Application of microbial huff and puff technology in enhancing oil recovery in Weixing oilfield

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Abstract: After a long term of water flooding, the near well area of Weixing oilfield was blocked by a large amount of colloids, asphaltenes and waxes, resulting in a decline in oil well production. It is urgent to explore new technologies to slow the decline of production and increase the production per well. The results of microbial reservoir adaptability evaluation show that the microbial huff and puff test is suitable for Weixing oilfield. 5 pilot test Wells were selected under the well selection principle, and the compatibility of bacillus subtilis SL-2 with native reservoir bacteria and the emulsifying effect on crude oil were evaluated. The corresponding huff and puff scheme is designed according to the production status, pay-zone thickness, treatment radius and porosity. After microbial huff and puff, the daily liquid production increased from 28.2 t/d to 63.4 t/d, the oil production increased from 9.7 t/d to 25.0 t/d. Throughput is valid for 240 days, the cumulative oil production of five wells was 2048 t, and the economic benefit was good. After resuming production, the bacterial concentration of the produced liquid rose significantly to more than 10⁷ cfu/mL, indicating that the injected microbial strain grew well in the target reservoir and had good oil-increasing potential.

1. Introduction
Microbial huff and puff technology is to inject microbial fluid and nutrients needed for growth into the oil well, shut down the well for a while and then reproduce it, use of microbial degradation and metabolism will deposit on the bottom and sticky near wellbore area of low viscosity emulsion dispersed formation of heavy component oil-in-water emulsion, cleaning and downhole plugging and reservoir to increase crude oil flow ability, improve the single well production [1,2], with low cost, simple operation, high return, do not pollute the environment and the advantages of reusable [3-5].

The weixing oil field is located in the north of Songliao Basin of china. Due to the long-term water injection production in Weixing Oilfield, heavy components such as colloid, asphaltenes and wax in crude oil are deposited, and reservoirs near the well are polluted to varying degrees, which leads to poor water injection efficiency, insufficient liquid supply capacity, low bottom hole pressure and decreasing crude oil production. It is urgent to explore new measures to slow down the decline of production. According to the reservoir characteristics of Weixing Oilfield, 10 wells were selected to carry out microbial single well huff and puff test. After 10~30 days of shut-in, the wells were started for normal production, and the fluid production and oil production of oil wells increased obviously, which achieved good effects of increasing oil production and reducing water and economic benefits.

2. Geological setting of Test area
The reservoir types of Tai11, Tai12 and Tai109 blocks in Weixing Oilfield are structural-lithologic
reservoirs, and the main layer is Putaohua reservoir, with an average effective porosity of 23.0% and an average air permeability of 108.2 mD, which is a medium porosity and medium permeability reservoir. The reservoir temperature ranges from 51.3°C to 56.9°C, with an average temperature of 54.14°C (-1196.6 m). Ground crude oil has a density of 0.8673 g/cm³, an average viscosity of 31.8 mPa.s, an average freezing point of 34.0°C, an average wax content of 22.5% and an average gum content of 18.18%. Chloride ion content is 3226.87 mg/L, total salinity is 9800.31 mg/L, and water type belongs to NaHCO₃ type. According to the high pressure physical property test results of the oilfield, the original formation pressure is 12.98 MPa, the original saturation pressure is 4.64 MPa, the gas-oil ratio is 20.8 m³/t, the volume coefficient is 1.091, and the crude oil viscosity is 10.54 mPa.s. As of May 2020, the average daily oil production of a single well in the test area is 1.2 t, the comprehensive water cut is 75.7%, the oil production rate is 0.96%, the liquid production rate is 3.68%, the recovery ratio is 17.3%, and the water flooding recovery ratio is 32.4%.

At present, the block as a whole is in the stage of medium production, high water cut development, and large proportion of low-efficiency Wells and long shut-in. This time, microbial stimulation control measures are mainly applied to two types of long-shut-in and low-efficiency Wells. One is that the well reservoir is well developed, but the initial liquid production is low or the current liquid production is gradually decreasing, and the phenomenon of dynamic and static inconsistency occurs. The other is that water injection in oil Wells is affected by poor efficiency or elastic exploitation, and the formation fluid supply capacity is seriously insufficient, which affects the output of crude oil.

3. Microbial huff and puff test scheme

3.1. Well selection of Microbial huff and puff

The key of microbial huff and puff oil recovery is that the injected microbial strains should adapt to the target reservoir environment, multiply and produce substances beneficial to improving oil recovery. Therefore, the target reservoirs should be screened before microbial huff and puff. The main reservoir conditions, such as temperature, permeability, crude oil density, crude oil viscosity, wax content, formation water salinity and total bacterial concentration in produced water, are evaluated. The results show that the satellite oilfield is suitable for microbial huff and puff. The well selection principles of microbial huff and puff oil recovery are as follows [6,7]:

- the reservoir sand body is developed, the permeability is more than 10 mD, and the crude oil viscosity is less than 500 mPa.s;
- The reservoir temperature is less than 80°C and the formation pressure is less than 50 MPa;
- The PH value is 6.0~8.5, and the salinity of formation water is less than 300 g/L;
- Residual oil saturation is greater than 30%, water cut is less than 90%, and crude oil density is less than 0.966 g/cm³;
- The wax content is more than 1%, and the crude oil gel leaching content is less than 50%;
- The total bacterial concentration of endogenous bacteria is more than 10 cfu/mL, and the best is more than 10³ cfu/ml;
- The oil well has not been subjected to chemical operations that are harmful to the growth of bacteria, such as pickling.

Under the guidance of the principle of microbial huff and puff, 10 production wells with low liquid yield and insufficient liquid supply were selected to carry out microbial huff and puff test, as shown in Table 1.

| Well name | Layer thickness /m | Effective thickness /m | Daily liquid /t | Daily oil production /t | Moisture content /% | Remarks                |
|-----------|--------------------|------------------------|----------------|-------------------------|---------------------|-----------------------|
| W325      | 1.2                | 1.2                    | 2.0            | 1.4                     | 32.0                | Poor liquid supply capacity |
| W225      | 3.2                | 3.2                    | 4.0            | 1.7                     | 56.3                | Elastic mining          |
### 3.2. Microbial design

#### 3.2.1. Strain evaluation

According to the parameters of reservoir temperature, formation water salinity and crude oil properties in the test block of Weixing Oilfield, Bacillus subtilis SL-2 is selected as the target strain from the strain library, which can produce lipopeptide surfactants, and the metabolites can obviously improve the oil displacement efficiency after interacting with crude oil and reservoir rocks in the reservoir.

1. **Culture medium and culture conditions**
   - **Culture medium**: sucrose 30.0 g/L, NaNO₃ 3.0 g/L, KH₂PO₄ 3.4 g/L, K₂HPO₄·H₂O 4.0 g/L, MgSO₄·7H₂O 0.6 g/L, yeast powder 1.2 g/L, Trace element solution 5 ml.
   - **Culture conditions**: the culture temperature was 37°C, the rotational speed was 180 rpm/min, the culture period was 6 days, and the pH value was controlled at about 6.8.

2. **Experimental method**
   1. **Plate counting method** [8,9]: Dilute the bacterial liquid according to gradient, and smear 0.1 mL on agar medium evenly. The process needs aseptic operation. After 48 hours of incubation in the incubator, take out the Petri dish, count the number of colonies, and calculate the average number of colonies on three plates with the same dilution. The calculation formula is: the number of colonies per milliliter of sample = the average number of colonies with the same dilution × dilution multiple ×10.
   2. **Discharge of oil ring method** [10,11]: Add 60 mL distilled water into a plate with a diameter of 9 cm, and then add 8 mL stained paraffin solution. After the paraffin is evenly distributed, add 1 mL bacterial solution with a pipette, and observe the size of the oil drain ring. Based on the standard curve of the diameter of the drain ring and the concentration of lipopeptide surfactant, the concentration of lipopeptide surfactant in the bacterial solution was obtained.
   3. **Surface tension measurement**: The surface tension of the target bacterial liquid was measured by interface tensiometer FTA1000B for 3 times and the average value was taken.

3. **Matching between target strain and original strain**

   The detection shows that the number of original bacteria in the formation water of the weixing oilfield test area is 10²~10³ cfu/mL. The formation water is used to prepare nutrient solution without sterilization, and target microorganisms are injected to detect the growth of target microorganisms. After two days of culture, the number of bacteria increased to 10⁶ cfu/mL, which showed that the target strain had a good match with the original microorganism.

4. **Evaluation of surfactant yield**

   The output of lipid peptide surfactants of 12 strains of Bacillus including SL-2 was measured by oil drain ring method, as shown in Figure 1. The results showed that the lipopeptide yield of SL-2 was significantly higher than that of other strains, up to 3294.7 mg/L. By measuring the changes of surface tension before and after culture, it was found that the lowest value of surface tension of strain liquid after culture of SL-2 could reach about 1 mN/m.
Fig.1 Comparison of lipopeptide production of different strains in medium

(5) Evaluation of emulsification effect of crude oil

Nutrients were prepared from unsterilized formation water, added with crude oil, and cultured in shaking table for 10 days. The results show that SL-2 bacillus subtilis has a good emulsifying effect on crude oil, uniform and emulsified oil particles in small, oscillation can form uniform suspension and ink shaped, oil and water can completely miscible, without oil and water line, after the emulsion static oil and water is not stratified, bottle wall without oil, The comprehensive rating of emulsifying effect is 5 [12].

3.2.2. Design of the amount of bacterial liquid

The preflush is composed of 5m³ nutrient solution, which aims to provide nutrition for long-term synergism of microorganisms. The volume of liquid below the dynamic liquid level in casing annular space is used as the displacement fluid, and potassium chloride solution or formation water is used as the displacement fluid. In the test, the consumption of each oil well is 10m³. The microbial huff and puff solution is made by mixing oil recovery bacteria and nutrients, and its injection amount is related to the effective thickness of oil layer, treatment radius and reservoir porosity, and its calculation formula is [13,14]:

\[ Q = \pi r^2 H \phi \]  

Where \( r \) is the processing radius (m); \( H \) is reservoir thickness (m); \( \phi \) is reservoir porosity (%).

The organic pollutants in oil Wells mainly occur in the near-well zone, and the test oil Wells are medium-permeability reservoirs, so the reservoir radius of microbial single-well treatment is set to be about 5 m [15], so that microorganisms can have more sufficient action space, grow and reproduce in the underground oil layer and complete various physiological and metabolic activities.

3.3. Construction design

According to the design of dynamic and static parameters and the amount of bacterial liquid in 10 test Wells, the design and construction parameters [16] are shown in Table 2. The construction steps are as follows [16]: ① stop the production operation, vent the air inside the casing, thoroughly clean the well, and remove the dead oil and other pollutants in the wellbore; ② Normal production according to the original standard, until the oil well liquid production and water content is normal in the construction; ③ Test note with water, check whether there is leakage; ④ In order to inject pre-liquid, bacterial liquid, displacing liquid, etc.; ⑤ After closing the well for 10~30 days, production shall be carried out according to the original working system.
Table 2 Construction parameters of microbial huff and puff

| Well name | Sandstone thickness /m | Effective thickness /m | Injection quantity /m³ | Processing radius /m |
|-----------|------------------------|------------------------|------------------------|----------------------|
| W325      | 3.6                    | 1.2                    | 22                     | 5                    |
| W225      | 3.6                    | 3.2                    | 57                     | 5                    |
| W3X11     | 9.6                    | 7.0                    | 124                    | 5                    |
| W121J     | 7.6                    | 3.0                    | 53                     | 5                    |
| W9X11     | 8.0                    | 5.0                    | 89                     | 5                    |
| W161J     | 12.6                   | 10.0                   | 183                    | 5                    |
| W215      | 6.0                    | 4.4                    | 80                     | 5                    |
| W130      | 6.0                    | 3.8                    | 69                     | 5                    |
| W136      | 10.2                   | 4.6                    | 84                     | 5                    |
| W227      | 2.8                    | 2.2                    | 40                     | 5                    |

4. Microbial huff and puff test effect

4.1. Production situation
After microbial huffing and puffing, the 10 wells generally showed good huffing and puffing and plugging removal effects, and the liquid production and oil production increased significantly. The fluid production of 10 wells increased from 28.2 t/d to 63.4 t/d; the oil production increased from 9.7 t/d to 25.0 t/d; as of May 2020, the cumulative oil production of 10 wells increased by 2048 t (table 3). In this test, two Wells, W325 and W3X11, had the best stimulation effect. After nearly 8 months of production, the total output of crude oil increased by 882 t. The stimulation effect of 5 Wells was moderate, and the oil stimulation effect of the other 3 Wells was slightly poor, mainly due to serious formation deficit, low formation pressure and insufficient liquid supply. At present, the daily oil production of each test well is still higher than that before stimulation. With the prolongation of production time, the accumulative oil increase will continue to increase.

Table 3  Microbial huff and puff result

| Well name | Before microbial huff and puff | After microbial huff and puff | Accumulated oil increase /t |
|-----------|--------------------------------|-------------------------------|-----------------------------|
|           | Daily liquid /t                | Daily oil production /t       | containing water /%          | Daily liquid /t | Daily oil production /t | containing water /% | Accumulated oil increase /t |
| W225      | 4.0                            | 1.7                           | 56.3                         | 8.7             | 4.8             | 45.0                         | 267                       |
| W3X11     | 5.3                            | 1.2                           | 76.6                         | 13.9            | 4.2             | 70.0                         | 420                       |
| W325      | 2.0                            | 1.4                           | 32.0                         | 5.6             | 3.9             | 30.0                         | 462                       |
| W9X11     | 0.7                            | 0.6                           | 16.0                         | 1.5             | 1.4             | 5.0                          | 104                       |
| W121J     | 0.8                            | 0.6                           | 30.0                         | 1.3             | 1.1             | 16.0                         | 138                       |
| W215      | 2.2                            | 0.9                           | 59.2                         | 5.4             | 3.5             | 34.9                         | 162                       |
| W161J     | 3.2                            | 0.4                           | 86.2                         | 7.9             | 0.9             | 88.0                         | 90                        |
| W130      | 2.4                            | 0.6                           | 75.9                         | 2.8             | 1.4             | 50.9                         | 141                       |
| W136      | 6.3                            | 1.4                           | 77.4                         | 14.3            | 2.1             | 85.0                         | 178                       |
| W227      | 1.3                            | 0.9                           | 30.0                         | 2.0             | 1.7             | 14.0                         | 86                        |
| Total     | 28.2                           | 9.7                           | 65.6                         | 63.4            | 25.0            | 60.6                         | 2048                      |

4.2. Effect analysis

4.2.1. Variation of bacterial concentration in huff and puff
In the process of microbial huff and puff, the daily liquid production, daily oil production and water cut of oil wells are closely related to the concentration of microbial bacteria. Figures 2 and Figures 3 show the production curve and bacterial concentration curve of well W325.
After opening the well, the bacterial concentration of the produced fluid increased by two orders of magnitude compared with that before injection, indicating that the target strain could proliferate greatly in the reservoir. At the initial stage of production, the produced liquid is mostly water and replacement liquid injected in the early stage, resulting in high water cut (about 90% water content) and cell concentration fluctuating around 10^7 cfu/mL. After that, the number of bacteria increased sharply, and the bacterial concentration reached the peak of 8.75 × 10^8 cfu/mL one month after injection. At this stage, microorganisms have enough nutrients to metabolize and reproduce, the daily liquid production tends to be stable, and the water content decreases rapidly (the water content drops to about 30%).

After the number of bacteria reached the peak, due to the decrease of nutrients in the reservoir environment, the death rate of bacteria was higher than the growth rate of bacteria, and the concentration of bacteria decreased gradually. However, due to the accumulation of a large number of active substances produced by bacteria in the early stage, the changes of liquid production and water content are relatively stable at this stage. The change of bacterial concentration fluctuated to a certain extent, and the overall downward trend was relatively gentle. The analysis of the reason may be due to the depletion of nutrients in the reservoir, and the bacteria survive by consuming the hydrocarbons in the reservoir and the sugars stored by the cells themselves for a period of time. At this stage, bacteria metabolize hydrocarbons in oil reservoirs, reducing the wax content in crude oil and increasing the fluidity of crude oil. at the same time, its metabolites also play a certain role in improving oil recovery [18].

The overall change trend of bacterial concentration in the 10 oil wells tested is similar to that of W325 (figure 4). In the early stage, the nutrient was rich, and the bacterial concentration increased greatly; then, due to the decrease of nutrients, it was difficult to support the metabolism and reproduction of a large number of bacteria, the bacterial mortality rate was gradually higher than the growth rate, and the bacterial concentration decreased gradually. the corresponding daily liquid production and oil production are also reduced.
4.2.2. Changes of surface tension and crude oil composition in throughput wells

From the results of stimulation well test (figure 5), it can be seen that microbial bacteria can grow and reproduce well under reservoir conditions, and the effect of strain activation is better. At the same time, after acting on crude oil, it can effectively degrade crude oil and improve crude oil fluidity, the proportion of heavy components in crude oil components decreases, the proportion of light components increases, and the surface tension decreases obviously (table 4). On the whole, the oil displacement system shows a good oil displacement effect.

![Fig.4 The variation tendency of bacterial concentration in produced fluid of test well](image)

![Fig.5 Changes of crude oil components in the test oil well](image)

### Table 4 Changes of surface tension of produced samples in microbial throughput wells

| Well name | Before huffing mN/m | The first day of opening the well mN/m | The fifth day of opening the well mN/m | The ninth day of opening the well mN/m | Thirteenth day of opening the well mN/m |
|-----------|---------------------|---------------------------------------|----------------------------------------|----------------------------------------|---------------------------------------|
| W225      | 43.1                | 33.8                                  | 34.5                                   | 33.5                                   | 32.3                                  |
| W130      | 49.3                | 31.6                                  | 32.7                                   | 32.9                                   | 34.7                                  |
| W227      | 42.7                | 34.2                                  | 33.5                                   | 31.9                                   | 31.9                                  |
| W161J     | 46.3                | 33.9                                  | 32.8                                   | 34.3                                   | 34.3                                  |
| W136      | 36.8                | 35.5                                  | 32.5                                   | 31.2                                   | 29.9                                  |

5. Conclusion

(1) After well opening, the concentration of microbial flora was greatly increased, indicating that the injected functional bacteria for oil production had good compatibility with the actual environment of the target reservoir and had the potential for long-term oil increase.

(2) In the implementation process, microbial oil displacement technology requires less raw materials and can be completed without the need for moving pipe string and construction of surface facilities, with low cost and good economic benefits. It is suggested to expand the application scale of microbial huff and unload or oil displacement in similar low-yield and low-efficiency Wells.

(3) When carrying out microbial stimulation, the well test data should give priority to Wells with...
reservoir pollution or Wells with obvious liquid production and oil production decline trend in the near well zone, and Wells with colloidal, asphaltic and waxy plugging causing production decline.

Acknowledgments
This work was supported by University Nursing Program for Youth Scholars with Creative Talents in Heilongjiang Province(UNPYSCT-2017037) and Northeast Petroleum University Research Start-up Project funding(rc201707).

References
[1] Zhu Weiyao, Liu Shengzhi, Wang Yuanji. (2006) Porous flow theory and prediction method of the microbe taking-in-and-sending-out production. Petroleum Exploration and Development, 33: 505-510.
[2] Wu Xiaolin, Le Jianjun, Wang Rui, et ct. (2013) Progress in pilot tests of microbial enhanced oil recovery in Daqing oilfield. Microbiology China, 40: 1478-1486.
[3] Sen Ramkrishna. (2008) Biotechnology in petroleum recovery: The microbial EOR. Progress in Energy and Combustion Science, 34: 714-724.
[4] Sarafzadeh Pegah, Hezave Ali Zeinolabedini, Ravanbakhsh Moosa, et ct. (2013) Enterobacter cloacae as biosurfactant producing bacterium: Differentiating its effects on interfacial tension and wettability alteration mechanisms for oil recovery during MEOR process. Colloids and Surfaces B: Biointerfaces, 105: 223-229.
[5] Wang Tianyuan, Yu Li, Xiu Jianlong, et ct. (2019) A mathematical model for microbial enhanced oil recovery considering the double-bacterial competition mechanism. Journal of Petroleum Science and Engineering, 178: 336-343.
[6] Zhang Yanrong, Liu Bo. (1998) Application of huff and puff technology in Huabei Oilfield. Oil Drilling & Production Technology, 1998, 20: 88-90.
[7] An Xiaokang. (2010) Application of microbial huff and puff technology in Pubei area of Daqing Oilfield. Journal of Yangtze University, 7: 245-248.
[8] Zhao Feng, Li Ping, Guo Chao, et ct. (2018) Bioaugmentation of oil reservoir indigenous pseudomonas aeruginosa to enhance oil recovery through in-situ biosurfactant production without air injection. Bioresource Technology, 251: 295-302.
[9] Baron Florence, Cochet Marie-Franoise, Ablain Wilfried, et ct. (2006) Rapid and cost-effective method for micro-organism enumeration based on miniaturization of the conventional plate-counting technique. Dairy Science & Technology, 86: 251-257.
[10] Youssef Noha H, Duncan Kathleen E, Nagle David P, et ct. (2004) Comparison of methods to detect biosurfactant production by diverse microorganism. Journal of Microbiological Methods, 56: 339-347.
[11] Wang Juanjuan, Zhang Yu, Fu Na, et ct. (2016) Microbial huff and puff field trial in ultra-low permeability reservoir. Microbiology China, 43: 241-253.
[12] Huang Lixin. (2014) The studying on the mechanism of microbial flooding and analysis of microflora in typical reservoir. University of Chinese Academy of Science.
[13] Sun Jianguo. (2008) Study and application of microbial huff and puff oil recovery in low permeability thin sand reservoir. Journal of Oil and Gas Technology, 30: 322-326.
[14] Li Chang. (2013) Application of microbial oil recovery technology in extra heavy oil block. China Petroleum and Chemical Standard and Qualit, 33: 85.
[15] Sun Shanshan, Luo Yijing, Zhou You, et ct. (2017) Application of bacillus spp. in pilot test of microbial huff and puff to improve heavy Oil Recovery. Energy & Fuels, 31: 13724-13732.
[16] Li Shengxian, Kang Hong, Chi Shuanghui, et ct. (2008) Single well huff and puff test of three oil production strains 982 and L-510. Oilfield Chemistry, 25: 181-185.
[17] Youssef Noha, Elshahed Mostafa S., Mcinerney Michael J. (2009) microbial processes in oil
fields: culprits, problems, and opportunities. Advances in Applied Microbiology, 66: 141.

[18] Varjani S. J. (2017) Microbial degradation of petroleum hydrocarbons. Bioresource Technology, 223: 277-286.