- Grind them into powder.

3. RESULTS AND ANALYSIS

3.1. Corrosion of FAAC to Mud Cake

The results of ESEM analysis carried out on samples A, B and C with different magnification are shown in Figs. (**2**), (**3**) and (**4**), respectively.

Fig. (**2**) shows that the structure of sample A is very loose and porous, and the cementation among the flaky clay particles in mud cake is poor. It could imply to obtain poor quality of well cementing, and lead to the isolation failure of CFI.

Fig. (**3**) shows that the surface of sample B is relatively smooth. But compared with sample A, the cementation among the flaky clay particles in mud cake is tighter. Besides, some gels and pores among the clay particles are formed. It is proved that the modification of FAAC on mud cake is obvious.

Fig. (**4**) shows that the corrosion spots and cracks are observed clearly. They distribute on the surface of mud cake and provide the channel for the diffusion of hydrated anion (OH^-) and alkali metal cations (Ca^{2+}, K^+, Mg^{2+}, Fe^{2+}, etc), into mud cake. Therefore, many gels are formed in the mud cake (*e.g.* MTA). Finally, the purpose of ISC at CFI could be achieved.

3.2. Diffusion of Hydrated Ions from Cement Slurry

The test results of alkali metal cation concentrations in inner and outer layers of agglomerated cake are listed in Table **2**.

Table **2** shows that the cation concentrations in inner layer of agglomerated cake are higher than those in the outer layer. The concentration difference provides power for the diffusion of hydrated ions from the cement slurry into mud cake.

3.3. Reaction Products of MCM with FAAC

The XRD spectrums of mud cake and agglomerated cake samples are shown in Fig. (**5**).

Fig. (**5a**) shows that the mud cake sample is mainly composed of quartz, calcite, illite, feldspar and montmorillonite. Fig. (**5b**) shows that the gel materials have formed at CFI, such as calcium silicate hydrates (CSH), ettringite, film zeolite, rod zeolite and natrolite. ISC at CFI is achieved by these gels.

4. SYNERGISM

4.1. Modification

FAAC is made of NaOH, Na_2SiO_3, Na_2SO_4, and H_2O, etc. The solution contains a lot of OH^-. It reacts with clay minerals in mud cake, and leads to corrosion of silicon and replacement of aluminum. Consequently, the interface be-

Fig. (3). ESEM micrographs of sample B: (**a**) 50 μm; (**b**) 20 μm.

Fig. (4). ESEM micrographs of sample C: (**a**) 50 μm; (**b**) 20 μm.

Table 2. Cation Concentrations in Inner and Outer Layer of Agglomerated Cake

Ion Species	Cation Concentrations in Inner Layer of Agglomerated Cake ($mg \cdot g^{-1}$)	Cation Concentrations in Outer Layer of Agglomerated Cake ($mg \cdot g^{-1}$)
K^+	10.749	9.492
Na^+	4.682	3.546
Ca^{2+}	84.948	70.338
Mg^{2+}	21.338	19.165
Fe^{2+}	7.323	7.263
Zn^{2+}	0.061	0.043
Al^{3+}	1.274	1.046

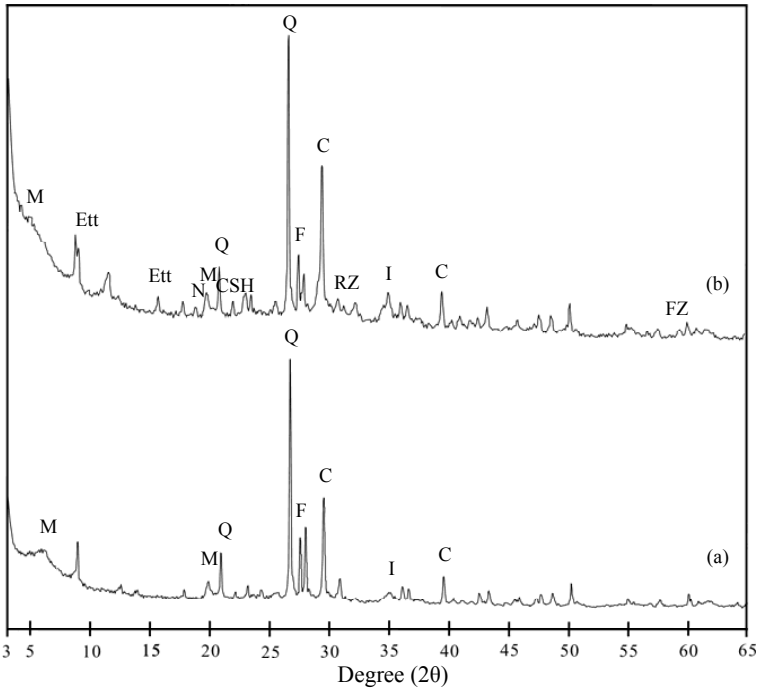

Fig. (5). XRD spectra for: (**a**) mud cake sample; (**b**) agglomerated cake sample. (Key: Q: Quartz; M: Montmorillonite; I: Illite; C: Calcite; F: Feldspar; RZ: Rod zeolite; FZ: Film zeolite; CSH: Calcium silicate hydrates; Ett: Ettringite; N: Natrolite.)

tween the cement paste and mud cake with MCM is modified. New ions such as $H_3SiO_4^-$ and AlO_2^- form during the process. The reaction equations are as follows:

$$H_2O + SiO_2 + NaOH \rightarrow NaH_3SiO_4$$

$$NaH_3SiO_4 \rightarrow Na^+ + H_3SiO_4^-$$

$$Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$$

$$NaAlO_2 \rightarrow Na^+ + AlO_2^-$$

4.2. Depolymerization

The main components of mud cake with MCM are bentonite and substances with pozzolantic activity. The bentonite is mainly composed of aluminate and silicate minerals, whose properties is up to the type and content of montmorillonite ($CaMg_2AlSi_4(OH)_2 \cdot H_2O$) in it. The substances with pozzolantic activity are mainly composed of calcium-rich phase and silicon-rich phase.

The hydration ions from the cement slurry are mainly Na^+, Ca^{2+}, OH^-, SiO_4^{4-}, AlO_2^- and SO_4^{2-}. OH^- can cause the bond breaking of Ca-O and Mg-O in the substances with pozzolantic activity. It accelerates the replacement of Ca^{2+} and Mg^{2+} with Na^+ in FCCA. The reaction equations in the calcium-rich phase are as follows:

$$\equiv Si{-}O{-}Ca{-}O{-}Si\equiv + NaOH \rightarrow 2(\equiv Si{-}ONa) + Ca(OH)_2$$

$$\equiv Si{-}O{-}Mg{-}O{-}Si\equiv + NaOH \rightarrow 2(\equiv Si{-}ONa) + Mg(OH)_2$$

The formation of $Ca(OH)_2$ during this reaction is similar to portlandite (a hydration product of class G oilwell cement). Then silicate minerals would be decomposed gradually in alkaline solution. The reaction equations are as follows:

$\equiv Si-O-Si\equiv + H\cdot OH \rightarrow 2(\equiv Si-OH)$

$\equiv Si-OH + NaOH \rightarrow \equiv Si-ONa + H\cdot OH$

In addition, the basic structural units of montmorillonite are silicon-oxygen tetrahedron ([SiO_4]), silicon-oxygen tetrahedron ([AlO_4]) and alumina octahedral ([AlO_6]). Under the effect of the cement slurry filtrate, the montmorillonite reacts with OH^- to form $H_3SiO_4^-$ and $H_3AlO_4^{2-}$. The reaction equations are as follows:

$H_2O + \equiv Si-O-Si\equiv + OH^- \rightarrow H_3SiO_4^-$

$H_2O + =Al-O-Al= + OH^- \rightarrow H_3AlO_4^{2-}$

The montmorillonite and substances with pozzolantic activity are depolymerized by OH^- from the hydration filtrate of cement slurry. The ions (OH^-, Ca^{2+}, K^+, Mg^{2+}, $H_3SiO_4^-$, $H_3AlO_4^{2-}$, etc) could diffuse into the mud cake through the corrosion spots and cracks.

4.3. Diagenesis

FAAC could lead to the bond breaking of Si-O and replacement of aluminum when it contacts mud cake with MCM. The formed soluble ions are mainly Ca^{2+}, Na^+, OH^-, SiO_4^{2-}, $H_3SiO_4^-$, AlO_2^- and SO_4^{2-}. The montmorillonite and substances with pozzolantic activity are depolymerized by OH^- from the hydration filtrate of cement slurry. The formed soluble ions are mainly Na^+, Ca^{2+}, OH^-, SO_4^{2-}, $H_3SiO_4^-$ and $H_3AlO_4^{2-}$.

Under the conditions of supersaturated solution and certain temperature, the synergism of MCM with FAAC results in the diagenesis at CFI. As a result, a great amount of gel materials are formed, such as zeolite hydration products and calcium silicate hydrates (CSH). These gels fill in CFI gradually. Consequently, ISC among cement paste, agglomerated cake and formation at CFI is achieved. The reaction equations of diagenesis are as follows:

$OH^- + SiO_4^{4-} + Ca^{2+} + H_2O \rightarrow Ca_{4.5}[Si_6O_{15}(OH)_3]\cdot 2H_2O$ (CSH)

$OH^- + AlO_2^- + SO_4^{2-} + Ca^{2+} + H_2O \rightarrow 3CaO\cdot Al_2O_3\cdot 3CaSO_4\cdot 32H_2O$ (Ett)

$OH^- + H_3AlO_4^{2-} + H_3SiO_4^- + Ca^{2+} + H_2O \rightarrow CaAl_2Si_7O_{18}\cdot 6H_2O$ (FZ)

$Na^+ + OH^- + H_3AlO_4^{2-} + H_3SiO_4^- + Ca^{2+} + H_2O \rightarrow NaCa_2Al_5Si_5O_{20}\cdot 6H_2O$ (RZ)

$Na^+ + OH^- + H_3AlO_4^{2-} + H_3SiO_4^- + H_2O \rightarrow Na_2Al_2Si_3O_{10}\cdot 2H_2O$ (N)

5. CONCLUSIONS

The mud cake with MCM can be modified by FAAC. A large amount of corrosion spots and cracks could be observed on the surface of mud cake. These corrosion spots and cracks provide channels for the diffusion of ions from the cement slurry, and accelerated the formation of gels. The concentrations of alkali metal cations (Na^+,Ca^{2+}, K^+, Mg^{2+}, Fe^{2+}, Zn^{2+}, Al^{3+}) in inner layer of agglomerated cake are higher than those in the outer layer. The concentration difference provides power for the diffusion of ions into mud cake.

The mud cake with MCM contained a mass of bentonite and substances with pozzolantic activity. They are depolymerized by OH^- from the hydration filtrate of cement slurry, and form the soluble ions (Na^+, Ca^{2+}, OH^-, SO_4^{2-}, $H_3SiO_4^-$ and $H_3AlO_4^{2-}$). These soluble ions react with the ions (Na^+, Ca^{2+}, OH^-, SiO_4^{4-}, AlO_2^-, SO_4^{2-} and $H_3SiO_4^-$) from FAAC and cement slurry filtrate, and forms gel materials (CSH, ettringite, film zeolite, rod zeolite and natrolite). These gels inserted among cement paste, agglomerated cake and formation, and ISC at CFI is achieved by these gels. Finally, the isolation quality of CFI is improved by the MTA method.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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