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Revision Memo

12/00	References have been updated. Text has been completely reviewed and revised to bring this DP in line with references and lessons learned on recent problems and larger projects.
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SCOPE

This section covers refinery offsite facilities for blending of components into finished petroleum products. A generalized procedure is presented, supplemented by considerations associated with selection of the basic blending method and system design.

In addition, a brief description of product characteristics and the more significant product specifications is included. Techniques used to estimate component and blended product qualities are not covered in this section, nor are techniques to develop actual blend recipes.

REFERENCES

DESIGN PRACTICES

Section XII	Instrumentation
Section XIII	Mixing Equipment
Section XV	Safety in Plant Design
Section XXII	Storage Facilities
Section XXIII	Product Loading Facilities

INTERNATIONAL PRACTICES

IP 3-12-1	Valve Selection
IP 4-3-3	Shelters for Process Analyzers
IP 15-4-1	Flow Instruments
IP 15-8-1	Process Stream Analyzers
IP 15-8-2	Sample Transport and Sample Conditioning Systems for Process Stream Analyzers

OTHER LITERATURE

1. *FT-IR Spectroscopic Composition/Octane/Cetane Analyzer*, ER&E Report No. EE.32E.94.
2. *FT-IR Closed Loop Control At Antwerp*, ER&E Report No. EE.40E96.
3. *Fuels Products Blending Best Practices*, (12/00 draft version), Chapter 8, h ECI Supply Best Practices.
4. *On-Line FTIR Spectroscopic Octane / Composition Analyzer on Mogas Blending*, from Utilities and Offsites Newsletter, Vol. 6, Exxon Research & Engineering Co., January 1995
5. *FT-IR Provides Cost Effective Analytical Data For Compliance With Low Emissions (Reformulated) Automobile Fuel Specifications*, ER&E Report No. EE.59E.99.
6. *FTIR Diesel (ADO) Fuel Cetane Number Analyzer*, ER&E Report No. EE.152E.96.
7. *Computer Control Practices (ECCP) Manual*, EMRE Manual No. EETD 019, Volume 3, Control for Specific Processes (CSP), Section 033, Blend Control and Optimization, first issued as ER&E Report No. EE.5E.99.

DEFINITIONS

Analog Control

Control System in which all controllers and signal transmissions use a continuous varying signal.

Battery Limits

Demarcation signifying onsite/offsite interface.

Digital Control

Control System in which all controllers and signal transmitters use a discrete binary value.

Direct Digital Control (DDC)

Regulatory control of a process loop by a computer without the use of any controller in the loop.

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DEFINITIONS (Cont)

FT-IR Analyzer

An analyzer which uses Fourier Transform InfraRed Spectroscopy to transform spectra in the mid infrared region to a component breakdown for a sample. The analyzer must be calibrated against all possible types of product components by comparison to known data from lab testing of samples. EMRE's Corporate Research Laboratory and Technology Department's Plant Computing Division have developed patented modeling software and proprietary modeling applications for the FT-IR analyzer. This platform permits the simultaneous measurement of several properties by translating the molecular information in the IR spectra into general properties for the whole sample. FT-IR analyzers have been successfully used in blending service (mogas, ADO) to measure most or all limiting product specifications. EMRE Technology Department's Plant Computing Division should be consulted for the latest approved applications.

In-Line Blending

The simultaneous introduction of components into a common product blending header.

On-Stream Analyzer

An analyzer which has been adapted for continuous or intermittent on-line sampling, automatic analysis of the quality being measured and readout/output of the results.

Orifice Meter

An in-line device used for measuring flow rate. Orifice meters consist of a restriction, usually a sharp-edged orifice plate, across which pressure drop is measured. The output is proportional to the square root of the flow rate.

Positive Displacement Meter (PDM)

An in-line device used for measuring flow rate. PDMs measure flow by mechanically isolating the flowing fluid into known volumes. Output is proportional to flow rate, and is in the form of an electrical pulse train.

Product Quality Giveaway

Product quality giveaway occurs when a blended product quality is within specification but exceeds the minimum or is below maximum specification in terms of value. For example, a fuel oil with a 0.2% sulfur level versus a maximum specification of 0.3% contains 0.1% sulfur giveaway. Giveaway is impossible to avoid for all grades or for all specifications within a grade simultaneously when there are insufficient degrees of blending freedom.

Supervisory Control

Control of a process loop by a conventional analog or digital controller, with computer adjustment of set point.

Turbine Meter

An in-line device used for measuring flow rate. Turbine meters consist of a rotor that senses the linear velocity of a flowing stream. The moving fluid imparts a rotational velocity to the rotor, which results in an output that is proportional to flow rate, and is in the form of an electrical pulse train.

PRODUCTS AND PRODUCT SPECIFICATIONS

Product specifications and demand patterns are in general developed by an affiliate's marketing organization. When a new refinery or expansion project is initiated, product quality and volume forecasts are developed to cover the future three, four or more years. This information serves as a starting point for process planning which involves developing the most economical methods of manufacturing these products. Typical product characteristics and the more important product specifications are described below.

MOTOR GASOLINE

Motor gasoline (mogas) is a complex blend of paraffins, olefins, naphthenes and aromatics, which contain low boiling point components (C₄) as well as materials boiling up to 400°F (200 °C) and higher. In addition, special additives or components are used to achieve certain qualities.

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PRODUCTS AND PRODUCT SPECIFICATIONS (Cont)

Mogas specifications within ExxonMobil vary with grade (e.g., regular and premium), location, and in most instances, season of the year. The primary specifications are octane ratings (which are indicative of antiknock performance), volatility specifications (which are indicative of warm-up, anti-stalling qualities and vapor emissions during handling) and limitation on certain components, e.g. benzene and lead components (TML and TEL).

Octane quality is specified by the following:

Research Octane Number (RON) is an indication of the relative antiknock quality based on comparison with a reference fuel. RON, by nature of the prescribed testing procedure, is a measure of engine performance at low speeds.

Motor Octane Number (MON) is a measure of antiknock quality under more severe operating conditions than for RON. MON is indicative of performance under wide-open throttle and high-speed conditions.

Road Octane Number (RdON) is established under actual road conditions and is thus the most important octane quality of gasoline. Road ratings are established for cars typical of a car population. The resultant RdONs are then correlated with RON and MON to permit quality control during blending using RON and MON techniques of analysis.

Octane Distribution (ΔR) is a comparison of the octane rating of a light fraction of the fuel with that of the whole fuel. This is a measure of the uniformity of octane distribution in a multi-cylinder engine. It has been found that with some engine designs (notably European) road octane number correlates best with RON and ΔR .

Volatility is specified by:

Reid Vapor Pressure (RVP) is vapor pressure at 100°F (38°C) when measured under special conditions. RVP, together with % distilled at 158°F (70°C), is an indication of the vaporlock tendency of the fuel. Vaporlock index (VLI) is a correlation of these two properties.

% Distilled at 158°F (70°C) is a measure of the quantity of low boiling point components and is used to calculate VLI (see RVP, above).

% Distilled at 212°F (100°C) characterizes the warm-up quality of the gasoline.

90% Distilled Temperature is another indicator of warm-up quality and the heavy ends in the gasoline.

In addition to these specifications, gasoline must also meet other qualities, for example specific gravity, minimum amounts of oxygenates, maximum amounts of aromatics, and satisfactory deposit and corrosion characteristics.

MIDDLE DISTILLATES AND FUEL OILS

Middle distillates are petroleum products within an approximate boiling range of 300 to 700°F (150 to 370°C). Principal products in the middle distillates category include the following:

PRODUCT	APPROXIMATE BOILING RANGE, °FVT (°CVT)
Jet Fuels	300 to 500 (150 to 260)
Kerosene	350 to 550 (175 to 290)
Diesel Fuels	300 to 700 (150 to 370)
Heating Oils	300 to 700 (150 to 370)

Jet fuels and Diesel fuels are used as fuel for transportation in aviation turbines and diesel engines, respectively. Kerosene is used for heating in smaller furnaces and for a number of other more specialized purposes. Heating oils are generally used in small furnaces for heating in domestic housing.

Fuel oils constitute that group of products with boiling points over about 700°F (370°C). The main applications for which these products are designed include steam and power generation, central heating and industrial processing.

The more important product qualities to which middle distillates and fuels oils are often blended are discussed below:

Flash point is the lowest temperature at which a fuel gives off sufficient vapor to form a fuel-air mixture that will ignite under specific test conditions. This is an indication of the fire and explosion hazards and the minimum acceptable and / or maximum allowable flash point is generally specified. See [Section XV-A](#) for further details on Flash points.

Pour point is the lowest temperature at which an oil will flow (under specific test conditions) under gravity and characterizes pumpability.

Cloud point is the temperature at which paraffin wax or other solid substances begin to crystallize out or separate from solution. Cloud point is indicative of the temperature at which plugging of fuel filters occur.

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PRODUCTS AND PRODUCT SPECIFICATIONS (Cont)

Freeze point is an important specification for aviation fuels both for turbine and reciprocating engines. It is the temperature at which crystals of hydrocarbons formed on cooling completely disappear again when the temperature is allowed to rise, thus it is an indication of when separated solids could be formed at temperatures encountered during flight or on the ground.

Pour point, Cloud point and Freeze point are all functions of the tail end of the product cut. Pour point and Cloud point are usually specifications associated with diesel type cuts, whereas Freeze point is usually associated the jet fuel cuts.

Cetane number and **Cetane index** are measurements of the fuel's ignition behavior. The number (or index) gives an indication of the time lag between the moment a fuel reaches combustion temperature and when spontaneous combustion occurs. This is an important specification for diesel fuels. Cetane number is measured in an ASTM standard engine against a reference fuel. Cetane index is calculated using an ASTM nomograph or ASTM formula and is based on distillation properties and density. Cetane number can be improved by additive injection whereas Cetane index cannot due to the way it is defined.

Heating value is a calculated property based on the product's density, boiling range and P/N/A composition. These properties are usually specifications in themselves leaving no flexibility to manipulate the Heating value. Therefore, the Heating value is usually not a specific blending target but a reported number.

Viscosity is a measure of resistance to flow and controls the ease of pumping as well as the quality of atomization. Heating oils and fuel oils are commonly graded according to viscosity.

Sulfur content is important because sulfur compounds are oxidized in the combustion process. These oxides are very corrosive in the presence of water and also contribute to air pollution. Government regulations control sulfur concentration, either directly, by setting the maximum allowable concentration in the fuel burned by the consumer, and/or indirectly, by specifying the maximum allowable SO₂ ground-level concentrations.

Distillation is a measure of a fuel's tendency to vaporize and is an important characteristic of middle distillates. These specifications usually take the form of a minimum percent overhead at certain temperatures and an upper limit on final boiling point. Percent overhead is a good measure of front-end volatility, which characterizes ease of ignition. Final boiling point imposes a limit on the quantity of heavy material, which is hard to vaporize, that can be included in a product.

LIQUIFIED PETROLEUM GAS (LPG)

LPG is gaseous at atmospheric temperature and pressure and consists essentially of propane or butane or any specific blend of these components. LPG products are used primarily for domestic purposes, such as cooking and heating. They are also used industrially, supplying fuel for utility stations, space heating, drying and some types of motorized vehicles. The most commonly specified product qualities are:

- **Vapor pressure**, which is an indirect measure of the percent C₃ and C₄.
- **Specific gravity**, which is sometimes correlated to heating value.
- **Water content**, which is usually specified as "nil," to avoid the problems associated with freezing.

Other LPG product qualities, which may be specified, include sulfur content and distillation (both previously discussed).

ASPHALT

The basic components of asphalt products are generally derived from a vacuum distillation process. The four major types of asphalt are:

- **Asphalt cements**, which are straight reduced asphalts used primarily for paving. Product grading is by the penetration test or viscosity. Blending may be employed to produce multiple product grades from high and low-penetration (or viscosity) grades.
- **Cutback asphalts** consist of a straight reduced component blended with a solvent, thus permitting handling at reduced temperatures. The most common solvents are naphtha for rapid-cure grade (RC), kerosene for medium-cure grade (MC), and gas oil for slow cure grade (SC).
- **Air-blown (or oxidized) asphalts** have a higher softening point than the straight reduced variety. These are employed primarily in the roofing industry.
- **Emulsified asphalts** are suitable for use at relatively low temperatures and consist of an asphalt-water emulsion. Water takes the place of the more expensive solvent required in the cutback grades.

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PRODUCTS AND PRODUCT SPECIFICATIONS (Cont)

Important asphalt product quality specifications include the following:

- **Penetration** is an empirical measure of consistency after hardening.
- **Viscosity** provides for control of consistency of the handling temperature.
- **Ductility** indicates the ability to stretch or elongate before breaking.
- **Solubility in trichloroethylene** is a measure of percent bitumen and serves as an indication of the level of contaminants.
- **Loss on heating** characterizes the amount of degradation (penetration and/or viscosity) as a result of exposure to heat and air during handling.
- **Softening point** is used as the basic measure of consistency for air-blown asphalts.

Other asphalt qualities which may be specified include distillation, minimum flash point (both previously discussed) and maximum ash content.

ADDITIVES

Small quantities of chemicals are added in varying degrees to blended or finished products to enhance certain properties. The majority of these are added before the product leaves the refinery, usually as a part of product blending or shipping operations; however some are added onsite during processing or later, in the distribution system outside the refinery. The more common additives in use today are listed in **Table 1**. Considerations associated with the design of additive facilities are covered under *Additive Handling and Injection* in this section. The requirement for additives is determined for each product by the (affiliate's) planning function.

BASIC DESIGN CONSIDERATIONS

BASIS FOR BLENDING RECIPES

During the Definitive Planning and Basic Design stages the offsite facilities designer should work closely with the planning function for the affiliate to ensure that the agreed upon blending recipes translates into a reasonable flexibility in the blender hardware. This should be done to optimize the number of new pumps, lines and control valves.

DESCRIPTION OF BLENDING METHODS

The basic methods of blending components into finished products are discussed below. Each product category (for example mogas, distillates, fuel oil) should be considered separately when one is evaluating blending methods. Differences in blending requirements have frequently led to the provision of two or more basic types of systems to blend a complete product slate.

The optimum blending method is selected based on investment, operating cost and operability considerations associated with both tankage and blending facilities. The prevailing conditions, which directly affect the outcome of this evaluation, are process characteristics, number of components and/or product segregations, degree of automation, and tankage requirements. Specific conditions, which frequently lead to selection of each of the basic systems, are discussed below under each type of blending system.

Batch Blending - This method consists of transferring calculated volumes of components, usually one at a time, from blendstock tankage to product tankage. The components are then mixed in the tanks by agitation or recirculation to insure correct and homogeneous quality. Component measurement can be done either by tank gauging (on the component tanks or on the finished product tanks, if components are transferred sequentially) or integrating flow meters.

Batch blending requires the least complex control system. However, it has a major disadvantage since the blended qualities cannot be tested until after the finished product tank is filled and fully mixed. This may result in repeated corrections and longer blending time in order to meet product specifications and/or avoid unacceptable product quality giveaway.

Batch blending has not been specified on recent heritage Exxon projects. When compared with other techniques, this method is characterized by less efficient tank utilization and increased blending time. However, under certain circumstances economics may favor this approach.

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BASIC DESIGN CONSIDERATIONS (Cont)

In-Line Blending from Tankage - This blending method also requires the use of both component tankage and product tankage. However, the components are pumped simultaneously under flow or flow ratio control through a common blending header. The contents of the product tank are approximately on-specification at any time during the blending operation provided the flow ratios correctly reflect the current component tank properties. An in-line blending system from tankage is shown in **Figure 1**. Each component is ratioed either to a master component on flow control or to a total blending rate signal. Analyzers provide both component and product properties input to an advanced computer blending control system which in turns control the various component flow rates. The blend quality control application calculates the component flow ratios (or component flows) required to meet blend header product quality specifications over the entire blend. Conventional on-line analyzers, such as octane engines (for RON and MON), RVP and distillation are suitable for blend quality control. However, more recently, FT-IR analyzers have been used. From strictly a blending standpoint, a single FT-IR analyzer is capable of monitoring multiple component streams as well as the finished product to allow the control system to make on-stream corrections during the blend operation to reflect minor changes in component qualities.

This type of blending system is frequently used for mogas (gasoline).

The following factors should be kept in mind when one is considering in-line blending from tankage:

1. Component tankage permits mixing and testing of components prior to blending. A minimum of two tanks per component is preferred. One tank is assigned for the blend and the other for production rundown. The tank assigned for the blend should be well mixed such that the component quality will not vary over the blend cycle. Provided component tank(s) are well mixed and isolated from production rundown, component qualities can be certified by lab analysis and periodic or continuous sampling is not required during blend operation. If blend component quality varies during blend operation (i.e. tank not well mixed and/or blend tank is not segregated from production rundown) on-line monitoring of component quality should be considered.
2. This type system is very flexible and permits minimizing product quality giveaway if components of appropriate quality are available.
3. Multiple grades per product and seasonal blend variations can often be handled sequentially through one blending header, thereby minimizing blender investment.
4. Tankage requirements to cover working and turnaround requirements (see **Section XXII**) may be split between blendstock components and finished product tankage. Consistent with the concept of minimizing total tankage, component storage is preferred to finished storage since it provides better flexibility to blend multiple finished products.
5. With accurate component flow/ratio control, the blend may be considered "on-spec" as soon as all components are mixed in the blending header. Thus, while the blending is in progress, sampling of this header will permit blend evaluation and fine point blend corrections to optimize the blend. Furthermore, this technique will result in multiple sampling and testing leading to reduced standard deviation for the blend which, in turn, results in much greater test accuracy/reliability and further blend optimization.

In-Line Off-Unit Blending - This method provides flow control of components into products as the components come off the unit. An off-unit system is shown in **Figure 2**. Each process stream is pressure controlled at one location in the blending manifold. Product components are ratioed to a pressure-controlled or flow-controlled master stream. In this type of system, there are essentially no component tanks and thus limited opportunity to optimize component utilization and product quality changes over a period of time. The most effective way to minimize product quality giveaway and stay within product specifications is by implementing closed loop blend quality control with on-line blend header analyzer(s).

This type of blending is typically used for distillate products. For further details, see discussion in *References 3 and 7*.

The following factors should be kept in mind when considering an In-line Off-unit of blending system:

1. Component production (quality and/or rate) should be reasonably stable to avoid blender upsets.
2. If all process units are turned around at one time, this type of blending system would be well suited. However, in most cases, partial turnarounds can be accommodated by varying blend formulations and perhaps accepting product giveaway for a limited period during the turn-around.
3. A constant crude slate would also suit this type of system, since blender operations would be stable. However, crude slate changes can be accommodated by changing blend formulations.
4. Product quality giveaway is harder to control with this type of blending system than with a component tankage system, since blends must be made from whatever is produced from the onsite units. Thus, normal variations in component blending qualities are undetected and uncompensated for in the volumetric flow and/or pressure control of the off-unit blender unless an analyzer system or predicted properties from the upstream unit are used on the streams going to the blender, see the general comment above. By the addition of recirculation and mixing systems, corrections can be made in the product tanks.