L. E. CURCIO
Refinery Automation Institute, Morristown, NJ

What is blending?

Not a day passes without publications, the blogosphere and pundits wringing their hands over the concept of fuel blending. In today's low-priced crude oil market, the fuel blending business gives blenders a competitive edge that grows every day, attracting new customers and potential new producers intrigued by the possibility of making "easy" money.

The US has more than 330 oil terminals spread across the country that move more than 2 Bgal of oil products. "Smart" blending adds another \$300 MM–\$400 MM in potential profits. This cash flow tempts some people to ask for loans to open a new blending facility to "get rich quick."

The real question for prospective facility owners before undertaking a blending venture should be: What is blending? This question is usually pondered too late, after the bank has already approved the mortgage for a new oil terminal, which may contain a blending facility. The situation becomes one of "learning after building," and can lead to disaster.

Blending vs. baking. Blending is similar to baking a cake. Ingredients and a recipe are needed to determine the amount to pour into a mixing bowl. After mixing, one would taste the mixture and decide whether to adjust the recipe.

Since the US is a huge daily "drinker" of gasoline (9 MMbpd), with more than 300 MM cars on the roads, the gasoline blending business is substantial—worth more than \$120 B/yr.

The gasoline "baking"—or blending—"ingredients" are called blend components or blendstocks.

Similar to baking, refiners require a recipe to determine the right amount of each ingredient to put into a blend. A master blender's product must be able to run a car without damaging the vehicle or causing undue pollution.

With blending, if more alkylate is added or reformate is cut down, the quality of the final product may not meet the final specs. To make sellable gasoline in the US, refiners must follow regulations, such as achieving an octane number of more than 87 or limiting vapor pressure to 7 psi. More than 28 gasoline specs must be met simultaneously. Producers must be careful about how the blend is made, otherwise it will not be possible to sell the final product and realize profits.

Generally, to produce gasoline that meet these specifications, refiners can create a simple blend recipe with three components, or a complex recipe with 10–20 components.

Keeping with the baking analogy, if the final recipe needs 20 grams of fat and 45 grams of carbohydrates, then the chef has to estimate which blend components to blend—i.e., butter (butter-1, butter-2, butter-3), the number of eggs and the quantity needed to meet the final specs.

For example, if the chef chooses butter-1 and one egg, the recipe meets the 20 grams of fat spec, but the carb limit may not be met. On the other hand, if butter-1 and 3 eggs are chosen, the recipe meets the carb specification, but exceeds the fat spec.

It can be understood how beautiful and complicated the blending world is, particularly when there are more than 28 specifications and several components.

Arithmetic of blending. Only the final recipe constraints (specifications) have been taken into account, as well as the number of blend components (ingredients). However, blending is the arithmetic of both properties and prices.

Blends should be used with the cheapest components that allow specs to be met, because the final goal is to make money. While "butter-1" is acceptable in terms of properties, it may not be acceptable in terms of prices because it is too expensive.

The basic arithmetic of blending is shown in Eq. 1:

$$Q = Q_1 V_1 + Q_2 V_2 + \ldots Q_i V_i \qquad (1)$$

where:

Q_i = property of component i
V_i = volume fraction of component i in blend
Q_b = property of blend.

Using Eq. 1, an "easy" example of calculating the final gasoline blend octane number and its price is illustrated in **TABLE 1**.

The goal in **TABLE 1** is to make a 95 research octane number (RON) and to calculate the final blend price. **TABLE 1** shows how the recipe needs to be adjusted—i.e., changing the blend component quantities to meet the final spec on the RON. Prices can also be calculated with the same blend equation to determine if a profit is achieved.

The example is applied to one property (RON) and uses a linear approximation.[1] The calculation becomes quite complex when the same "iteration" is done for the remaining 28+ properties. With blending, the following must be considered:

TABLE 1. Linear gasoline RON octane calculator

Theory: RON_{Blend}(linear) = Sum of octane – bbl/total quantity(bbl)

			Property		Price
Component	**Recipe, V%**	**Quantity, bbl**	**RON**	**Octane, bbl**	**Price, \$/bbl**
Butane	7	7,000	96	672,000	44.00
Light FCC gas (LCN)	29	29,000	90	2,610,000	70.50
Alkylate	19	19,000	92	1,748,000	74.10
Reformate	45	45,000	100	4,500,000	77.00
Totals	**100**	**100,000**		**9,530,000**	
Blend RON octane				**95.30**	**72.25**

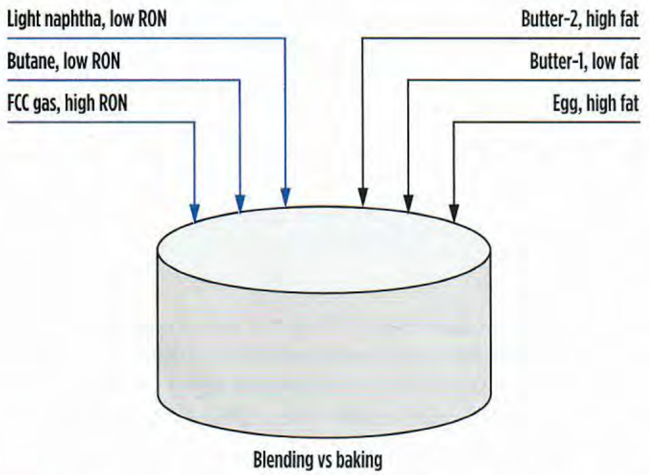

FIG. 1. Blending is similar to baking a cake or cooking a delicious dish. Ingredients and a recipe to decide the amount to pour in a mixing bowl are needed.

- Ingredients—blend components and their properties.
- Recipe—the quantity of each component to blend.
- Inventory—what happens if the recipe requires three eggs but there is only one? Can a blend still be made?
- Prices—try to make the cheapest blend to obtain the highest profit.
- Blend sample and analysis—does it meet the final specs?
- Correcting the blend—if it doesn't meet the final spec, adjust it.

These factors are taken into account using a type of blending calculation software, called an optimizer. Several types of optimizers are available, depending on the complexity of the problem.

In theory, a simple, single-blend optimizer uses liner programming (LP) to calculate the most profitable recipe. This means the user can optimize one recipe at a time. If a user seeks to optimize several blends simultaneously, then a multi-time, multi-blend optimizer that takes into account the change of the inventory should be used.

Single-blend optimizer. A simplified gasoline blending optimization model uses three types of equations:

1. Material/volume balance: $\Sigma\, V_{ci} = V_{\text{batch + heel}}$
2. Quality balance: $\Sigma\, V_{ci}\, Q_{ij} + B_j + g_j = V_{\text{batch + heel}} Q_j$
   a. Where: V = volume of blend component i, Q = quality of component i, B = bias for nonlinear model error, G = giveaway of quality.
   b. If the property Q is non-linear [e.g., octane, $\text{RON}_i = \text{Ri} + g_1(\text{Ri} - \text{Ra})^2 + g_2(\text{Ri} - \text{Ra}) \times (\text{Oi} - \text{Oa}) + g_3(\text{Oi} - \text{Oa})^2 + g_4[(\text{Si} - \text{Sa})^2 \times (S^2)\,a]$, then a non-linear LP solver should be used.
3. Blend profit is the equation that the optimizer uses to maximize profit or minimize costs.
   a. Maximize objective function (OF): OF = Sell Price-Ct
   b. Where: P = profit, C = total cost of blend components.

The blending problem has constraints, including:

- Inventory—not an infinite supply
- Product specifications—28 different specs for each grade
- Delivery time—liftings
- Blend properties
- Prices
- Final batch size.

TABLE 2. Single-blend optimizer

Blend components	% in blend	Amount, bbl
Raffinate	23.7	9,605
Isomerate	6.16	2,496
LVN	1.1	446
HN	0	0
Butane	7.4	2,999
FCC gas	37	14,995
Alkylate	24.64	9,986
Total	**100**	**40,527**
	Batch size, bbl	40,527
	Cost of blend, \$/bbl	64.18
	Sales price, \$/bbl	70.2
	Total profit, \$/bbl	**6.02**
	Batch profit, \$	**243,973**

This results in a system of "n + 2" simultaneous equations to be solved. If using non-linear equations, the solver must then be able to solve a system of non-linear equations, one for each "n" quality and volume balance plus profit equation. At the end of the optimization, a general blend optimizer tool—if using the single optimizer and not the multi-time, multi-blend optimizer—shows the optimized recipe and the profit (**TABLE 2**).

Takeaways. Interest in blending is born of enormous economic potential. With the present oil glut and component availability, buying cheap components around the world and blending them together can potentially yield great profits, even with transportation costs and contango premiums. Those looking to facilitate blending should have the following:

- A small facility with three to four components—many of them use "anchor" components, such as light naphtha, cat gas and butane, as they are cheap, widely available and have great blending properties to achieve the final blend.
- Blending software that helps achieve the goal with little effort.
- A few million dollars to invest, with a breakeven point seen in a few months. HP

REFERENCES

[1] Barsamian, A. and L. E. Curcio, "Gasoline blend optimization via linear and non-linear programming optimizers," Refinery Automation Institute LLC, April 2016.

LEE ELISEO CURCIO is a chemical engineer and vice president at RAI. He has worked with RAI for the past 4 yr in the areas of gasoline, diesel, bunker blending, ethanol non-linear property correlations and octane boost, and naphtha and butane blending. Mr. Curcio also teaches the gasoline, diesel and bunker blending optimization section of RAI's blending public course. He previously worked at Catholic University of Louvain in advanced modeling and optimization. He holds BS and MS degrees in chemical engineering with honors from the University of Calabria, Italy.