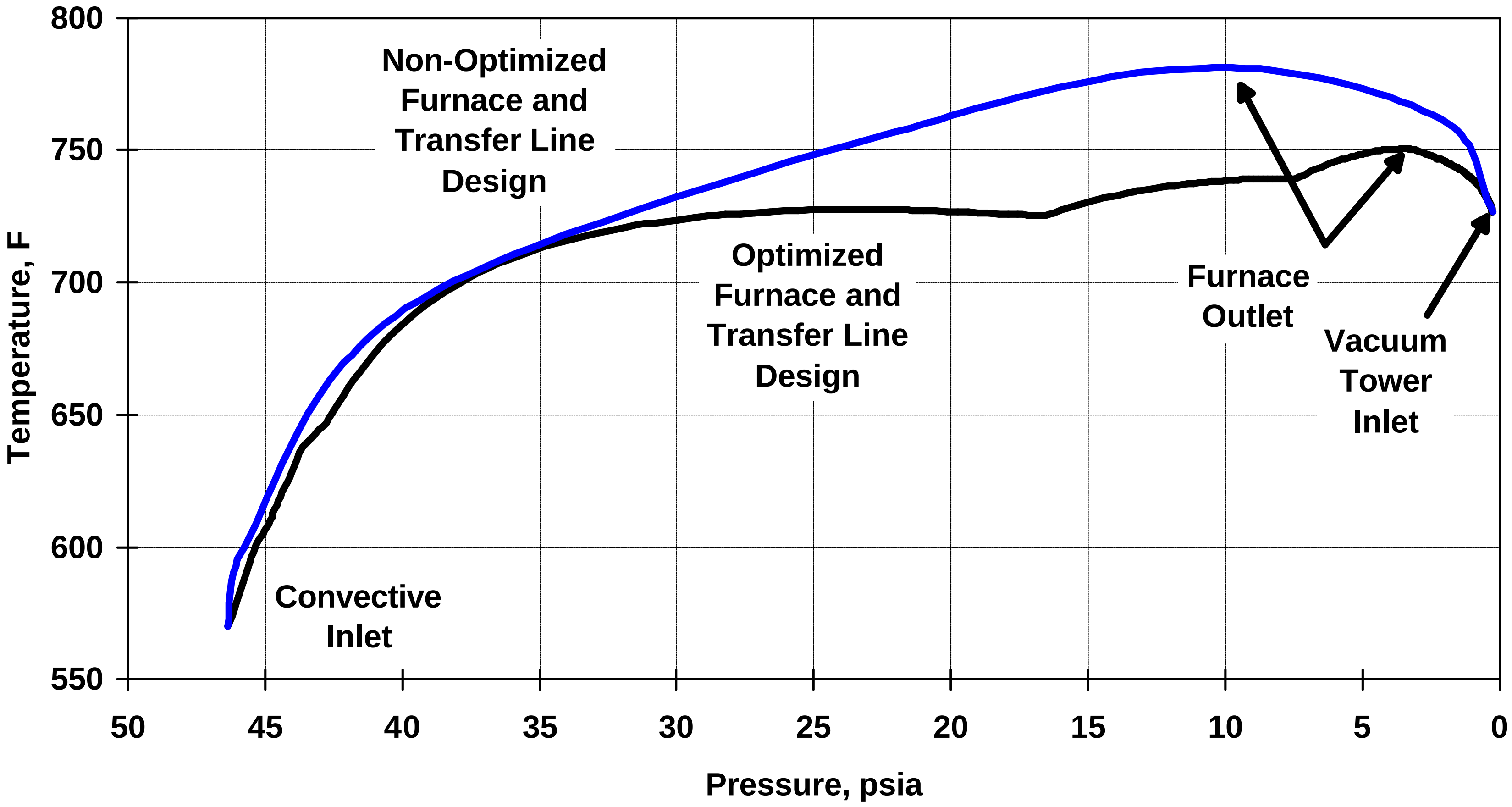

Table 1 - Incremental Profit per Year for Increased HVGO Recovery, $1000/yr

Upgrade Incentive $/bbl	Recovered HVGO, BPSD						
	0	**500**	**1,000**	**2,000**	**5,000**	**10,000**	**20,000**
0.0	0	0	0	0	0	0	0
0.5	0	91	183	365	913	1,825	3,650
1.0	0	183	365	730	1,825	3,650	7,300
1.5	0	274	548	1,095	2,738	5,475	10,950
2.0	0	365	730	1,460	3,650	7,300	14,600
2.5	0	456	913	1,825	4,563	9,125	18,250