Product Blending

Blending purpose is to allocate the available blending components in such a way to meet product demands and specification at the least cost. We now review how the properties of mixtures are estimated based on the properties of the components.

Octane Blending

True octane numbers do not blend linearly. It is therefore necessary to use especial "blending" octane numbers to obtain linear expressions. The blending is performed on a volumetric average basis.

The formula used for calculation is:

$$B_t ON_t = \sum_{i=1}^{n} (B_i ON_i) \quad (1)$$

where

B_t = total amount of blended gasoline *, bbl*

ON_t = desired octane of blend

B_i = bbl of component i

ON_i = blending octane number of component i.

contributing to product t and blending octane numbers, respectively. The practice has been to use the following expression for the "blending" octane number:

$$ON_i = (MON_i + RON_i)/2 \quad (2)$$

where MON and RON are the motor and research octane numbers, respectively. Note that the true octane number is the one obtained using a CFR test engine. For example, consider a 30% isomerate and 70% reformate blend. Isomerate has the following octane values: MON=81.1, RON=83.0, whereas reformat has the following octane numbers: MON=86.9 and RON=98.5. When blended in the proportion given above, the blended pool has ON=89.505.

Pool Octane : is the average octane of the total gasoline production of the refinery, if the regular, mid- premium, and super- premium gasolines are blended together.

Posted Octane numbers (PON): are the arithmetic average of the motor octane number (MON) and research octane number (RON).

Reid vapor pressure

The desired RVP of a gasoline is obtained by blending n-butane with C_5 (380 ^oF) with C_5 (193 ^oF) naphtha. The amount of n-butane required to give the needed RVP is calculated by

$$M_t (RVP)_t = \sum_{i=1}^{n} M_i (RVP)_i \quad (3)$$

Where

M_t = total moles blended product

$(RVP)_t$ = specification RVP for product, psi

M_t = moles of component i

$(RVP)_i$ = RVP of component I, psi or kPa

The desired RVP for a blended gasoline is obtained by adding n-butane to reach the desired value.

Example (1): calculate the amount of n-butane to be added to following base stock to achieve an RVP of 10 psi(n- butane: MW=58, RVP=52)

Base stock	BPD	Lb/hr	MW	RVP (psi)
LSR gasoline	4000	39320	86	11.1
Reformate	6000	69900	115	2.8
Alkylate	3000	30690	104	4.6
FCC gasoline	8000	87520	108	4.4
Total	21000			5.38

Solution

Base stock	BPD	Lb/hr	MW	mol/hr	mol%	RVP	PVP
LSR gasoline	4000	39320	86	457	21	11.1	2.32
Reformate	6000	69900	115	617	28.4	2.8	0.80
Alkylate	3000	30690	104	295	13.4	4.6	0.62
FCC gasoline	8000	87520	108	810	37.2	4.4	1.64
Total	21000			2179	100		

Butane requirement : (use Eq. (3))

(2179) (5.38) + M (52) = (2179+ M)(10)

11732+52 M=21790 +10 M

M= 240 moles n-butane required.

The above method requires obtaining the molecular weight of each of the streams involved, which could be a problem sometimes, although there are good ways of estimating such molecular weights. To makes matter simpler, one can use the method developed at Chevron. In this method “Vapor blending indices” (VPBI), which work well. The RVP of a blend is then calculated using the following volume averaging formula

$$(RVP)_{blend} = \sum V_i (RVP)_i \qquad (4)$$

In the case where the volume of the butane to be blended for a given RVP is desired :

$$A(VPBI)_a + B(VPBI)_b + C(VPBI)_c + \text{-------} + W(VPBI)_w = (Y+W)(VPBI)_m \qquad (5)$$

where

A= bbl of component a, etc

W= bbl of n- butane (w)

Y= A+B+C+ ----------- (all component except n- butane)

$(VPBI)_m$ = VPBI corresponding to the desired RVP of the mixture

w= subscript indicating n- butane.

Table 11-1 and 11-2 show the blending component values for different blending streams and the blending indexes as a function of RVP values.

Table 11-1: Blending Component values (Gary and Handwerk, 2001)

No.	Component	RVP, psi	MON	RON	°API
1.	iC_4	71.0	92.0	93.0	
2.	nC_4	52.0	92.0	93.0	
3.	iC_5	19.4	90.8	93.2	
4.	nC_5	14.7	72.4	71.5	
5.	iC_6	6.4	78.4	79.2	
6.	LSR gasoline (C_5-180°F)	11.1	61.6	66.4	78.6
7.	LSR gasoline isomerized once-through	13.5	81.1	83.0	80.4
8.	HSR gasoline	1.0	58.7	62.3	48.2
9.	Light hydrocrackate	12.9	82.4	82.8	79.0
10.	Hydrocrackate, C_5-C_6	15.5	85.5	89.2	86.4
11.	Hydrocrackate, C_6-190°F	3.9	73.7	75.5	85.0
12.	Hydrocrackate, 190–250°F	1.7	75.6	79.0	55.5
13.	Heavy hydrocrackate	1.1	67.3	67.6	49.0
14.	Coker gasoline	3.6	60.2	67.2	57.2
15.	Light thermal gasoline	9.9	73.2	80.3	74.0
16.	C_5^+ light thermal gasoline	1.1	68.1	76.8	55.1
17.	FCC gasoline, 200–300°F	1.4	77.1	92.1	49.5
18.	Hydrog. light FCC gasoline, C_5^+	13.9	80.9	83.2	51.5
19.	Hydrog. C_5-200°F FCC gasoline	14.1	81.7	91.2	58.1
20.	Hydrog. light FCC gasoline, C_6^+	5.0	74.0	86.3	49.3
21.	Hydrog. C_5^+ FCC gasoline	13.1	80.7	91.0	54.8
22.	Hydrog. 300–400°F FCC gasoline	0.5	81.3	90.2	48.5
23.	Reformate, 94 RON	2.8	84.4	94.0	45.8
24.	Reformate, 98 RON	2.2	86.5	98.0	43.1
25.	Reformate, 100 RON	3.2	88.2	100.0	41.2
26.	Aromatic concentrate	1.1	94.0	107.0	
27.	Alkylate, $C_3^=$	5.7	87.3	90.8	
28.	Alkylate, $C_4^=$	4.6	95.9	97.3	70.3
29.	Alkylate, $C_3^=$, $C_4^=$	5.0	93.0	94.5	
30.	Alkylate, $C_5^=$	1.0	88.8	89.7	
31.	Polymer	8.7	84.0	96.9	59.5

Table 11-2: Blending Component values (Gary and Handwerk, 2001)

Vapor Pressure, psi	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.05	0.13	0.22	0.31	0.42	0.52	0.64	0.75	0.87
1	1.00	1.12	1.25	1.38	1.52	1.66	1.79	1.94	2.08	2.23
2	2.37	2.52	2.67	2.83	2.98	3.14	3.30	3.46	3.62	3.78
3	3.94	4.11	4.28	4.44	4.61	4.78	4.95	5.13	5.30	5.48
4	5.65	5.83	6.01	6.19	6.37	6.55	6.73	6.92	7.10	7.29
5	7.47	7.66	7.85	8.04	8.23	8.42	8.61	8.80	9.00	9.19
6	9.39	9.58	9.78	9.98	10.2	10.4	10.6	10.8	11.0	11.2
7	11.4	11.6	11.8	12.0	12.2	12.4	12.6	12.8	13.0	13.2
8	13.4	13.7	13.9	14.1	14.3	14.5	14.7	14.9	15.2	15.4
9	15.6	15.8	16.0	16.2	16.4	16.7	16.9	17.1	17.3	17.6
10	17.8	18.0	18.3	18.5	18.7	18.9	19.1	19.4	19.6	19.8
11	20.0	20.3	20.5	20.7	20.9	21.2	21.4	21.6	21.9	22.1
12	22.3	22.6	22.8	23.0	23.3	23.5	23.7	24.0	24.2	24.4
13	24.7	24.9	25.2	25.4	25.6	25.9	26.1	26.4	26.6	26.8
14	27.1	27.3	27.6	27.8	28.0	28.3	28.5	28.8	29.0	29.3
15	29.5	29.8	30.0	30.2	30.5	30.8	31.0	31.2	31.5	31.8
16	32.0	32.2	32.5	32.8	33.0	33.2	33.5	33.8	34.0	34.3
17	34.6	34.8	35.0	35.3	35.5	35.8	36.0	36.3	36.6	36.8
18	37.1	37.3	37.6	37.8	38.1	38.4	38.6	38.9	39.1	39.4
19	39.7	39.9	40.2	40.4	40.7	41.0	41.2	41.5	41.8	42.0
20	42.3	42.6	42.8	43.1	43.4	43.6	43.9	44.2	44.4	44.7
21	45.0	45.2	45.5	45.8	46.0	46.3	46.6	46.8	47.1	47.4
22	47.6	47.9	48.2	48.4	48.7	49.0	49.3	49.5	49.8	50.1
23	50.4	50.6	50.9	51.2	51.5	51.7	52.0	52.3	52.6	52.8
24	53.1	53.4	53.7	54.0	54.2	54.5	54.8	55.1	55.3	55.6
25	55.9	56.2	56.5	56.7	57.0	57.3	57.5	57.9	58.1	58.4
26	58.7	59.0	59.3	59.6	59.8	60.1	60.4	60.7	61.0	61.3
27	61.5	61.8	62.1	62.4	62.7	63.0	63.3	63.5	63.8	64.1
28	64.4	64.7	65.0	65.3	65.6	65.8	66.1	66.4	66.7	67.0
29	67.3	67.6	67.9	68.2	68.4	68.8	69.0	69.3	69.6	69.9
30	70.2									
40	101									
(nC_4) 51.6	138									
(iC_4) 72.2	210									
(C_3) 190	705									

Equation:

$$VPBI = VP^{1.25}$$

Example:
Calculate the vapor pressure of a gasoline blend as follows:

Component	Volume Fraction	Vapor Pressure, psi	Vapor Pressure Blending Index No.	Volume Fraction x VPBI
n-Butane	0.050	51.6	138	6.90
Light Straight Run	0.450	6.75	10.9	4.90
Heavy Refined	0.500	1.00	1.00	0.50
Total	1.000	7.4	12.3	12.30

Example (2): Repeat Example (1) use vapor blending indices (VPBI) method.

Component	BPCD	RVP	VPBI	Vol x VPBI
n-Butane	W	51.6	138	138 W
LSR gasoline	4000	11.1	20.3	81200
Reformat	6000	2.8	3.62	21720
Alkylate	3000	4.6	6.73	20190
FCC gasoline	8000	4.4	6.37	50960
Total	21000 + W			174070 + 138 W

Given : VPBI of n- butane =138

For 10 psi RVP, $(VPBI)_m$ = 17.8

Solution

17.8 (21000 + W) =174070 +138 W

(138-17.8) W =373800-174070

W= 1660 bbl n-butane required

Total 10 psi RVP gasoline =21000 + 1660 = 22660 BPCD

Although this differs slightly from the result in Example (1)

Example (3): Consider the following gasoline blending streams are available from the various units. It is desired to produce a 50-50 split of premium and regular gasoline having 91 and 87 posted octane numbers respectively, with both having an RVP= to 10.2 psi . calculate the quantity of n- butane required to give the desired vapor pressure.

Component	Volume	MON	RON	VPBI
Isomerate	5735	81.1	83	25.9
Reformat	14749	86.9	98.5	2.7
FCC gasoline	20117	76.8	92.3	6.4
Light hydrocrackate	814	82.4	82.8	24.4
Alkylate	4117	95.9	97.3	6.7
Polymer	2071	84	96.9	14.9
Total	47603			

Given : VPBI of n- butane =138

For 10.2 psi RVP, $(VPBI)_m$ = 18.2

Solution

Starting with the given flow for all of the above streams and calculating the amount of n-butane to add to fix the RVP

Component	Vol.	RVP	VPBI	Vol (VPBI)
n- butane	W	51.6	138	138 W
Isomerate	5735	13.5	25.9	148395
Reformate	14749	2.2	2.7	39517
FCC gasoline	20117	4.4	6.4	128199
Light hydrocrackate	814	12.9	24.4	19895
Alkylate	4117	4.6	6.7	27732
Polymer	2071	8.7	14.9	30950
Total	47603 +W			394688+138W

18.2 (47603 + W)= 394688 + 138 W

W = 3937 bbl n- butane

The total volume of 10.2 psi RVP premium gasoline = 47603 + 3937 = 51540 BPCD

Octane calculations for pool Gasoline

Component	Volume	Vol. fract.	MON	∑ MON	RON	∑ RON
n- butane	3937	0.077	92.0	7.05	93.0	7.12
Isomerate	5735	0.111	81.1	9.02	83.0	9.23
Reformate	14749	0.286	86.9	24.85	98.5	28.18
FCC gasoline	20117	0.390	76.8	29.97	92.3	36.02
Light hydrocrackate	814	0.016	82.4	1.30	82.8	1.31
Alkylate	4117	0.080	95.9	7.66	97.3	7.77
Polymer	2071	0.040	84.0	3.38	96.9	3.89
Total	51540	1.000		83.23		95.53

Pool octane [(∑ MON + ∑ RON) / 2)] = 88.38 PON

This is not acceptable, as the octane requirement for pool gasoline is 89 PON.

There are several ways of correcting this. Among the possibilities are :

1. Increase severity of reforming to produce a 98.8 to 100 RON clear reformate.
2. Use an octane blending agent, such as MTBE (methyl tertiary butyl ether) and ETBE (ethyl tertiary butyl ether)

Recalculating pool gasoline RVP and PON after adding sufficient MTBE to increase the PON to 89.0 gives the following .

Component	Vol.	RVP	VPBI	Vol (VPBI)
n- butane	W	51.6	138	138 W
Isomerate	5735	13.5	25.9	148395
Reformate	14749	2.2	2.7	39517
FCC gasoline	20117	4.4	6.4	128199
Light hydrocrackate	814	12.9	24.4	19895
Alkylate	4117	4.6	6.7	27732
Polymer	2071	8.7	14.9	30950
MTBE	1593	9.0	15.6	24832
Total	49195 +W			419520+138W

49195 +W=18.2 (419520+138W)

119.8W=895349-419520=475829

W=3984 bbl

Total pool 10.2 RVP, 89.0 PON gasoline= 53179 BPCD

Other properties

Several other properties of blend pools (viscosities, aniline point, pour points, flash points) can be estimated using a technique similar to that of the Chevron Method for RVP, that is

$$P_t = \sum_{i=1}^{n} (v_i P_i) \quad (7)$$

where v_i is the volume fraction of blending stream *i* as above, and P_t as well as P_i are the "blending" properties of the product and the blending streams, respectively. The blending properties are, of course, compiled in tables much in the same way as in the case of RVP. These additional properties are important for Diesel blending. Finally, properties like sulfur or nitrogen content are monitored and blended linearly with percentages.

Home work (1) :

Using the value from the following table, calculate the number of barrels of n- butane that have to be added to a mixture of 1250 barrels of HSR gasoline, 750 barrels of LSR gasoline, and 620 barrels of C_5 FCC gasoline to produce a 9.0 psi Reid vapor pressure . What are the research and motor octane number of the blend?

Component	Volume	MON	RON	RVP	VPBI
HSR gasoline	1250	58.7	62.3	1.0	1.0
LSR gasoline	750	61.6	66.40	11.1	20.3
C_5 FCC gasoline	620	77.1	92.1	4.4	6.4

Given : VPBI of n- butane =138

For 8 psi RVP, $(VPBI)_m = 13.4$

Home work (2) :

Calculate the octane number of the final blend and amount of n- butane needed for producing a 9.5 psi RVP gasoline from 5100 BPSD of LSR gasoline, 3000 BPSD light hydrocrackate,4250 BPSD alkylate, 10280 BPSD heavy hydrocrackate, 14500 BPSD C_5 FCC gasoline,14200 BPSD of 96 RON reformat, and 2500 BPSD of polymer gasoline.

Component	Volume	MON	RON	RVP	VPBI
LSR gasoline	5100	61.6	66.4	11.1	20.3
light hydrocrackate	3000	82.4	82.8	12.9	24.4
alkylate	4250	95.9	97.3	4.6	6.7
heavy hydrocrackate	10280	67.3	67.6	1.1	1.24
C_5 FCC gasoline	14500	77.1	92.1	4.4	6.4
Reformate RON 96	14500	86.5	98.0	2.2	2.7
Polymer	2500	84	96.9	8.7	14.9

Given : VPBI of n- butane =138

For 9.5 psi RVP, $(VPBI)_m = 17.6$