State of California
Office of Administrative Law

In re:
Department of Food and Agriculture

Regulatory Action:

Title 04, California Code of Regulations

Adopt sections: **4192.1, 4192.2**
Amend sections: **4206**
Repeal sections: **4207**

NOTICE OF APPROVAL OF REGULATORY ACTION

Government Code Section 11349.3

OAL Matter Number: 2025-0417-01

OAL Matter Type: Regular Resubmittal (SR)

This regular rulemaking action by the California Department of Food and Agriculture adopts fuel specification requirements for natural gas used as motor vehicle fuel and amends labeling requirements pertaining to natural gas motor vehicle fuel dispensers.

OAL approves this regulatory action pursuant to section 11349.3 of the Government Code. This regulatory action becomes effective on 7/1/2025.

Date: May 22, 2025

Timothy Findley
Senior Attorney

For: Kenneth J. Pogue
Director

Original: Karen Ross, Secretary
Copy: Andrew Adkins

STATE OF CALIFORNIA–OFFICE OF ADMINISTRATIVE LAW

RESUBMITTAL

NOTICE PUBLICATION/REGULATION SUBMISSION

STD. 400 (REV. 10/2019)

For use by Secretary of State only

ENDORSED - FILED
in the office of the Secretary of State
of the State of California
MAY 22 2025
1:50PM AB

OAL FILE NUMBERS	NOTICE FILE NUMBER	REGULATORY ACTION NUMBER	EMERGENCY NUMBER
	Z-2024-0416-04	2025-0417-01S	

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OFFICE OF ADMINISTRATIVE LAW

Electronic Submission

RECEIVED DATE	PUBLICATION DATE
04/16/2024	04/26/2024

OFFICE OF ADMIN. LAW
2025 APR 17 PM2:03

NOTICE REGULATIONS

AGENCY WITH RULEMAKING AUTHORITY
California Department of Food and Agriculture

AGENCY FILE NUMBER (If any)

A. PUBLICATION OF NOTICE (Complete for publication in Notice Register)

1. SUBJECT OF NOTICE	TITLE(S)	FIRST SECTION AFFECTED	2. REQUESTED PUBLICATION DATE
Fuel Specifications and Labeling of Natural Gas	Title 4	Section 4192.1	April 26, 2024
3. NOTICE TYPE: [X] Notice re Proposed Regulatory Action [ ] Other	4. AGENCY CONTACT PERSON: Andrew Adkins	TELEPHONE NUMBER: (714) 680-7880	FAX NUMBER (Optional)
OAL USE ONLY — ACTION ON PROPOSED NOTICE: [ ] Approved as Submitted [ ] Approved as Modified	[ ] Disapproved/ Withdrawn	NOTICE REGISTER NUMBER: 2024, 17-Z	PUBLICATION DATE: 4/26/24

B. SUBMISSION OF REGULATIONS (Complete when submitting regulations)

1a. SUBJECT OF REGULATION(S)	1b. ALL PREVIOUS RELATED OAL REGULATORY ACTION NUMBER(S)
Fuel Specifications and Labeling of Natural Gas	2024-1007-01S

2. SPECIFY CALIFORNIA CODE OF REGULATIONS TITLE(S) AND SECTION(S) **(Including title 26, if toxics related)**

SECTION(S) AFFECTED (List all section number(s) individually. Attach additional sheet if needed.)	
	ADOPT: 4192.1 and 4192.2
	AMEND: 4206
TITLE(S): 4	REPEAL: 4207

3. TYPE OF FILING

- [ ] Regular Rulemaking (Gov. Code §11346)
- [X] Resubmittal of disapproved or withdrawn nonemergency filing (Gov. Code §§11349.3, 11349.4)
- [ ] Emergency (Gov. Code, §11346.1(b))
- [ ] Certificate of Compliance: The agency officer named below certifies that this agency complied with the provisions of Gov. Code §§11346.2-11347.3 either before the emergency regulation was adopted or within the time period required by statute.
- [ ] Resubmittal of disapproved or withdrawn emergency filing (Gov. Code, §11346.1)
- [ ] Emergency Readopt (Gov. Code, §11346.1(h))
- [ ] File & Print
- [ ] Other (Specify)
- [ ] Changes Without Regulatory Effect (Cal. Code Regs., title 1, §100)
- [ ] Print Only

4. ALL BEGINNING AND ENDING DATES OF AVAILABILITY OF MODIFIED REGULATIONS AND/OR MATERIAL ADDED TO THE RULEMAKING FILE (Cal. Code Regs. title 1, §44 and Gov. Code §11347.1)
2/14/2025-3/3/2025

5. EFFECTIVE DATE OF CHANGES (Gov. Code, §§ 11343.4, 11346.1(d); Cal. Code Regs., title 1, §100)

- [X] Effective January 1, April 1, July 1, or October 1 (Gov. Code §11343.4(a))
- [ ] Effective on filing with Secretary of State
- [ ] §100 Changes Without Regulatory Effect
- [ ] Effective other (Specify)

6. CHECK IF THESE REGULATIONS REQUIRE NOTICE TO, OR REVIEW, CONSULTATION, APPROVAL OR CONCURRENCE BY, ANOTHER AGENCY OR ENTITY

- [ ] Department of Finance (Form STD. 399) (SAM §6660)
- [ ] Fair Political Practices Commission
- [ ] State Fire Marshal
- [ ] Other (Specify)

7. CONTACT PERSON	TELEPHONE NUMBER	FAX NUMBER (Optional)	E-MAIL ADDRESS (Optional)
Andrew Adkins	(714) 680-7880		andrew.adkins@cdfa.ca.gov

8. I certify that the attached copy of the regulation(s) is a true and correct copy of the regulation(s) identified on this form, that the information specified on this form is true and correct, and that I am the head of the agency taking this action, or a designee of the head of the agency, and am authorized to make this certification.

SIGNATURE OF AGENCY HEAD OR DESIGNEE
Arima Kozina
Digitally signed by Arima Kozina
Date: 2025.04.16 13:51:06 -07'00'

DATE

TYPED NAME AND TITLE OF SIGNATORY
Arima Kozina, Deputy Secretary

For use by Office of Administrative Law (OAL) only

ENDORSED APPROVED
MAY 22 2025
Office of Administrative Law

CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
Fuel Specifications and Labeling of Natural Gas
CCR Title 4, New Sections 4192.1 and 4192.2; and Sections 4206 and 4207
April 8, 2025

FINAL TEXT OF THE REGUALTION

Proposed additions are underlined.
Proposed deletions are ~~struck through~~.

Chapter 6. Automotive Products Specifications

Article 10. Specifications — Natural Gas

Section 4192.1. Definitions.

(a) The following are varieties of natural gas as defined in Business and Professions Code Division 5, Section 13400 (b)(10):

(1) "Compressed Natural Gas" or "CNG" is natural gas that has been compressed after processing for storage or transportation purposes.

(2) "Liquefied Natural Gas" or "LNG" is natural gas that has been liquefied after processing for storage or transportation purposes.

(b) The following term defines a variety of natural gas, distinct from subdivision (a), and determined by the secretary to be an alternative motor vehicle fuel in accordance with Business and Professions Code Division 5, Section 13400 (b)(12):

(1) "Compressed Natural Gas – Hydrogen Blend" or "CNG – Hydrogen Blend" is a blend of natural gas and hydrogen, such that the total hydrogen exceeds 0.3 volume percent, that has been compressed after processing for storage or transportation purposes.

Credits

NOTE: Authority cited: Sections 12027, 13400 (b)(12), 13440 and 13446, Business and Professions Code. Reference: Sections 13400, 13404, 13440, 13441 and 13446, Business and Professions Code.

Section 4192.2. Specifications — Natural Gas.

(a) Compressed Natural Gas shall meet the fuel specification adopted in the California Code of Regulations Title 13, Section 2292.5.

(1) If California Code of Regulations Title 13, Section 2292.5 is repealed or modified to be less or equally stringent than the latest specification set forth in ASTM International Standard Specification D8080, then Compressed Natural Gas shall meet the latest specification set forth in ASTM International Standard Specification D8080.

(b) Liquefied Natural Gas shall meet the latest specification set forth in ASTM International Standard Specification D8080.

(c) Compressed Natural Gas – Hydrogen Blend shall meet the latest specification set forth in ASTM International Standard Specification D8487.

Credits

NOTE: Authority cited: Sections 12027, 13400 (b)(12), 13440 and 13446, Business and Professions Code. Reference: Sections 13400, 13404, 13440, 13441 and 13446, Business and Professions Code.

Chapter 7. Advertising and Labeling of Gasoline and Other Motor Vehicle Fuels

Section 4206. ~~Dispenser~~ Labeling Requirements for ~~Compressed Natural Gas and Liquefied Natural Gas~~ Natural Gas.

~~(a) Definitions Used in This Section:~~

~~(1) "Consumer" means, with respect to any item, the first person who purchases such item for purposes other than resale.~~

~~(2) "Fuel dispenser" means the dispenser through which a retailer sells the fuel to a consumer.~~

~~(3) "Methane Number" means the antiknock index of compressed natural gas or liquefied natural gas motor vehicle fuel. The Methane Number of compressed natural gas or liquefied natural gas is a calculated value determined by the chemical composition of the fuel, including inert components.~~

~~(4) "MWM Method" means the algorithm for the calculation of the Methane Number of a natural gas fuel from its composition. The MWM Method algorithm is available in the European Committee for Standardization (CEN) standard EN 16726 "Gas infrastructure -- Quality of gas -- Group H" (EN16726), Annex A, pages 9 through 30, published December 2015, which is herein incorporated by reference.~~

~~A spreadsheet calculator implementing the MWM Method algorithm and a pdf file of instructions for its use ("readme.pdf") are available for download at no cost at: http://euromot.org/media_and_events/publications/mn.~~

~~(5) "Minimum MWM Methane Number" means the lowest MWM Methane Number of natural gas fuel offered for retail sale.~~

~~(6) "Producer" means any person who purchases component elements and combines them to produce and market natural gas motor vehicle fuels.~~

~~(7) "Retailer" means any person who markets natural gas motor vehicle fuels to the general public for ultimate consumption.~~

~~(b) The name of the product and grade designation, if any, shall be conspicuously displayed on each customer side of all natural gas fuel dispensers. For all natural gas fuels, the name of the product and grade designation, if any, shall also appear on all advertising signs and storage tank labels as required in Sections 13480 and 13532 of the Business and Professions Code.~~

~~(c)(1) A person shall not sell at retail to the general public any compressed or liquefied natural gas for use as a motor vehicle fuel from any place of business in this state unless there is displayed and labeled on the fuel dispenser in a conspicuous place on the customer side the following statement: "MINIMUM METHANE NUMBER XX BY THE MWM METHOD (4 CCR 4206)," where XX is the MWM Methane Number of the dispensed natural gas fuel expressed in a number rounded down to a whole number. This statement shall be displayed in Helvetica Black or equivalent font type with characters not less than 1/2 inch in height.~~

~~(2) Natural gas motor vehicle fuel producers shall be responsible for determining the minimum MWM Methane Number to be displayed for the fuel they produce for retail sale to the general public. In making this determination, they may rely on information received from the utility supplying the pipeline gas used to produce their fuel, independent laboratory testing of the composition of the pipeline gas, or any other~~

~~reliable information available to them. The minimum MWM Methane Number shall be accurate at all times.~~

~~(d)(1) A person shall not sell at retail to the general public any compressed natural gas for use as a motor vehicle fuel from any place of business in this state unless there is displayed and labeled on the fuel dispenser in a conspicuous place on each customer side the following statement: "1 Gasoline Gallon Equivalent (GGE) equals 5.66 lb of Compressed Natural Gas".~~

~~(2) The statement "1 Gasoline Gallon Equivalent (GGE) equals 5.66 lbs. of Compressed Natural Gas" shall be in characters of Helvetica Black or equivalent font type, no less than 3/4 inch in height and on a contrasting background. All lines or marks used in the making or forming of all the characters which are a part of the label shall be at least one-eighth of an inch in width.~~

~~(e)(1) A person shall not sell at retail to the general public any liquefied natural gas for use as a motor vehicle fuel from any place of business in this state unless there is displayed and labeled on the fuel dispenser in a conspicuous place on each customer side the following statement: "1 Diesel Gallon Equivalent (DGE) equals 6.06 lb of Liquefied Natural Gas".~~

~~(2) The statement "1 Diesel Gallon Equivalent (DGE) equals 6.06 lbs. of Liquefied Natural Gas" shall be in characters of Helvetica Black or equivalent font type, no less than 3/4 inch in height and on a contrasting background. All lines or marks used in the making or forming of all the characters that are a part of the label shall be at least one-eighth of an inch in width.~~

<u>(a) Notwithstanding any other labels required by California law, the following labels shall be displayed in a conspicuous, legible, and indelibly marked manner on each customer-facing side of the dispenser:</u>

<u>(1) The natural gas fuel rating label meeting the retail sale requirements of the Federal Trade Commission in accordance with:</u>

<u>(A) 16 CFR Part 309 "Labeling Requirements for Alternative Fuels and Alternative Fueled Vehicles," for Compressed Natural Gas and Compressed Natural Gas – Hydrogen Blend; or</u>

(B) 16 CFR Part 306 "Automotive Fuel Ratings, Certification and Posting," for Liquefied Natural Gas.

(2) In accordance with Business and Professions Code Section 13480, and meeting size and height requirements therein, the product name label shall be either:

(A) "Compressed Natural Gas" or "CNG" for Compressed Natural Gas; or

(B) "Liquified Natural Gas" or "LNG" for Liquified Natural Gas; or

(C) "Compressed Natural Gas – Hydrogen Blend" or "CNG – Hydrogen Blend" for Compressed Natural Gas – Hydrogen Blend.

(3) In accordance with Business and Professions Code Section 13480, and meeting size and height requirements therein, the fuel grade designation label shall be either:

(A) the calculated methane number (MN_C) as "MN_C 65" or "MN_C 75" which corresponds with the applicable fuel grades described and determined by ASTM International Standard Specification D8080 for Compressed Natural Gas and Liquefied Natural Gas; or

(B) the calculated methane number (MN_C) and hydrogen (H) limit as "MN_C 65 H10" or "MN_C 75 H10" which corresponds with the applicable fuel grades described and determined by ASTM International Standard Specification D8487 for Compressed Natural Gas – Hydrogen Blend.

(4) The equivalent conversion factor statement label printed in Helvetica Black or Arial Bold font type with a cap height of no less than one-quarter inch shall read either:

(A) "1 Gasoline Gallon Equivalent (GGE) equals 5.66 lb of Compressed Natural Gas" for Compressed Natural Gas and Compressed Natural Gas – Hydrogen Blend; or

(B) "1 Diesel Gallon Equivalent (DGE) equals 6.06 lb of Liquefied Natural Gas" for Liquefied Natural Gas.

Credits

NOTE: Authority cited: Sections 12027, 13400 (b)(12), 13440, 13446 and 13480, Business and Professions Code. Reference: Sections 13400, 13404, 13440, 13446, ~~13451, 13470, 13471, 13473, 13474,~~ 13480~~,~~ and 13484,~~13531, 13532 and 13536,~~ Business and Professions Code.

Section 4207. Additional Dispenser Labeling Requirements for Liquefied Natural Gas and Compressed Natural Gas. [Repealed]

~~The labeling of all natural gas dispensers shall meet the following retail sale requirements of the Federal Trade Commission for the natural gas fuel rating:~~

~~(a) 16 CFR Part 306 "Automotive Fuel Ratings, Certification and Posting," for liquefied natural gas.~~

~~(b) 16 CFR Part 309 "Labeling Requirements for Alternative Fuels and Alternative Fueled Vehicles," for compressed natural gas.~~

Credits

NOTE: Authority cited: Sections 12027 and 13480, Business and Professions Code. Reference: Sections 12026, 13400, 13480, 13590 and 13591, Business and Professions Code.

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 16726

REPEAL

December 2015

ICS 75.060

English Version

Gas infrastructure - Quality of gas - Group H

Infrastructure gazière - Qualité du gaz - Groupe H

Gasinfrastruktur - Beschaffenheit von Gas - Gruppe H

This European Standard was approved by CEN on 24 October 2015.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 16726:2015 E

Annex A
(normative)

Calculation of methane number of gaseous fuels for engines

A.1 Introduction

The methane number of a gaseous fuel can be calculated from its composition according to several different methods, all of which can give different results. For the purposes of compliance with this European standard the methodology described in this Annex shall be employed.

The method is based on the original data of the research program performed by AVL Deutschland GmbH /1/ for FVV (the Research Association for Combustion Engines) but employs amendments implemented in 2005 and 2011 by MWM GmbH. These amendments have been unpublished until the publication of this European standard.

The method requires input of composition in the form of volume fractions at reference conditions of 0 °C and 101,325 kPa and expressed as a percentage. Composition is more likely to be available either as mole fraction (e.g. in the natural gas transmission and distribution industry) or as mass fraction (e.g. in the automotive fuel industry) and conversion to volume fraction shall be performed using the methods in ISO 14912.

Numerical examples are provided so as to enable software developers to validate implementations of the methodology described in this annex. As an aid to validation a relatively large number of decimal places has been retained. For expression of the final result rounding to zero decimal points is recommended.

A.2 Calculation of methane number

A.2.1 Applicability

The method described in this European Standard is applicable to gaseous fuels comprising the following gases: carbon monoxide; butadiene; butylene; ethylene; propylene; hydrogen sulphide; hydrogen; propane; ethane; butane; methane; nitrogen and carbon dioxide. The method treats hydrocarbons other than those specified as butane and is therefore applicable to gaseous fuels containing such higher hydrocarbons.

The numerical examples provided in this annex are appropriate to gases of the second family and hence consider mixtures comprising methane, ethane, propane, butane, nitrogen and carbon dioxide. Hydrogen is also included in one example because of the growing interest in injection of hydrogen into gas pipelines. During the preparation of this standard MWM GmbH has confirmed that the method is applicable to both 2H and 2L gases.

Oxygen and water vapour shall be ignored and the fuel gas composition shall be calculated on a dry, oxygen-free basis.

A.2.2 General approach

The methane number of a gaseous fuel is calculated from its composition in five steps. The steps are outlined below and discussed more fully in turn in A.3. Additional examples are discussed in A.4 and A.5. Table A.10 provides results of calculations for further software validation purposes.

a) The composition of the gaseous fuel is simplified by converting it into an inert-free mixture comprising the combustible compounds carbon monoxide, ethylene, propylene, hydrogen sulphide, hydrogen, propane, ethane, butane and methane.

For gases of the second family conveyed in pipeline systems carbon monoxide, ethylene, propylene, hydrogen sulphide are unlikely to be present at concentrations that would impact on methane number and can be ignored.

b) The simplified mixture is sub-divided further into a number of partial ternary mixtures. The number and particular partial ternary mixtures chosen is decided by inspection of available ternary systems in a given order, including those systems that contain the relevant combustible compounds. Selection is ceased when all combustible compounds are contained in at least two ternary systems.

c) The composition and fraction of the selected partial mixtures is adjusted iteratively so as to minimize the difference between the methane numbers of each partial mixture.

d) The methane number of the simplified mixture is determined from the weighted average of the methane number of the selected partial mixtures.

e) Finally, the methane number of the gaseous fuel is calculated by correcting the methane number of the simplified mixture to allow for the presence of inerts in the original fuel gas.

A.3 Example 1: 2H-gas

A.3.1 Simplification of the composition of the gaseous fuel

The description of the calculation is illustrated by reference to a 2H-gas of composition shown in Table A.1. The composition of the gas (column 1) is simplified by increasing the quantity of butanes to allow for the presence of butadiene, butylene, pentanes and hydrocarbons of carbon number greater than 5. The adjustment made is as follows:

— Butadiene and butylene are replaced with an equivalent amount of butanes by multiplying their quantities by 1.

— Pentanes are replaced with an equivalent amount of butanes by multiplying the quantity of pentanes by 2,3.

— Hydrocarbons of carbon number greater than 5 ("hexanes+") are replaced with an equivalent amount of butanes by multiplying the quantity of hexanes+ by 5,3.

In the case of example 1 the quantity of butanes

$= 0{,}2100 + 0{,}1900 + (0{,}0400 + 0{,}0500) \times 2{,}3 + 0{,}0600 \times 5{,}3$

$= 0{,}9250$ (Column 2)

The simplified mixture is then re-normalized to 100 % (Column 3).

A.3.2 Selection of the ternary systems

A.3.2.1 Ternary mixtures

The ternary mixtures are chosen from the following list:

- A1: Methane – Hydrogen – Ethane
- A2: Propane – Ethane – Butane
- A3: Hydrogen – Propane - Propylene
- A4: Methane – Ethane – Propane
- A5: Methane – Hydrogen – Propane
- A6: Methane – Hydrogen – Butane
- A7: Methane – Propane – Butane
- A8: Methane – Ethane – Butane
- A9: Methane – Ethylene – Butane
- A10: Methane – Hydrogen Sulphide – Butane
- A11: Methane – Ethane – Hydrogen Sulphide
- A12: Methane – Propylene
- A13: Ethane – Propylene
- A14: Carbon Monoxide – Hydrogen
- A15: Ethane – Ethylene
- A16: Propane – Ethylene
- A17: Butadiene
- A18: Butylene

NOTE Mixtures A12 – A16 are clearly not ternary systems; however, for ease of mathematical treatment the coefficients have been adjusted so as to allow the expression of the methane number using a single equation.

A.3.2.2 Range of applicability of ternary mixture data

The range of applicability of most ternary systems is wide (each component can vary from 0 to 100 %). However, for some ternary systems there is a reduced range of applicability. This is a major issue when selecting ternary mixtures. The range of applicability of each ternary system is specified in Table A.2, expressed as maximum and minimum content of each component.

A.3.2.3 Factors affecting the ternary system selection process

The ternary systems are selected in accordance with three main considerations:

a) The number of gases in the ternary system that are present in the simplified mixture. Priority is always given to ternary systems that have all three of their components present in the simplified mixture. Systems with two of their components present in the simplified mixture are acceptable if insufficient systems with three components present in the simplified mixture are available.

b) Where there is a choice of ternary systems, the system with the highest fitness, W_j, takes priority.

c) Each component in the simplified mixture shall be represented in at least two ternary systems.

Fitness of a system is calculated from the following formula:

$$W_j = \sum_{i=1}^{i=n} \frac{V_i . min\left(100, \left(Vmax_{i,j} + 15\right)\right)}{Vsum_i} \tag{A.1}$$

where

n	is the number of components in the simplified mixture
V_i	is the volume fraction of component i in the simplified mixture
$Vmax_{i,j}$	is the maximum content of component i for the range of applicability of system j
$Vsum_i$	is the sum of all maximum contents of component i for the range of applicability of all systems, i.e.

$$Vsum_i = \sum_{j=1}^{j=18} min\left(100, \left(Vmax_{i,j} + 15\right)\right) \tag{A.2}$$

Values of $Vsum_i$ are independent of the composition of the simplified mixture. However, W_j is dependent upon the composition of the simplified mixture and so shall be calculated prior to selection. Note that this also means that the choice of ternary mixtures may be different for mixtures containing the same components, but in different proportions.

***In the case of example 1**, the calculation of $Vsum_i$ and W_j is shown in Tables A.3 and A.4.*

A.3.2.4 Description of the ternary system selection process

The aim is to identify the optimum number of ternary systems that meet the three criteria described in A.3.2.3 and this is achieved by consideration of each component present in the simplified mixture in the following sequence:

1) Carbon Monoxide

2) Butadiene

3) Butylene

4) Ethylene

5) Propylene

6) Hydrogen Sulphide

7) Hydrogen

8) Propane

9) Ethane

10) Butane

11) Methane

Step 1: For the first component in the simplified mixture, one ternary system that contains that component is selected. The priority of selection is as follows:

a) Ternary systems with all three components present in the simplified mixture have priority over systems having one or two components present.

b) The ternary mixture with the highest fitness has priority.

Step 2: Consideration is then given to the second component in the simplified mixture. If this component is not present in the ternary system selected for the first component, then a ternary system is selected for this component using the same priority of selection as in step 1. If, however, the ternary system selected for the first component contains the second component, then the selection proceeds for the third component (step 3).

Step 3: Consideration is then given to third, fourth, fifth, etc. components in the same manner as Steps 1-2.

Step 4: When all components in the simplified mixture have been examined once, steps 1-3 are repeated in the same component order. If any component is represented in only one selected ternary mixture, then an additional ternary mixture is selected, again using the same priority of selection as in step 1.

The selection process ends when all components in the simplified mixture are represented in at least two ternary systems.

In the case of example 1:

— *The first component in the simplified mixture is propane and this is present in four ternary systems that have all their components present in the simplified mixture – A2, A4, A7 and A8. In this case, A4 is selected because it has the largest value of fitness (i.e. 10,3138).*

— *The second component in the simplified mixture is ethane and this is already represented in system A4, so no ternary mixture is selected.*

— *The third component of the simplified mixture, butane, is not represented in system A4, so system selection continues and system A8 is selected because it has the highest value of fitness (10,2859).*

— *The fourth component in the simplified mixture is methane and this is already represented in systems A4 and A8, so no ternary mixture is selected.*

— *Selection is repeated with the first component in the simplified mixture, propane, and ternary system A7 is selected because it has the next highest value of fitness (9,6263; system A4 has already been selected).*

All components in the simplified mixture are now represented in at least two of the ternary systems selected and the selection process ends. The systems selected are therefore: A4, A7 and A8.

A.3.3 Sub-division of the inert-free mixture into the selected partial mixtures

The simplified mixture is divided into the selected partial ternary mixtures. A preliminary division of the simplified mixture is made by assigning each component equally between the ternary systems in which it is represented.

In the case of example 1, three ternary systems – A4, A7 and A8 – are selected. The preliminary division is made by assigning: methane equally between A4, A7 and A8; ethane equally between A4 and A8; propane equally between A4 and A7; and butanes equally between A7 and A8 (Columns 4, 6 and 8).

A.3.4 Calculation of the methane number of the partial mixtures

The methane number of each partial mixture is calculated from the general formula

$$MN_t = \sum_{i=0}^{i=7}\sum_{j=0}^{j=6}\left(a_{i,j}x^i y^j\right) \qquad \text{(A.3)}$$

Where x and y are the volume fractions of the first and second components in each partial ternary mixture, expressed as a percentage. In order to calculate the methane number of each partial mixture, therefore, the composition of each is normalized to 100 %.

In the case of example 1 the composition of each partial mixture is calculated by renormalizing to 100 % (Columns 5, 7 and 9).

Table A.2 lists the values of coefficients $a_{i,j}$ for the partial ternary systems A1–A18.

In the case of example 1 application of Formula (A.3) for each preliminary composition of partial mixture results in calculated methane numbers of 76,2489, 77,3777 and 71,9706 for A4, A7 and A8 respectively (Columns 5, 7 and 9).

A.3.5 Adjustment of the composition and fraction of the partial mixtures

The composition and fraction (F_t) of each partial mixture is adjusted iteratively by varying the quantity of each component in each partial mixture so as to minimize the difference between the methane numbers of each partial mixture.

The value to be minimised is therefore:

$$(MN_{\text{max}} - MN_{\text{min}}),$$

where MN_{max} and MN_{min} are the maximum and minimum methane numbers for the selected partial mixtures.

In the case of example 1, three ternary partial mixtures are selected and hence there are nine quantities to be determined, however four of these may be obtained by material balance considerations.

$$N_{\text{A8, methane}} = N_{\text{methane}} - N_{\text{A4, methane}} - N_{\text{A7, methane}}$$

$$N_{\text{A8, ethane}} = N_{\text{ethane}} - N_{\text{A4, ethane}}$$

$$N_{\text{A7, propane}} = N_{\text{propane}} - N_{\text{A4, propane}}$$

$$N_{\text{A8, butane}} = N_{\text{butane}} - N_{\text{A7, butane}}$$

Where $N_{t,comp}$ is the quantity of the respective component in partial mixture t.

The composition and fraction of each partial mixture is therefore performed by adjustment of five quantities: the quantities of methane, ethane and propane in A4, and the quantity of methane and butane in A7.

During adjustment the volume fraction of any component in any partial mixture shall be within the range for which the coefficients of Formula (A.3) are valid. Table A.2 lists the ranges of validity.

The problem of adjusting the composition and fraction of each partial mixture is therefore a constrained minimization one and in principal any appropriate numerical procedure may be employed. For the examples described in this Annex, the Solver supplied with Microsoft Excel (using default settings) produces an acceptable solution.

Depending upon the ending criterion of the numerical method employed, slight differences in the value of $(MN_{max} - MN_{min})$ will result in slightly different values of methane number of the simplified mixture. In addition, the use of different starting values for the composition and fraction of each partial mixture will result in slightly different values of methane number of the simplified mixture. These differences are within the uncertainties of this method and it is recommended that the final value of methane number is rounded to zero decimal places before reporting.

***In the case of example 1**, the composition and fraction of partial mixtures is provided in Table A.5 (Columns 4 – 9). For clarity, the five adjusted quantities are shown in underlined text.*

A.3.6 Calculation of the methane number of the simplified mixture

The methane number of the simplified mixture is determined from the weighted average of the methane number of the relevant partial ternary mixtures:

$$MN' = \sum_{t=1}^{t=N_{sys}} \left(MN_t \cdot F_t\right) \tag{A.4}$$

Where

MN' is the methane number of the simplified mixture

MN_t is the methane number of partial mixture t

F_t is the fraction of the partial mixture t

N_{sys} is the number of ternary systems selected

***In the case of example 1**, this results in a methane number of the simplified mixture of $MN' = 74{,}9018$.*

A.3.7 Calculation of the methane number of the gaseous fuel

The methane number of the gaseous fuel is calculated by correcting the methane number of the simplified mixture to allow for the presence of inerts in the original fuel gas:

$$MN = MN' + MN_{inerts} - MN_{methane} \tag{A.5}$$

In the original work of AVL/1/MN_{inerts} is the methane number of a methane-carbon dioxide-nitrogen mixture having the same inerts content as that of the original mixture. However in the amendment of MWM the MN_{inerts} is calculated for a methane-carbon dioxide-nitrogen mixture containing only carbon dioxide and methane. $MN_{methane}$ is calculated for a methane-carbon dioxide-nitrogen mixture containing pure methane and is equal to 100,0003.

The methane number of the methane-carbon dioxide-nitrogen mixture is calculated using Formula (A.3). Table A.2 lists the appropriate coefficients (system A20).

In the case of example 1, the methane-carbon dioxide-nitrogen mixture comprises methane (97,8750 volumes, the sum of the volumes of combustible components in the simplified mixture), nitrogen (1,0400 volumes) and carbon dioxide (1,4600 volumes) (Table A.5, column 10), which is normalized to a nitrogen-free mixture comprising methane (98,5302 % vol/vol) and carbon dioxide (1,4698 % vol/vol) (Table A.5, column 11). Application of Formula (A.3) results in a methane number of $MN_{\text{inerts}} = 101{,}4201$.

Application of Formula (A.5) results in a methane number of the gaseous fuel of

$74{,}9018 + 101{,}4201 - 100{,}0003 = 76{,}33217.$

The value of methane number is reported as 76.

A.4 Example 2: enriched biomethane

A.4.1 Simplification of the composition of the gaseous fuel

This example illustrates the calculation for a biomethane derived from anaerobic digestion that has been enriched by addition of propane. The composition is shown in Table A.6.

In the case of example 2 the quantity of butanes

$= 0{,}1461 + 0{,}0292 \times 2{,}3 + 0{,}0000 \times 5{,}3$

$= 0{,}2133$ *(Column 2)*

The simplified mixture is then re-normalized to 100 % (Column 3).

A.4.2 Calculation of fitness of the ternary systems

Application of Formula (A.1) to example 2 results in the values of W_i *shown in Table A.7.*

A.4.3 Selection of ternary mixtures

The first component in the simplified mixture is propane and this is present in ternary systems that have all their components present in the simplified mixture – A2, A4, A7 and A8. In this case, A7 is selected because it has the largest value of fitness (10,6652).

The second component in the simplified mixture is ethane and this is not represented in system A7, so system selection continues and system A4 is selected because it has the highest value of fitness (10,6380).

The third and fourth components of the simplified mixture are represented in system A7 (butane and methane) and A4 (methane) so the selection process restarts.

The selection process is repeated with the first component in the simplified mixture (propane), which is already represented in selected systems A4 and A7.

Selection continues with the second component in the simplified mixture (ethane), which is represented in only one selected system (A4), so system A8 is selected because it has the next highest value of fitness (9,0508).

All components of the simplified mixture are represented in at least two systems and so selection ends. The systems selected are therefore: A4, A7 and A8.

A.4.4 Calculation of the methane number

After preliminary division of the simplified mixture the calculation of methane number according to the methods in A.3.3 to A.3.7 the methane number of the gaseous fuel of example 2 is shown in Table A.5. Again, for clarity, the five adjusted quantities are shown in underlined text. The value of methane number obtained (69,0336) is reported as 69.

A.5 Example 3: 2H-gas with hydrogen addition

A.5.1 Simplification of the composition of the gaseous fuel

This example illustrates the calculation for the 2H-gas of composition of example 1 to which hydrogen has been added. The composition is shown in Table A.8.

In the case of example 3 the quantity of butanes

$= 0{,}1909 + 0{,}1727 + (0{,}0364 + 0{,}0455) \times 2{,}3 + 0{,}0545 \times 5{,}3$

$= 0{,}8408$ *(Column 2)*

The simplified mixture is then re-normalized to 100 % (Column 3).

A.5.2 Calculation of fitness of the ternary systems

Application of Formula (A.1) to example 3 results in the values of W_i *shown in Table A.9.*

A.5.3 Selection of ternary mixtures

The first component in the simplified mixture is hydrogen and this is present in ternary systems that have all their components present in the simplified mixture – A1, A5 and A6. In this case, A1 is selected because it has the largest value of fitness (10,5906).

The second component in the simplified mixture is propane and this is not represented in system A1, so system selection continues and system A5 is selected because it has the largest value of fitness (9,9921).

The third component in the simplified mixture is ethane and this is already represented in system A1, so no additional system is selected.

The fourth component in the simplified mixture is butane and this is not represented in the systems already selected. System A6 is selected because it has the largest value of fitness (9,9668).

The fifth component of the simplified mixture (methane) is represented in all three of the systems already selected, so no additional system is required.

Selection is repeated with the first component in the simplified mixture (hydrogen) and this is already represented in systems A1, A5 and A6, so no additional system is required.

Selection is continued with the second component in the simplified mixture (propane) and ternary system A4 is selected because it has the largest value of fitness (9,7749).

The third component in the simplified mixture (ethane) is represented in systems A1 and A4, so no additional system is required.

The fourth component in the simplified mixture (butane) is represented in one system (A6) and so system A8 is selected because it has the next largest value of fitness (7,9495).

All components in the simplified mixture are now represented in at least two of the ternary systems selected and the selection process ends. The systems selected are therefore: A1, A4, A5, A6 and A8.

A.5.4 Calculation of the methane number

In the case of example 3, five ternary partial mixtures are selected and hence there are 15 quantities to be determined, however five of these may be obtained by material balance considerations.

$$N_{\text{A8, methane}} = N_{\text{methane}} - N_{\text{A1, methane}} - N_{\text{A4, methane}} - N_{\text{A5, methane}} - N_{\text{A6, methane}}$$

$$N_{\text{A8, ethane}} = N_{\text{ethane}} - N_{\text{A1, ethane}} - N_{\text{A4, ethane}}$$

$N_{A5,\ propane} = N_{propane} - N_{A4,\ propane}$

$N_{A8,\ butane} = N_{butane} - N_{A6,\ butane}$

$N_{A6,\ hydrogen} = N_{hydrogen} - N_{A5,\ hydrogen} - N_{A1,\ hydrogen}$

The composition and fraction of each partial mixture is therefore determined by adjustment of 10 quantities: the quantities of methane, ethane and hydrogen in A1, the quantities of methane, ethane and propane in A4, the quantities of methane and hydrogen in A5 and the quantities of methane and butane in A6.

After preliminary division of the simplified mixture and calculation of methane number according to the methods in A.3.3 to A.3.7 the methane number of the gaseous fuel of example 3 is shown in Table A.8. For clarity, the 10 adjusted quantities are shown in underlined text. The value of methane number obtained (75,695) is reported as 76.

A.5.5 Additional numerical examples

Table A.10 provides the results of calculations for a variety of compositions for additional software validation purposes.

Table A.1 — Worked example of methane number calculation (example 1) - preliminary assignment of partial mixtures

	1	2	3	4	5	6	7	8	9
				mix A4		mix A7		mix A8	
				$N_{A4,i}$	$V_{A4,i}$	$N_{A7,i}$	$V_{A7,i}$	$N_{A8,i}$	$V_{A8,i}$
	% vol/vol		% vol/vol		% vol/vol		% vol/vol		% vol/vol
methane	90,0900	90,0900	92,0460	30,6820	89,7490	30,6820	96,3968	30,6820	90,2818
ethane	5,5400	5,5400	5,6603	2,8301	8,2785			2,8301	8,3277
propane	1,3200	1,3200	1,3487	0,6743	1,9725	0,6743	2,1186		
butanes		0,9250	0,9451			0,4725	1,4846	0,4725	1,3905
i-butane	0,2100								
n-butane	0,1900								
i-pentane	0,0400								
n-pentane	0,0500								
hexanes+	0,0600								
nitrogen	1,0400								
carbon dioxide	1,4600								
hydrogen	0,0000								
total	100,0000	97,8750	100,0000	34,1865	100,0000	31,8289	100,0000	33,9847	100,0000
Fraction, F_t					0,3419		0,3183		0,3398
MN_t					76,2489		77,3777		71,9706

Table A.2 — Components, coefficients and their ranges of validity of Formula (A.1) for the ternary partial mixtures

	A1	A2	A3	A4	A5	A6	A7
x:	methane	propane	hydrogen	methane	methane	methane	methane
y:	hydrogen	ethane	propane	ethane	hydrogen	hydrogen	propane
z:	ethane	butane	propylene	propane	propane	butane	butane
a(0, 0)	4,3628190E+01	1,0245130E+01	1,8627940E+01	3,3539090E+01	3,4758040E+01	1,2299020E+01	1,0169140E+01
a(1, 0)	−9,2508870E-02	8,5906610E-02	−1,2035810E-01	−1,0282240E-01	−5,1949050E-01	−7,5182070E-01	4,3666120E-01
a(0, 1)	−1,0488580E-02	1,4982130E-01	1,0871090E-01	2,0683750E-01	5,4737050E-02	−4,5103700E-01	3,8170960E-02
a(2, 0)	1,6449270E-02	7,3843960E-03	1,9298010E-02	2,3981410E-02	4,4054460E-02	5,1433330E-02	−8,7264540E-02
a(1, 1)	−2,5007730E-03	9,5705040E-03	−1,3050630E-03	3,3161370E-03	2,6425310E-02	5,1261470E-02	−7,9478640E-03
a(0, 2)	−4,3202740E-03	5,1369710E-03	1,7985000E-03	−3,5536890E-03	−1,0567810E-02	1,7866300E-02	1,0365010E-02
a(3, 0)	−3,1191690E-04	−1,0036620E-04	−1,3018080E-03	−9,5847460E-04	−8,7433290E-04	−1,0241590E-03	5,9397950E-03
a(2, 1)	−6,0486960E-05	−2,0203270E-04	2,9904470E-05	−2,4096040E-04	−1,0846450E-03	−1,6406520E-03	3,2678860E-04
a(1, 2)	−5,3528010E-05	−4,5802770E-05	8,5613760E-05	3,9418400E-05	−3,5553270E-04	−1,0022400E-03	2,3714910E-04
a(0, 3)	6,8507420E-05	−5,6856150E-05	−2,5836670E-05	5,0018560E-05	2,2897690E-04	−1,4279120E-04	−1,6152150E-04
a(4, 0)	2,1223340E-06	4,1273050E-07	4,1692950E-05	2,0052880E-05	5,4767420E-06	6,6995630E-06	−1,8541270E-04
a(3, 1)	2,1993700E-06	1,2511380E-06	2,0011240E-07	3,4585100E-06	1,1309800E-05	1,5661210E-05	−3,3085860E-07
a(2, 2)	1,2109690E-06	3,1147030E-07	−6,8546460E-07	8,0364540E-07	7,9874880E-06	1,5763060E-05	−4,9758630E-06
a(1, 3)	2,9706580E-07	−3,1401570E-07	−6,2626130E-07	−4,3338760E-07	7,4860850E-07	5,2498880E-06	−8,7822910E-07
a(0, 4)	−6,7138020E-07	2,4039480E-07	1,1987890E-07	−2,5042560E-07	−1,6340240E-06	0,0000000E+00	7,7408400E-07
a(5, 0)	0,0000000E+00	0,0000000E+00	−6,9526380E-07	−2,1154170E-07	0,0000000E+00	0,0000000E+00	2,9565980E-06
a(6, 0)	0,0000000E+00	0,0000000E+00	5,7989840E-09	9,0540200E-10	0,0000000E+00	0,0000000E+00	−2,3370740E-08
a(7, 0)	0,0000000E+00	0,0000000E+00	−1,9133740E-11	0,0000000E+00	0,0000000E+00	0,0000000E+00	7,3223480E-11
a(0, 5)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00
a(0, 6)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00
x(max), % vol/vol	100,0	100,0	100,0	100,0	100,0	100,0	100,0
x(min), % vol/vol	0,0	0,0	0,0	0,0	0,0	0,0	0,0
y(max), % vol/vol	100,0	100,0	100,0	100,0	100,0	100,0	100,0
y(min), % vol/vol	0,0	0,0	0,0	0,0	0,0	0,0	0,0
z(max), % vol/vol	100,0	100,0	100,0	100,0	100,0	100,0	100,0
z(min), % vol/vol	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table A.2 *(continued)*

	A8	A9	A10	A11	A12	A13	A14
x:	methane	methane	methane	methane	methane	ethane	carbon monoxide
y:	ethane	ethylene	hydrogen sulphide	ethane	propylene	propylene	hydrogen
z:	butane	butane	butane	hydrogen sulphide			
a(0, 0)	1,0777610E+01	−1,2408570E+05	1,8388506E+05	−1,1788466E+05	5,9095515E+01	3,1550700E+01	0,0000000E+00
a(1, 0)	1,6474900E-01	1,1938458E+04	−1,5396773E+04	1,1251043E+04	1,0602705E-01	7,9749400E-02	1,5000000E+00
a(0, 1)	−1,4050070E-01	−1,9962282E+02	−1,4160386E+01	−2,6712519E+02	−3,4069240E+00	−1,7706875E-01	0,0000000E+00
a(2, 0)	−5,1987300E-02	−4,8574811E+02	5,4158924E+02	−4,5492745E+02	−3,1884830E-03	4,8659675E-04	−7,5000000E-03
a(1, 1)	−7,0448690E-03	7,8748002E+00	5,6775484E-01	1,0645736E+01	0,0000000E+00	0,0000000E+00	−7,5000000E-03
a(0, 2)	1,6154370E-02	2,5929804E+00	1,1942148E+00	3,6669421E+00	1,5370325E-01	4,8659675E-04	0,0000000E+00
a(3, 0)	3,9913150E-03	1,0855881E+01	−1,0358971E+01	1,0120505E+01	−1,0801210E-04	0,0000000E+00	0,0000000E+00
a(2, 1)	1,4794820E-04	−1,0266703E-01	−7,7071033E-03	−1,3986048E-01	0,0000000E+00	0,0000000E+00	0,0000000E+00
a(1, 2)	3,3848030E-04	−6,9109752E-02	−2,4873835E-02	−9,7497566E-02	0,0000000E+00	0,0000000E+00	0,0000000E+00
a(0, 3)	−1,7546700E-04	−1,4504600E-02	−3,1209902E-02	−2,4662769E-02	−3,6748700E-03	0,0000000E+00	0,0000000E+00
a(4, 0)	−1,2774870E-04	−1,4417120E-01	1,1603083E-01	−1,3401172E-01	8,4599300E-06	0,0000000E+00	0,0000000E+00
a(3, 1)	2,7564440E-06	4,4431373E-04	3,3083382E-05	6,0764355E-04	0,0000000E+00	0,0000000E+00	0,0000000E+00
a(2, 2)	−4,0416670E-06	4,5679208E-04	1,7311782E-04	6,4613035E-04	0,0000000E+00	0,0000000E+00	0,0000000E+00
a(1, 3)	−1,9710210E-06	1,9871610E-04	4,1754490E-06	3,1927693E-04	0,0000000E+00	0,0000000E+00	0,0000000E+00
a(0, 4)	6,0752130E-07	2,6937182E-05	1,5364226E-03	7,6292913E-05	4,6273625E-05	0,0000000E+00	0,0000000E+00
a(5, 0)	2,0157030E-06	1,1395330E-03	−7,5743018E-04	1,0579750E-03	−1,3928745E-07	0,0000000E+00	0,0000000E+00
a(6, 0)	−1,5580170E-08	−4,9703336E-06	2,6462473E-06	−4,6175613E-06	7,1638300E-10	0,0000000E+00	0,0000000E+00
a(7, 0)	4,7976930E-11	9,2406348E-09	−3,7606039E-09	8,6063163E-09	0,0000000E+00	0,0000000E+00	0,0000000E+00
a(0, 5)	0,0000000E+00	0,0000000E+00	−3,5650030E-05	0,0000000E+00	−2,9054230E-07	0,0000000E+00	0,0000000E+00
a(0, 6)	0,0000000E+00	0,0000000E+00	3,0668448E-07	0,0000000E+00	7,1638300E-10	0,0000000E+00	0,0000000E+00
x(max), % vol/vol	100,0	100,0	100,0	100,0	100,0	100,0	100,0
x(min), % vol/vol	0,0	75,0	75,0	75,0	0,0	0,0	0,0
y(max), % vol/vol	100,0	25,0	25,0	25,0	100,0	100,0	100,0
y(min), % vol/vol	0,0	0,0	0,0	0,0	0,0	0,0	0,0
z(max), % vol/vol	100,0	25,0	25,0	25,0			
z(min), % vol/vol	0,0	0,0	0,0	0,0			

Table A.2 *(continued)*

	A15	A16	A17	A18	A20
x:	ethane	propane	butadiene	butylene	methane
y:	ethylene	ethylene			carbon dioxide
z:					nitrogen
a(0, 0)	2,9655595E+01	2,4494755E+01	1,2000000E+01	2,0000000E+01	2,9917430E+02
a(1, 0)	1,7064685E-01	1,3676575E-01	0,0000000E+00	0,0000000E+00	−1,5119580E+01
a(0, 1)	−1,2344405E-01	−5,4597900E-02	0,0000000E+00	0,0000000E+00	−3,1156360E-01
a(2, 0)	−2,3601400E-04	−4,1083915E-04	0,0000000E+00	0,0000000E+00	7,6359480E-01
a(1, 1)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	4,5480690E-02
a(0, 2)	−2,3601400E-04	−4,1083915E-04	0,0000000E+00	0,0000000E+00	1,1230410E-02
a(3, 0)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	−2,3762630E-02
a(2, 1)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	−7,8562940E-04
a(1, 2)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	6,5557090E-04
a(0, 3)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	−2,1468550E-03
a(4, 0)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	4,3554940E-04
a(3, 1)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	3,8606680E-06
a(2, 2)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	1,3816990E-06
a(1, 3)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	−7,9339020E-06
a(0, 4)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	6,6993640E-05
a(5, 0)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	−4,6077260E-06
a(6, 0)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	2,6105700E-08
a(7, 0)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	−6,1439140E-11
a(0, 5)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	−8,3693870E-07
a(0, 6)	0,0000000E+00	0,0000000E+00	0,0000000E+00	0,0000000E+00	3,9280730E-09
x(max), % vol/vol	100,0	100,0	100,0	100,0	100,0
x(min), % vol/vol	0,0	0,0	100,0	100,0	50,0
y(max), % vol/vol	100,0	100,0			30,0
y(min), % vol/vol	0,0	0,0			0,0
z(max), % vol/vol					50,0
z(min), % vol/vol					0,0

Table A.3 — Calculation of $Vsum_i$

	$min(100,(Vmax_{ij}+15))$										
System	CO	Butadiene	Butylene	Ethylene	Propylene	H_2S	Hydrogen	Propane	Ethane	Butane	Methane
1	0	0	0	0	0	0	100	0	100	0	100
2	0	0	0	0	0	0	0	100	100	100	0
3	0	0	0	0	100	0	100	100	0	0	0
4	0	0	0	0	0	0	0	100	100	0	100
5	0	0	0	0	0	0	100	100	0	0	100
6	0	0	0	0	0	0	100	0	0	100	100
7	0	0	0	0	0	0	0	100	0	100	100
8	0	0	0	0	0	0	0	0	100	100	100
9	0	0	0	40	0	0	0	0	0	40	100
10	0	0	0	0	0	40	0	0	0	40	100
11	0	0	0	0	0	40	0	0	40	0	100
12	0	0	0	0	100	0	0	0	0	0	100
13	0	0	0	0	100	0	0	0	100	0	0
14	100	0	0	0	0	0	100	0	0	0	0
15	0	0	0	100	0	0	0	0	100	0	0
16	0	0	0	100	0	0	0	100	0	0	0
17	0	100	0	0	0	0	0	0	0	0	0
18	0	0	100	0	0	0	0	0	0	0	0
$Vsum_i$	100	100	100	240	300	80	500	600	640	480	1000

Table A.4 — Calculation of fitness, W_j (example 1)

	V_i											
	CO	Butadiene	Butylene	Ethylene	Propylene	H_2S	Hydrogen	Propane	Ethane	Butane	Methane	
	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,3487	5,6603	0,9451	92,0460	
	$\frac{V_i \cdot Vmax_{i,j}}{Vsum_i}$											
System	CO	Butadiene	Butylene	Ethylene	Propylene	H_2S	Hydrogen	Propane	Ethane	Butane	Methane	W_j
1	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,8844	0,0000	9,2046	10,0890
2	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2248	0,8844	0,1969	0,0000	1,3061
3	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2248	0,0000	0,0000	0,0000	0,2248
4	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2248	0,8844	0,0000	9,2046	10,3138
5	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2248	0,0000	0,0000	9,2046	9,4294
6	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,1969	9,2046	9,4015
7	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2248	0,0000	0,1969	9,2046	9,6263
8	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,8844	0,1969	9,2046	10,2859
9	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0788	9,2046	9,2834
10	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0788	9,2046	9,2834
11	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,3538	0,0000	9,2046	9,5584
12	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	9,2046	9,2046
13	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,8844	0,0000	0,0000	0,8844
14	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,8844	0,0000	0,0000	0,8844
16	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2248	0,0000	0,0000	0,0000	0,2248
17	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
18	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Table A.5 — Worked example of methane number calculation (composition 1) – final calculation

	1	2	3	4	5	6	7	8	9	10	11
				mix A4		mix A7		mix A8		mix A20	
				$N_{A4,i}$	$V_{A4,i}$	$N_{A7,i}$	$V_{A7,i}$	$N_{A8,i}$	$V_{A8,i}$	$N_{A20,i}$	$V_{A20,i}$
	% vol/vol		% vol/vol		% vol/vol		% vol/vol		% vol/vol		% vol/vol
methane	90,0900	90,0900	92,0460	27,9390	88,7108	27,3417	95,8205	36,7653	91,9793	97,8750	98,5302
ethane	5,5400	5,5400	5,6603	2,9012	9,2119			2,7590	6,9025		
propane	1,3200	1,3200	1,3487	0,6542	2,0773	0,6944	2,4337				
butanes		0,9250	0,9451			0,4982	1,7458	0,4469	1,1181		
i-butane	0,2100										
n-butane	0,1900										
i-pentane	0,0400										
n-pentane	0,0500										
hexanes+	0,0600										
nitrogen	1,0400									1,0400	0,0000
carbon dioxide	1,4600									1,4600	1,4698
hydrogen	0,0000	0,0000	0,0000								
total	100,0000	97,8750	100,0000	31,4944	100,0000	28,5343	100,0000	39,9713	100,0000	100,3750	100,0000
Fraction, F_i					0,3149		0,2853		0,3997		
MN_i					74,9017		74,9019		74,9019		101,4201

ΔMN	0,000262
MN'	74,9018
MN	76,3217

Table A.6 — Worked example of methane number calculation (example 2) – final calculation

	1	2	3	4	5	6	7	8	9	10	11
				mix A4		mix A7		mix A8		mix A20	
				$N_{A4,i}$	$V_{A4,i}$	$N_{A7,i}$	$V_{A7,i}$	$N_{A8,i}$	$V_{A8,i}$	$N_{A20,i}$	$V_{A20,i}$
	% vol/vol		% vol/vol		% vol/vol		% vol/vol		% vol/vol		% vol/vol
methane	86,6475	86,6475	89,8575	41,1188	88,8181	46,3797	90,6616	2,3590	92,5995	96,4277	96,3911
ethane	0,1169	0,1169	0,1212	0,0585	0,1263			0,0628	2,4632		
propane	9,4500	9,4500	9,8001	5,1182	11,0556	4,6819	9,1520				
butanes		0,2133	0,2212			0,0954	0,1864	0,1258	4,9373		
i-butane	0,0000										
n-butane	0,1461										
i-pentane	0,0000										
n-pentane	0,0292										
hexanes+	0,0000										
nitrogen	0,0000									0,0000	0,0000
carbon dioxide	3,6103									3,6103	3,6089
hydrogen	0,0000	0,0000	0,0000								
total	100,0000	96,4277	100,0000	46,2955	100,0000	51,1569	100,0000	2,5476	100,0000	100,0380	100,0000
Fraction, F_t					0,4630		0,5116		0,0255		
MN_t					65,3039		65,3059		65,3039		103,7290

ΔMN 0,002016

MN' 65,3049

MN 69,0336

Table A.7 — Calculation of fitness, W_j (example 2)

	V_i											
	CO	Butadiene	Butylene	Ethylene	Propylene	H_2S	Hydrogen	Propane	Ethane	Butane	Methane	
	0,0000	0,000	0,0000	0,0000	0,0000	0,0000	0,0000	9,8001	0,1212	0,2212	89,8575	
	$\frac{V_i \cdot Vmax_{i,j}}{Vsum_i}$											
System	CO	Butadiene	Butylene	Ethylene	Propylene	H_2S	Hydrogen	Propane	Ethane	Butane	Methane	W_j
1	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0189	0,0000	8,9858	9,0047
2	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,6333	0,0189	0,0461	0,0000	1,6984
3	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,6333	0,0000	0,0000	0,0000	1,6333
4	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,6333	0,0189	0,0000	8,9858	10,6380
5	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,6333	0,0000	0,0000	8,9858	10,6191
6	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0461	8,9858	9,0318
7	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,6333	0,0000	0,0461	8,9858	10,6652
8	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0189	0,0461	8,9858	9,0508
9	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0184	8,9858	9,0042
10	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0184	8,9858	9,0042
11	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0076	0,0000	8,9858	8,9933
12	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	8,9858	8,9858
13	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0189	0,0000	0,0000	0,0189
14	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0189	0,0000	0,0000	0,0189
16	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,6333	0,0000	0,0000	0,0000	1,6333
17	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
18	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Table A.8 — Worked example of methane number calculation (example 3) – final calculation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				mix A1		mix A4		mix A5		mix A6		mixA8		mix A20	
				$N_{A1,i}$	$V_{A1,i}$	$N_{A4,i}$	$V_{A4,i}$	$N_{A5,i}$	$V_{A5,i}$	$N_{A6,i}$	$V_{A6,i}$	$N_{A8,i}$	$V_{A8,i}$	$N_{A20,i}$	$V_{A20,i}$
	% vol/vol		% vol/vol		% vol/vol		% vol/vol		% vol/vol		% vol/vol		% vol/vol		% vol/vol
methane	85,991	85,991	87,685	14,001	80,221	16,424	88,778	14,270	84,092	15,601	89,710	27,389	92,258	98,068	98,665
ethane	5,036	5,036	5,136	1,667	9,549	1,599	8,645					1,870	6,298		
propane	1,200	1,200	1,224			0,477	2,577	0,747	4,402						
butanes		0,841	0,857							0,429	2,465	0,429	1,444		
i-butane	0,191														
n-butane	0,173														
i-pentane	0,036														
n-pentane	0,046														
hexanes+	0,055														
nitrogen	0,946													0,946	0,000
carbon dioxide	1,327													1,327	1,335
hydrogen	5,000	5,000	5,099	1,785	10,229			1,952	11,506	1,361	7,824				
total	100,000	98,068	100,000	17,453	100,000	18,500	100,000	16,969	100,000	17,391	100,000	29,687	100,000	100,341	100,000
Fraction, F_t					0,175		0,185		0,170		0,174		0,297		
MN_t					74,411		74,411		74,411		74,411		74,411		101,284

ΔMN	0,00012
MN'	74,411
MN	75,695

Table A.9 — Calculation of fitness, W_j (example 3)

	V_i											
	CO	Butadiene	Butylene	Ethylene	Propylene	H_2S	Hydrogen	Propane	Ethane	Butane	Methane	
	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	5,0985	1,2236	5,1356	0,8574	87,6849	
	$\frac{V_i \cdot Vmax_{i,j}}{Vsum_i}$											
System	CO	Butadiene	Butylene	Ethylene	Propylene	H_2S	Hydrogen	Propane	Ethane	Butane	Methane	W_j
1	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,0197	0,0000	0,8024	0,0000	8,7685	10,5906
2	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2039	0,8024	0,1786	0,0000	1,1850
3	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,0197	0,2039	0,0000	0,0000	0,0000	1,2236
4	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2039	0,8024	0,0000	8,7685	9,7749
5	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,0197	0,2039	0,0000	0,0000	8,7685	9,9921
6	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,0197	0,0000	0,0000	0,1786	8,7685	9,9668
7	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2039	0,0000	0,1786	8,7685	9,1510
8	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,8024	0,1786	8,7685	9,7495
9	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0714	8,7685	8,8399
10	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0714	8,7685	8,8399
11	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,3210	0,0000	8,7685	9,0895
12	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	8,7685	8,7685
13	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,8024	0,0000	0,0000	0,8024
14	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,0197	0,0000	0,0000	0,0000	0,0000	1,0197
15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,8024	0,0000	0,0000	0,8024
16	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,2039	0,0000	0,0000	0,0000	0,2039
17	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
18	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Table A.10 — Additional numerical examples for software validation purposes

Component	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10	Mix 11	Mix 12	Mix 13	Mix 14	Mix 15	Mix 16
carbon dioxide		1,00	0,20	2,30	2,00		3,90									
nitrogen	13,00	13,00	0,20	0,80	0,74	3,70	0,40									
oxygen																
hydrogen								70	5	5	65	5	50	5	20	90
carbon monoxide													20			
methane	83,53	82,43	94,68	86,30	87,34	84,62	85,58	15	80	70	10	65	5	75	55	4
ethylene										5	5	5	5			
ethane	3,47	3,00	3,20	8,70	7,00	8,00	5,70	5	5	5	5	5	5	5	5	2
propylene										5	5	5	5			
propane		0,20	1,05	1,60	2,20	1,70	2,10	5	5	5	5	5	5	5	5	2
butylene																
butane		0,27	0,47	0,30	0,41	1,47	0,90	5	5	5	5	5	5	5	5	2
pentane		0,10	0,20		0,11	0,51	0,82									
hexanes+					0,20		0,60									
hydrogen sulphide												5		5	10	
total	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100	100	100	100	100	100	100	100	100
methane number	90,02	85,03	80,00	75,03	70,02	65,00	59,97	21,55	53,20	41,25	19,59	35,01	23,89	44,15	30,45	10,04
Ternary mixtures selected	A1 A4	A4 A7 A8	A4 A7 A8	A4 A7 A8	A4 A7 A8	A4 A7 A8	A4 A7 A8	A1 A3 A5 A6 A8	A1 A5 A6 A7 A8	A1 A6 A7 A8 A9 A12	A1 A3 A6 A7 A12 A15 A16	A6 A7 A8 A9 A10 A11 A12	A1 A2 A3 A6 A13 A14 A15 A16	A5 A6 A7 A8 A10 A11	A1 A5 A6 A7 A10 A11	A1 A3 A5 A6 A8