Butane Blending

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discuss the economic benefits obtained through optimisation of butane content within gasoline.

One barrel of crude oil produces 80 – 85% of blended fuel products such as gasoline, diesel, and fuel oil. Gasoline fuel production is between 45 – 55% of one barrel of crude oil. These fuels products are made by blending 6 – 12 components which are produced in the refinery process units and have different qualities such as research octane number/motor octane number (RON/MON), Reid vapour pressure (RVP), distillation points, olefins, aromatics etc., to meet the final product specifications. Each of these quality specifications are controlled by regulatory agencies such as the US Environmental Protection Agency (EPA) who impose restrictions for greenhouse gas emissions both for the regional climate and population centres. In addition, quality specifications are seasonally adjusted for proper functioning of vehicles in all weather conditions.

Gasoline properties and significance

RVP is a measure of volatility of the fuel and has absolute maximum value of atmospheric pressure of 14.7 psi (101.35 kPa). It has both minimum and maximum specifications and varies regressively from winter to summer. Modern fuel injection systems have greatly decreased the impact of changing fuel volatility that was a routine problem for carbureted engines. However, the impact still exists and the systems still require liquid (non-gaseous) fuel with adequate volatility. Cold temperatures will not properly atomise low RVP fuel within a cold engine and a high temperature with high RVP fuel will tend to produce vapour in the fuel supply. Naturally, RVP specifications are higher for the winter season than the summer season and can vary from region to region.

Table 1. Gasoline properties and their significance

Quality	Specification limits	Typical range	Seasonal/regional variation?	Significance of quality
RON	Minimum	94 – 95	No	Prevention of pre-ignition or knocking at low RPM of approximately 600
MON	Minimum	84 – 85	No	Prevention of pre-ignition or knocking at higher RPM of approximately 900
RDOI	Minimum	89 – 90	No	(R+M)/2
RVP	Minimum/maximum	7 – 14.25 psi	Yes	Low RVP will not vaporise fuel to start the engine in winter, higher RVP in summer will cause vapour lock and health hazard due to ozone layer inverson
T10	Minimum	122 – 158˚F	Yes	Engine performance from cold start to warm behaviour
T50	Minimum/maximum	250 – 365˚F	Yes	
T90	Maximum	374 – 365˚F	Yes	
EP	Maximum	437˚F	No	
Sulfur	Maximum	10 – 95 ppm	No	Corrosion of engine parts, exhaust system, emission toxicity
Olefins		3 – 14%		Exhaust emission toxicity
Aromtics		20 – 40%		
Benzene		0.09 – 0.31%		
Drivability index		850 – 1275˚F		Engine performance over temperature range calculated from T10, T50, T90 and % ethanol
Vapour/liquid (V/L)				Measure of temperature at V/L ratio = 20 to facilitate spark ignition

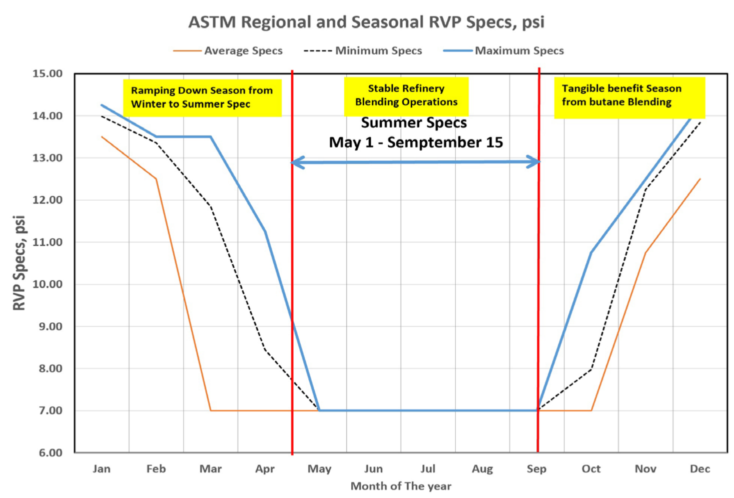

Figure 1. Regional and seasonal RVP specifications.

Refiners sometimes make 20+ boutique grades of gasoline with different RVP specifications alone to meet the regional and seasonal demands of gasoline. Table 1 shows an example of gasoline qualities, range, and types of specifications and their environmental and vehicle-related significance.

From Table 1 it can be seen that RVP is the only direct gasoline specification that has regional and seasonal maximum values as controlled by EPA. The maximum value of RVP for most states is 9 psi but also has lower values of 7 and 7.8 for some population centres. The RVP limit is extended to 10 psi if the formulation has 9 – 10% ethanol. The addition of ethanol in the gasoline reduces the vapour pressure of ethanol – gasoline blend and lowers the temperature to achieve critical vapour/liquid (V/L) of 20 to avoid vapour lock.

Regional and seasonal RVP specifications

The controlled period for the summer blend RVP is as follows:

- For refiners and terminals – 1 May to 15 September.
- For retailers and wholesalers – 1 June to 15 September.

However, the RVP controlled period in California, US, is from 1 May to 31 October with a different period for different air basins and counties within that timeline to start earlier or later. Figure 1 shows variation of RVP specifications for various California air basin and counties. EPA limits highest RVP summer value as 9 for all states other than California. This historical data for California will be used to discuss the concept of this article.

Figure 1 shows that refiners gradually ramp down the gasoline production with lower RVP to meet 1 May deadline for the summer specification and again start ramping up from 15 September or later, as the case may be, for winter gasoline blends. During the summer period of 1 May to 15 September, refiners produce gasoline blends with constant RVP value of 9 psi in most states.

RVP can be increased for winter blends by adding externally or in-line blending as butane can blend with gasoline in liquid form, but refiners face the challenge of lowering the RVP of winter blend ramping down to summer blend as butane cannot be simply taken down. Hence, refiners use lower RVP value components in winter blend to meet summer specifications during ramp-down period. This lower RVP value gasoline is expensive and hence the price of gasoline is higher in summer than is in winter. Figure 2 shows the variation of mid-grade (RON 87) prices over 2018, revealing how gasoline prices synchronise with transition of winter grade to summer grade.[1, 2]

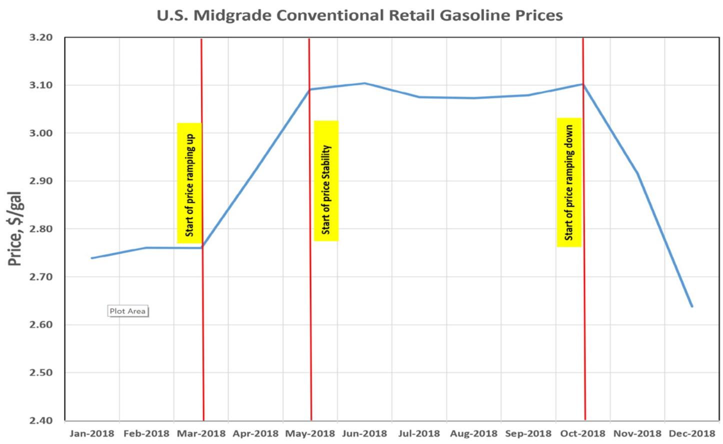

Figure 2. Variation of 2018 prices for mid-grade conventional gasoline.

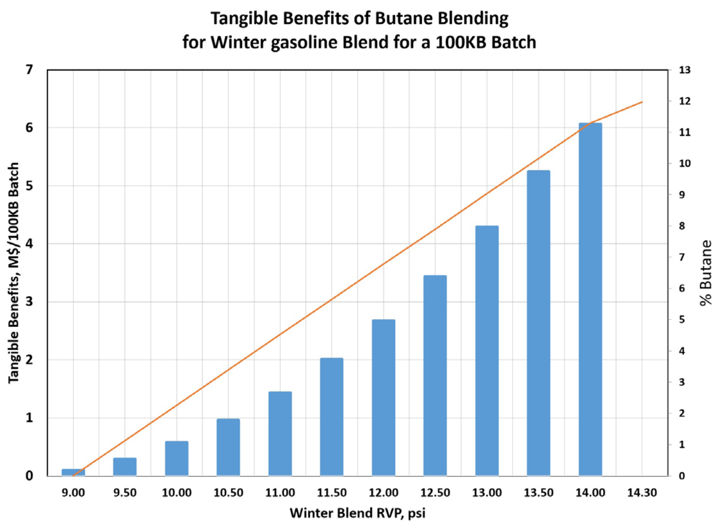

Figure 3. Butane blending tangible benefits.

Figure 4. Blending system hardware.

Tangible benefits

Refiners, pipeline operators, and terminals will obtain the maximum economic benefits of optimal butane blend during RVP ramping stage for the period of 15 September to 31 December. However, all parties can see some economic benefit throughout the cooler months by reducing the difference between the blended product and the regulatory (SAE and EPA) restrictions. The tangible benefits come from the fact that butane can be added more profitably to gasoline than to the LPG pool. This increases the sale value of gasoline US$2/gal higher than LPG. This increase is calculated based on the average winter price of gasoline and butane as US$3/gal. and US$0.94, respectively.

The analysis conducted in this article used a simple 2 by 2 algebraic equation to blend mid-grade (RON87) with butane for octane and RVP values. Furthermore, a linear blend model for RVP was used for simplicity, to illustrate the order of magnitude of tangible benefits at various levels of RVP's in winter blends. However, it is important to note that a properly designed butane blending control system uses a non-linear equation for the control of final blend RVP.

Figure 3 shows the results of the simple calculations, demonstrating that the tangible cost benefits can vary from US$100 000 to US$6 million for a gasoline batch of 100 000 bbl as a function of the butane content in the gasoline being as high as 11 – 12% based on blend RVP value. The tangible benefits increase during the winter period RVP ramping steps. It was also estimated that the refiners (or downstream parties) can realise maximum tangible benefits of over US$600 million for 100+ batches of 100 000 bpd gasoline for the entire duration of the winter season. This huge benefit simply should not be ignored by the refiners and retailers as it provides a rapid ROI for a butane blending system.

Process of butane blending

The blending of butane into gasoline at both the refinery and in downstream operations is not new. However, as the industry matures, it is no longer a race for innovation but instead one focused on optimising existing assets.

Historically, gasoline blending has occurred in a storage tank with the butane content determined by outdated mathematical models. This method is still widely used but has two major deficiencies: the economic giveaway inherent to mathematical (best-guess) determination, and the risk involved in adding free butane to a floating roof tank that is not designed for LPG storage as the cost for both equipment and the downtime associated with a floating roof failure is significant.

Most modern refineries have an inline blending facility for gasoline where the RVP can be measured through the Fourier-transform infrared spectroscopy (FTIR) analyser, which also measures other characteristics such as octane. However, the FTIR method has proven to be an unreliable tool for RVP measurement, which provides little benefit over traditional mathematical modelling.

An optimal design, which provides the maximum tangible benefits, is an inline system that accurately measures the two feedstocks and controls the butane feed to prevent any upset. The system should utilise an online RVP analyser with the same triple expansion method used in the laboratories of the regulators.

Blending infrastructure

A terminal butane blending must consider the following aspects of its infrastructure:

Storage

If LPG storage does not exist at the site, the choice of permanent or temporary storage is largely a matter of the expected usage, which plays into the economic calculation. A permanent storage facility can be costly, but it offers a guaranteed supply if the logistics in the locale are difficult. However, as propane and butane are used for heating and cooking fuel worldwide, obtaining a local contractor for installation, regulatory support, and maintenance is a simple proposition. Temporary storage, on the other hand, occurs in the form of trucks or rail. This method is less expensive, with the main disadvantage being a supplier's inability or unwillingness to provide the tank for an extended period or with a limited tanker capacity.

Transfer

It is imperative for the proper operation of the blending unit that it be supplied with full liquid phase butane as any gas production will not bond with the gasoline. Care must be placed on the effects of overflow prevention, strainers, and shut-off valves prior to the pump.

Commonly a sliding vane pump is used for transfer from trucks and permanent storage. This style of pump is resilient to some amount of cavitation, but its suction capability needs to be cared for because, as mentioned, the production of the gas phase can be an issue. The use of a vertical (canned) turbine pump can eliminate many problems due to its inability to create vacuum conditions.

Figure 4 shows a typical blender system with 12 in. pipeline for gasoline stream and a Coriolis meter for custody transfer. The system uses a pair of Coriolis meters and flow control valves (FCVs) to obtain a 100:1 turndown ratio on the butane feed.

Figure 5. A RVP online analyser system.

Metering, blending, and analysis

It remains imperative that the gaseous phase is eliminated not just for the proper operation of a blender but for the safety and environmental risk imposed downstream. Therefore, best practice is to monitor this gaseous phase and return it to the storage tank with an automated valve commanded by the Coriolis flowmeter through the control system.

This type of meter handles two phase flow and the latest technology can provide fairly precise estimates of its proportion to liquid.

All systems will have to manage at least a 10:1 turndown ratio but in many cases a 100:1 turndown is justified. The 100:1 turndown scenario is easily managed using a dual high and low stream with the maximum expected controlled flow of the smaller stream being approximately 10% of the larger.

Once the butane has been properly measured and metered, it is important to blend the mixture as rapidly as possible in order to both provide a representative sample for analysis as well as to ensure that the light end is retained. If the downstream process does not have a back pressure greater than vapour pressure of the butane at the operating temperature, a restriction needs to be in place which can be in the form of a simple orifice plate or a throttling valve. The injection design should ensure a distribution throughout the gasoline pipeline's cross section prior to the mixing element.

The benefits of using an online analyser for the RVP measurement will typically justify the capital expense and maintenance involved in these systems. The use of these devices allows for a repeatability of ≤ 0.50 kPa (0.073 psi) and ensures that the customers and regulatory authorities will be satisfied while optimising revenues.

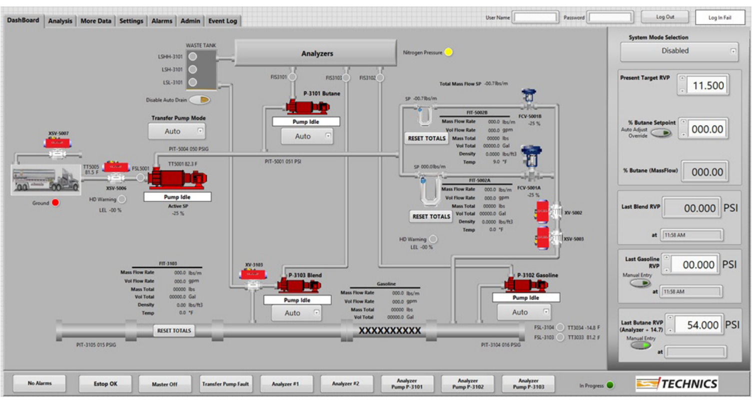

Figure 6. A typical graphical user interface for a blending system.

Finally, the blended product is measured by an RVP analyser that complies with the latest vapour pressure standards such as ASTM D6378 for the measurement of gasoline and ASTM D6897 for the measurement of LPG.

Figure 5 shows a typical control and analysis system with fast loop pumps for butane, gasoline, and the blend.

Control system

The control system should be designed as mission critical not only due to the regulatory and safety implications caused by a butane-rich blend, but also due to the fact that revenues occur in batches during the year. A typical butane blending operation proceeds as follows:

- The controller is placed in ready mode and it immediately samples the butane feed, measuring and recording its RVP.
- After the butane is measured, the system sits idle, waiting for gasoline flow. Once detected, the raw gasoline is sampled and its vapour pressure and density are recorded.
- The system begins to add butane to the flow. The amount of butane delivered is calculated through a specific algorithm equating the density and RVP of the feed streams along with certain assumptions on their composition.
- At this point the system begins analysing the homogenised fuel and adjusts the transfer of butane to match the overall target given the value of the blend already transferred to the storage tank.
- The system re-enters idle mode when the gasoline flow is stopped. A batch report is generated and stored in the computer. The deviation between calculated and actual RVP is used by the computer to modify its stored algorithm in preparation for the next transfer.
- For systems that directly feed tankers, the next instance of gasoline RVP is assumed to be the same and thus the first three steps are bypassed.

Figure 6 shows a typical graphical user interface display to control and monitor the butane blending system.

Conclusion

This article has discussed the concept of butane blending with respect to its significance for gasoline properties and tangible RVP giveaway benefits due to seasonal and regional changes in RVP specifications. The attributes of modern butane blending infrastructure have also been discussed, describing butane storage options, hardware, quality measurement and control system.

Overall, this article has shown that tangible benefits from butane blending can be significant.

References

1. 'Reid Vapor Pressure (RVP) Control Periods for California Air Basins and Counties', http://www.arb.ca.gov/desig/adm/basincnty.htm
2. 'Gasoline Reid Vapor Pressure', https://www.epa.gov/gasoline-standards/gasoline-reid-vapor-pressure