**Product Blending**
Refining processes do not generally produce commercially usable products directly, but rather semi-finished products which must be blended in order to meet the specifications of the demanded products. The main purpose of product blending is to find the best way of mixing different intermediate products available from the refinery and some additives in order to adjust the product specifications. For example, gasoline is produced by blending a number of components that include alkylate, reformate, FCC gasoline and an oxygenated additive such as methyl tertiary butyl ether (MTBE) to increase the octane number.

1- Reid Vapour Pressure Blending
RVP is the vapour pressure at 100 F of a product determined in a volume of air four times the liquid volume. RVP is not an additive property. Therefore, RVP blending indices are used. A commonly used RVP index is based on an empirical method, which is

\[ BI_{RVP_i} = RVP_i^{1.25} \]  
\[ \text{……………………… (1)} \]

where \( BI_{RVP_i} \) is the RVP blending index for component \( i \) and \( RVP_i \) is the RVP of component \( i \) in psi. Using the index, the RVP of a blend is estimated as

\[ BI_{RVP,\text{Blend}} = \sum_{i=1}^{n} x_{vi} BI_{RVP_i} \]  
\[ \text{……………………… (2)} \]

where \( x_{vi} \) is the volume fraction of component \( i \).
Example E9.1
Calculate the RVP of a blend of LSR gasoline, HSR gasoline, Reformate and FCC gasoline. Properties and available quantities of the components are given in Table E9.1.1.

Solution:
As illustrated in Table E9.1.2, the RVP of the blend is calculated through the following steps:

- The volume fraction of each component $x_{vi}$ is calculated and listed in Table E9.1.2.
- The RVP index of each component is calculated. For example, the calculation of LSR gasoline gives $BI_{RVP} = 11.1^{1.25} = 20.26$
- The volume fraction is multiplied by the index for each component (Table E9.1.2)

From the summation, $BI_{RVP,Blend} = 14.305$, then

$$RVP_{Blend} = (14.305)^{1/1.25} = 8.4 \text{ psi}$$

Hence, the RVP of the blended product is 8.4 psi.

<table>
<thead>
<tr>
<th>Table E9.1.1</th>
<th>Quantities and RVP values of the blending components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>Quantity (BPD)</td>
</tr>
<tr>
<td>LSR gasoline</td>
<td>5000</td>
</tr>
<tr>
<td>HSR gasoline</td>
<td>4000</td>
</tr>
<tr>
<td>Reformate 94 RON</td>
<td>6000</td>
</tr>
<tr>
<td>FCC gasoline</td>
<td>7000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table E9.1.2</th>
<th>Summary of RVP calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>Quantity (BPD)</td>
</tr>
<tr>
<td>LSR gasoline</td>
<td>5000</td>
</tr>
<tr>
<td>HSR gasoline</td>
<td>4000</td>
</tr>
<tr>
<td>Reformate 94 RON</td>
<td>6000</td>
</tr>
<tr>
<td>FCC gasoline</td>
<td>7000</td>
</tr>
<tr>
<td>Sum</td>
<td>22,000</td>
</tr>
</tbody>
</table>

Additives, such as propane, i-butane and n-butane can be added to the gasoline blend to adjust the RVP requirements. Example E9.2 illustrates how the amount of an additive is calculated using the method of RVP index.

Example E9.2
Determine the amount of $n$-butane required to produce a gasoline blend with $RVP = 10$ psi from the components listed in Table E9.1.1. The RVP of $n$-butane is 52 psi.
Solution:
Assume \( V_{\text{Butane}} \) is the volume flow rate (BPD) of \( n \)-butane needed to be added to the blend. RVP indices are calculated for all components including \( n \)-butane and listed in Table E9.2.1.

**Table E9.2.1  Summary of calculations**

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity ( V' ) (BPD)</th>
<th>( B_{\text{RVP}i} )</th>
<th>( V_i \times B_{\text{RVP}i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSR gasoline</td>
<td>5000</td>
<td>20.26</td>
<td>101,300</td>
</tr>
<tr>
<td>HSR gasoline</td>
<td>4000</td>
<td>1.6</td>
<td>4000</td>
</tr>
<tr>
<td>Reformate 94 RON</td>
<td>6000</td>
<td>3.62</td>
<td>21,732</td>
</tr>
<tr>
<td>FCC gasoline</td>
<td>7000</td>
<td>26.84</td>
<td>187,880</td>
</tr>
<tr>
<td>( n )-Butane</td>
<td>( V_{\text{Butane}} )</td>
<td>139.64</td>
<td>139.64 ( V_{\text{Butane}} )</td>
</tr>
<tr>
<td>Sum</td>
<td>22,000 + ( V_{\text{Butane}} )</td>
<td></td>
<td>314,912 + 139.64 ( V_{\text{Butane}} )</td>
</tr>
</tbody>
</table>

The volume is first multiplied by the index and then divided by the total volume. The summation yields the RVP index for the blend.

\[
B_{\text{RVP,Blend}} = 10^{1.25} \frac{314,912 + 139.64 V_{\text{Butane}}}{22,000 + V_{\text{Butane}}}
\]

The above equation is solved for \( V_{\text{Butane}} \) to be 625.7 BPD, which is the amount of \( n \)-butane needed to adjust the RVP of the blend to 10 psi.

2- Flash Point Blending

If the flash point of a petroleum product does not meet the required specifications, it can be adjusted by blending this product with other fractions. Flash point is not an additive property and flash point blending indices are used, which blend linearly on a volume basis. The flash point of a blend is determined using the following equation:

\[
B_{\text{FP,Blend}} = \sum_{i=1}^{n} x_{vi} B_{\text{FP}i}
\]  \( ......................(3) \)

where \( x_{vi} \) is the volume fraction of component \( i \), and \( B_{\text{FP}i} \) is the flash point index of component \( i \) that can be determined from the following correlation

\[
B_{\text{FP}i} = F_{pi}^{1/x}
\]  \( ......................(4) \)

\( F_{pi} \) is the flash point temperature of component \( i \), in K, and the best value of \( x \) is -0.06. Another relation to estimate the flash point blending index is based on the flash point experimental data

\[
B_{\text{FP}i} = 51708 \times \exp[(\ln(F_{pi}) - 2.6287)^2/(-0.91725)]
\]  \( ......................(5) \)

\( F_{pi} \) is the flash point temperature of component \( i \), in F. The flash point blending index is blended based on wt% of components.
Example E9.3
Calculate the blend flash point of the components listed in Table E9.3.1. If the resulted temperature is lower than 130 °F, component D is added to the blend to increase the flash point. Knowing that the flash point of D is 220 °F, calculate the amount (BPD) of component D (SG = 0.95) to be added to adjust the flash point.

Solution:
The flash point indices are calculated using equation (9.6) and listed in Table E9.3.2.
The mass flow rates are calculated for each component based on the given specific gravity and BPD.

For component A \( \left( \frac{2500 \text{ bbl}}{\text{day}} \right) \left( \frac{5.6 \text{ ft}^3}{1 \text{ bbl}} \right) \left( \frac{0.8 \times 62.4 \text{ lb}}{\text{ft}^3} \right) \left( \frac{\text{day}}{24 \text{ h}} \right) = 29,120 \text{ lb/h} \)

The weight fractions \( (x_{wi}) \) are then calculated and listed in Table E9.3.2.

<table>
<thead>
<tr>
<th>Component</th>
<th>BPD</th>
<th>SG</th>
<th>Flash point (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2500</td>
<td>0.80</td>
<td>120</td>
</tr>
<tr>
<td>B</td>
<td>3750</td>
<td>0.85</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>5000</td>
<td>0.90</td>
<td>150</td>
</tr>
</tbody>
</table>

\[
\text{Table E9.3.1 Quantities and flash points of the blending components}
\]

\[
\text{Table E9.3.2 Summary of calculations}
\]

\[
\text{BI}_{\text{FFI Blend}} = \sum_{i=1}^{n} x_{wi} \text{BI}_{\text{FFI}} = 356.55
\]

\[
\text{FP}_{\text{Blend}} = \exp \left[ \left( -0.91725 \right) \times \ln \left( \frac{356.06}{51708} \right) \right]^{0.5} + 2.6287 = 117.36 \text{ °F}
\]

The calculated flash point is less than 130 °F therefore, component D need to be added.
The flash point index for component D is
\[
\text{BI}_{\text{FFI}} = 51708 \exp [\ln (220) - 2.6287]/(-0.91725) = 12.41
\]
The blend flash point index is
\[
\text{BI}_{\text{FFI}} = 51708 \exp [\ln (130) - 2.6287]/(-0.91725) = 218.94
\]
If \( W_D \) is the mass flow rate for component D, then
\[
29,120 (321.36) + 46,410 (731.07) + 65,520 (106.47) + 12.41 W_D = (141,050 + W_D) 218.94
\]
\[
W_D = 93,843 \text{ lb/hr}
\]
The volumetric flow rate of component D is 6785 BPD.
### 3- Pour Point Blending

The pour point is the lowest temperature at which oil can be stored and still capable of flowing or pouring, when it is cooled without stirring under standard cooling conditions. Pour point is not an additive property and pour point blending indices are used, which blend linearly on a volume basis. The pour point of a blend is determined using the following equation:

\[
BI_{PP,\text{Blend}} = \sum_{i=1}^{n} x_{vi} BI_{PPi}
\]

where \( x_{vi} \) is the volume fraction of component \( i \), and \( BI_{PPi} \) is the pour point index of component \( i \) that can be determined from the following correlation:

\[
BI_{PPi} = 3,262,000 \times (PP_i/1000)^{12.5}
\]

where \( PP_i \) is the pour point of component \( i \), in °R. The pour point of the product, \( PP_{Blend} \), is then evaluated using the reverse form of equation (7).

Another relation to estimate the pour point blending index is the same formula for the flash point with different value of the exponent:

\[
BI_{FPi} = PP_i^{1/x}
\]

\( PP_i \) is the pour point temperature of component \( i \), in K, and the best value of \( x \) is 0.08.

#### Example E9.4

What is the pour point of the following blend?

<table>
<thead>
<tr>
<th>Component</th>
<th>BPD</th>
<th>Pour Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalytic cracked gas oil</td>
<td>2000</td>
<td>-15</td>
</tr>
<tr>
<td>Straight run gas oil</td>
<td>3000</td>
<td>-3</td>
</tr>
<tr>
<td>Light vacuum gas oil</td>
<td>5000</td>
<td>42</td>
</tr>
<tr>
<td>Heavy vacuum gas oil</td>
<td>1000</td>
<td>45</td>
</tr>
</tbody>
</table>

**Solution:**

The given pour point temperatures are converted to Kelvin then the pour point indices are calculated for each component and listed in Table E9.4. The blend pour point is calculated from the blend index shown in Table E9.4:

\[
PP_{Blend} = \left( \frac{1697.2}{3,262,000} \right)^{12.5} \times 1000 = 546 \, °R
\]

\( PP_{Blend} = 86 \, °F = 30 \, °C \)

**Table E9.4  Summary of calculations**

<table>
<thead>
<tr>
<th>Component</th>
<th>( x_{vi} )</th>
<th>( BI_{PPi} )</th>
<th>( x_{vi} \times BI_{PPi} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalytic cracked gas oil</td>
<td>0.1818</td>
<td>227.3</td>
<td>41.32</td>
</tr>
<tr>
<td>Straight run gas oil</td>
<td>0.2727</td>
<td>461.0</td>
<td>125.7</td>
</tr>
<tr>
<td>Light vacuum gas oil</td>
<td>0.4545</td>
<td>2748</td>
<td>1249</td>
</tr>
<tr>
<td>Heavy vacuum gas oil</td>
<td>0.0909</td>
<td>3093</td>
<td>281.2</td>
</tr>
<tr>
<td>Sum</td>
<td>1</td>
<td></td>
<td>1697.2</td>
</tr>
</tbody>
</table>