# How to maximize the value of mature HC fields?

## Workshop

**Budapest, 18th November 2010.**

**Society of Petroleum Engineers**

# Simplified method to determine $CO_2$ storage capacity of depleted CH reservoirs

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# Outlines

- Introduction
- General simplifications and assumptions
- Special assumptions for oil reservoir
- Determination the volume of $CO_2$ can be stored in oil reservoir (Method I, and Metod II)
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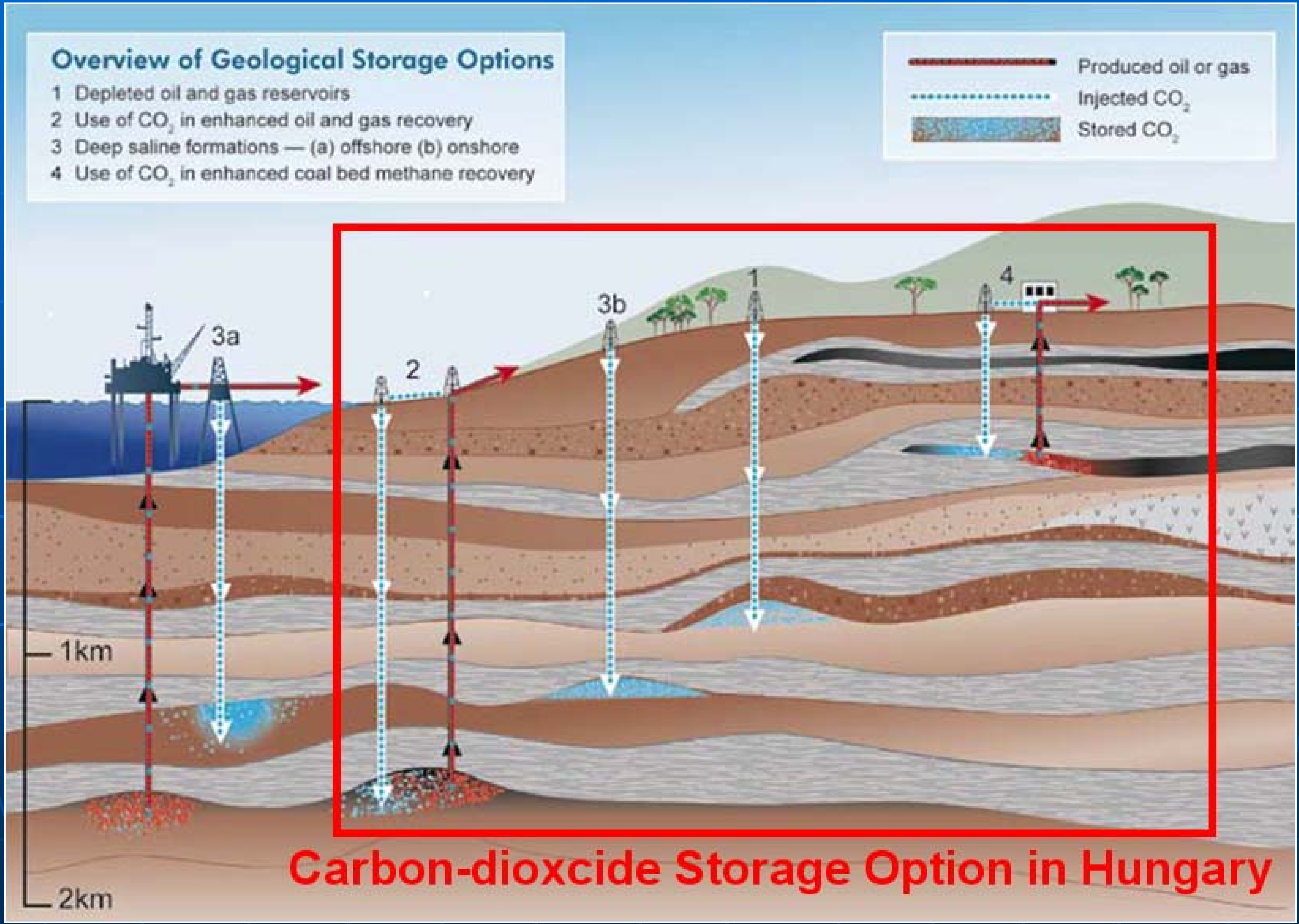
# Introduction

In the forthcoming decades, due to issues of environment protection and in order to ensure the sustainable development, the European Union and Hungary must subsequentally decrease the emission of carbon dioxide and of other so-called greenhouse gases (GHG)

One of the possible methods to decrease $CO_2$ emission is the capture of the concentratedly emitted carbon dioxide and its storage in geological formations

# Introduction




Source: IPCC Special Report on Carbon Dioxide Capture and Storage Published in the United States of America by Cambridge University Press, New York 2005

# Introduction

The oil and gas fields have already proven that they are capable of trapping the fluids for millions of years

There's the biggest chance of long-time safe carbon dioxide storage in these reservoirs

Taking into account that in Hungary, we have more than 30 years of experience of $CO_2$ injection as an EOR technology

It's obvious that both for the technology and the security concerns, the most reliable and feasible solution is the storage of carbon dioxide in depleted or partially depleted oil and gas fields

# Introduction

Earlier MOL-ELGI-AFKI researches found that in ten years time, 22 oil/gas reserviors will be available in Hungary for storage of carbon dioxide.

In the Research Institute of Applied Earth Sciences, we developed calculation methods to estimate the carbon dioxide storage capacity of depleted oil and gas fields, which is apart from the simple volumetric estimations, it takes the current state of depletion into account as well.

# Introduction

We designed methods based on analytical relationships, two for gas, two for oil reservoirs, to determine the $CO_2$ capacity of them.

One method is a simplified calculation method, but it takes the current state of depletion into account.

The other one is a more detailed calculation method, which takes the actual storage conditions into account to the biggest available extent, and its based on iteration

# General simplifications and assumptions

1. Evaluation of the amount of the injectable $CO_2$ were determined by using the last available production data ($N_p$, $G_p$, $W_p$, $p_{res}$).

   We haven't dealt with the question that if we inject the $CO_2$, the further (EOR, EGR) exploitation of the reservoir results in additional hydrocarbon production, and it also creates additional 'space' for further $CO_2$ injection.

# General simplifications and assumptions

2. We assume that the hydrocarbon production has finished, and the reservoir would only operate for $CO_2$ storage purposes.

   **This assumption can’t be made for gas fields where the exploitation has not yet started. For these, our assumption is that the reservoir will be produced up to the given abandonment pressure, and the $CO_2$ injection (storage) will only be started after it.**

# General simplifications and assumptions

3. During $CO_2$ injection, in order to ensure the proper isolation of $CO_2$, the maximum available pressure can't be greater than the original reservoir pressure, and we assume that the storage of the $CO_2$ will take place in the pore volume which was saturated with hydrocarbon and water initially.

# General simplifications and assumptions

4. At the calculations, we assume that the original oil-water phase boundary can be restored by injecting the $CO_2$, i.e. the amount of influxed water, which flowed into the reservoir until exploitation, can be displaced from the reservoir.

   We didn't consider the fact that the displaced water also contains dissolved gases, and some part of the injected $CO_2$ gas also escapes with the displaced water by getting dissolved in it from the pore volume which was saturated with hydrocarbon and water initially

# General simplifications and assumptions

5. When we estimate the $CO_2$ storage capacity, we don't count with the time dimension, we don't examine how long the injection of the gas amount would last, we don't take the time into account which would be necessary to displace the earlier influxed water via the well pattern

# General simplifications and assumptions

6. During the calculations of gas injection and mixing, we assumed that the injected carbon dioxide is not pure, i.e. for example, we used the following composition:

| Composition | mole fraction |
|---|---|
| $CO_2$ | 0.98 |
| $N_2$ | 0.02 |

# Special assumptions for oil reservoir

a. Depending on the pressure and temperature of the reservoir, the injected $CO_2$ will be in
- free gas,
- gas dissolved in oil,
- gas dissolved in connate water state.

b. We take the amount and composition of dissolved (in water, in oil) gas and free gas into consideration, which were in the reservoir before the injection.

# Special assumptions for oil reservoir

c. By knowing the amount of the gas in the reservoir, and the amount of the injected gas, the evolved composition of the mixture can be calculated with using the mixing rules

d. The gas mixture composition at standard condition is determined with iteration taking the weight ratio of the gases into account

# Special assumptions for oil reservoir

e. At calculations of the amount and composition of the gas mixture, we only take the gas amount which is dissolved in oil and the free gas amount into account.

   We neglect the gas amount which is saturated in the connate water.

f. At gas mixing calculations, we assume that the gas dissolved in oil mixes like it would mix if it was in free gas form.

# Special assumptions for oil reservoir

g. We don't consider the fact that the mixing and dissolving between the gas injected, dissolved and free gas can only happen if the injected gas reaches each spot of the reservoir, and it gets in connection with the fluids at equilibrium state, i.e. there's available time for the equilibrium to set in, and at each spot of the reservoir, for setting the equilibrium, there are fluids of suitable composition and quality.

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method I)

$$G_{i\,CO_2} = \frac{\left(V_{p\,CH}\right)_p}{B_{g\,CO_2}} = \frac{\left(N_p B_{oi} + G_{pf} B_{gi}\right)_p}{B_{g\,CO_2}}$$

- **$G_{i\,CO_2}$** amount of injectable $CO_2$ gas at standard condition, $m^3$;
- **$B_{g\,CO_2}$** the formation volume factor of $CO_2$ gas at initial pressure **$p_i$**, and temperature **$T_i$** of the layer.
- **$N_p$** cumulative oil production, $m^3$;
- **$G_p$** cumulative gas production, $m^3$
- **$B_{oi}$** initial oil formation volume factor at (**$p_i$**, **$T_i$**)
- **$B_{gi}$** initial gas formation volume factor at (**$p_i$**, **$T_i$**)
- **$G_{pf}$** cumulative free gas production, $m^3$

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method I)

**Where the amount of the produced free gas is**

$$G_{pf} = \left(G_p - N_p \cdot R_{si}\right)$$

**$R_{si}$** the gas-in-oil solubility factor at initial conditions of the field $m^3/m^3$

**The gas deviation factor of the natural gas and the injected $CO_2$ at the examined reservoir pressure and temperature condition was calculated from equations of state by knowing the mole fraction of the components, while other fluid parameters were determined with the known correlational relationships.**

# Determination of the volume of $CO_2$ can be stored in oil reservoir (Method II)

During the application of Method II (earlier referred to as „detailed” iteration calculation) we tried to model the processes of solution, mixing and volume change as accurately as possible which occur when $CO_2$ is injected into a depleted or partially depleted hydrocarbon (oil and gas) field.

During the application of this method we took all mentioned presumptions into consideration regarding the storage of $CO_2$ gas in oil fields.

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method II)

During the development of the method, our basic presumptions were that there's no production any longer in the field during the $CO_2$ injection, and by the time we finish the $CO_2$ injection, we reach the initial reservoir pressure.

We also assume that by the time we reach the initial reservoir pressure, we've already managed to displace the influx water from the reservoir.

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method II)

Meanwhile, when we calculated the $CO_2$ storage capacity, we neglected the fact that during the $CO_2$ injection, there's some dissolved $CO_2$ and hydrocarbon gas in the displaced water, too.

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method II)

$$G_{i\,CO_2} = \frac{V_{pCH} - (N - N_p) \cdot B_{ok} - \Delta V_{Sw}}{B_{gk}} - G_{CH\,f} + [(N - N_p) \cdot R_{sk} - G_{d\,CH}] + G_{wd\,CO_2}$$

**$G_{i\,CO_2}$** amount of injectable $CO_2$ gas at standard condition, $m^3$

**$V_{p\,CH}$** pore volume at initial reservoir conditions saturated with hydrocarbons (oil, gas)

**N** Original Oil In Place at standard condition (O.O.I.P), $m^3$

**$N_p$** cumulative oil production before the $CO_2$ injection, $m^3$

**$\Delta V_{Sw}$** volume change of water and connate water caused by the $CO_2$ dissolved in water

**$B_{ok}$** oil formation volume factor for oil containing mixed gas ($p_i$, $T_i$)

**$B_{gk}$** gas formation volume factor of mixed gas ($p_i$, $T_i$)

**$R_{sk}$** gas in oil solubility factor for mixed gas ($p_i$, $T_i$)

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method II)

$$G_{i\,CO_2} = \frac{V_{pCH} - (N - N_p) \cdot B_{ok} - \Delta V_{Sw}}{B_{gk}} - G_{CH\,f} + [(N - N_p) \cdot R_{sk} - G_{d\,CH}] + G_{wd\,CO_2}$$

**$G_{CHf}$** current volume of free hydrocarbon gas down in the reservoir at the beginning of the $CO_2$ injection, $m^3$

**$G_{dCH}$** amount of hydrocarbon gas dissolved in the oil remained in the reservoir, at the beginning of the $CO_2$ injection, $m^3$

**$G_{wdCO2}$** amount of $CO_2$ in the connate water and in the initial formation water when we reach the initial reservoir conditions, $m^3$

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method II)

**Volume change of water and connate water caused by the $CO_2$ dissolved in the water**

$$\Delta V_{Sw} = \frac{V_{Sw}}{B_{w\,CH}} \cdot B_{w\,CO_2} - V_{Sw}$$

**where**

$$V_{Sw} = \frac{V_{p\,CH}}{1 - S_{wi}} \cdot S_{wi}$$

$S_{wi}$ initial water saturation

$B_{w\,CH}$ water formation volume factor of water which contains the hydrocarbon gas, at the beginning of the $CO_2$ injection,

$B_{w\,CO_2}$ formation volume factor of the water which contains the $CO_2$ gas when it reaches the initial reservoir conditions

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method II)

**Amount of hydrocarbon gas dissolved in oil at the beginning of the $CO_2$ injection, $m^3$**

$$G_{d\,CH} = (N - N_p) \cdot R_{S\,CH}$$

**$R_{sw\,CH}$** initial gas-water solubulity factor before the CO2 injection

**Amount of free hydrocarbon gas down in the reservoir at the beginning of the $CO_2$ injection, $m^3$**

$$G_{CH\,f} = (G - G_{d\,CH} - G_p)$$

**G** Original Gas In Place (cap gas + dissolved gas) O.G.I.P, $m^3$.

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method II)

## Gas mixing calculations

**First, by knowing the determined amount of the injectable $CO_2$ gas, we calculated the mixing of the gas.**

1. **By knowing the composition of both the hydrocarbon gas in the reservoir and the injected $CO_2$ ($y_{i_{CH}}$, $y_{i_{CO_2}}$), we determined the mass of the components ($m_{iCH}$, $m_{iCO2}$), the mole number of the components ($n_{iCH}$, $n_{CO2}$), and the total mass of the mixed gas ($m_{ik}$), respectively.**
2. **By knowing the molar mass of the components ($M_i$), we determined the total mole number of the mixed gas ($n_{ik}$), and the mole fraction of the mixture ($y_{ik}$), respectively.**

# Determination of the volume of $CO_2$ which can be stored in oil reservoir (Method II)

## Gas mixing calculations

3. By knowing the new composition, we determined the parameters ($B_{ok}$, $R_{sk}$, $B_{gk}$) of the mixed hidrocarbons at initial reservoir conditions ($p_i$ $T_i$), then we determined the volume of the injectable $CO_2$ gas ($G_{iCO_2}$) again, and we continued the calculations until there was no more change in the composition of the mixed gas.

The amount of the injectable gas determined by this method, $G_{iCO2}$, is the maximum carbon dioxide storage capacity of the oil field with previously mentioned assumptions

# Determination the volume of $CO_2$ which can be stored in an Hungarian saturtaed oil reservoir (case study)

## Base Data

| | | | |
|---|---|---|---|
| $V_{pCH}$ ($Mm^3$) | 46.23 | $P_i$ (bar) | 316.30 |
| G ($Mm^3$) | 10050.39 | $T_i$ (K) | 400.10 |
| $G_p$ ($Mm^3$) | 6314.96 | P (bar) | 230.92 |
| N ($Mm^3$) | 5.440 | $\rho_o$ ($kg/m^3$) | 806.90 |
| $N_p$ ($Mm^3$) | 0.265 | $B_o$ ($p_i$,$T_i$) | 1.61 |
| $S_{wi}$ | 0.51 | $R_{si}$ ($p_i$,$T_i$) | 195.80 |
| | | $\rho_{gr}$ | 0.7051 |

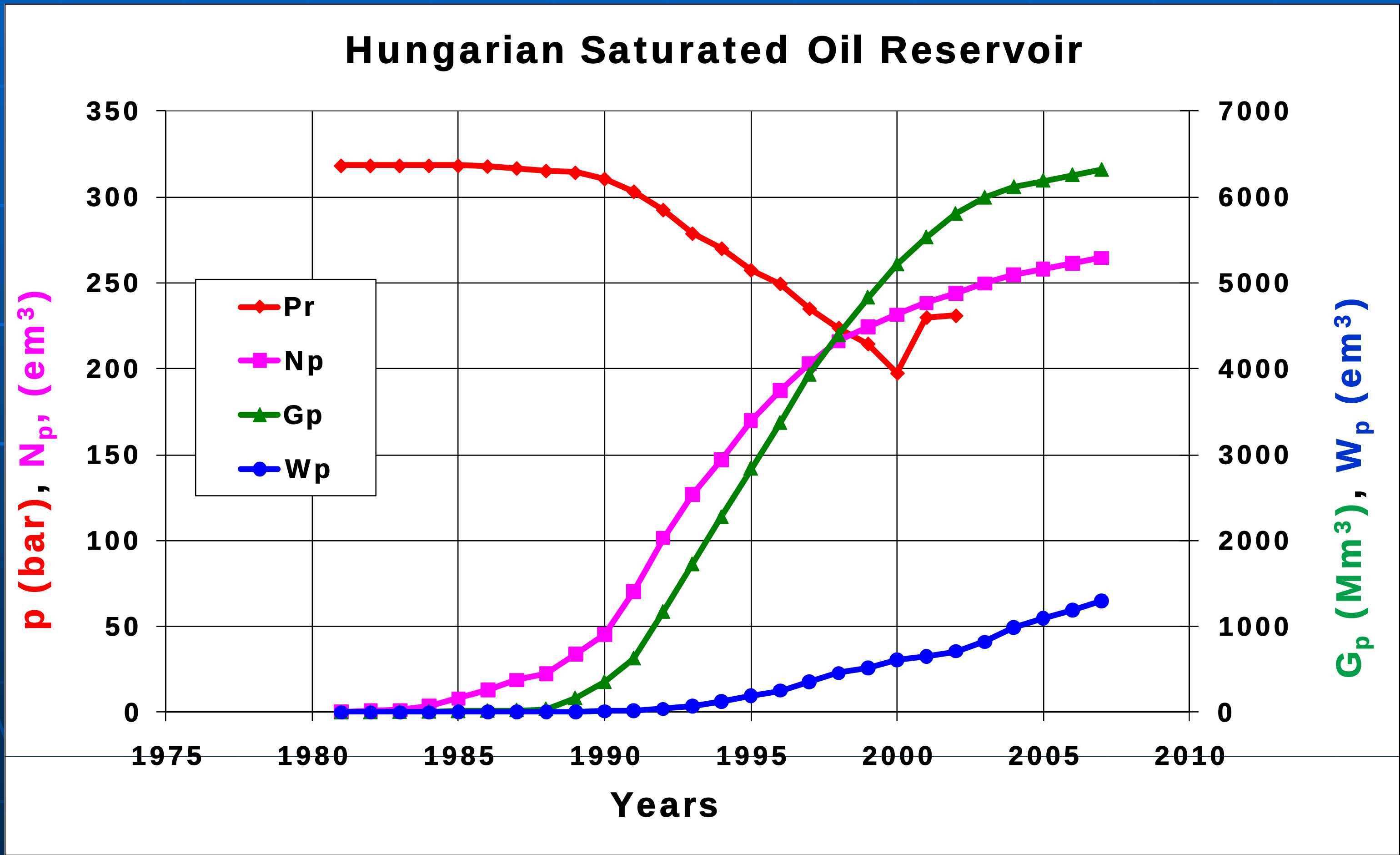
# Determination the volume of $CO_2$ which can be stored in an Hungarian saturtaed oil reservoir (case study)

## Base Data

| Components | Original gas | Injected |
|---|---|---|
| | mole fraction | mole fraction |
| $C_1$ | 0.8111 | - |
| $C_2$ | 0.0690 | - |
| $C_3$ | 0.0298 | - |
| $C_4$ | 0.0190 | - |
| $C_{5+}$ | 0.0155 | - |
| $N_2$ | 0.0534 | 0.02 |
| $CO_2$ | 0.0022 | 0.98 |
| $H_2S$ | 0.0000 | - |

# Determination the volume of $CO_2$ which can be stored in an Hungarian saturtaed oil reservoir (case study)

## Production history



# Determination the volume of $CO_2$ which can be stored in an Hungarian saturtaed oil reservoir (case study)

## Results

| Method I | |
|---|---|
| $G_{iCO2}$, ($Mm^3$) | 8779.4 |
| $G_{iCO2}$, (kt) | 16256.6 |
| **Method II** | |
| $G_{iCO2}$, ($Mm^3$) | 6846.1 |
| $G_{iCO2}$, (kt) | 12676.8 |

| Components | mole fraction |
|---|---|
| $C_1$ | 0.2863 |
| $C_2$ | 0.0244 |
| $C_3$ | 0.0105 |
| $C_4$ | 0.0067 |
| $C_{5+}$ | 0.0055 |
| $N_2$ | 0.0318 |
| $CO_2$ | 0.6348 |
| $H_2S$ | 0.0000 |

# Thank you for attention and patience!