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ENERGETICS

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Calculation procedure of oxidizers consumption coefficients in the gasification of the solid carbon-containing mediums

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Abstract.
The paper presents the calculation procedure of determining the stoichiometric coefficients of oxidizer consumption in the gasification of solid carbon-containing mediums, which takes into account its physical and chemical parameters and type of oxidizer, and allows you to specify their values. These values of stoichiometric consumption coefficients are necessary for subsequent technological and thermodynamic calculations of thermal processing of carbon-containing mediums.

Keywords:
stoichiometric consumption coefficient
gasification
carbon-containing mediums

ENERGETICS

The results of transformations of carbon-containing media by their gasification are determined by the type of medium, its composition, nature, ratio of reacting components, heat exchange conditions, temperature in the reaction space, and other factors. The high value of the degree of thermal recycling of carbon contained in the recycled medium is achieved precisely by the stoichiometric ratio of the reacting components.

Stoichiometric or theoretical ratio in gasification of carbon-containing media (CCM) is the ratio of masses of the reacting components (oxidizer/carbon), when the oxidizer is supplied in the necessary and sufficient amount for complete conversion of carbon and other gas-forming elements of the medium.

Stoichiometric oxidizer consumption factor (α) is a specific index, denoting the required amount of oxidizing medium of a certain nature for the complete conversion of a unit mass of CCM, taking into account its physical and chemical properties. Thus, the stoichiometric oxidizer consumption factor will be different both for CCM with different elemental composition and for oxidizer of different nature.

The maximum yield of products of thermal transformations in the gasification of CCM occurs at the concentration of the reacting components corresponding to their stoichiometric mass ratios, which enter into reactions of thermal transformations.

Thus, the purpose of the research is to develop a calculation method for determining stoichiometric coefficients of oxidizer consumption during gasification of solid CCM, which takes into account the type of oxidizer and physical and chemical parameters of CCM.

The physicochemical parameters of solid CCM affecting the yield of gasification products are carbon content in CCM - C^p, water content - W^p, and oxygen content - O^p (*% (wt.)*).

Gasification processes of CCM, depending on the type of oxidizer, are subdivided into oxygen, steam, air, and their various combinations [1-4].

Let's consider the main chemical reactions of carbon conversion that occur in these types of gasification of solid

CCS.

In oxygen gasification of CCM, the following chemical reactions occur:

1) Reaction with injected $(O_{2(i)})$ and with own $(O_{2(o)})$ oxygen –

$$2C + O_{2(i)} + O_{2(o)} = 2CO \quad (1)$$

2) Reaction with its own water $(H_2O_{(o)})$ –

$$C+H_2O_{(o)} = CO + H_2 \quad (2)$$

In steam gasification of CCM:

1) Reaction with input $(H_2O_{(i)})$ and with own $(H_2O_{(o)})$ water –

$$C+ H_2O_{(i)} + H_2O_{(o)} = CO + H_2 \quad (3)$$

2) Reaction with its own oxygen $(O_{2(o)})$ –

$$2C + O_{2(o)} = 2CO \quad (4)$$

In air gasification of CCM:

1) Reaction with injected air –

$$2C + (air\ (O_2 + (N_2,\ Ar,\ CO_2,\dots)) = 2CO+(N_2,\ Ar,\ CO_2,\dots) \quad (5)$$

2) Reaction with its own oxygen $(O_{2(o)})$ –

$$2C + (O_{2(o)}) = 2CO \quad (6)$$

3) Reaction with its own water $(H_2O_{(o)})$ –

$$C+ H_2O_{(o)} = CO + H_2 \quad (7)$$

In oxygen-steam gasification of CCM:

1) Reaction with injected (O2(i)) and with own (O2(o)) oxygen –

$$2C + O_{2(i)} + O_{2(o)} = 2CO \quad (8)$$

2) Reaction with injected $(H_2O_{(i)})$ and with own $(H_2O_{(o)})$ water –

$$C + H_2O_{(i)} + H_2O_{(o)} = CO + H_2 \quad (9)$$

In air-steam gasification of CCM:
1) Reaction with injected air –

$$2C + (air\ (O_2 + (N_2,\ Ar,\ CO_2,\ldots)) = 2CO + (N_2,\ Ar,\ CO_2,\ldots) \quad (10)$$

2) Reaction with input $(H_2O_{(i)})$ and own $(H_2O_{(o)})$ water –

$$C + H_2O_{(i)} + H_2O_{(o)} = CO + H_2 \quad (11)$$

3) Reaction with its own oxygen $(O_{2(o)})$ –

$$2C + (O_{2(o)}) = 2CO \quad (12)$$

In oxygen-air gasification of CCM:
1) Reaction with injected $(O_{2(i)})$ and with own $(O_{2(o)})$ oxygen –

$$2C + O_{2(i)} + O_{2(o)} = 2CO \quad (13)$$

2) Reaction with injected air –

$$2C + (air\ (O_2 + (N_2,\ Ar,\ CO_2,\ldots)) = 2CO + (N_2,\ Ar,\ CO_2,\ldots) \quad (14)$$

3) Reaction with its own water $(H_2O_{(o)})$ –

$$C + H_2O_{(o)} = CO + H_2 \quad (15)$$

In oxygen-air-steam gasification of CCM:
1) Reaction with injected $(O_{2(i)})$ and with own $(O_{2(o)})$ oxygen –

$$2C + O_{2(i)} + O_{2(o)} = 2CO \quad (16)$$

2) Reaction with injected air –

$$2C + (air\ (O_2 + (N_2,\ Ar,\ CO_2,\ldots)) = 2CO + (N_2,\ Ar,\ CO_2,\ldots) \quad (17)$$

ENERGETICS

3) Reaction with injected $(H_2O_{(i)})$ and with own water $(H_2O_{(o)})$ –

$$C + H_2O_{(i)} + H_2O_{(o)} = CO + H_2 \quad (18)$$

That is, the gasification of CCM involves the following basic reactions:

$$2C + O_2 = 2CO \quad (19)$$

$$C + H_2O = CO + H_2 \quad (20)$$

$$2C + (\text{ air } (O_2 + (N_2, Ar, CO_2, \dots)) = 2CO + (N_2, Ar, CO_2, \dots) \quad (21)$$

Let's make up material balances of reactions (19-21):

$$24 \text{ kg } (C) + 32 \text{ kg } (O_2) = 56 \text{ kg } (CO) \quad (22)$$

$$12 \text{ kg } (C) + 18 \text{ kg } (H_2O) = 28 \text{ kg } (CO) + 2 \text{ kg } (H_2) \quad (23)$$

Given that the air contains 23.15 % $(wt.)$ of O_2, and the inert component $(N_2, Ar, CO_2, \dots)$ is $100-23,15=76,85$ % $(wt.)$, then the material balance of reaction (21):

$$24 \text{ kg } (C) + 32 \text{ kg } (O_2) + 32 \cdot 76,85 / 23,15 \text{ kg } (N_2, Ar, CO_2, \dots) =$$

$$= 56 \text{ kg } (CO) + 32 \cdot 76,85 / 23,15 \text{ kg } (N_2, Ar, CO_2, \dots) \quad (24)$$

or

$$24 \text{ kg } (C) + 32 \text{ kg } (O_2) + 106,2 \text{ kg } (N_2, Ar, CO_2, \dots) =$$
$$= 56 \text{ kg } (CO) + 106,2 \text{ kg } (N_2, Ar, CO_2, \dots) \quad (25)$$

Let us rewrite reactions (22), (23), (25) for 1 kg of carbon:

$$1 \text{ kg } (C) + 32/24 \text{ kg } (O_2) = 56/24 \text{ kg } (CO) \quad (26)$$

$$1 \text{ kg } (C) + 18/12 \text{ kg } (H_2O) =$$
$$28/12 \text{ kg } (CO) + 2/12 \text{ kg } (H_2) \quad (27)$$

$$1\ kg\ (C) + 32/24\ kg\ (O_2) + 106,2/24\ kg\ (N_2, Ar, CO_2,…) = = 56/24\ kg\ (CO) + 106,2/24\ kg\ (N_2, Ar, CO_2,…) \quad (28)$$

or

$$1\ kg\ (C) + 1,333\ kg\ (O_2) = 2,333\ kg\ (CO) \quad (29)$$

$$1\ kg\ (C) + 1,5\ kg\ (H_2O) = 2,333\ kg\ (CO) + 0,167\ kg\ (H_2) \quad (30)$$

$$1\ kg\ (C) + 1,333\ kg\ (O_2) + 4,425\ kg\ (N_2, Ar, CO_2,…) = = 2,333\ kg\ (CO) + 4,425\ kg\ (N_2, Ar, CO_2,…) \quad (31)$$

Since the CCM contains some amount of water ($W^p/100$) and oxygen ($O^p/100$) (where W^p, O^p are water and oxygen content in the CCM, respectively, (*in % (wt.)*), the need for an oxidizer will decrease.

According to (19), (20) and considering (29), (30), the amount of carbon $C_{(o)}$, that will react with its own oxidizer is:

$$C_{(o)} = C_{(O2(o))} + C_{(H2O(o))} = 0,75 \cdot O^p/100 + 0,667 \cdot W^p/100 \quad (39)$$

Then, the amount of carbon (C_m), that requires additional oxidizer from outside, that is, the amount of residual carbon (*kg C/kg CCM*):

$$C_m = C^p/100 - (C_{(O2(o))} + C_{(H2O(o))}) = = C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100 \quad (40)$$

Consider the oxygen-air-steam gasification of CCM (joint reactions (16), (17) and (18)) and determine the oxidizer (oxygen, air and water) consumption ratios - $\alpha_{(o-a-w.g.)O2}$, $\alpha_{(o-a-w.g.)air}$ и $\alpha_{(o-a-w.g.)H2O}$.

In oxygen-air-steam gasification of CCM, the oxidizing agents are the injected oxygen, the oxygen contained in the injected air, and water.

Let's write down the general chemical reaction that takes place when oxidizers are introduced:

$$3C + O_2 + (air\ (O_2 + (N_2, Ar, CO_2,…)) + H_2O = = 3CO + (N_2, Ar, CO_2,…) + H_2 \quad (41)$$

To observe the oxidizer/carbon stoichiometric, we introduce stoichiometric coefficients of oxidizers, given that their total stoichiometric consumption coefficient in the oxygen-air-steam gasification of CCM ($k_{(o\text{-}a\text{-}w.g.)}$) is *1*:

$$k_{(o\text{-}a\text{-}w.g.)} = k_{(o\text{-}a\text{-}w.g.)O2} + k_{(o\text{-}a\text{-}w.g.)air} + k_{(o\text{-}a\text{-}w.g.)H2O} = 1, \quad (42)$$

where $k_{(o\text{-}a\text{-}w.g.)O2}$, $k_{(o\text{-}a\text{-}w.g.)air}$, $k_{(o\text{-}a\text{-}w.g.)H2O}$ *are stoichiometric coefficients of oxygen, air and water consumption during oxygen-air-steam gasification of CCM, respectively, i.e. mass fraction of oxygen, air and water from stoichiometric oxidizer consumption during oxygen-air-steam gasification of CCM (kg ox./kg mix. ox.).*

Then:

- given formula (29), the stoichiometric coefficient of oxygen consumption ($\alpha_{(o\text{-}a\text{-}w.g.)O2}$, *kg* O_2 */ kg CCM*) for oxygen-air-steam gasification of CCM:

$$\alpha_{(o\text{-}a\text{-}w.g.)O2} = k_{(o\text{-}a\text{-}w.g.)O2} \cdot 1,333 \cdot C_m = k_{(o\text{-}a\text{-}w.g.)O2} \cdot 1,333 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100), \quad (43)$$

- taking into account formula (30) stoichiometric coefficient of water consumption ($\alpha_{(o\text{-}a\text{-}w.g.)air}$, *kg air / kg CCM*):

$$\alpha_{(o\text{-}a\text{-}w.g.)H2O} = k_{(o\text{-}a\text{-}w.g.)H2O} \cdot 1,5 \cdot C_m = k_{(o\text{-}a\text{-}w.g.)H2O} \cdot 1,5 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100), \quad (44)$$

- taking into account formula (31), the stoichiometric coefficient of air consumption ($\alpha_{(o\text{-}a\text{-}w.g.)air}$, *kg air. / kg CCM*):

$$\alpha_{(o\text{-}a\text{-}w.g.)air} = k_{(o\text{-}a\text{-}w.g.)air} \cdot (1,333 + 4,425) \cdot C_m = k_{(o\text{-}a\text{-}w.g.)air} \cdot 5,758 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100), \quad (45)$$

The total stoichiometric coefficient of oxidizer consumption in oxygen-air-steam gasification of CCM

($\alpha_{(o-a-w.g.)}$, kg ox. / kg CCM) is:

$$\alpha_{(o-a-w.g.)} = \alpha_{(o-a-w.g.)O2} + \alpha_{(o-a-w.g.)air} + \alpha_{(o-a-w.g.)H2O} =$$
$$= k_{(o-a-w.g.)O2} \cdot 1,333 \cdot C_m + k_{(o-a-w.g.)air} \cdot 5,77 \cdot C_m + k_{(o-a-w.g.)H2O} \cdot 1,5 \cdot C_m =$$
$$= k_{(o-a-w.g.)O2} \cdot 1,333 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) +$$
$$+ k_{(o-a-w.g.)air} \cdot 5,77 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100)) +$$
$$+ k_{(o-a-w.g.)H2O} \cdot 1,5 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) =$$
$$= (1,333 \cdot k_{(o-a-w.g.)O2} + 5,758 \cdot k_{(o-a-w.g.)air} + 1,5 \cdot k_{(o-a-w.g.)H2O}) x$$
$$x\ (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) \quad (46)$$

Let's consider the obtained formula (46).
In oxygen gasification of CCM:

$$k_{(o.g.)O2} = 1 \text{ and } k_{(o.g.)H20} = 0,\ k_{(o.g.)air} = 0,$$

then, substituting these values into formula (46), we obtain a formula for calculating the stoichiometric coefficient of oxygen consumption during the oxygen gasification of CCM ($\alpha_{(o.g.)O2}$, kg O_2/kg CCM):

$$\alpha_{(o.g.)} = (1,333 \cdot 1 + 5,758 \cdot 0 + 1,5 \cdot 0)\ x$$
$$x\ (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) =$$
$$= 1,333 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) \quad (47)$$

At the steam gasification of CCM:

$$k_{(w.g.)H20} = 1 \text{ and } k_{(w.g.)O2} = 0,\ k_{(w.g.)air} = 0,$$

then by substituting these values into formula (46), we obtain a formula for calculating the stoichiometric coefficient of water consumption during steam gasification of CCM ($\alpha_{(w.g.)H2O}$, kg $H_2$0/kg CCM):

$$\alpha_{(w.g.)} = (1,333 \cdot 0 + 5,758 \cdot 0 + 1,5 \cdot 1)\ x$$
$$x\ (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) =$$
$$= 1,5 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) \quad (48)$$

ENERGETICS

At the air gasification of CCM:

$$k_{(a.g.)air} = 1 \text{ and } k_{(a.g.)O2} = 0,\ k_{(a.g.)H2O} = 0,$$

then by substituting these values into formula (46), we obtain a formula for calculating the stoichiometric coefficient of air consumption in the air gasification of CCM ($\alpha_{(a.g.)air}$, *kg air./kg CCM*):

$$\alpha_{(a.g.)} = (1{,}333 \cdot 0 + 5{,}758 \cdot 1 + 1{,}5 \cdot 0)\ x$$
$$x\ (C^p/100 - 0{,}75 \cdot O^p/100 - 0{,}667 \cdot W^p/100) =$$
$$= 5{,}758 \cdot (C^p/100 - 0{,}75 \cdot O^p/100 - 0{,}667 \cdot W^p/100) \quad (49)$$

At the oxygen-steam gasification of CCM:

$$k_{(o-w.g.)O2} \neq 0,\ k_{(o-w.g.)H2O} \neq 0 \text{ and } k_{(o-w.g.)air} = 0.$$

Let us write down the general chemical reaction that occurs when oxidizers are introduced:

$$3C + O_2 + H_2O = 3CO + H_2 \quad (50)$$

Material balance of reaction (50) for *1 kg* carbon:

$$1\ kg\ (C) + 0{,}889\ kg\ (O_2) + 0{,}5\ kg\ (H_2O) = 2{,}333\ kg\ (CO) +$$
$$+ 0{,}056\ kg\ (H_2) \quad (51)$$

Let's find $k_{(o-w.g.)O2}$ and $k_{(o-w.g.)H2O}$ from formulae (51) and (46), from which it follows that

$$0{,}889 = 1{,}333 \cdot k_{(o-w.g.)O2}$$
$$0{,}5 = 1{,}5 \cdot k_{(o-w.g.)H2O},$$

where $k_{(o-w.g.)O2} = 0{,}667,\ k_{(o-w.g.)H2O} = 0{,}333,$

i.e. condition $k_{(o-w.g.)O2} + k_{(o-w.g.)H2O} = 0{,}666 + 0{,}333 = 1$ *is satisfied.*

Thus, at the oxygen-steam gasification of CCM the stoichiometric coefficients of oxygen to observe the stoichiometric of the reacting substances and water are constant and equal to $k_{(o\text{-}w.g.)O2} = 0,667$, $k_{(o\text{-}w.g.)H2O} = 0,333$, respectively.

Substituting values of $k_{(o\text{-}w.g.)O2} = 0,667$, $k_{(o\text{-}w.g.)H2O} = 0,333$, $k_{(o\text{-}w.g.)air} = 0$ into formula (46), we obtain a formula for calculating the total stoichiometric coefficient of oxidizer consumption during oxygen and steam gasification of CCM ($\alpha_{(o\text{-}w.g.)}$, *kg ox. / kg CCM*):

$$\alpha_{(o\text{-}w.g.)} = (1,333 \cdot 0,667 + 5,758 \cdot 0 + 1,5 \cdot 0,333) \times (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) = 1,389 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100), \quad (52)$$

Whence the stoichiometric coefficient of oxygen consumption in oxygen-steam gasification of CCM ($\alpha_{(o\text{-}w.g.)O2}$, *kg O_2 / kg CCM*) is equal:

$$\alpha_{(o\text{-}w.g.)O2} = 1,333 \cdot 0,667 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) = 0,889 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100), \quad (52a)$$

and the stoichiometric coefficient of water consumption in oxygen-steam gasification of CCM ($\alpha_{(o\text{-}w.g.)H2O}$, *kg H2O/kg CCM*):

$$\alpha_{(o\text{-}w.g.)H2O} = 1,5 \cdot 0,333 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) = 0,5 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) \quad (52b)$$

In air-steam gasification of CCM:

$$k_{(a\text{-}w.g.)air} \neq 0,\ k_{(a\text{-}w.g.)H2O} \neq 0 \text{ and } k_{(a\text{-}w.g.)O2} = 0.$$

Let's write down the general chemical reaction that occurs when oxidizers are introduced:

$$3C + (air\ (O_2 + (N_2, Ar, CO_2,\ldots)) + H_2O = 3CO + H_2 + (N_2, Ar, CO_2,\ldots) \quad (53)$$

Material balance of reaction (53) for *1 kg* of carbon:

ENERGETICS

$$1\ kg\ (C) + 0{,}889\ kg\ (O_2) + 0{,}5\ kg\ (H_2O) + 2{,}95\ kg\ (N_2,\ Ar,\ CO_2,\ldots) =$$
$$= 2{,}333\ kg\ (CO) + 0{,}056\ kg\ (H_2) + 2{,}95\ kg\ (N_2,\ Ar,\ CO_2,\ldots) \quad (54)$$

Let's find $k_{(a\text{-}w.g.)air}$ and $k_{(a\text{-}w.g.)H2O}$ from formulae (54) and (46), from which it follows that

$$3{,}84 = 5{,}758 \cdot k_{(a\text{-}w.g.)air}$$
$$0{,}5 = 1{,}5 \cdot k_{(a\text{-}w.g.)H2O},$$

whence $k_{(a\text{-}w.g.)air} = 0{,}666$, $k_{(a\text{-}w.g.)H2O} = 0{,}333$,
that is, the condition $k_{(a\text{-}w.g.)air} + k_{(a\text{-}w.g.)H2O} = 0{,}666 + 0{,}333 = 1$ *is satisfied.*

Thus, at air-steam gasification of CCM to observe stoichiometric of reacting substances the stoichiometric coefficients of air and water are constant and equal to $k_{(a\text{-}w.g.)air} = 0{,}666$, $k_{(a\text{-}w.g.)H2O} = 0{,}333$, respectively.
Substituting the values of $k_{(a\text{-}w.g.)air} = 0{,}666$, $k_{(a\text{-}w.g.)H2O} = 0{,}333$, $k_{(a\text{-}w.g.)O2} = 0$ into formula (46), we obtain:

$$\alpha_{(a\text{-}w.g.)} = (1{,}333 \cdot 0 + 5{,}758 \cdot 0{,}666 + 1{,}5 \cdot 0{,}333) \times$$
$$\times\ (C^p/100 - 0{,}75 \cdot O^p/100 - 0{,}667 \cdot W^p/100) =$$
$$= 4{,}34 \cdot (C^p/100 - 0{,}75 \cdot O^p/100 - 0{,}667 \cdot W^p/100)), \quad (55)$$

where is the stoichiometric coefficient of air consumption during air-steam gasification of CCM ($\alpha_{(a\text{-}w.g.)air}$, *kg* O_2 / *kg CCM):*

$$\alpha_{(a\text{-}w.g.)air} = 5{,}758 \cdot 0{,}666 \cdot (C^p/100 - 0{,}75 \cdot O^p/100 - 0{,}667 \cdot W^p/100)) =$$
$$= 3{,}84 \cdot (C^p/100 - 0{,}75 \cdot O^p/100 - 0{,}667 \cdot W^p/100), \quad (55a)$$

and the stoichiometric coefficient of water consumption during air-steam gasification of CCM ($\alpha_{(a\text{-}w.g.)H2O}$, *kg* H_2O / *kg CCM*):

$$\alpha_{(a\text{-}w.g.)H2O} = 1{,}5 \cdot 0{,}333 \cdot (C^p/100 - 0{,}75 \cdot O^p/100 - 0{,}667 \cdot W^p/100) =$$
$$= 0{,}5 \cdot (C^p/100 - 0{,}75 \cdot O^p/100 - 0{,}667 \cdot W^p/100) \quad (55b)$$

ENERGETICS

At the oxygen-air gasification of CCM:

$k_{(o-a.g.)O2} \neq 0$ and $k_{(o-a.g.)air} \neq 0$, a $k_{(o-a.g.)H2O} = 0$.

However, in this case the stoichiometric coefficients of oxygen and air ($k_{(o-a.g.)O2}$ and $k_{(o-a.g.)air}$) are variable, which means that it is possible to vary these parameters while observing the condition:

$$k_{(o-a.g.)} = k_{(o-a.g.)O2} + k_{(o-a.g.)air} = 1 \quad (56)$$

Then, according to formula (46), the total stoichiometric oxidizer consumption factor for oxygen-air gasification of CCM ($\alpha_{(o-a.g.)}$, *kg ox. / kg CCM*):

$$\alpha_{(o-a.g.)} = (1,333 \cdot k_{(к-в.г)O2} + 5,758 \cdot k_{(o-a.g.)air} + 1,5 \cdot 0) \times \\ \times (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100) = \\ = (1,333 \cdot k_{(к-в.г)O2} + 5,758 \cdot k_{(o-a.g.)air}) \times \\ \times (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot W^p/100), \quad (57)$$

where is the stoichiometric coefficient of oxygen consumption in the oxygen-air gasification of CCM ($\alpha_{(o-a.g.)O2}$, kg O_2 / kg CCM):

$$\alpha_{(o-a.g.)O2} = k_{(o-a.g.)O2} \cdot 1,333 \cdot C_m = \\ = k_{(o-a.g.)O2} \cdot 1,333 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot \\ W^p/100), \quad (57a)$$

and the stoichiometric coefficient of air consumption in the oxygen-air gasification of CCM ($\alpha_{(o-a.g.)air}$, *kg air. / kg CCM*):

$$\alpha_{(o-a.g.)air} = k_{(o-a.g.)air} \cdot (1,333 + 4,425) \cdot C_m = \\ = k_{(o-a.g.)air} \cdot 5,758 \cdot (C^p/100 - 0,75 \cdot O^p/100 - 0,667 \cdot \\ W^p/100), \quad (57b)$$

At oxygen-air-steam gasification CCM:

$k_{(o-a-w.g.)O2} \neq 0$, $k_{(o-a-w.g.)air} \neq 0$, и $k_{(o-a-w.g.)H2O} \neq 0$.

In this case, the stoichiometric coefficients of oxygen, air, and water ($k_{(o-a-w.g.)O2}$, $k_{(o-a-w.g.)air}$, $k_{(o-a-w.g.)H2O}$) are also variable and it is possible to vary these parameters subject to condition (42). That is, at the oxygen-air-steam gasification of CCM we use formulas (43), (44), (45), and (46) to determine the oxidizer consumption coefficients.

Let's calculate the coefficients of oxidizer consumption at different types of gasification of the sludge, the elemental composition of which is given in table 1 [5], using the above methodology.

Table 1

Elemental composition of the sludge

Initial composition, % wt.														
A	*W*	*S*	*C*	*H*	*O*	*N*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*CaO*	*MgO*	*K_2O*	*Na_2O*	*TiO_2*
44,1	*1,2*	*2,8*	*26,8*	*1,8*	*20,4*	*2,9*	*24,82*	*9,11*	*4,86*	*3,24*	*0,22*	*1,1*	*0,26*	*0,49*

The results of calculations of oxidizer consumption coefficients for different types of sludge gasification are given in table 2.

Table 2

Oxidizer consumption coefficients for sludge gasification

Type of gasification	Stoichiometric coefficients oxidizer consumption				
	Type of oxidizer	Parameter	Value	Unit of measurement	Remark
oxygen	oxygen	$\alpha_{(o.g.)O2}$	0,1426	kg O_2 / kg CCM	
steam	water	$\alpha_{(w.g.)H2O}$	0,1605	kg H_2O / kg CCM	
air	air	$\alpha_{(a.g.)air}$	0,6174	kg air. / kg CCM	
oxygen-steam	oxygen	$\alpha_{(o-w.g.)O2}$	0,0951	kg O_2 / kg CCM	
	water	$\alpha_{(o-w.g.)H2O}$	0,0535	kg H_2O / kg CCM	
	total	$\alpha_{(o-w.g.)}$	0,1486	kg ox. / kg CCM	
air-steam	air	$\alpha_{(a-w.g.)air}$	0,4109	kg air. / kg CCM	
	water	$\alpha_{(a-w.g.)H2O}$	0,0535	kg H_2O / kg CCM	
	total	$\alpha_{(a-w.g.)}$	0,4644	kg ox. / kg CCM	
oxygen-air	oxygen	$\alpha_{(o-a.g.)O2}$	0,0713	kg O_2 / kg CCM	for $k_{(o-a.g.)O2}$ = 0,5 $k_{(o-a.g.)air}$ = 0,5
	air	$\alpha_{(o-a.g.)air}$	0,3087	kg air. / kg CCM	
	total	$\alpha_{(o-a.g.)}$	0,3800	kg ox. / kg CCM	
oxygen-air- steam	oxygen	$\alpha_{(o-a-w.g.)O2}$	0,0428	kg O_2 / kg CCM	for $k_{(o-a-w.g.)O2}$ = 0,3 $k_{(o-a-w.g.)air}$ = 0,3 $k_{(o-a-w.g.)H2O}$ = 0,4
	air	$\alpha_{(o-a-w.g.)air}$	0,1852	kg air. / kg CCM	
	water	$\alpha_{(o-a-w.g.)H2O}$	0,0642	kg H_2O / kg CCM	
	total	$\alpha_{(o-a-w.g.)}$	0,2922	kg ox. / kg CCM	

Thus the presented calculation procedure of determining the stoichiometric coefficients of oxidizer consumption for gasification of solid CCM which takes into account a type of oxidizer and physical and chemical parameters of CCM, allows determining their values necessary for technological and thermodynamic calculations of thermal processing of CCM.

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