Whitepaper on Crude Blending

Reasons for Blending Crude Oils at a Refinery

Oil refineries, and especially their on-process units that process the primary crude feed stocks, are not uniform in either design or operation. The refinery process units and the combination of units built and in service at a given refinery location are part of a plan to accommodate a certain slate of crudes based on their properties. These decisions are also balanced against the availability and cost of crudes to determine an operating profit point. The more consistent the supply of crude oil to a specific refinery, the more that refinery can tailor its operation to that specific crude supply. However, economics makes that level of optimization difficult to achieve or sustain. Necessity forces refiners to have to retain some flexibility in the refinery process to handle a wider range of crude types than that preferred. Crude blending works hand in hand with refinery process flexibility in crude types by enabling the ability to mix crudes that may not, as individual feeds, satisfy the operating range of the refinery, but as components of a mixed feed will meet the refinery operating requirements.

Refineries can change themselves to accommodate a different crude slate in one of two ways. If the properties of the crude vary only in a minor amount then process cut points, charge rate, and operating setpoints of existing units can accommodate the changes. Depending on the degree of crude component change, these alterations can be done through the operating conditions or through alterations of the process units during regularly scheduled unit turnarounds. More dramatic changes in crude processing may require the actual construction of different process units at a refinery, an expensive and time consuming step, but one that definitely changes the range of crudes a given site can process.

The practical implications of crude blending are intermixed with the requirements of purchasing and market analysis. These different, often conflicting requirements, determine the optimal crude slate and refinery operation at any given time, but reflect constantly changing conditions.

- Refiners may have based the original design of a refinery on a local oil field characteristic’s, only to find after many years of operation that the local field yield has declined, forcing them to source other crudes. The properties of no two crude fields are identical, so no direct replacement is available. However, a blend of two or three available crude oils may come quite close to being the same in properties as the original field. In fact, some crude blending occurs at the field gathering stage itself, as different wells in the same crude field may even have varying properties.
- Even if the local field yield is still capable of supporting the refinery, changing market demands may force a refinery to change its crude source to be able to create more of the range of finished products that are demanded in the local market.
- Refiners would always like to run a crude slate that is low in source sulphur and high in component materials that match local market demand. That is why there is a cost premium for such crudes. By contrast, crude oils high in sediments, sulphur and other contaminants, while
low in preferred component materials are sold at discount. Much of the more recent oil fields and supplies coming online have been of these heavy crudes. For a refinery that can’t process the heavy crudes, costs are driven up by premium to purchase light-sweet crudes. However, a refinery that can’t run pure heavy crude may still be able to run some heavy crude when it is diluted into the light-sweet crude. This allows the refinery to purchase some percentage of their crude at lower prices.

- At current refinery operating margins, nothing can be wasted. Offspec and slops materials are reprocessed when they are not capable of being sold as product, or reprocessed when the available prices of those products aren’t viable. However, no crude process unit can afford to receive a feed stream of undiluted slops and seconds, the variability of the properties is too high.

- International politics can play havoc with the supply of crudes. Refiners have been forced in the past to change their crude sourcing on a moment’s notice for no economic reason, and the odds are will have to again. Changing the source region or country for the origin of crude is a similar problem to the original field or crude slate type becoming economically unviable, the refiner is forced to source what is available at competitive prices, and figure out a mix of those that corresponds to the refinery process capabilities.

- Crude blending may even be done by terminals and suppliers prior to a refinery. Under this scenario, crude blending is done to meet a refiner’s target spec range for crude. Question arise about how to best co-ordinate plant optimization with crude slate optimization when separate entities are involved.

**Property Consideration**

Crude oil is not a homogenous material. It is a mix of many different component hydrocarbon compounds, elemental substances, and contaminants. Any given oil field has its own unique signature mix. In general terms, crudes are classified by the ratio of shorter to longer chain hydrocarbons in their base mixture (heavy, light), sulphur content (sweet, sour), geography (North Sea, West Texas), or some combination (West Texas Intermediate, Kuwaiti Sweet)

The content of the crude has as large an impact on its purchase as its price. A North American refiner will favour light crude given the higher percentage of component that, without further refining, supplies material for the higher profit and higher demand gasoline pool. This favouritism has a limit. If the price differential is high enough, the refinery itself will build the secondary process units to further refine heavy materials from heavy crude despite the cost, because the savings in original crude price more than offsets the increased processing costs and investment costs of additional units.

Changing a refinery to be capable of heavier crudes is tempered by that crudes make up. Although the process units to further refine heavy stock into gasoline may be economically viable, if the available heavy crude has too high of a sulphur content, the resultant process costs for removal of the sulphur to meet low sulphur diesel targets may make the overall decision untenable. Properties such as crude oil acidity or sediment content have similar affects on the decision process.
These considerations all play into the decision to blend crude stocks to achieve a feed crude composition to the process units that is not attainable, for a variety of reasons, as a single crude.

**Planning**

The three steps of crude purchasing, crude blend planning, and crude processing do not occur in a vacuum. Crude purchasing is driven by the economics of availability and price, but requires the specifications of the crudes required. Crude processing define what properties are required in the crudes, but also what ranges and abilities the refineries units have to adapt to changes in the crude slate, and require the coming crude slates characteristics for planning. Crude blend planning is in the middle, needing to know what crudes are coming in the future, needing to know what mix of properties is required from those crudes, feeding back requirements for amounts and types of crudes to meet the mixing requirements, and feeding forward the predicted crude properties of the planned crude mixes to operations.

What makes this all manageable is the comparative simplicity of crude blend planning versus complex planning problems like gasoline products.

- More readily available information on the properties of the crudes involved. Most crude oil shipments received at a refinery will not deviate much from the standard issue assay reports. These assay reports will give much of the required information on component percentage and properties. This allows a fair level of predictability in crude purchasing and planning. If a crude appears to match the required needs of a refinery based on its assay values, it can be generally assumed that a particular shipment will arrive meeting those values and not cause a last minute upset to the existing plan.

- Linear behaviour of the properties of crude mixing. Unlike a motor gasoline component pool, where the actual properties are difficult to predict and require both complex non linear models to estimate, and analysis after mixing to be confidently known, the predictability and linear behaviour of crude oil properties during mixing can be more safely assumed.

Given the less complex planning requirements versus gasoline product blending does not mean that there is not an opportunity in planning process for benefits. That the individual crude blend mix can be done by linear estimation does not mean that a spreadsheet based model is the best technique. Financial losses can be incurred, often without knowing, when a multi-period planning tool is not used. A planning tool that both models the mixing behaviour and takes into account a multi-period planning horizon will yield better results and aid in resolving the planning problems presented above. Using a spreadsheet based solution may give an optimal one time solution, but a multi-period planning tool will recognize when a single given crude blend may be best run suboptimal to create an optimal solution across multiple crude blends.

Additionally, the best solution must span as large an optimization problem as possible. Optimizing only the crude blend recipe ignores the opportunity to optimize the crude and process unit’s cut-point, set-
point, and rate targets. As crude prices vary for each available type, modifying the refinery process unit’s operation may yield a better yield overall using a different crude target specification.

**Execution Challenges**

Certain physical characteristics of both crude oils themselves and the equipment associated with the crude tank area have an effect on the ability to execute and monitor crude oil blending.

**Physical Challenges**

Foremost among the difficulties inherent to crude oil itself is the difficulty to monitor properties of the blended crude using inline analyzers. This can be compared against inline motor gasoline blending, where a selection of analyzers are available to provide real-time inline property monitoring of the mixed fuel. Octane engines, NIR, FTIR, Distillation, RVP, and other analyzers are proven technology. However, for crude blending, due to the viscosity and composition of the crude material itself, there are very limited analyzer choices for property monitoring, and the track record of these when used for crude property monitoring are limited. This results in a situation where the assumptions on mixed crude properties must be taken as original estimated (assuming correct ratios of the component crudes were achieved in the blending process) during blending, or as a result of unit performance when processing the crude. For this reason, when inline blending of crude to the process units is done, accurate control becomes critical because the process already requires flying blind on actual blended properties. As long as control is tight, the predictive assumptions on the mixed properties are reliable.

Alternately, if the tankage is available, crude blended into intermediary tanks (day tanks) before being used as feed charge can be sampled and tested in the lab, but this imposes large penalties in terms of inventory, tank use, and time delays due to lab testing. Often this creates a situation where multiple day tanks must be mixed with the newest being in sample for the lab, with the oldest mixed tank being ready for use. This adds additional tankage on top of the already costly crude tanks (often the largest on site) containing intermediate product. This can be exasperated when a day tank does not contain the correct blend and must be rebled, adding pressure to the number of tanks used for crude and possibly leaving little material readily available for use as feed stock. This is often handled at a given site by mixing component crudes together in a single tank before final blending to save space, but with the corresponding increase in planning difficulty of tracking these hybrid crude tank properties. Add this to the problems of seaside refineries receiving crude by ship, where there is already a large time and capacity demand in the crude tankfarm to accommodate settling and dewatering needs on imported crude.

**Equipment Challenges**

Foremost among the difficulties inherent in the equipment associated with the crude tank area is the common lack of flow control valves and meters in sufficient quantities and locations to allow concurrent crude movements to form a feed blend. There may or may not be sufficient pumps available to allow concurrent crude blending, although the criticality of the crude feed stream usual results in redundant crude charge pumps at a given site.
As discussed above, there are two general process ways to handle crude blending, inline mixing of the crudes as part of the feed stream, or the mixing of intermediate day tanks. The costs in terms of increased inventory, increased demand for tanks (both in number and capacity), and the inherent time delays involved in the creation of mixed crude day tanks has already been described. Given the cost of construction of additional tanks (assuming the land resources to host additional tanks is even available within the battery limits), the finances quickly point to the idea of inline blending of crudes.

To achieve inline crude blending, the following equipment needs to be available at the refinery:

1. A design plan of the maximum number of concurrent crude components that would be used at any given time. This is the determining factor in the decision of how many pump, meter, valve combinations (here on referred to as streams) are required for crude blending. Note that this number is somewhat reduced by preblending some crudes. That is, if a site’s crude blend slate almost always involves 2 crude types as both the most consistent and prominent member of ever blend (Crude A is in every mix at 20% to 40% of the ratio, and Crude B is also in every mix in similar ratios), then those two crudes can be imported into the same crude tanks at a 50/50 ratio. This requires the tracking of the exact ratio of the two crudes in each source crude tank but does reduce the number of component pump, meter, and valve combinations by one.

2. Based on the maximum number of streams calculated for the site, combinations of piping to allow each component crude to have individual use of a pump, a meter, and a flow control valve. The more accurate the ratio of mixing crudes, the more accurately the blended crude will match the predicted properties for that blend and meet the property specifications and operating setpoints that the process units are expecting. The inability to correctly control the blended crude ratio will result in suboptimal processing and unexpected deviations in yields that will have to corrected for at the downstream units. Sites must be wary of the temptation to shorten the amount of equipment available for controlling the crude blending.

   a. Although operational personnel have managed in the past to control crude flow rates by the throttling of non-control valves on the crude tank discharges, such techniques can be seen as both inaccurate and time consuming. Inaccurate due to the gross control achievable, and time consuming as any manual setting of the valve must be constantly re-evaluated as the changing head pressure of the tank, any viscosity changes due to layering of the crude within the tank, and any changes in downstream line pressure will change the flow rate. Flow control valves that are controlled by a PID algorithm continuously and automatically adjust to these changes to maintain a requested setpoint.

   b. The determination of flow can be done two ways, either by inline meter or by fast scan tank gauges feeding flow calculations based on level change. In the second case, it can be seen that due to the time delays to register changes in outlet flow from a crude tank (remember the size of typical crude tanks means that level changes are slow for crude tanks) meters are far more accurate for control.

   c. Where meters are in use, attempts have been made to have a meter on most flows, and calculate the remaining flows by comparison with the total flow reported by the crude
units. This places undue emphasis on the accuracy of all the meters involved and no automated way to determine if one or more of the meters involved has drifted in terms of accuracy and requires proving.

d. As with many other processes at a refinery, it is desirable to have at least one redundant stream set of equipment to prevent any upset to the crude blending capabilities while allowing standard maintenance procedure for the pumps, meters, and flow control valves involved.

3. An inline blend header with static mixer is desirable, but not a necessity. Complete homogenous mixing of the crudes is not a strong requirement of crude blending. At a given site, the combination of piping length, turbulence in the flow, and the injection process of the crude into the units will usually accomplish enough mixing to satisfy the requirements.

4. Inline analysers, as discussed above, would aid the operation, but have proven difficult to implement in practical usage for crude blending.

Application Requirements
Should a refinery have the physical equipment required to support best practices in crude blending, the following four types of applications are available to help maximize the benefits.

Tank Composition Tracking
It is a rare occurrence that a refinery has enough crude tankage available that each crude type imported can be dedicated to an individual tank exclusively. Under any other circumstance, any given crude tank will hold a number of different crude types at different times, and is seldom completely drained before the arrival of the next crude. As a result, there is a need to be able to track the composition of crude tanks. This can be linear by volume as a minimum, based on the different crude types pumped in, and the assumption of uniform mixing when calculating remaining composition after use. Linear by mass, or the option to use dedicated property equations all enhance the accuracy.

Ideally, the component tank tracking feature should be automatic with the use of an application that performs Equipment Path and Tracking Control.

Inline Ratio Control
At some point all of the effort expended in crude purchasing, crude blend planning, and unit process control depend on accurately blending crude oils as feed stock according to the recipe calculated and agreed. This is the reason for construction of enough blending equipment (streams) to be able to correctly ratio the mix of different crudes into the crude charge feed line. To achieve this, a ratio control application that will maintain the correct balance of individual crude components and the correct overall combined crude charge rate is required. Such a ratio control application should at the least include basic functionality for alarming under unexpected events, flow and volume monitoring, daily report capabilities, the ability to adjust to changes in rates, and an operator interface for ratio adjustments.

Ideally, a ratio control application should be integrated with the Equipment Path and Tracking Control application so that changes in recipe (new crude or different source tanks) are matched in parallel with
adjustments to the motorized discharge valves on the tank outlets while calculating and maintaining path isolation to prevent contamination of the either the crudes in use or other product piping at the refinery.

**Multi-period Blend Planning with Purchase Analysis**

As previously discussed, a spreadsheet planning tool may be able to calculate a given crude blend recipe that meets the required property specifications for the process units, but will not generate the best benefits to the refiner. An application that can do multi-period planning based on the expected crude slate for the refinery will be far better at meeting the overall and continuous property specifications. As well, any solver based planning tool can do predictive calculations such as calculation of future periods where, given the current expected crude imports, periods where property specifications can not be met.

A good planning package should be capable of doing ‘what if’ calculations where the additional amounts and types of crude required to allow the crude blends to meet property requirements for the full planning horizon can be calculated for the planner. As well, such a planning package should also calculate the time, size, and duration of the crude blends in such a way as to respect tank limits and inventory requirements. All calculated blends must be possible given the crudes on hand, expected, and the available tankage.

Ideally, the crude blend planning package should be able to automatically distribute the blend recipes to the Ratio Control package for execution.

**Equipment Path and Tracking Control**

The final application to achieve the highest level of benefits in crude blending is one that performs Equipment Path and Tracking Control of the piping equipment involved in the crude area. Such a package should both monitor the crude movements and control the equipment involved. Monitoring of the crude movements, especially when expanded to all the crude movements (import, inter-tank transfer, and blending/outflow) will create the information base required to automatically perform Tank Composition Tracking and full reporting of available inventories and usage for planning and yield accounting users. Control of the crude movements is possible because the bulk of the equipment in the crude tank area is of such a size that critical valves are motor operated, unlike the balance of the valves in the offsites area of a typical refinery. Control of the crude movements is desirable because the application can do continuous monitoring of equipment status and path isolation to alarm on unexpected conditions immediately, alerting the operators. Best in class applications can automatically react to field conditions by actions such as automatic start of redundant pumps under a pump fail as well as perform path selection and maintenance of path isolation of the crude movements preventing contaminations or incidents.

Ideally, the Equipment Path and Tracking Control application should be integrated into the Tank Composition Tracking application and the Ratio Control Application so that all material movement, lineup, calculations and reporting are uniform and coordinated.
Summary
With the ever tightening margins of refinery operation combined with cost increases in the base crude feed stocks of the refiner, crude blending has taken on an increased importance in allowing for optimal operation of refineries. However, there is a large gap in crude blending ability between best in class and what is often performed at many sites. This paper has given an insight into steps required to achieve best in class performance in crude blending.