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Investigation of heat formation of thermochemical mass during processing of the bottom-hole zone of a high-temperature productive formation

Mubariz M. Veliyev · Le Viet Dung · Denis V. Pridannikov

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Abstract. *The article presents the results of determining the thermal effect of the reaction between magnesium and hydrochloric acid for the purpose of processing the bottom-hole zone of a productive reservoir. Due to the high chemical activity of hot acid with respect to magnesium and the limited number of inhibitors that are sufficiently active at high temperatures, thermochemical treatment for the intensification of oil production should be used mainly in wells so that the reaction temperature does not exceed the bottom-hole temperature by* $30-40°C$*. It is noted that the dynamics of heat generation depends many times on the reaction rate, on the ability of transporting reagents to the reaction site, the ability to remove creation products, and the ability of heat transfer of materials involved in this process.*

Keywords. bottom-hole formation zone · heatgeneration · auxiliaryreagents · reaction rate · thermal effect · down hole conditions · reactive · acid volume · mass component · water heat capacity.

Mathematics Subject Classification (2010): 80A30, 80A20

1 Introduction

Impact on the bottom-hole zone of wells is one of the main measures aimed at improving the efficiency of oil and gas field development. However, the effectiveness of these measures in various geological and physical conditions of deposits is not always high enough, and in some cases it is absent [1, 7, 8, 11, 12].

One of the promising areas for increasing the productivity of high-temperature production wells in the Bely Tigr field is the use of thermochemical reaction methods. The essence of the thermochemical method of processing the bottom-hole zone of wells is to use the

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released heat of the thermochemical reaction between magnesium powder and hydrochloric acid to purposefully influence the factors that contribute to restoring and increasing the permeability of the bottom-hole zone of wells and reducing the hydraulic resistance of the movement of reservoir fluids to the well [5, 10, 8, 19, 16, 3].

American author J. T. Rollin was the first to use heat generated by the reaction of magnesium powder with hydrochloric acid to dissolve sediments of organic and inorganic substances in the bottom-hole zone of wells [5, 4].

The heat generated by the reaction heats up the solvent (oil or diesel fuel), rapid dewaxing occurs, and an excess amount of acid will dissolve the sediments on the surface of the channels in the productive zone, while heat is also released. Ultimately, the reservoir filtration increases and leads to an increase in the fluid flow rate.

The equation of the chemical reaction between magnesium and hydrochloric acid and the mass ratio of the initial reactants and reaction products is irreversible and is expressed as follows [5]:

$$2HCl + Mg = MgCl_2 + H_2 + Q. \tag{1.1}$$

$$\begin{array}{cccc} 2(1+35,5) & 24 & (24+35,5\times 2) & (1\times 2) \\ 73 & 24 & 95 & 2 \end{array}$$

Reaction (1.1) is a substitution reaction in which magnesium replaces hydrogen with the release of hydrogen gas (H_2).

When magnesium reacts with hydrochloric acid, heat is released and therefore the reaction is an exothermic reaction.

The products of reaction (1.1) are magnesium chloride ($MgCl_2$) and hydrogen (H_2). Magnesium chloride is a soluble salt that does not settle in an acidic environment. Therefore, when using this reaction, you need to pay attention to the fact that the final products remain in an acidic environment (a solution with a $pH < 7$ content can be used, for example, add CH_3COOH). Hydrogen easily causes an explosion when mixed with air, so you need to pay special attention to safety during work.

According to the reaction scheme (1.1), 73 g $of\ HCl$ reacts with 24 g of magnesium to form 95 g $of\ MgCl_2$ salt Cl_2 and 2 g of hydrogen gas (H_2).

The process following equation (**??**) describes the chemical nature of the reaction. But, in practice, another component is involved in the process – water, which is absent from the equation because the amount of water in the right and left parts of the equation is the same. In other words, during the reaction, magnesium comes into contact with water. The magnesium hydration reaction is described as follows [5]:

$$Mg + 2H_2O = Mg\,(OH)_2 + H_2. \tag{1.2}$$

The magnesium hydroxide $Mg\,(OH)_2$formed in the reaction is in a gel-like state. When treating the bottom-hole zone by the reaction of magnesium with hydrochloric acid, in many cases a gel (magnesium hydroxide) is formed in the working equipment. Similarly, according to the reaction equation, each 1 kg of magnesium reacts with water to form 2.4 kg $of\ Mg\,(OH)_2$.

The reaction of magnesium hydroxide formation reduces the treatment effect due to the fact that one part of magnesium is not involved in heat generation. The reaction rate between magnesium and water is relatively high, so the magnesium consumption in this process should be taken into account (according to [14], the magnesium consumption for 3 hours of contact by this mechanism is in the range of 5-7 %). However, the formation of magnesium hydroxide may have a negative effect on the treatment of the bottom-hole zone, since it is a source of contamination of the productive reservoir.

Calculation of the thermal balance of the thermochemical mass is necessary in order to know whether the volume that will make up magnesium, acid and other auxiliary materials can meet the conditions of the deposit, and how much magnesium is needed for 1 m of the effective reservoir capacity.

First, we will determine the heat capacity of a physical and chemical system, measure and calculate the heat of chemical processes, and establish the dependence of the heat of chemical processes on temperature and system components [13,1].

2 Heat Effect of Reaction and Thermodynamic Foundations.

Consider a closed system in which a reaction occurs.

$$aA + bB = cC + dD. \tag{2.1}$$

The thermal effect of a reaction is the amount of heat released during a chemical reaction, when a mole (a) of substance A reacts with a mole (b) of substance B, a mole (c) of substance C and a mole (d) of substance D are formed at $T = const$.

A reaction occurring at constant pressure is called isobaric, with $Q_p = \Delta H$, and a reaction occurring at constant volume is called isochoric, with $Q_v = \Delta U$.

The relationship between ΔH and ΔU is represented by the formula:

$$\Delta H = \Delta U + \Delta nRT, \tag{2.2}$$

where Δn is the number of moles of gas in the right and left sides of the equation are the same (assuming that the gas is in an ideal state): $R = 8.314 \frac{J}{mol} J$ K.

The reaction that releases heat in the medium is called exothermic. In this $\Delta H case,\ \Delta H = Q_v < 0$, or $\Delta U = Q_v < 0$, and the reaction absorbing heat from the medium is endothermic, and $\Delta H = Q_p > 0$, or $\Delta U = Q_v > 0$.

To calculate the thermal effect, you need to know the reaction conditions: the number of starting materials and reaction products, the physical state of the substances, and the heat of formation under standard conditions.

The standard condition for a pure substance is its physical and chemical state at a pressure of 101,325 kPa (1 atm.) and a temperature of 298 K (25°C).

The heat of formation of a single substance is the amount of heat released or absorbed during the formation of 1 mole of a given substance from stable simple substances under a given condition.

The heats of formation of substances from elements are extremely convenient for calculating the thermal effects of any reactions in which these substances might participate. The heat of any reaction (even if not yet implemented in practice) can be calculated as the difference between the sum of the heat of formation of all products and the sum of the heat of formation of all reactants in a given reaction [2,9,15].

However, here it is necessary to strictly observe the "rules of the game " adopted in thermochemistry. For example, we write "Cr", but "solid" carbon can be either graphite or diamond. In thermochemical measurements, the standard state of carbon is graphite, not diamond. Secondly, it is necessary to agree on the temperature and pressure at which substances are located, since these parameters can significantly affect the magnitude of the thermal effect. It is customary to use the heat of formation of substances under standard conditions. If the heat of formation is determined at a pressure of 101.325 kPa (1 atm.) and a temperature of 298 K (25°C), then it is called the standard heat of formation and is denoted by ΔH^{O}_{298}. For example, $\Delta H^{O}_{298}\,(CO_2) = 393.51\ kJ/mol$ is the standard heat of reaction formation [7]:

$C_{graphite} + O_{2\ gas} = CO_{2\ gas}$ at 25° C and $PO_2 = PCO_2 = 1\ atm.$

The standard heat of formation of a stable simple substance is 0.

The principle of calculating the thermal effect is described below.

As mentioned above, the thermal effect of the reaction is equal to the sum of the heat of formation of products with subtraction of the heat of formation of the initial reactants:

$$\Delta H = \sum \Delta N_{reaction\ products} - \sum \Delta N_{starting\ agents}. \quad (2.3)$$

The thermal effect of the reaction of certain substances is usually determined under standard conditions based on the standard heat of formation pre-defined in the reference book.

To determine the thermal balance of one reaction or other thermal process, there is a concept - heat capacity.

The molar heat *capacity* C of a single substance is the amount of heat required to increase the temperature of one mole of a given substance by 1 K, without changing the aggregate state. To increase the temperature of 1 mole of any substance from T to T_2, it is necessary to add the amount of heat *Q* to it, the average heat capacity of this substance will rise, it can be determined by the formula [7]:

$$\bar{C} = \frac{Q}{T_2 - T_1} = \frac{Q}{\Delta T}. \quad (2.4)$$

For $\Delta T \to 0$, we have the true molar heat capacity:

$$C = \frac{\delta Q}{dT}. \quad (2.5)$$

The unit of heat capacity is usually measured in J/K mol.

Another concept is the isobaric molar C_p heat capacity and isochoric molar heat capacity C_v.

The isobaric molar heat capacity C_p is the heat capacity of the reaction taking place at $P = const$:

$$C_p = \left(\frac{\partial H}{\partial T}\right)_p \Delta dH = C_p dT \Rightarrow \Delta H = \int_{T_1}^{T_2} C_p dT. \quad (2.6)$$

The isochoric molar C_v heat capacity is the heat capacity of the reaction taking place at $V = const$:

$$C_v = \left(\frac{\partial U}{\partial T}\right)_v \Delta dU = C_v dT \Rightarrow \Delta U = \int_{T_1}^{T_2} C_v dT. \quad (2.7)$$

C_p and C_v are functions of temperature: $C = f\,(T)$.

The thermal effect depends on the temperature according to Kirchhoff's law. The basis of this law and the standard thermal effect can be determined at any temperature T (ΔH_T) by the formula:

$$\Rightarrow \Delta H_T^0 = \Delta H_{298}^0 + \int_{298}^{T} \Delta C_p dT, \quad (2.8)$$

where,

$$\Delta C_p^0 = \sum C_p^0\,(sp) - \sum C_p^0\,(tg)\,. \quad (2.9)$$

C_p^0 is the isobaric mole heat capacity under standard conditions. The temperature interval can be considered $\Delta C_p^0 = Const$ and calculated ΔH_T^0 as follows:

$$\Delta H_T^0 = \Delta H_{298}^0 + \Delta C_p^0\,(T - 298)\,. \quad (2.10)$$

We use the above concepts to determine the thermal effect of the reaction between magnesium and hydrochloric acid for further purposes.

3 Calculation of the Heat Effect of the Reaction Between Magnesium and Hydrochloric Acid

The reaction equation between magnesium and hydrochloric acid is written as follows [3, 19]:

$$2HCl_{(g)} + MgCl_{(T_v)} = MgCl_{2\ (T_b)} + H_{2\ (d)} + Q.. \quad (3.1)$$

In equation (3.1), HCl, $MgCl_2$ and H_2 are gases, and Mg is a solid. To determine the thermal effect of reaction (3.1), we assume that the reaction takes place under standard conditions, i.e. at $T = 298$ K and $P = 1$ atm. According to the data of [1], it is possible to obtain the physico-chemical parameters of the reaction, which are shown in Table 3.1.

Table 3.1. Physical and chemical parameters of the reaction between magnesium and hydrochloric acid

Elements	Magnesium	Hydrochloric acid	Water	Magnesium chloride	Hydrogen
Standard heat of formation, kJ/mol	0	92,31	-286,84	-641,82	0

Then from (3.1) we get [6,7]:

$$\Delta H^0_{298} = [(-641,82) + (-0)] - [2\Delta(-92,31) + (-0)] =$$

$$= -641,82 + 184,62 = -457,2\ kJ/mol.$$

Due to the fact that the reaction occurs at a constant volume, the thermal effect of the reaction from (2.2) will be equal to (the sum of moles of the gas starting reagents is assumed to be 1-2=-1):

$$Q_v = -457,2 - [-1 \cdot 0,008314 \cdot 298] = -457,2 + 2,477 = -454,723\ KJ.$$

For further calculations, we will calculate the mass unit of magnesium. Obviously, the thermal effect of the reaction is the amount of heat released, i.e., when converted to 1 g of magnesium, we have the amount of heat released when 2 moles of hydrochloric acid (73 g) react with 1 mol of magnesium (24 g).

Therefore, when converted to 1 g of magnesium, we have the amount of heat released: $454,723/24 = 18,946kJ/g$, when converted to $1kg - 18946kJ$, and for $1000kg - 18946000kJ$. The calculated indicators are presented in Table 3.2.

To calculate the reaction temperature with the participation of all reagents, we will summarize the standard thermodynamic parameters and calculated indicators in Table 3.2.

Table 3.2. Calculated values of reaction heat between magnesium and hydrochloric acid

N	Indicators	Value, kJ
1.	Standard thermal effect when 24 g of magnesium reacts with 2 moles (73 g) of hydrochloric acid	454.723
2.	Heat released when 1 kg of magnesium completely reacts with hydrochloric acid	18946
3.	Heat generated when 1000 kg of magnesium completely reacts with hydrochloric acid	18946000

Calculation of the transition from the isobaric molar heat capacity under standard conditions (C_p^0) to the isocharic molar heat capacity under standard conditions (C_v^0):

- for a liquid or solid the difference between C_p^0 and C_v^0 is insignificant.

- for gases:

$$C_v^0 = C_p^0 - R, \tag{3.2}$$

where, R is the ideal gas constant, $R = 8.314\ J \cdot K^{-1} = 0.008314\ KJ \cdot K^{-1}$.
For hydrochloric acid [**12**]:

$$C_v^0 = C_p^0 - R = 0,799968 - 0,008314 = 0,791365.$$

For hydrogen [**7**]:

$$C_v^0 = C_p^0 - R = 14,24314 - 0,008314 = 14,23483.$$

Table 3.3 Indicators for calculating the temperature of the reactive mass

Indicators	Elements or conpounds				
	Magnesium	Hydrochloric acid	Water	Magnesium chloride	Hydrogen
Standard heat of formation, kJ/mol	0	92,31	285,84	641,82	0
Isobaric molar heat capacity under standard conditions, J/mol	23,89	29,12	75,30	71,30	28,84
Isobaric molar heat capacity under standard conditions (for solid), kJ/kg	0,983898	0,799968	4,182630	0,794729	14,24314
Isocharic molar heat capacity under standard conditions (for gas), kJ/kg	-	0,791365	-	-	14,23483

For research and practical purposes, we will perform a thermal calculation for the following cases:

- the first case: 15 % concentration of hydrochloric acid (HCl) solution sufficient for reaction with magnesium (Mg);

- the second case: an excess of 15% HCl concentration of 15% compared to the total consumption;

- the third case: an excess of 15% HCl concentration of 15% and the presence of carrier water for magnesium suspension;

- fourth case: in addition to the substances specified in the third case, a buffer solution will also be added.

4 Sufficient 15% HCl Concentration for Complete Reaction with Magnesium

Detailed calculations for each case are presented below.

1). The first case: 15% concentration $of\ HCl$ solution is sufficient for reaction with Mg.

For the calculation, assume that the reaction mass has a composition as shown in the first column of Table 3.2. In this case, Mg completely reacts with HCl 15% solution. We record the heat input in Table 4.1, and the heat consumption in Table 4.2 **[7]**.

The mass of hydrochloric acid is determined from (1.1): 73:24=3,04167, 73 g of hydrochloric acid reacts with 24 g of magnesium to form 95 g $of\ Mg\ Cl2\ saltCl_2$ and 2 g of hydrogen gas, i.e. 1 g of magnesium reacts with 3.04167 g of hydrochloric acid.

Table 4.1 Heat supplied with raw materials - heat input (first case: HCl of 15% is sufficient for reaction with Mg)

Starting materials		Mass of reagents, kg	Isocharic molar heat capacity under standard conditions, kJ / kg	Amount of heat supplied with starting materials, kJ
Magnesium		1000	0,983898	293201,604
Hydrochloric acid sufficient for the reaction	HCl	3041,7	0,791365	717314,286
	H_20	16999,99	4,182630	21189202,334
Heat of reaction (Q_r)				18946000.0
Amount of heat				supplied 41145718.224

The mass H_2O is determined from (2.2).

The amount of heat supplied with the starting materials is determined as follows:

$$Q_v = m \cdot C_v^0 \cdot 298, \tag{4.1}$$

The sum of the required amount of heat is defined as $\sum m_i \times \left(C_v^0\right)_i$.

The mass temperature after the reaction is determined as follows:

$$T = \frac{Q_v}{\sum m_i \cdot C_{pi}}. \tag{4.2}$$

Then, using Tabel 4.1 and 4.2:

$$T = \frac{Q_v}{\sum m_i \cdot C_{pi}} = \frac{41145718,224\ kJ}{75436,243\ kJ/\text{K}} = 545,437\ \text{K},$$

or Celsius: 545,437-273=272,437 °C.

Let's imagine a different calculation method, and assume:

1. After the reaction, all the initial components are at $25°C(298°C)$. Then the heat input is 18946,000 kJ (see heat of reaction-column 4 of Table 4.3).

2. The temperature of the mass of products after the reaction rises by ΔT from the temperature of $25°C(298°K)$. The required amount to raise the temperature of the mass of products after the reaction by 1 degree is the sum $\sum of\ m_i \times \left(C_v^0\right)_i$, as shown in Table 5.

Then, ΔT is calculated by the following formula:

$$\Delta T = \frac{Q_p}{\sum m_i \times \left(C_v^0 CV0\right)_i} = \frac{18946000\ kJ}{75436.243\ kJ/^oS} = 251,15\ ^\text{o}\text{C}.$$

Table 4.2 Heat consumption carried away with the reaction products (first case: *HCl* of 15% concentration is sufficient for reaction with *Mg*)

Obtained products after the reaction	Mass of the obtained products, kg	Isocharic molar heat capacity under standard conditions, kJ/kg	Required amount of heat to raise the temperature of the obtained products by 1 degree, kJ/K
Water	16999,9 4,18263	71104,706	Magnesium chloride
Magnesium Chloride	3958,3	0,794729	3145,776
Hydrogen	83,3	14,234830	1185,761
Sum of the required amount of heat $(\sum m_i \times (C_v^0)_i)$			75436,243

The mass temperature after the reaction is:

251,15°C + 25°C = 276,152°C.

The difference between this and the previous calculation method will be 3.715°C.

2) The second case: an excess of hydrochloric acid of 15% $HCl\ concentration$ of 15% compared to the total consumption.

Material and thermal calculations of raw materials are presented in Table 4.3.

Calculation of the amount of heat carried away with the reaction products-heat consumption is shown in Table 4.4.

Mass temperature after reaction:

$$T = \frac{Q_v}{\sum m_i \cdot C_{pi}} = \frac{44431684.619\ kJ}{86462.976\ kJ/^oK} = 513.881K,$$

or when converted to ^{o}C: 513.881-273=240.881^{o}C.

Let's present the calculation of $\varDelta T$ in another way:

$$\varDelta T = \frac{18946000}{86462,976} = 219,123\ ^\circ\text{C}.$$

The mass temperature after the reaction is:

220°C + 25 ° C = 244,123°C (the difference between this method and the previous one is 3.23°C.

3) The third case: an excess of 15% HCl concentration of 15% compared to the total flow rate and the presence of carrier water in the magnesium suspension.

Water for the preparation of the carrier solution is calculated in the ratio of 140-150 kg $\frac{Mg}{1}$1 m^3 of water. For 1000 kg of Mg, 6896,55 liters of water are needed to prepare the carrier solution.

Calculations of raw materials are presented in Table 4.5.

Table 4.3 Heat supplied with starting materials - heat input (second case: excess of 15% *HCl* 15%)

Starting materials		Mass of reagents, kg	Isocharic molar heat capacity under standard conditions, kJ/kg	Amount of heat supplied with starting materials, kJ
Magnesium		1000	0,983898	293201,604
Hydrochloric acid, sufficient for the reaction	*HCl*	3041,7	0,791365	717314,286
	H_2O	16999,99	4,182630	21189202,334
16999.99 4.182630 21189202.334 Excess 15% *HCl*	*HCl*	456,260	0,791365	107598,322
	H_2O	4,182630	3178368,073	3178368,073
Heat Reactions (Q_p)				18946000,0
Amount of incoming heat				44431684,619

Table 4.4 Amount of heat carried away with the reaction products - heat consumption (with an excess of 15% *HCl* 15%)

Obtained products after the reaction		Mass of the obtained products, kg	Isocharic molar heat capacity under standard conditions, kJ / kg	Required amount of heat to raise the temperature of the obtained products by 1 degree ($m_i * \left(C_v^0\right)_i$), kJ /°K
Water		16999,999 4,18263	71104,706	Magnesium
chloride Magnesium Chloride		3958,3	0,794729	3145,776
Hydrogen		83,3	14,234830	1185,761
Excess 15 % *HCl*	*HCl*	456,26	0,791365	361,068
	H_2O	2549.99	4.182630	10665,665
Sum of the required amount of heat ($\sum m_i \cdot \left(C_v^0\right)_i$)				86462,976

Calculations of the amount of heat carried away with the reaction products-heat consumption are presented in Table 4.6.

$$T = \frac{53027708.263\ kJ}{115308.693\ kJ/^oK} = 459,9K.$$

Conversion to °C: 460,9-273 = 186.9°C.

Table 4.5 Material and thermal calculations of initial reagents (with an excess of 15% *HCl* of 15% and the presence of water in the carrier solution)

<table>
<tr><th colspan="2">Starting materials</th><th>Mass of reagents, kg</th><th>Isocharic molar heat capacity under standard conditions, kJ/kg</th><th>Amount of heat supplied with starting materials, kJ</th></tr>
<tr><td colspan="2">Magnesium</td><td>1000</td><td>0,983898</td><td>293201,604</td></tr>
<tr><td rowspan="2">Hydrochloric acid, sufficient for the reaction</td><td>HCl</td><td>3041,7</td><td>0,791365</td><td>717314,286</td></tr>
<tr><td>H_2O</td><td>16999,99</td><td>4,182630</td><td>21189202,334</td></tr>
<tr><td rowspan="2">16999.99
4.182630
21189202.334
Excess 15% HCl</td><td>HCl</td><td>456,260</td><td>0,791365</td><td>107598,322</td></tr>
<tr><td>H_2O</td><td>2549,990</td><td>4,182630</td><td>3178368,073</td></tr>
<tr><td colspan="2">Water in the composition of the carrier solution</td><td>6896,550</td><td>4,182630</td><td>8596023,644</td></tr>
<tr><td colspan="4">8596023,644 Heat of reaction (Q_p)</td><td>18946000,0</td></tr>
<tr><td colspan="4">Amount of incoming heat</td><td>53027708,263</td></tr>
</table>

Calculation using a different method:

$$\varDelta T = \frac{18946000\ kJ}{115308.693\ kJ/^{o}C} = 164.3^{o}\text{C} = 164.0^{o}\text{C}$$

The mass temperature after the reaction is:

164°C + 25°C = 189°C.

The difference between this and the previous calculation method is 2,1°C.

4) The fourth case: an excess of 15% $HCl\ concentration$ of 15% compared to the total flow rate and the presence of water in the carrier solution and buffer solution.

As already noted, the amount of buffer solution between the layers is 0.8 m^3. For 3 layers, the amount of buffer solution is 2.4 m^3. In addition, a solvent is also added to dissolve asphaltenes with an amount of approximately 3 m^3. In practice, it is possible to use diesel fuel as a solvent in large quantities. It is forced into the well after the reaction, so reducing the temperature due to pumping diesel fuel does not worsen the processing result.

The results of calculations of the initial materials are presented in Table 4.7, and the results of calculations of the amount of heat carried away with the reaction products (heat consumption) are shown in Table 4.7.

Then,

$$T = \frac{55411708.263\ kJ}{123308.693\ kJ/^{o}K} = 449.37\ K,$$

or in Celsius:

449.37-273 = 176.37°C.

Table 4.6. Heat carried away with the reaction products – heat consumption (with an excess of 15% *HCl* 15% and water in the carrier solution)

Obtained products after the reaction		Mass of the obtained products, kg	Isocharic molar heat capacity under standard conditions, kJ / kg	Required amount of heat to raise the temperature of the obtained products by 1 degree ($m_i * (C_v^0)_i$), kJ /K
Water		16999,999	4,18263	71104,706
Magnesium Chloride		3958,3	0,794729	3145,776
Hydrogen		83,3	14,234830	1185,761
Excess 15 % *HCl*	*HCl*	456,26	0,791365	361,068
	H_20	2549,99	4,182630	10665.665
Water for preparation of carrier solution		6896,550	4.182630	10665.665
Sum of required amount of heat ($\sum m_i * (C_v^0)_i$)				115308.693

Table 4.7. Material and thermal calculations of initial reagents for the total reaction mass

Starting materials		Mass of reagents, kg	Isocharic molar heat capacity under standard conditions, kJ/kg	Amount of heat supplied with starting materials, kJ
Magnesium		1000	0,983898	293201.604
Hydrochloric acid, sufficient for the reaction	HCl	3041,7	0,791365	717314,286
	H_20	16999,99	4,182630	21189202,333
16999.99 4.182630 21189202.333 Excess 15% *HCl*	HCl	456,260	0,791365	107598,322
	H_20	4,182630	4.182630	3178368,073
Water in the composition of the carrier solution		6896,550	4,182630	8596023,644
8596023.644 Buffer solution 4 $m3^3$		4000,0	2,0	2384000,0
Heat of reaction (Q_p)				18946000,0
Amount of incoming heat				**55411708,263**

Calculation using a different method:

$$\Delta T = \frac{18946000\ kJ}{123308.693\ kJ/^o!} = 153.64^oS = 154^oC$$

The mass temperature after the reaction is:

154°C + 25°C = 179°C.

The difference between this and the previous calculation method is 2.63°C.

When magnesium is combined with water, a hydrolysis reaction occurs to produce magnesium hydroxide ($Mg\,(OH)_2$). As the temperature increases, the rate of hydrolysis increases.

It should be noted that at a high temperature, which is achieved by creating certain conditions during a thermochemical reaction, i.e., at a low pumping rate of an acidic solution and an excess volume of magnesium, magnesia cement can form. It is possible to "bake" granulated magnesium and magnesium hydroxide powder with magnesia cement and completely block the pore space and cracks of the bottom-hole zone with the cessation of both water and oil inflow.

Table 11-Heat carried away with reaction products and other residual materials

Obtained products after the reaction		Mass of the obtained products, kg	Isocharic molar heat capacity under standard conditions, kJ/kg	Required amount of heat to raise the temperature of the obtained products by 1 g ($m_i * (C_v^0)_i$), kJ/K
Water		16999,999	4,18263	71104,706
Magnesium chloride		3958,3	0,794729	3145,776
3145.776 Hydrogen		83,3	14,234830	1185,761
Excess 15% HCl	HCl	456,26	0,791365	361,068
	H_2O	2549,99	4,182630	10665,665
Water for preparation of carrier solution		6896,550	4,182630	28845,717
Buffer solution 4m3		4000,0	2,0	8000,0
Sum of the required amount of heat ($\sum m_i \times (C_v^0)_i$)				**123308,693**

It is known that to increase the ability to dissolve asphalt-tar deposits with an organic solvent, it is necessary to raise the temperature of the bottom-hole zone of the wells of the White Tiger oil field by 15°C. Processing will be more effective if the temperature rises even more. It is also known that the bottom-hole zone with a distance from the wall of no more than 15 cm is a necessary processing zone, especially when processing organic deposits [17].

Due to the high chemical activity of hot acid with respect to magnesium and the limited number of inhibitors that are sufficiently active at high temperatures, thermochemical treatment for the intensification of oil production should be used mainly in wells of the White Tiger field so that the reaction temperature does not exceed the bottom-hole temperature by 30-40°C. [17].

Due to the fact that this temperature determined in the fourth case (176°C) is higher than the deposit temperature by about 36°C, we can use this result to determine the required amount of magnesium for thermochemical treatment of wells in the White Tiger oil field [7].

Thus, the temperature calculated for the composition of the fourth case can be used to determine the temperature with different amounts of magnesium.

5 Conclusions.

Thus, based on the analysis of the results of calculating the thermal effect of the reaction between magnesium and hydrochloric acid, it is established:

1. There is no need to pay attention to the reaction rate, the main thing is to choose the method of safe supply of reactive components to a given treatment interval.

2. To obtain a high temperature, acid of the maximum possible concentration should be used (in most cases, an HCl concentration of 15% is chosen for heat treatment of the bottom-hole zone$HCl$to reduce the effect of acid on deep-pumping equipment).

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