Petroleum Science
https://doi.org/10.1007/s12182-020-00467-5

A review of development methods and EOR technologies for carbonate reservoirs

Received: 21 April 2020

Abstract

C , , . B - , . T EOR , . T , . I , . C , - . T - - , , . I EOR , EOR . O , , EOR , - .

Keywords C – R – F – D – EOR

1 Introduction

C - (, ,). M - , . T (, , .) , (W . 2012). G - , . G , , , . M E - , 80% M E - (N A 1997). O N A 1/2 N A (W 1980 ,). T 3 10^6 ^{2} C , 1/3 C . T - . T 20% ; 70%

H E : K M

E -H S

S - L
@163.

-M L
@ . .

[1] S P E , C U P (E C), Q 266580, S , C

[2] K L U O G D , C U P (E C), M F , Q 266580, S , C

[3] S G , B 100728, C

,
50%
(L . 2018). T
60% (R C
2012). M
90%
,
. T 389
,
208 . B
2013, (2P)
,
3.534 10^{11} , 3.27 10^{14} ^{3}
2.24 10^{10} , ,
6.383 10^{11} . A , 2P
-
, ,
1.296 10^{11} , 1.2 10^{14} ^{3},
1.22 10^{10} , . T
2.382 10^{11} . T ,
36.7%, 36.7% 54.5%
, , 37.3%
. F 1 -
-
. I
: M E ,
S U , N A , A P
(W . 2016).
W
,
. M 10%

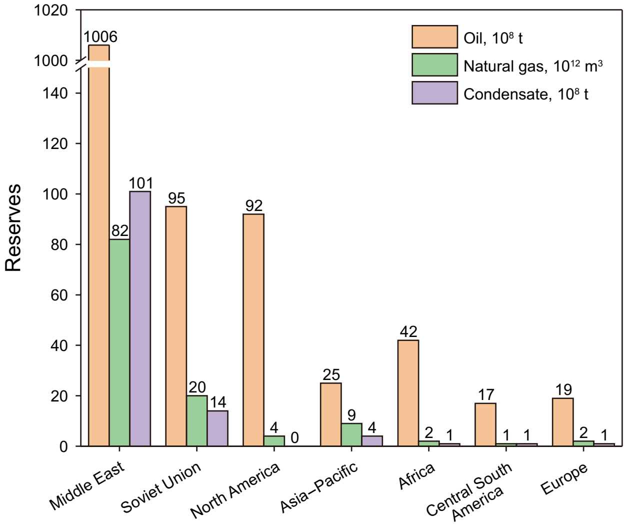

Fig. 1 T -
(E 2008; G . 1995; USGS 2000)

3500 . A ,
5000 -
N A , R , I . I
, C
T B
(M . 2011). C . W
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. T
, ,
(TSR) ,
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C ,
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EOR
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2 Stimulation of carbonate reservoirs

T
; 80% -
4% 16%,

1 500 D. W

N

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I

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A

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, A . (2019)

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I

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H,

. E

(DEA), . I

, DEA

. H

(N -E -D A M
2007). A (VES)

H

VES (B L 2014). I

. F

(MSF)
(R 2018). T

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. H

W

. G . (G . 2019)
(HVS)

. T

. T

F 2. T

. HVS

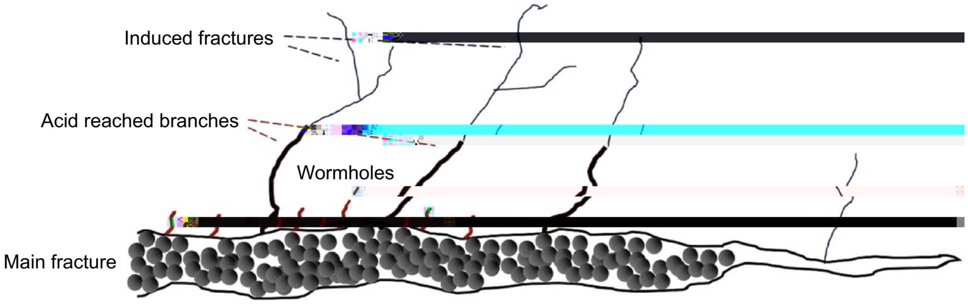

Fig. 2 I HVS. R G . (2019)

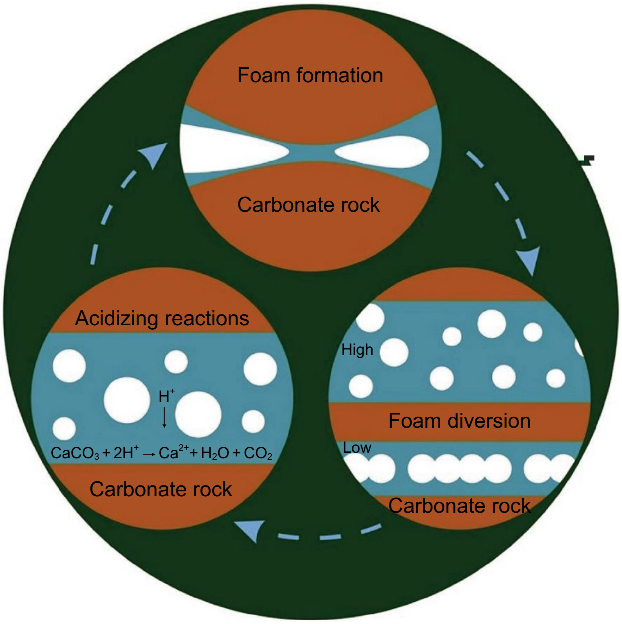

Fig. 3 M . R - . (2019)

(L . 2015).

A . W , , . T . A , . A , , . U , .

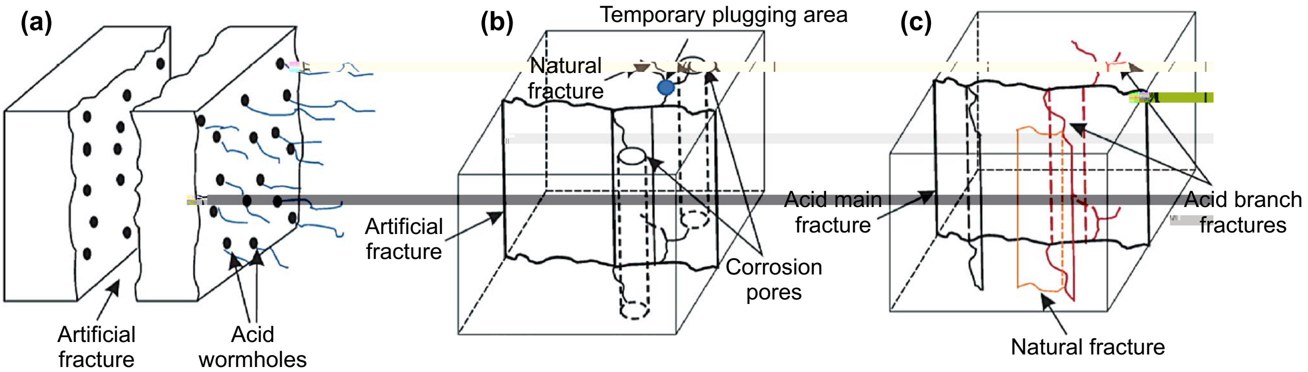

Fig. 4 T - : **a** , **b** , **c** . R - G . (2020)

3 Flow characteristics of carbonate reservoirs

[illegible] (G[illegible] 2012). [illegible]

[illegible]

3.1 Displacement of the matrix system

[illegible]

[illegible]

3.2 Displacement of the fracture system

[illegible]

. W , . I , , - . T , . W , . U , . B , - , . T . T , - . O , . C - , . C , - , , - . T - , - , . D , , . T . T , . O (W . 2017).

4 Development methods of carbonate reservoirs

4.1 Water flooding

C , , - - (. 2011). I , - . T

. H , - , . T , .

4.1.1 Smart water flooding

S - , . L - - 1960 (H . 1991). T , , - (H . 2019).

T . H . (H . 2010) - ; - (C^{2+}, M^{2+} SO$_4^{2-}$) , (C CO$_3$, C M (CO$_3$)$_2$ C SO$_4$) , . I , - , . H - , (A - . 2009). M ; , , (R D . 2009). T F . 6. . (2012) - S A - . C , . S , - , . T , . I ,

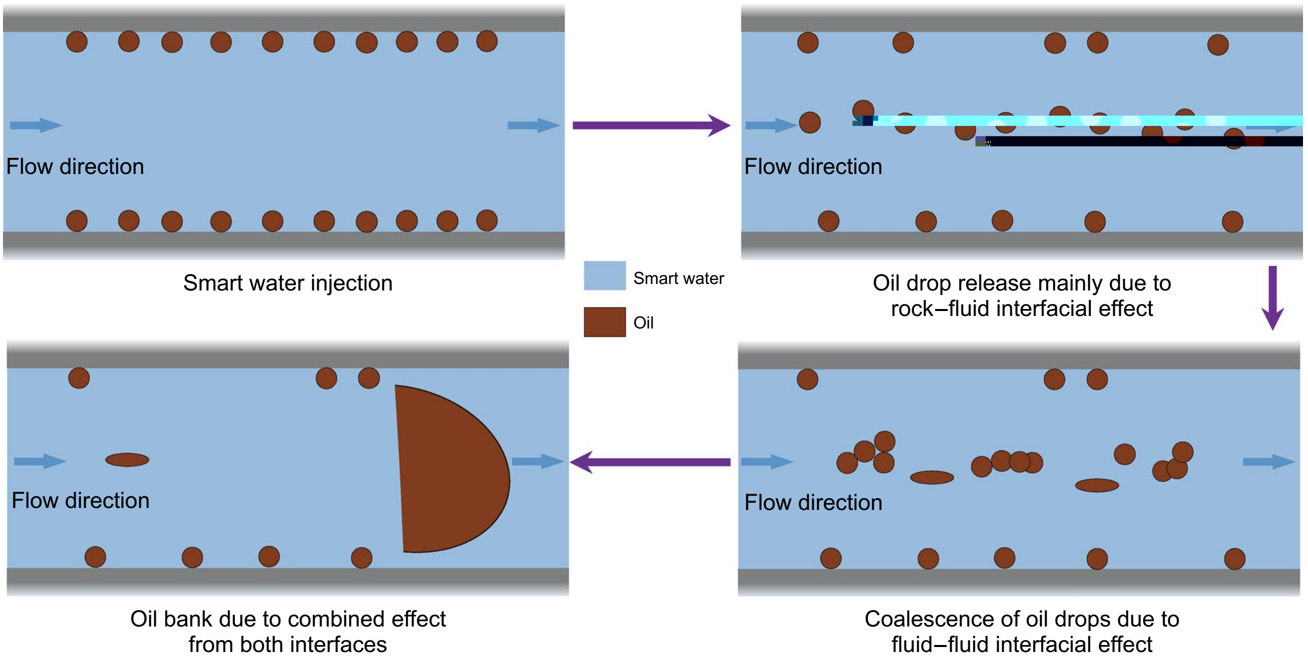

Fig. 6 S . A A - . (2016)

-

(. 2011 , ,).
A 2008, S A

-

. S A

(A . 2016). I
S A

. T

. H ,

. T
S P , -
(R 2016). W -
, -
(L L
2019).

4.1.2 Carbonated water flooding

C (CWI)
- CO_2 . B , CO_2 -
. C

CO_2 ,
: (1) CWI CO_2,
CO_2.
(2) T CO_2-
,
CO_2
CO_2 . (3)
W CO_2 , ,
CO_2
. (4) T -

, ,
, ,
(M
J 2019).
A , CWI -
, -
CWI
, -
. T -
CWI -
, J (2019) L
K ,
-
. I
CWI
,
. I ,

. T -
, . M . (2019)
CO$_2$-
-
DP . I
,
CO$_2$
, -
(IFT) -
,
. G . (2019)
IFT ,
-
.

T
. M -
,
,
. R (2011) -
-
CWI. F 7
R CWI. F
F . 7 ,
(WI),
; , F . 7 ,
, CWI,

, (S . 2015).

4.1.3 Variable strength water injection

B , -
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,
- -
, ,
, ,
(L . 2018).
U
EOR
. T -
.

. B

, ,

.
T

. I , -
,

. U

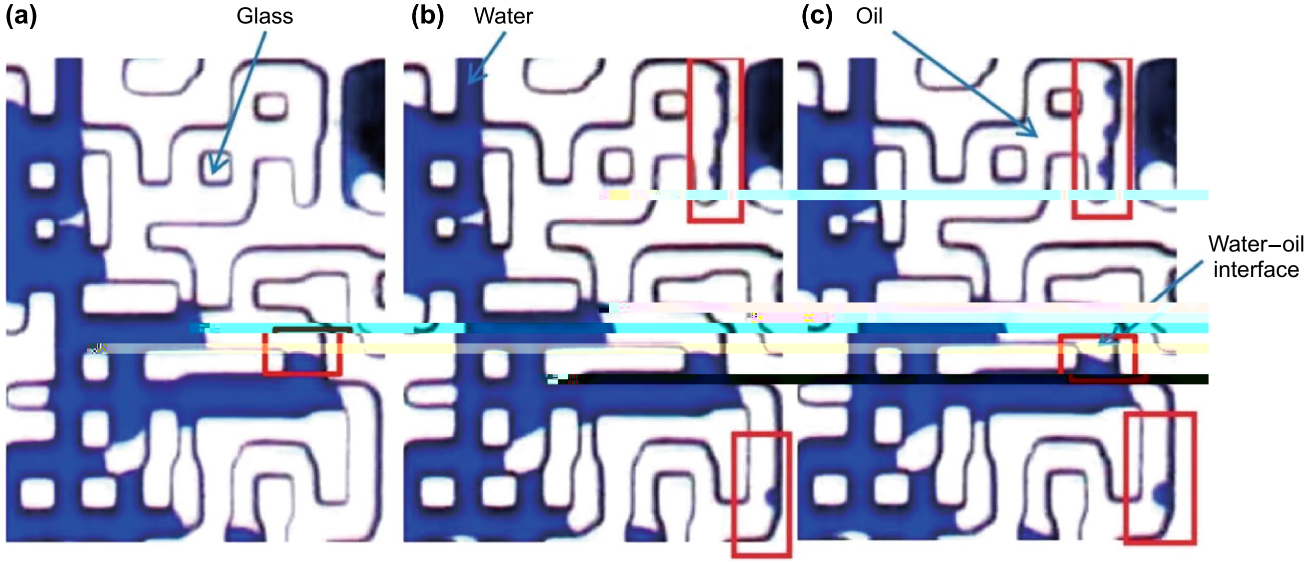

Fig. 7 F (**a**) WI (**b, c**) 19.6 47.12 CWI, . R S . (2015)

C . P

(. 2017).

W

. (2016)

P -C B , PVT

. (2020)

T

C

S L (2018)

M E

. T M F

H

F . 8.

4.2 Gas flooding

G . A , CO_2, N_2 EOR . T (, ,) , (P M 2014). A W EOR S A O G J 2000 2010, F . 9 (L 2008; K 2010; A A B 2011). T CO_2 61%, 36% 3% N_2 . T CO_2 USA. I , N_2 . T CO_2 N_2. U CO_2 , N_2

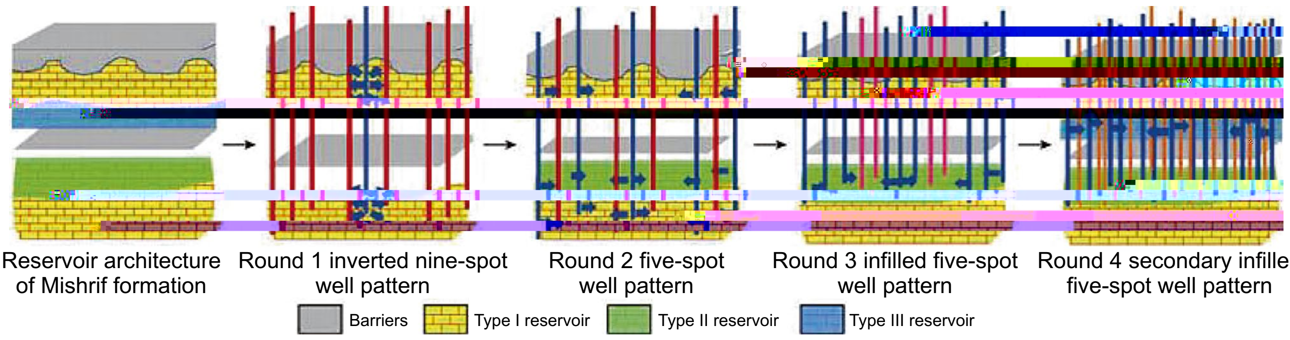

Fig. 8 S . R S L (2018)

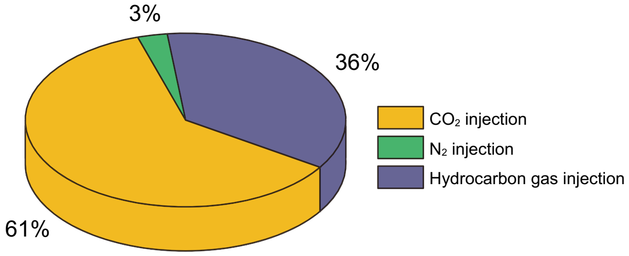

Fig. 9 T

. B

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C

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T :

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( ) ,

- -

. T

-

. M

(FCM) -

(MCM). T

. T

(MMP). G

MMP. O -

-

. T -

MMP.

S

. W

,

. I , ,

,

(L . 2018).

4.2.1 Non-hydrocarbon gas flooding

N_2 , , -

, . C -

CO_2, N_2 ,

,

, . T -

N_2 ,

. T N_2

CO_2 . H , USA, CO_2

-

. A

,

, . U

,

(. 2015).

A - , N_2 -

- - (HP/HT)

. G , , N_2

. H , -

N_2

. I

, USA

N_2 .

M (L 2008) WAG-N_2 J

LEC. I USA, C

N_2 G M . D

N_2 , N_2

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I , - N_2

. I , HPAI (-

) , -

, N_2

. I , HPAI

, USA

(M 2009).

T CO_2

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CO_2 . T ,

. CO_2

. I 3-9

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. A , CO_2

. T CO_2

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I -

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(L

. 2018 , , 2019). H ,

. C

CO_2 . N CO_2

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CO_2 ,
CO_2 . A -
2014, EOR
CO_2 1371 10^4 , 93%
EOR CO_2 (K -
2010).
T CO_2
. I ,
CO_2
- . T
,
CO_2 ;
N_2 (J
. 2019). Q . (2020)
-
. O
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PIR .
T , PIR
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-
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I ,
,
(WAG) -
. WAG -
, ,
. T
WAG -
. A ,
- , -
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. A
. G ,
WAG
. T
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WAG . W WAG
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4.2.2 Hydrocarbon gas flooding

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EOR
M E (K . 2017). T
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(LPG). T -
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. LPG ,
. A
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, . T
LPG. I
, (C_2 C_6) -
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. T
(D . 2016).
L -
. K . (K . 2015)
/ / (PVT)
-
. T
(MMP)
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(, 1.45
). A
200 -
70%,
92%. I
WAG
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I A
D ,
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(A -H . 2011). T -
(/ /) .
EOR A D .
D . (2010)
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. B -
4 ,
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USA,
EOR (M

. 2007). I ,
C , -
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(WAG)
. I WAG ,
. T
. A ,
(. .,)
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C -
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. D
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. W
-
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. R ,
,
. A ,
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4.3.1 Polymer flooding

P . F , . B - , , , (A . 2013). P - . T 1327 USA, - (M . 2011). U C C A , 100 . B - 130 C 220,000 /L, , (L . 2009). A - - . A , (S M 2016; C . 2018). P - (HPAM) EOR (S 2010; S 2013). HPAM (COOH) - H, , . W H , , , (C . 2010). I , , (A . 2012; U . 2018). C , PA BA (PEI) . M - (E . 2007; B . 2015). H , BA PEI , PA BA-PEI . C . (2019) / - /2- -2 - (AM/AA/AMPS) . I AM/AA/AMPS - - - .

D - - , - (LSPF) EOR . P (K . 2017; V . 2014). T . I , , - , - (. 2012). I - , - , - (S . 2016). L . (2019) H PDI LSPF . I SO_4^{2-} , , .

4.3.2 Surfactant flooding

S . L IFT , (D A 2015). I , , - . T , (/) . B , - (. ., - , , ITF) , - (A M 2010). B - , / , - (F D 2010; A M 2010; K . 2011). A (S A 2000 , , 2003; A

M 1997). T (DTAB) (OOIP 70%) CMC (1 %). T : (1) I . (2) T . (3) A , . W . (2010) ( ), C-EOR, IFT 50% . . (2015) , IFT 5.4 10 3 N/ 10 /L. T - - . S , . C , , - . T , (9.2, 7.4). T , . C EOR . C , . H , . A , . T . A , , . M , , . T . T , A I , S - K A D U A E (C . 2014). A T (C . 2000) C C W (M . 2007), M A B (S 2003) S S S , I (R . 2010). M , .

4.3.3 ASP flooding and foam flooding

ASP , . I ASP, H . T , . B , , . S , (K . 2002; S 2003). ASP . I , ASP . A ASP , . G , 0.5, 0.9, 200 P . H , . O , ASP , , . T , , , . T , SP . D . F (W . 2017; . 2017). T , (S 2013; L . 2020). T

(L . 2019). T -
F . 11. F
(W . 2019; H .
2018; L . 2020). H , -
- (HTHS) ,
. F ,
. S ,
HTHS . S
- HTHS . C .
(2016) C12 -
HTHS -
. T H (
4) C12
. . (2015) -
CO

(EDS) , PM : , . B - - , / (A P 2013) - (A . 2018). A . (2019) - / . T - , . A F . 12, . T . B , - (S M 2020). S . (2014) SO_2 . I SO_2 - , . T - . T F . 13.

4.4 Application of emerging technologies

4.4.1 Electromagnetic oil production

R , - , - . A - , H . (2014) . I , - . F , . E . B , , - (K . 2011; . 2019; . 2014). I , ,

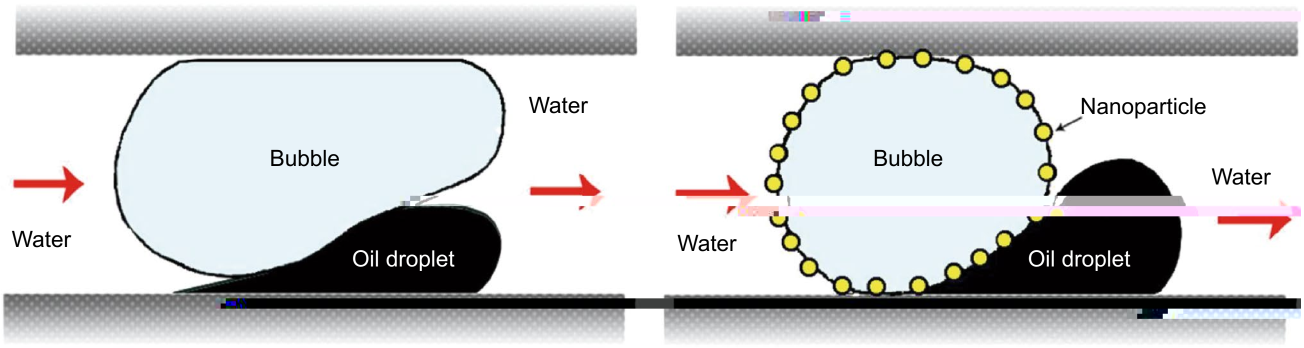

Fig. 13 D SDS (S O_2/SDS ( ). R S . (2014)

, . B , - , (A . 2019).

4.4.2 Steam-over-solvent injection

S - (SAGD) C - (B 1994, 1998). T (VAPE) - . I B M (1991) . T , - - - (SOS-FR) (A B B - 2009, 2012). SOS-FR 2008 ( ) - . I . T , . T , . U , ( ) . D , ,

( ) (A -B B 2011). A SOS-FR , M - B (2016) - G - . T , , . B - - SOS-FR , A -G . (2015) SOS-FR , - .

4.4.3 In-situ oil recovery

I , . I . T . O , . I (ISC) . H (A . 2017). D , , . O , , . A , ISC .

H , ISC (C . 2019).

I - (ISUT) , . I , (VR) , - (E . 2019). T - F . 14. ISUT , - (SAGD). I , , ISUT SAGD (N . 2017).

5 Challenges and prospects

T - , , , . T). T - , EOR .

T , , - . A , , , . F , , , , - , , . I , - , . D - , , . H , , . T (- - - . I , , .

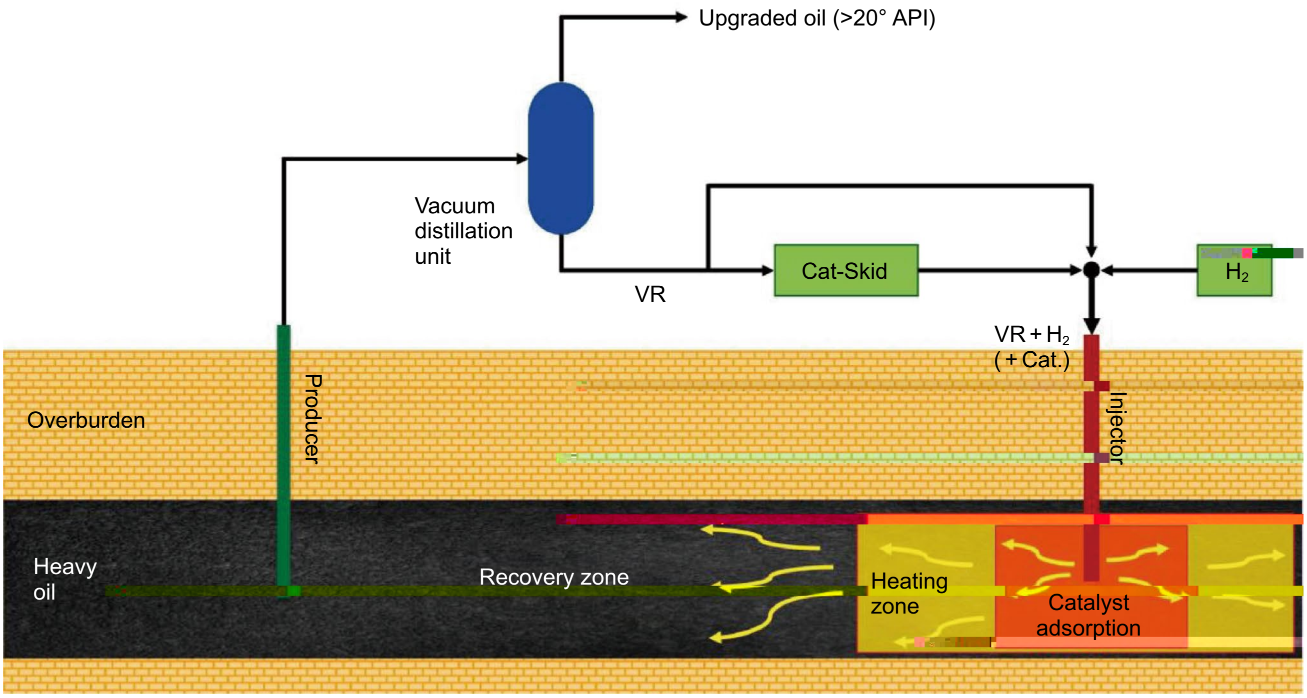

Fig. 14 S ISUT . R E . (2019)

A -B A-M, B T. L - - (SOS-FR) - . J P S E . 2012;84:42 56. :// . /10.1016/ . .2012.01.021.

A -G M, B T, L J, A -B A. I - - - : - - . J P S E . 2015;130:77 85. :// . /10.1016/ . .2015.03.011.

A -H SK, G SG, A - AH, N S. I - CO_2-EOR A D . I : SPE M E ; M , B . S E ; 2011. :// . /10.2118/142623-MS.

A A A, B B. A EOR - . J P S E . 2011;79(1 2):10 24. :// . /10.1016/ . .2011.07.005.

A B AMM, B T. S - - - (SOS-FR) - : . I : A P ; J , I . S E ; 2009. :// . /10.2118/123568-MS.

A D, K P, H B. V - . J P S E . 2017;154:488 94. :// . /10.1016/ . .2017.02.002.

A JA, K K, M AK, S KD. P - - : IFT , , - . J M L . 2019;284:735 47. :// . /10.1016/ . .2019.04.053.

A MS, A H, H B, D M. I , , : - . J P S E . 2019;181:106158. :// . /10.1016/ . .2019.06.022.

A AM, L JS, H M, A S. N . J P S E . 2013;111:184 96. :// . /10.1016/ . .2013.09.009.

A V, M E. E : . E . 2010;3(9):1529 75. :// . /10.3390/ 309 1529.

A S, D C, T V, P M, J KP. H - - - - . J C I S . 2017;488:79 91. :// . /10.1016/ . .2016.10.054.

A F, G SR, I M, D . N - . E F . 2019;33(11):10602 10. :// . /10.1021/ . . .9 02296.

A D, P P. N - - - . C S A. 2013;436:803 14. :// . /10.1016/ . .2013.08.022.

A T, M J. S - . I : I ; H , T . S E ; 1997. :// . /10.2118/37236-MS.

A T, S S, P T. I - . I : SCA - ; 2009 S ; N , T N - : S A . P SCA2009-43.

A SC, S SH, AA. M - -

SPE : . I : SPE ; T , O , USA. S E ; 2016. :// . /10.2118/179590-MS.

B T, S S, K U, C D, K U, T NNS. D B R - : - CO_2 . I : SPE - ; D , C , USA. S E ; 2008. :// . /10.2118/115400-MS.

B B, J, M. A - . P E D . 2015;42(4):525 32. :// . /10.1016/S1876-3804(15)30045-8.

B M, , C , S K. S . R S - E R . 2017;75:1464 71. :// . /10.1016/ . .2016.11.142.

B R, L JT. A . J A P S . 2014. :// . /10.1002/ . .40735.

B J, H SF, L SDL, A - F, A -M GO, D AR, . E 1 E R , W F , P . I : SPE ; K C , K . S E ; 2011. :// . /10.2118/150605-MS.

B R. SAGD ! J C P T . 1998. :// . /10.2118/98-07-DA.

B RM. S - : , , . J C P T . 1994;33(02):44 50. :// . /10.2118/94-02-05.

B RM, M IJ. A (VAPE) . J C P T - . 1991. :// . /10.2118/91-01-09.

C C, A -M E, A -S B, B C, F R, P G. O -S S -M C - F K . I : SPE ; T , O , USA. S E ; 2014. :// . /10.2118/169153-MS.

C HL, L LR, N LAD, HD, K DE. L - . I : SPE M ; V , M . S - E ; 2000. :// . /10.2118/59006-MS.

C L, , W L, H, W D, F M. E - - . E F . 2018;32(11):11269 78. :// . /10.1021/ . . .8 02576.

C L, , F M, H, L G, J. E - - . C S A. 2019 ;570:251 9. :// . /10.1016/ . .2019.03.025.

C , P W, L , L , V MA, H J. A - . J P S E . 2019 ;174:446 55. :// . /10.1016/ . .2018.11.054.

C SK, S MM, B S, H C. H- - - - . SPE R E E . 2010;13(06):926 39. :// . /10.2118/121686-PA.

C L, M K, P M, A AA, T I, L LJ, . M - C12 (CO_2) / . SPE J. 2016;21(04):1151 63. :// . /10.2118/179726- .

D AM, E M A, B CR, B M, A MR, A S AS . E M A D . I : SPE EOR & W A ; M , O . S P E ; 2010. :// . /10.2118/129238-MS.

D M, W , W W, S S, J. V - . P S T . 2016;34(6):491 8. :// . /10.1080/10916466.2016.1149488.

D H, A A. O . I : A D I ; A D , UAE. S E ; 2015. :// . /10.2118/177489-MS.

E SM, S CE, C , P -A P. I - - : . F . 2019;252:262 71. :// . /10.1016/ . .2019.04.094.

E I. I E : IHS E ; 2008.

E LS, D ED, E DM, V JE. W - . SPE P O . 2007;22(02):231 5. :// . /10.2118/98119- .

F MA, D M. M . I : SPE ; T , O , USA. S E - ; 2010. :// . /10.2118/129749-MS.

G J, N J, L SE, W KJ. A . G S L S P . 2012;370(1):1 15. :// . /10.1144/SP370.15.

G DL, D GL, T KI, V KL. N - S , - , . US G S D D S DDS-30. 1995;1. :// . /10.3133/ 30.

G E, P R, R M. E - - . P S . 2019;16(6):1361 73. :// . /10.1007/ 1218 2-019-0355-1.

G C, D H. S - . J N R . 2017;19(1):23. :// . /10.1007/ 11051-016-3705-6.

G J, R J, W S, C C, L J, G B. C . J P S E . 2019;174:362 73. :// . /10.1016/ . .2018.11.006.

G J, G B, Q N, J, W L, W K, . A - : - . N G I . 2020;40(2):61 74 **(in Chinese)**.

H L, S J, E D, T L. I E . SPE F E . 1991;6(03):284 90. :// . /10.2118/19838- .

H J, M S, S H, E MN, S A. M - . J P S E . 2019;179:276 91. :// . /10.1016/ . .2019.04.049.

H A, G M, T A, H M. T . P S T . 2014;32(9):1038 42. :// . /10.1080/10916466.2011.634875.

H A, C L, M M. T - . T P M . 2010;85(1):1 21. :// . /10.1007/ 1124 2-010-9543-6.

H J, L M, D. F -EOR - - : . J P S E . 2018;164:546 58. :// . /10.1016/ . .2018.01.057.

J B. C (CWI) - . J T I C E . 2019;104:82 93. :// . /10.1016/ . .2019.08.014.

J G, L, D C, P M, J KP, B SL, . E - CO_2 - - . E F . 2019;33(7):6038 47. :// . /10.1021/ . .9 00667.

K M, N, H, S A, J M, N N, . O . J A S . 2011;11(7):1366. :// . /10.3923/ .2011.1366.1370.

K S, Q C, J RT. D - . SPE J. 2017;22(02):417 30. :// . /10.2118/179695- .

K M, K H, O E, W -S. P T EOR L . I : SPE ; D , C - , USA. S E ; 2011. :// . /10.2118/146840-MS.

K W, P MJ, S H. M - - . I : SPE ; L , K . S E ; 2002. :// . /10.2118/78711-MS.

K L. S R 2010 EOR . O & G J. 2010;108(14):41 53

K V F, N D, S A, H J, W P, P GA EOR - K . I : SPE K ; M K . S E ; 2015. :// . /10.2118/175348-MS.

K J, FS, N T. G EOR S - . I : A D ; A D , UAE. S E ; 2015. :// . /10.2118/177505-MS.

K J, A P, D E. A - - M E . SPE R E E . 2017;20(01):19 29. :// . /10.2523/ -18513- .

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