Technical Reference TR 56-2:2020

LNG bunkering
Part 2 : Requirements for custody transfer

AMENDMENT NO. 1

April 2022

1. Page 5, Table of content, Annexes

Replace “Annex I – Methane number (informative)” with “Annex I – Methane number (knock resistance) and Wobbe index (thermal input through a restriction) (informative)” and *insert* “Annex J – Propane knock index: Methane number calculation method (informative)”.

2. Pages 6 and 7, Foreword

a) *Insert* the following after the acknowledgement of IMO:

International Organization for Standardization

Annex I and J of this TR are reproduced from Annex C and Annex A of ISO 23306 respectively. ISO standards can be purchased from Enterprise Singapore.

b) *Delete* “and clause 5.4 into TR 56 : Part 2 : 2020” from the acknowledgement to SGMF.

3. Page 18, Annex B, LNG bunker delivery note

a) *Replace* the NOTE with the following:

NOTE – Refer to Annex I and J for calculation of methane number and indicate the method of calculating the methane number in the bunker delivery note.

b) *Replace* “Methane number” with “Methane number*”

4. Page 32, Annex I, Methane number

Replace Annex I with the Annex as shown below.

5. New Annex J

Insert the new Annex J as shown below after Annex I.

6. Bibliography – International Organization for Standardization

Insert “ISO 23306 Specification of liquefied natural gas as a fuel for marine applications” after ISO 10715.

Annex I
(informative)

Methane number (knock resistance) and Wobbe index (thermal input through a restriction)

I.1 Methane number

The ability of a fuel to resist engine knock for given conditions in the cylinder of an engine is referred to as its knock resistance. The knock resistance for a gaseous fuel is usually characterised using a methane number. The knock resistance of the fuel is an important parameter for engine operation; the maximum non-knocking power output of many marine engine types can depend on the methane number.

Originally, the methane number was derived in analogy with the octane number for gasoline; it is a measure for the specific knock intensity in a reference engine. The knock intensity for a given fuel is compared to a mixture of reference fuels. For the methane number, pure methane was assigned the value of "100", while pure hydrogen was assigned the value of "0".

There are several calculation tools for determining the methane number, which often give different methane numbers for the same fuel composition. The same method can for some gas compositions overestimate the methane number and for other gas compositions underestimate it. The differences between the tools reflect different engine conditions for which the tools are intended (e.g. stoichiometric vs. lean-burn) and differences in how the methane numbers are derived from experimental, empirical and theoretical data. This results in different approaches for how the effects of higher hydrocarbons and their isomers, as well as the impact of inert gases, are incorporated in the tools.

NOTE – Commonly used calculation methods for methane number includes MWM method in EN 16726 and propane knock index (PKI) method in ISO 23306. Refer to Annex J for details of PKI method.

I.2 Wobbe index

While the net calorific value (NCV) is important for characterising LNG for reciprocating engines, natural gas for other end-use equipment (e.g. boiler) is characterised by the Wobbe index. At constant pressure drop, the heat input to such end-use equipment is proportional to the Wobbe index.

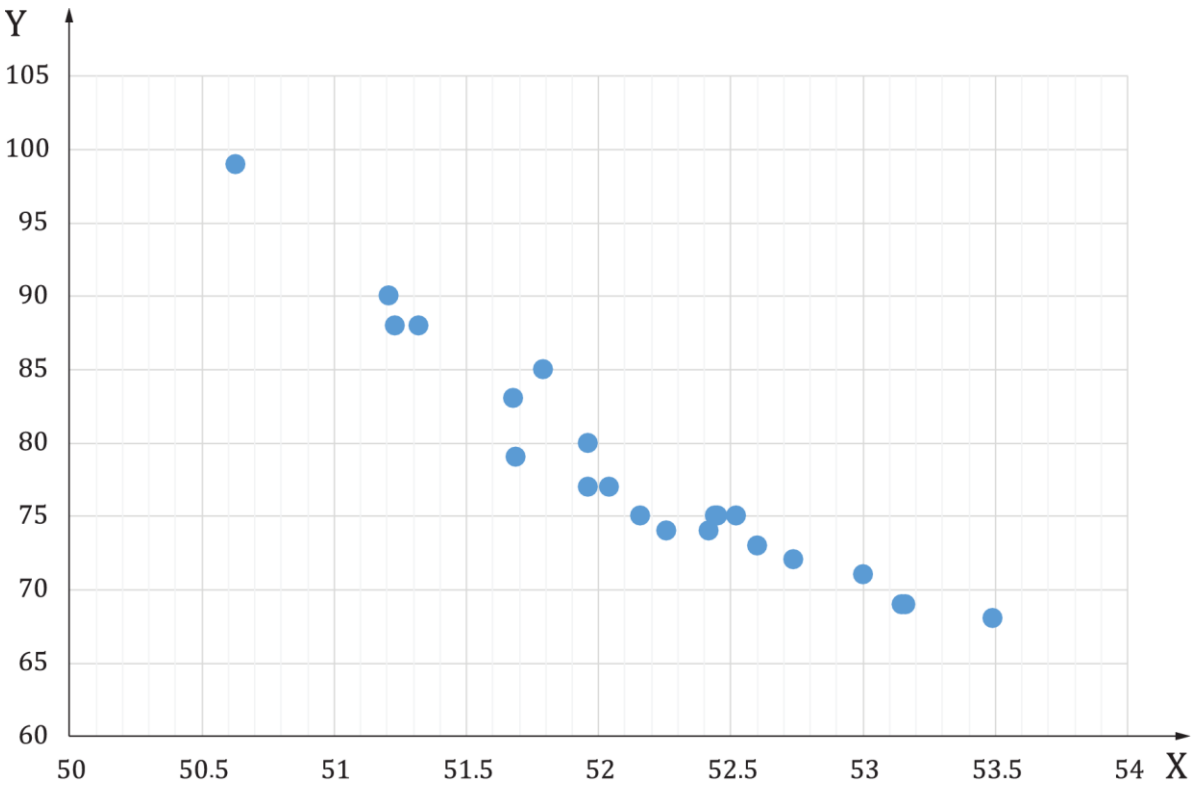
The gross Wobbe index is the gross calorific value (GCV) divided by the square root of the relative density (d) of the fuel as shown in Formula (I.1):

$$grossWI = GCV / \sqrt{d} \qquad \text{(I.1)}$$

While the methane number decreases, and the Wobbe index increases, with an increasing fraction of higher hydrocarbons (ethane, propane, butanes, etc), the methane number, which depends upon the detailed composition of the fuel, is not reliably predicted by the Wobbe index. For LNG compositions, the methane number can vary by 5-10 points for fuels having similar Wobbe index, as illustrated in Figure I.1, below, showing the methane number for the 2018 GIIGNL list as a function of Wobbe index.

NOTE – The different methods to calculate the methane number show similar results when plotted vs. Wobbe index; the results shown reflect the MWM method.

Since specifications for MN are given to whole numbers, using a correlation with Wobbe index does not possess enough predictive power for this purpose.



Key
X Wobbe index [MJ/m3] (15 °C/15 °C)
Y methane number [-] (EN 16726)
The data come from LNG composition given in LNG Industry GIIGNL Annual Report 2018.

Figure I.1 — Methane number plotted vs. Wobbe index

Annex J
(informative)

Propane knock index: Methane number calculation method

The MN of a gaseous fuel can be calculated from its composition according to several different methods, all of which can give different results. The methodology described in this Annex shall be employed to calculate MN (PKI).

For components listed in Table 3, the mole fraction can be taken as equal to "0".

DNV developed a MN method ("PKI MN") that characterises gases for their knock resistance based on the combustion properties of the fuel mixtures themselves. The PKI MN method is based on a methane-propane scale (PKI, Propane Knock Index) where the knock resistance of gas composition is compared to the knock resistance of a methane-propane gas mixture under identical engine conditions.

To calculate the PKI values a polynomial, Formula (J.1) is used:

$$PKI = \sum \alpha_{i^n} X_i^n + \sum \beta_{i^n * j^m} X_i^n X_j^m \quad \text{(J.1)}$$

where:

X is the (normalised) mole fraction,

i = CH_4, C_2H_6, C_3H_8, i-C_4H_{10}, n-C_4H_{10}, n-C_5H_{12}, i-C_5H_{12}, neo-C_5H_{12}, CO_2, CO, H_2 and N_2;

j = C_2H_6, C_3H_8, i-C_4H_{10}, n-C_4H_{10}, n-C_5H_{12}, i-C_5H_{12}, neo-C_5H_{12}, CO_2, CO, H_2 and N_2;

n = 1 to 4;

m = 1, 2;

α and β values are given in Table J.2.

The calculation is valid for PKI values ≤20 (or MN (PKI)≥ 53, see below) and the gas composition range in Table J.1.

Table J.1 – Gas composition range

Species	Min, mol %	Max, mol %
CH_4	65	100
C_2H_6	0	20
C_3H_8	0	20
i-C_4H_{10}	0	5
n-C_4H_{10}	0	5
n-C_5H_{12}	0	2
i-C_5H_{12}	0	2
neo-C_5H_{12}	0	2
C_6+	0	1.5

Species	Min, mol %	Max, mol %
H_2	0	20
CO	0	10
CO_2	0	20
N_2	0	20
H_2S	0	0.5

To account for the presence of C_6+ and H_2S in the gas mixture scaling factors are derived based on autoignition measurements in a rapid compression machine at DNV GL®[1]. These scaling factors are used in the algorithm to translate the effect of C_6+ and H_2S on the knock resistance of a gas mixture to an equivalent fraction of n-C_5H_{12}. The factors are used to correct the methane and n-pentane mole fractions as in Formulae (J.2) and (J.3).

$$X_{CH4,new} = X_{CH4\,in\,gasmixture} - 0{,}3 \times X_{C6+} \tag{J.2}$$

$$X_{nC5H12,new} = X_{nC5H12\,in\,gasmixture} + X_{H2S} + 1{,}3 \times X_{C6+} \tag{J.3}$$

Where X denotes the mole fraction. Here we note that the results of the algorithm are only valid if the total mole percentages of the gas mixture is 100 %.

Table J.2 — α and β coefficients in Formula (J.1)

Coefficient	Value	Description
α_{CH4}	569.285 536 016 002 0	CH_4
$\alpha_{(CH4)^2}$	−650.854 339 490 7	CH_4^2
$\alpha_{(CH4)^3}$	64.359 575 257 386 2	CH_4^3
$\alpha_{(CH4)^4}$	17.214 959 222 053 6	CH_4^4
α_{C2H6}	−645.099 966 662 855 0	C_2H_6
$\alpha_{(C2H6)^2}$	694.229 376 857 102 0	C_2H_6^2
$\alpha_{(C2H6)^3}$	−675.381 075 231 165 0	C_2H_6^3
$\alpha_{(C2H6)^4}$	1 474.790 791 373 33	C_2H_6^4
α_{C3H8}	499.398 492 651 52	C_3H_8
$\alpha_{(C3H8)^2}$	−576.665 945 472 394 0	C_3H_8^2
$\alpha_{(C3H8)^3}$	252.193 674 060 28	C_3H_8^3
$\alpha_{(C3H8)^4}$	593.958 975 466 507 0	C_3H_8^4
$\alpha_{n\text{-}C4H10}$	934.466 273 223 240 0	N_C_4
$\alpha_{(n\text{-}C4H10)^2}$	−86.872 357 077 023 8	N_C_4^2
$\alpha_{(n\text{-}C4H10)^3}$	−20 418.906 767 397 9	N_C_4^3
$\alpha_{(n\text{-}C4H10)^4}$	633 286.561 358 521 0	N_C_4^4
$\alpha_{iso\text{-}C4H10}$	735.223 884 113 728 0	I_C_4

Coefficient	Value	Description
$\alpha_{(iso\text{-}C4H10)^2}$	−3 182.614 393 379 67	I_C4^2
$\alpha_{(iso\text{-}C4H10)^3}$	20 945.186 725 021 9	I_C4^3
$\alpha_{(iso\text{-}C4H10)^4}$	159 067.868 032 595 0	I_C4^4
$\alpha_{n\text{-}C5H12}$	2 571.930 793 605 35	N_C5
$\alpha_{(n\text{-}C5H12)^2}$	10 516.494 109 227 50	N_C5^2
$\alpha_{(n\text{-}C5H12)^3}$	−770 539.377 197 693	N_C5^3
$\alpha_{(n\text{-}C5H12)^4}$	28 633 475.586 565 4	N_C5^4
$\alpha_{iso\text{-}C5H12}$	−3 582.967 844 353 79	I_C5
$\alpha_{(iso\text{-}C5H12)^2}$	0	I_C5^2
$\alpha_{(iso\text{-}C5H12)^3}$	403 155.950 864 334	I_C5^3
$\alpha_{(iso\text{-}C5H12)^4}$	−11 917 333.837 932 9	I_C5^4
$\alpha_{neo\text{-}C5H12}$	1 123.396 367 098 65	NEC5
$\alpha_{(neo\text{-}C5H12)^2}$	1 679.728 075 248 10	NEC5^2
$\alpha_{(neo\text{-}C5H12)^3}$	−172 182.649 067 176	NEC5^3
$\alpha_{(neo\text{-}C5H12)^4}$	3 467 918.607 466 990	NEC5^4
α_{N2}	−469.428 097 827 742	N2
$\alpha_{(N2)^2}$	352.688 107 288 763	N2^2
$\alpha_{(N2)^3}$	−220.491 687 402 358	N2^3
$\alpha_{(N2)^4}$	1 419.680 053 962 420	N2^4
α_{CO2}	−953.460 328 339 263	CO2
$\alpha_{(CO2)^2}$	1 148.487 258 682 280	CO2^2
$\alpha_{(CO2)^3}$	−601.339 855 375 907	CO2^3
$\alpha_{(CO2)^4}$	448.125 565 457 084	CO2^4
α_{CO}	−5 813.759 963 900 21	CO
$\alpha_{(CO)^2}$	5 511.721 025 828 67	CO^2
$\alpha_{(CO)^3}$	1 647.043 065 843 26	CO^3
$\alpha_{(CO)^4}$	−3 471.241 525 554 25	CO^4
α_{H2}	−906.859 878 136 883	H2
$\alpha_{(H2)^2}$	1 059.747 810 140 28	H2^2
$\alpha_{(H2)^3}$	−1 302.861 581 498 63	H2^3
$\alpha_{(H2)^4}$	3 639.859 493 045 20	H2^4
$\beta_{CH4\times C2H6}$	201.788 909 592 169	CH4*C2H6
$\beta_{CH4\ \bullet C3H8}$	−865.856 657 223 225	CH4*C3H8
$\beta_{CH4\ \bullet n\text{-}C4H10}$	−1 210.227 541 932 4	CH4*N_C4
$\beta_{(CH4\ \bullet n\text{-}C4H10)^2}$	1 331.555 523 696 450	(CH4*N_C4)^2
$\beta_{CH4\ \bullet iso\text{-}C4H10}$	−1 023.278 147 470 3	CH4*I_C4

Coefficient	Value	Description
$\beta_{(CH4 \times iso\text{-}C4H10)^2}$	1 550.095 184 612 58	(CH4*I_C4)^2
$\beta_{CH4 \times n\text{-}C5H12}$	−2 811.677 404 325 23	CH4*N_C5
$\beta_{CH4 \times iso\text{-}C5H12}$	3 363.981 505 063 56	CH4*I_C5
$\beta_{CH4 \times neo\text{-}C5H12}$	−1 534.525 674 887 23	CH4*NEC5
$\beta_{CH4 \times N2}$	−1.053 973 329 306 09	CH4*N2
$\beta_{CH4 \times CO2}$	473.574 764 109 71	CH4*CO2
$\beta_{(CH4 \times CO2)^2}$	−308.259 010 229 21	(CH4*CO2)^2
$\beta_{CH4 \times CO}$	5 356.433 570 549 5	CH4*CO
$\beta_{CH4 \times H2}$	118.685 621 913 274	CH4*H2
$\beta_{CH4 \times (H2)^2}$	252.885 168 496 247	CH4*(H2^2)
$\beta_{(CH4)^2 \times H2}$	325.305 174 695 724	(CH4^2)*H2
$\beta_{C2H6 \times C3H8}$	0	C2H6*C3H8
$\beta_{C2H6 \times n\text{-}C4H10}$	−437.695 363 730 406	C2H6*N_C4
$\beta_{C2H6 \times iso\text{-}C4H10}$	−109.983 789 902 769	C2H6*I_C4
$\beta_{C2H6 \times n\text{-}C5H12}$	−1 870.347 465 005 63	C2H6*N_C5
$\beta_{C2H6 \times iso\text{-}C5H12}$	3 909.509 060 762 45	C2H6*I_C5
$\beta_{C2H6 \times neo\text{-}C5H12}$	−886.578 525 827 322	C2H6*NEC5
$\beta_{C2H6 \times N2}$	968.887 620 927 515	C2H6*N2
$\beta_{(C2H6)^2 \times N2}$	267.472 766 191 96	(C2H6^2)*N2
$\beta_{C2H6 \times (N2)^2}$	337.464 863 958 288	C2H6*(N2^2)
$\beta_{C2H6 \times CO2}$	1 431.950 116 993 15	C2H6*CO2
$\beta_{C2H6 \times CO}$	6 463.144 442 956 27	C2H6*CO
$\beta_{C2H6 \times H2}$	1 865.090 903 843 57	C2H6*H2
$\beta_{C3H8 \times n\text{-}C4H10}$	−118.490 180 710 956	C3H8*N_C4
$\beta_{C3H8 \times iso\text{-}C4H10}$	0	C3H8*I_C4
$\beta_{C3H8 \times n\text{-}C5H12}$	−1 734.805 682 394 27	C3H8*N_C5
$\beta_{C3H8 \times (n\text{-}C5H12)^2}$	127 551.642 193 201	C3H8*(N_C5^2)
$\beta_{(C3H8)^2 \times n\text{-}C5H12}$	11 318.418 395 072 2	(C3H8^2)*N_C5
$\beta_{C3H8 \times iso\text{-}C5H12}$	3 318.968 208 193 38	C3H8*I_C5
$\beta_{C3H8 \times neo\text{-}C5H12}$	0	C3H8*NEC5
$\beta_{C3H8 \times N2}$	13.345 337 812 469	C3H8*N2
$\beta_{C3H8 \times CO2}$	292.275 289 330 565	C3H8*CO2
$\beta_{C3H8 \times CO}$	5 403.502 607 948 29	C3H8*CO
$\beta_{(C3H8)^2 \times CO}$	2 333.823 463 429 21	(C3H8^2)*CO
$\beta_{C3H8 \times H2}$	957.887 281 487 301	C3H8*H2
$\beta_{n\text{-}C4H10 \times iso\text{-}C4H10}$	3 500.702 828 522 74	N_C4*I_C4

Coefficient	Value	Description
$\beta_{n\text{-}C4H10 \times n\text{-}C5H12}$	−4 737.328 494 949 99	N_C4*N_C5
$\beta_{n\text{-}C4H10 \times (n\text{-}C5H12)^2}$	525 591.310 711 326	NC4*(NC5^2)
$\beta_{(n\text{-}C4H10)^2 \times n\text{-}C5H12}$	297 556.039 242 685	(NC4^2)*NC5
$\beta_{n\text{-}C4H10 \times iso\text{-}C5H12}$	6 095.059 988 750 87	N_C4*I_C5
$\beta_{n\text{-}C4H10 \times neo\text{-}C5H12}$	−953.002 183 779 388	N_C4*NEC5
$\beta_{n\text{-}C4H10 \times N2}$	0	N_C4*N2
$\beta_{n\text{-}C4H10 \times CO2}$	−103.571 484 346 062	N_C4*CO2
$\beta_{n\text{-}C4H10 \times CO}$	5 869.190 506 527 74	N_C4*CO
$\beta_{n\text{-}C4H10 \times H2}$	1 267.619 534 835 89	N_C4*H2
$\beta_{iso\text{-}C4H10 \times n\text{-}C5H12}$	5 056.603 091 637 61	I_C4*N_C5
$\beta_{iso\text{-}C4H10 \times iso\text{-}C5H12}$	6 619.278 776 370 44	I_C4*I_C5
$\beta_{iso\text{-}C4H10 \times neo\text{-}C5H12}$	−1 363.961 016 448 41	I_C4*NEC5
$\beta_{iso\text{-}C4H10 \times N2}$	14.803 895 799 972 4	I_C4*N2
$\beta_{iso\text{-}C4H10 \times CO2}$	211.752 602 673 394	I_C4*CO2
$\beta_{iso\text{-}C4H10 \times CO}$	5 786.325 257 174 88	I_C4*CO
$\beta_{iso\text{-}C4H10 \times H2}$	1 458.460 720 431 54	I_C4*H2
$\beta_{n\text{-}C5H12 \times iso\text{-}C5H12}$	12 268.283 772 748	N_C5*I_C5
$\beta_{n\text{-}C5H12 \times neo\text{-}C5H12}$	0	N_C5*NEC5
$\beta_{n\text{-}C5H12 \times N2}$	−1 573.688 937 706 25	N_C5*N2
$\beta_{n\text{-}C5H12 \times CO2}$	−898.466 856 535 774	N_C5*CO2
$\beta_{(n\text{-}C5H12)^2 \times CO2}$	−42 401.411 139 182 4	(N_C5^2)*CO2
$\beta_{n\text{-}C5H12 \times CO}$	3 985.110 420 511 03	N_C5*CO
$\beta_{(n\text{-}C5H12)^2 \times CO}$	48 265.319 103 373 7	(N_C5^2)*CO
$\beta_{n\text{-}C5H12 \times H2}$	−1 112.443 527 705 6	N_C5*H2
$\beta_{(n\text{-}C5H12)^2 \times H2}$	99 558.333 341 943 2	(N_C5^2)*H2
$\beta_{iso\text{-}C5H12 \times neo\text{-}C5H12}$	3 773.449 267 853 97	I_C5*NEC5
$\beta_{iso\text{-}C5H12 \times N2}$	4 490.678 300 326 75	I_C5*N2
$\beta_{iso\text{-}C5H12 \times CO2}$	5 122.009 935 455 09	I_C5*CO2
$\beta_{(iso\text{-}C5H12)^2 \times CO2}$	−28 087.848 186 432 6	(I_C5^2)*CO2
$\beta_{iso\text{-}C5H12 \times CO}$	10 248.340 825 423 2	I_C5*CO
$\beta_{iso\text{-}C5H12 \times H2}$	5 464.934 669 232 21	I_C5*H2
$\beta_{neo\text{-}C5H12 \times H2}$	−642.170 828 416 611	NEC5*N2
$\beta_{neo\text{-}C5H12 \times CO2}$	0	NEC5*CO2
$\beta_{(neo\text{-}C5H12)^2 \times CO2}$	−11 320.112 689 948 1	(NEC5^2)*CO2
$\beta_{neo\text{-}C5H12 \times CO}$	4 772.677 301 186 82	NEC5*CO
$\beta_{neo\text{-}C5H12 \times H2}$	0	NEC5*H2

Coefficient	Value	Description
$\beta_{N2 \times CO2}$	1 156.200 327 160 21	N2*CO2
$\beta_{(N2)^2 \times CO2}$	359.342 203 118 816	(N2^2)*CO2
$\beta_{N2 \times CO}$	6 076.818 092 916 31	N2*CO
$\beta_{(N2)^2 \times CO}$	389.853 153 629 781	(N2^2)*CO
$\beta_{N2 \times (CO)^2}$	367.319 351 280 689	N2*(CO^2)
$\beta_{N2 \times H2}$	1 506.655 641 914 57	N2*H2
$\beta_{CO2 \times CO}$	6 557.376 349 418 7	CO2*CO
$\beta_{(CO2 \times CO)^2}$	1 824.585 879 374 03	(CO2*CO)^2
$\beta_{CO2 \times H2}$	1 924.917 595 080 54	CO2*H2
$\beta_{(CO2 \times H2)^2}$	−1 656.219 745 263 47	(CO2*H2)^2
$\beta_{CO \times H2}$	6 896.458 388 070 18	CO*H2
$\beta_{(CO \times H2)^2}$	911.791 848 875 967	(CO*H2)^2

To put the method on a scale analogous to the currently used methane number methods, the propane-based scale (PKI) has been converted to a 0 - 100 scale, referred to as $MN_{(PKI)}$ in Formula (J.4):

$$MN_{(PKI)} = a_1\,PKI + a_2\,PKI\text{^}2 + a_3\,PKI\text{^}3 + a_4\,PKI\text{^}4 + a_5\,PKI\text{^}5 + a_6\,PKI\text{^}6 + b \qquad \text{(J.4)}$$

By using Formula (J.4) and the coefficients presented in Table J.3, the PKI values calculated by using Formula (J.1) are converted to a $MN_{(PKI)}$.

Table J.3 — Coefficients in Formula (J.4) for conversion of PKI into $MN_{(PKI)}$

Coefficients	Values
a_1	−9.757 977
a_2	1.484 961
a_3	−0.139 533
a_4	0.007 031 306
a_5	−0.000 177 002 9
a_6	0.000 001 751 212
b	100

EXAMPLE

In general, α values are for the individual components and β values are for the interaction between individual components.

For example, if we consider a mixture of 90 % CH_4 and 10 % C_2H_6 then the PKI can be calculated using Formula (J.1) in the document.

$X_{CH4} = 0.9$

$X_{C2H6} = 0.1$

$PKI = X_{CH4}*\alpha_{CH4} + (X_{CH4})^2*(\alpha_{CH4})^2 + (X_{CH4})^3*(\alpha_{CH4})^3 + (X_{CH4})^4*(\alpha_{CH4})^4 + X_{C2H6}*\alpha_{C2H6} + (X_{C2H6})^2*(\alpha_{C2H6})^2 + (X_{C2H6})^3*(\alpha_{C2H6})^3 + (X_{C2H6})^4*(\alpha_{C2H6})^4 + X_{CH4}*X_{C2H6}*\beta_{CH4xC2H6} =$

(see also values in Table J.2)

0.9*569.285 536 016 002 0 + (0.9*0.9)* −650.854 339 490 7 + (0.9*0.9*0.9)* 64.359 575 257 386 2 + (0.9*0.9*0.9*0.9)* 17.214 959 222 053 6+ 0.1*−645.099 966 662 855 0 + (0.1*0.1)* 694.229 376 857 102 0 + (0.1*0.1*0.1)* −675.381 075 231 165 0 + (0.1*0.1*0.1*0.1)* 1 474.790 791 373 33 +

0.1*0.9*201.788 909 592 169 = 3.4

Thus, a PKI value of 3.4 is calculated for this mixture.

Next, using Formula (J.4), we can calculate the $MN_{(PKI)}$ using the values from Table J.3:

$MN_{(PKI)}$=a_1 *PKI*+a_2 *PKI*^2+a_3 *PKI*^3+a_4 *PKI*^4+a_5 *PKI*^5+a_6 *PKI*^6+b

=−9.757 977*3.4 + 1,484 961*(3.4*3.4) + −0.139 533*(3.4*3.4*3.4)+ 0,007 031 306*(3.4*3.4*3.4*3.4) + −0,000 177 002 9*(3.4*3.4*3.4*3.4*3.4) + 0.000 001 751 212*(3.4*3.4*3.4*3.4*3.4*3.4) + 100 = 79

Please note that 0.9*0.9 is mathematically equal to $(0.9)^2$. In Formula (J.1), this is shown as (for example in this case with $X_{CH4} = 0.9$) X_{CH4}^2 or $(X_{CH4})^2$.