CHARACTERISTICS OF BACKWASH RECOVERY WATER FROM FILTER FOR OILFIELD PRODUCED WATER-SUSPENDED SOLIDS

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Abstract. The characteristics of suspended solids in backwash recovery water (BRW) from external scrubbing-walnut shell filter in the 'gravitational sedimentation and filtration' water treatment process (WTP) for produced water in an oilfield are analysed, then the influence of BRW on WTP efficiency is discussed. The results show that there are a lot of amorphous powder particle flocs or clusters with the diameter from several microns to several tens of microns in produce water, and the amorphous powder particle flocs or clusters are deformable and compressible, they are flocculated and compacted to form larger flocs or clusters under the force of hydraulic pressure in the filtration process while during the scrubbing process, some of these larger flocs or clusters are unable to be separated to small particles. So, in the process of 'filtration and backwashing' the small suspended solid particles are aggregated or even coalesced to form larger flocs, which can be removed through gravitational sedimentation, but there is still a considerable amount of small suspended solid particles recycled back to filter through recovery of backwashing water. Recycling rate for suspended solids is 38.5%, which causes a decreased removal rate from the filter. The removal rate from filtration for suspended solids is 59.1% apparently, and 36.4% actually. So, the treatment efficiency of WTP is lowered with unqualified outlet water. This work provides technical support for the operation of the oilfield filter and produced water treatment and provides strong help for the selection of the filter material and backwashing mode of oilfield produced water.

Keywords: produced water; filter; backwash; suspended solids.

Introduction

The content and particle size of suspended solids in oilfield reinjection water are important parameters of reinjection water, which determine the injectability of reinjection water and whether it causes pollution to oil reservoir. Produced water must be treated to reach reinjection standard through a variety of gravitational sedimentation, coagulation, air flotation, filtration, etc. [1], while filtration (such as sand filter, cartridge filter, multi-media filter, and membrane filter) is the most commonly used [1-3] for removal of suspended solids.

Operation of filter relies on the periodic backwashing process for renewal of filter media [4; 5]. The disadvantages of this process have attracted attention in recent years. De Souza et al reported that one of the disadvantages is the backwashing outlet water destination [6]. This problem is being more discussed in China because water flooding circulation is performed for oil production with an ultra-high water cut, and water treatment is one of the most fundamental problems faced within the oil industry. The backwashing water containing impurities is discharged as backwash recovery water (BRW), which is generally delivered to the backwash recovery water tank (BRWT) for settling, and then pumped back to inlet water of the water treatment process (IWWTP). It was proved that the separation properties under gravitational sedimentation of BRW are worse than that of IWWTP [7]. Introduction of BRW into IWWTP makes IWWTP water quality worse and affects water treatment, and in situ treatment of BRW has lower energy consumption and cost [8].

However, there is no further or deep investigation either on what causes the poor separation properties of BRW or on the impact of recycling BRW to the treatment efficiency of WTP. In our previous work [9], the quality difference of backwash recovery water (BRW) from three filters in an oilfield was carried out. It shows that the recycling rate of oil from filters in TL water treatment station (TL-WTS) is the highest (52%), because the filters in TL-WTS use the external scrubbing rather than in-tank backwashing and the water treated in TL-WTS is polymer containing produced water, while other filters give a relatively high and acceptable treatment efficiency for oil. In contrast with oil, in spite of different filter media, backwash model and water properties, filters give a recycling rate of about 40% for suspended solids. This work takes the example of TL-WTS to explain how the 40% comes from. It presents an investigation on evolution of suspended solids during water filtration and filter backwashing in oilfield produced water treatment, and the influence of recycling BRW on the treatment

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efficiency of WTP as well it provides fundamental data for the design of facilities with a high removal level of suspended solids.

Materials and methods

As in the previous work [9], TL-WTS from an oil field was selected for this research, and the WTP in TL-WTS is shown in Fig. 1. The temperature of treated produced water is 50 ºC. The processing capacity of WTP is about 20000 $m^3 \cdot d^{-1}$, and the outlet water of WTP should reach the reinjection standard of suspended solids content (SSC) less than 7 $mg \cdot L^{-1}$ and the median diameter of suspended solid particles (MDSSP) less than 3 μm. WTP is composed of 'two-stage gravitational sedimentation and filtration'. Gravitational sedimentation gives water a total settling time of 8.7 h with two 2000 m^3 tanks parallel for primary settling and two 2000 m^3 tanks parallel for secondary settling, and two 1000 m^3 tanks parallel for buffering. 35 $mg \cdot L^{-1}$ corrosion inhibitor and 35 $mg \cdot L^{-1}$ bactericide are respectively dosed to IWWTP before the primary settling tank. Eight external scrubbing-walnut shell filters are employed for the filtration process. When one filter is under backwashing, the other seven filters are performing filtration. Each single filter is backwashed with 62.5 m^3 outlet water of WTP twice a day. The backwashing water containing impurities is discharged as BRW. So, totally 1000 $m^3 \cdot d^{-1}$ BRW accounting for 5% of the total treatment water are continuously delivered to a 400 m^3 BRWT for 7 hs' settling, and then pumped back into IWWTP. Draining of each filter tank during backwashing lasts for about 1 h, during which water was sampled every 20 minutes, and the three water samples were mixed together and marked as inlet water of the backwash recovery water tank (IWBRWT ④), while the outlet water of the backwash recovery water tank (OWBRWT ⑤), IWWTP (①), the inlet water (②) and the outlet water (③) of one single filter were also taken as comparatives.

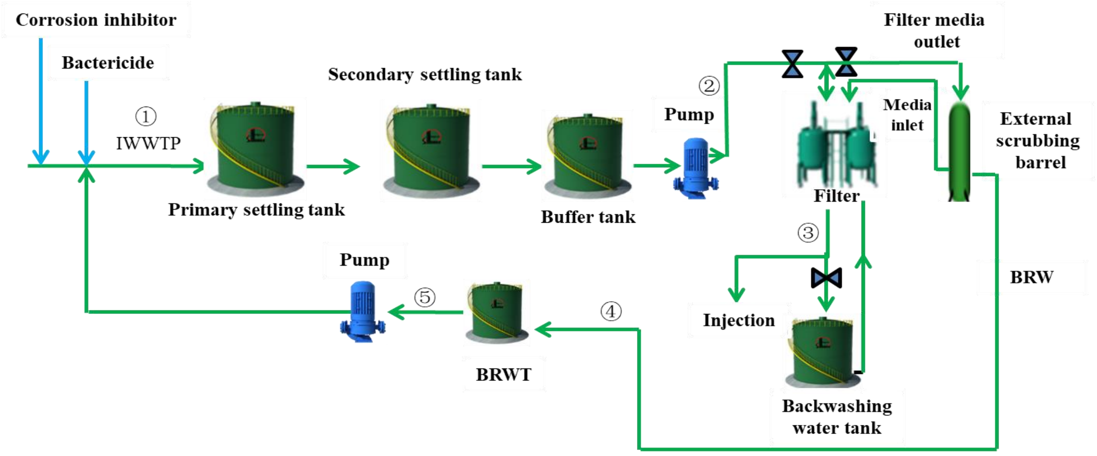

Fig. 1. **WTP in TL-WTS**

Evaluation of SSC and MDSSP

SSC was measured according to SY/T 5329-2012. Mastersizer 3000 from Malvern Company was employed to analyse the size of suspended solid particles and MDSSP (D50) was extracted from particle size distribution.

Stationary-state sedimentation

Water was kept in 7 measuring cylinders of 250 ml for stationary-state sedimentation at 50 ºC. 60 ml, 50 ml and 20 ml water was taken from the same position in the middle of the measuring cylinder with a pipette at 0, 4h, 8h, 12h, 24h, 32h, 48h respectively. SSC and MDSSP were analysed for each water sample.

Results and discussion

SSC of water from WTP

Table 1 shows the quality of water from WTP. SSC and MDSSP are decreased from IWWTP to outlet water of the filter, which is in line with the design principle of gravity settlement and filtration, but 9 $mg \cdot L^{-1}$ SSC of filter outlet cannot meet the reinjection standard of 7 $mg \cdot L^{-1}$ SSC, and treatment efficiency of WTP is lowered.

Table 1

Quality of water from WTP

Water sample	SSC/(mg·L^{-1})	MDSSP/µm
① IWWTP	45	8.2
② Inlet water of filter	22	5.3
③ Outlet water of filter	9	3.0
④ IWBRWT	180	21.5
⑤ OWBRWT	150	11

Residual suspended solids in BRW

From Table 1 it can be seen that through filtration the removal of suspended solids is 13 mg·L^{-1}. SSC in IWBRWT is much higher than the removed SSC, which is coincided with that the removed suspended solids retained on the filter media were collected by the backwashing water of 5% total treatment water. Also, the SSC in IWBRWT is much higher than that in IWWTP.

Fig. 2 shows during stationary-state sedimentation the change of SSC in IWWTP, IWBRWT and OWBRWT. After gravitational sedimentation most of the big suspended solid particles have been removed through gravitational sedimentation, and the SSC in OWBRWT is lower than in IWBRWT, and MDSSP from IWBRWT to OWBRWT is decreased as well, which can be seen in Fig. 3 and Table 1. Besides, three water samples showed a similar trend. In the first 8 hours, SSC is decreased significantly, and then the change is relatively small, which shows that after gravitational sedimentation for 8 hours, small suspended solid particles of about 8 µm which had to be removed under gravitational force [10] remained.

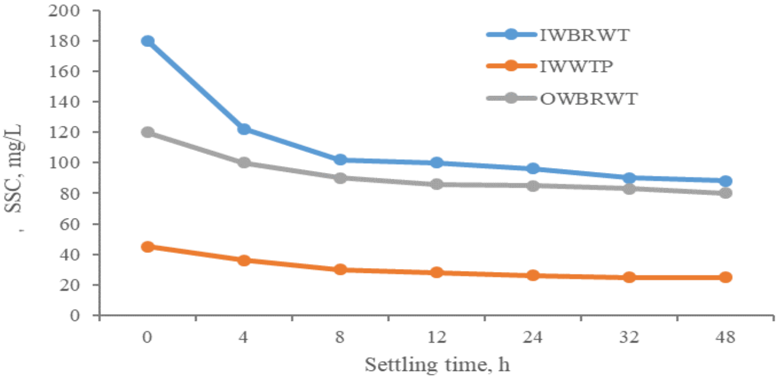

Fig. 2. **Change of SSC in IWWTP, IWBRWT and OWBRWT respectively during stationary-state sedimentation**

Fig. 3 also shows that MDSSP in IWBRWT is 21.5 µm, bigger than that in IWWTP which is 8.2 µm. The volume density and accumulative volume density of the suspended solid particles in IWWTP, IWBRWT and OWBRWT in Fig. 4 and Fig. 5 imply that the volume density of the suspended solid particles with the diameter bigger than 20 µm in IWBRWT occupies the highest of 50.46%, and the diameter of the biggest suspended solid particle is 127 µm, while the volume density of the suspended solid particles with the diameter bigger than 20 µm in IWWTP only occupies 2.66%. The volume density and the accumulative volume density of the suspended solid particles with the diameter of 1.5µm~20 µm in IWBRWT is lower than that of in IWWTP, while the volume density of the suspended solid particles with the diameter bigger than 20 µm in IWBRWT is higher than that in IWWTP. Therefore, compared with IWWTP, IWBRWT is characterized with small particles less and big particle more, and the biggest particle has a large diameter, which led to that MDSSP in IWBRWT is bigger than in IWWTP. IWBRWT containing small particles less is due to some small particles passed through the pore media of the filter during the filtration process, while there are many large particles in IWBRWT, and the size of the biggest particle is large as well, which can be explained with the flocculation of solid particles in the filtration process. Solids in produced water might be formation solids, corrosion and scale products, bacteria, waxes, and asphaltenes [11]. Obviously, suspended solid in produced water can be crystals easy to be detected with diffraction of x-rays (XRD) and amorphous powder hard to be characterized [11]. Here Transmission the Electron Microscope (TEM) was hired to watch the suspended solids. From the images of particles in IWWTP in Fig. 6, it can be seen there are a lot of amorphous powder particle flocs or clusters with the diameter from several microns to several tens of microns, in which a large number of particles of around 0.01 μm are embraced. Also, hexagonal crystal can be seen in Fig. 6 b. The amorphous powder particle flocs or clusters are deformable and compressible [12], and they are flocculated and compacted to form larger flocs or clusters under the force of hydraulic pressure in the filtration process while during the scrubbing process, some of these larger flocs or clusters are unable to be separated to small particles.

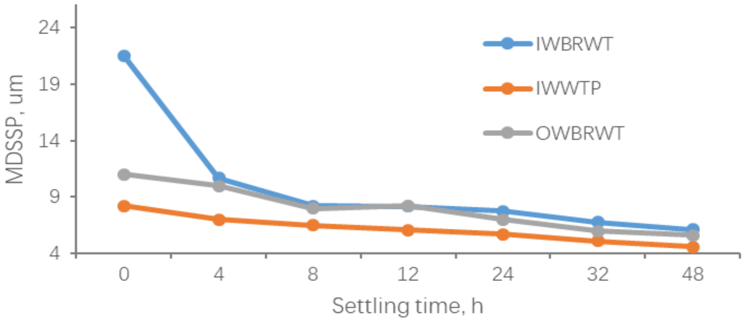

Fig. 3. **Change of MDSSP in IWWTP, IWBRWT and OWBRWT respectively during stationary-state sedimentation**

Fig. 4. **Volume density of the suspended solid particles in IWBRWT and OWBRWT**

Fig. 5. **Accumulative volume density of the suspended solid particles in IWBRWT and OWBRWT**

As MDSSP either in IWBRWT or in OWBRWT is bigger than that in IWWTP, generally it is easier for the suspended solids to settle under gravity, so as to achieve removal. However, it can be seen from Fig.2 that after a total 15.7 hs’ gravitational sedimentation the suspended solids mainly with the diameter of about 8 μm in BRW is at a high content level of 100 mg·L^{-1}. The suspended solids of 100 mg·L^{-1} are actually diluted by mixing BRW with IWWTP at a ratio of 1000 m^3: 20000 m^3 equivalent to 20 times of dilution, which means SSC increased by 5 $mg \cdot L^{-1}$ needs to be treated by the filter.

a) b)

Fig. 6. **TEM images of particles in IWWTP:**
a – magnified 40000 times; b – magnified 100000 times)

Effect of recycling suspended solids on treatment efficiency of WTP

Here several parameters can be defined to identify the removal efficiency from the filter. The apparent removal from the filter is the impurities content difference between the inlet water and outlet water of the filter. The actual removal is the apparent removal subtracted by the content of impurities recycled to the filter. The apparent removal rate or the actual removal rate from the filter is the apparent removal or the actual removal divided by impurities content in inlet water of the filter respectively. Recycling rate is the ratio of the content of impurities recycled to the filter to the apparent removal. In this case the parameters are shown in Table 2. The recycling rate for suspended solids is 38.5%. The filter has to repeatedly treat the impurities recycled so as to reduce the removal rate from the filter, and from the whole WTP as well. The apparent and actual removal rate for the suspended solids is 59.1% and 36.4% respectively. So, the treatment efficiency of WTP is lowered with unqualified outlet water of 9 $mg \cdot L^{-1}$ suspended solids.

Table 2

Parameters for suspended solid removal efficiency from the filter

Parameter	**Recovery of backwashing water**	**Treatment of backwashing recovery water**
Inlet water of the filter	22 $mg \cdot L^{-1}$	17 $mg \cdot L^{-1}$
Outlet water of the filter	9 $mg \cdot L^{-1}$	6.9 $mg \cdot L^{-1}$
Apparent removal	13 $mg \cdot L^{-1}$	10.1 $mg \cdot L^{-1}$
Recycled	5 $mg \cdot L^{-1}$	0
Actual removal	8 $mg \cdot L^{-1}$	10.1 $mg \cdot L^{-1}$
Apparent removal rate	59.1%	59.1%
Actual removal rate	36.4%	
Recycling rate	38.5%	0

Individual treatment of IWBRWT will improve the suspended solid removal efficiency as shown in Table 2. In this case, recycling of suspended solids during the filtration-backwashing process will disappear. The recycling suspended solid content is 5 $mg \cdot L^{-1}$, so the suspended solid content in inlet water of the filter is 17 $mg \cdot L^{-1}$ instead of 22 $mg \cdot L^{-1}$. The apparent removal rate for suspended solids by the filter is 59.1%, so the suspended solid content in outlet water of the filter is 6.9 $mg \cdot L^{-1}$, which is much closer to the reinjection standard.

Conclusions

In the filtration-backwashing process, a considerable amount of small suspended solid particles that cannot be removed through gravitational sedimentation are recycled back to the filter so as to reduce the removal rate. The recycling rate for suspended solids is 38.5%, and the apparent and actual removal rate for the suspended solids is 59.1% and 36.4% respectively. Recycling of backwashing water declines the treatment efficiency of WTP with unqualified outlet water. This work provides technical support for the operation of the oilfield filter and produced water treatment, and provides strong help for the selection of the filter material and backwashing mode of oilfield produced water.

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Author contributions:

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