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# Refining 101: The Assay Essay

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When a refinery purchases crude oil, the key piece of information they need to know about that crude, besides price, is what the crude oil assay looks like. There has been a lot of discussion here at various times about "light sweet", or "heavy sour", and how these qualifiers affect the ability of a refiner to turn these crudes into products. So, I thought it would be good to devote an essay to this subject, and discuss how different types of crude can affect a refiner's bottom line.

Let's compare light sweet oil to heavy sour oil by looking at a pair of assays:

| Liquid Volume % | Generic Light Sweet | Generic Heavy Sour |
|---|---|---|
| Gas (Boiling Point to 99°F) | 4.40 | 3.40 |
| Straight Run (99 to 210°F) | 6.50 | 4.10 |
| Naphtha (210 to 380°F) | 18.60 | 9.10 |
| Kerosene (380 to 510°F) | 13.80 | 9.20 |
| Distillate (510 to 725°F) | 32.40 | 19.30 |
| Gas Oil (725 to 1050°F) | 19.60 | 26.50 |
| 1050+ Residuals | 4.70 | 28.40 |
| Sulfur % | 0.30 | 4.90 |
| API | 34.80 | 22.00 |

**Table 1.** Comparison Between Assays of Light and Heavy Crudes

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Note that for this essay we are only concerned with a portion of the assay. The full assay would have information on metals concentration, salt concentration, vapor pressure, etc. What the two assays above tell us is that one is light (the higher the API gravity – a measure of density – the lighter the crude) and one is heavy. It also tells us that one is sweet (low sulfur %) and one is sour. Now, to be clear, a heavy crude can be sweet and a light crude can be sour. But refiners that are equipped to handle heavy crudes are generally also equipped to handle sour crudes, so that's what they buy. Heavy sour is cheaper than light sweet, and there is more money to be made with heavy sour crudes as long as a refinery is configured to handle them. Gasoline doesn't care whether it came from cheap heavy sour or more expensive light sweet; the product price will be the same in either case.

Now, back to the assay, and what the various categories mean. The way the assay is done is that the crude oil is boiled, and the amount boiled off at various temperatures is measured. This defines the various products, or cuts. When 99°F has been reached, the gases have been boiled off. This is the dissolved methane, ethane, propane, some butane, and some trace higher gases. This cut can end up being purified for sales, or it can end up as fuel gas to help satisfy a refinery's need for steam.

The next cut is straight run, or natural gasoline. Gasoline is a mixture of hydrocarbons that are characterized by the boiling point, and the gasoline you purchase at the gas station will contain many different blending components. One of these will usually be light straight run gasoline. This cut will contain things like butane, octane, and every manner of branched and cyclic hydrocarbon that boils in a specific range. Most gasoline has been subject to additional processing (more on that later). The straight run gasoline is what can be expected to be distilled from the crude oil with no additional processing. Typically, straight run gasoline has pretty low octane, so refiners are limited in how much can be added to the gasoline pool. However, lower octane blends will probably contain some portion of straight run gasoline.

The next cut is naphtha. You can do a couple of things with naphtha. You can blend it into gasoline, but the octane is even worse than for light straight run. Therefore, you are seriously limited on how much can be blended. More commonly, naphtha is fed to a catalytic reformer, which processes the naphtha into reformate and boosts the octane from less than 40 in the naphtha to greater than 90 in the reformate. Reformate is then a very desirable gasoline blending component.

We then come to kerosene (also called "jet"), which starts to get into the range of diesel components. This cut also has more energy content per gallon than the earlier cuts, but is too heavy (less volatile) to be blended into gasoline. The sulfur components start to become more concentrated in these heavier cuts, so kerosene is typically subject to hydrotreating. In this step, hydrogen is added to the kerosene in a reactor to convert sulfur components into hydrogen sulfide, which is then removed. Kerosene has a number of uses. It is used as fuel for jet engines, and it is also blended into diesel. It is also used in some portable heating and lighting applications.

The next cut is distillate (specifically, No. 2 Distillate; kerosene is sometimes called No. 1 Distillate). Like kerosene, this cut contains sulfur and must be treated (as do all the heavier cuts). Distillate has two major end uses: as diesel fuel and as home heating oil. In fact, as seen in the assays above, a substantial portion of a barrel of oil ends up as heavy distillate. For the light sweet crude assay above, 32.4% ended up as distillate, and for the heavy sour crude 19.3% ended up as distillate.

We then come to gas oil, which is also known as fuel oil or heavy gas oil (distillate also being known as light gas oil). This cut is typically processed in a catalytic cracker to make cracked gasoline. By the name, you might guess that cracking involves breaking these heavy, long-chain hydrocarbons down into shorter hydrocarbons that boil in the gasoline range. The cracked gas is then blended into the gasoline pool.

The final cut, residuals, or just plain "resid", is the cut of greatest interest when we talk about the economics of heavy crudes versus light crudes. Note in the assay above, that less than 5% of the barrel of light crude ends up as resid. However, the heavy crude yields over 28% resid. Resid is sold as asphalt and roofing tar, and is not a very profitable end product. Therefore, more and more refiners are installing cokers to further process the resid. A coker can take that resid and turn it into additional gasoline, diesel, and gas oils. The economics of doing this are typically very attractive, given the historical price spread between light oil and heavy oil. A coker can turn over 80% of the resid from low-value asphalt into valuable products like diesel and gasoline. (The resid can also be processed by hydrocrackers, but this entails different economics because they require hydrogen.)

### Examples (For Illustrative Purposes Only)

Let's compare two hypothetical refineries. Refinery A has no coker, and thus is restricted to either buying light crude, or buying heavy crude and selling a lot of low-value asphalt and roofing tar. So let's say that Refinery A pays $55 a barrel for West Texas Intermediate. They will turn that barrel into 0.909 barrels of liquid fuel product (per the light assay above, 4.4% ends up as gas, 4.7% ends up as resid, and 90.9% ends up as liquid products), which let's say has a value of $80/bbl. They therefore grossed $80*0.909 - $55 (the purchase price of the barrel), or $17.72 a barrel before we consider the value of the asphalt and the gases. Historically, the value of asphalt has been very low – less than $0.10/lb. Given that a barrel of crude weighs around 300 lbs, and we got a 4.7% asphalt yield, the barrel yielded 300*0.047 = 14.1 lbs of asphalt worth $1.40. Let's value our gases at the value of propane (about $0.14/lb on the spot market), and we get a value of 300*.044*$0.14 = $1.85 for the propane. Our gross profit (before operating costs, taxes, etc. are considered) is then $17.72 + $1.40 + $1.85, or $20.97 per barrel for the light crude.

Now consider Refinery B. Instead of buying WTI at $55/bbl, they buy a heavy Canadian crude for $38/bbl (this is an actual recent price). Again, their barrel of oil weighs some 300 lbs, and as we can see from the assay above their resid yield may be in the range of 28%. So, of the 300 lbs, 84 lbs ends up as resid. But with our coker, we can turn 80% of that into high-value products, and only 20% (16.8 lbs) ends up as low-value coke (a coal substitute). Therefore, the overall yield from the heavy crude amounts to the sum of the cuts up to resid (71.6%), plus the resid that was turned into products (80% of 28%, or 22.4%) minus the gas cut (3.4%) for a total of 90.6%. The overall liquid yield is almost the same as for the light crude, but much less was paid for the heavy crude. So, the economics look like this: For the liquid fuels, we grossed $80*0.906 - $38 = $34.48 a barrel on the heavy crude. This is almost double the profit of the light crude. We have slightly less propane yield than in our previous example. The value of propane is $1.43. Finally, we end up with 16.8 lbs of coke, which is worth only $0.015/lb (about $0.25 total). Our total gross profit then is $34.48 + $1.43 + $0.25 = $36.16.

This explains why so many refiners are rushing to install cokers. This is also why I don't get too excited when someone comments that the build in crude inventories could be a build in "undesirable" heavy sour. Refiners don't buy what they don't need, so if heavy sour inventories are increasing then this is primarily coming from refiners that can process heavy sour.

As light sweet supplies continue to deplete, refiners will increasingly turn to heavy sour crude. But not enough refiners yet have a demand for heavy sour, so it trades at a significant discount to light sweet. This will of course change as more cokers are installed. There will be a higher demand for heavy crudes, and the asphalt market will become more lucrative as the asphalt supply gets rerouted to cokers.

Of course the caveat is that a coker is a major capital expense (hundreds of millions of dollars), and it is only part of the equation. I have focused here on processing heavy crudes, but not at all on sour crudes. The story is similar to that for the heavy crudes. Sour crudes trade at a significant discount to sweet crudes, and the refiners need additional processing equipment to handle them. But the economics currently favor installing the cokers and hydrotreaters to handle the heavy sour crudes, and will continue to do so as long as they trade at a substantial discount to light sweet crudes.

As always, comments, corrections, and questions are encouraged. Do note that while the examples above are approximate, they are not exact. There is more to the economics than what I have presented, but for the purposes of understanding some basic refining economics, this should suffice.

### Additional Reading

Refining 101 at Tesoro
Basic Refining Overview
Petroleum Refining and Processing from the EIA
What is the difference between gasoline, kerosene, diesel fuel, etc.?
How Oil Refining Works