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Optimum backwash method for granular media filtration of seawater

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ABSTRACT

In order to determine an effect backwash method in granular media filtration of seawater, effectiveness of three backwash methods was evaluated in this study. The first method (W) is water wash alone at fluidization velocity. The second method (AW) is air scouring followed by fluidized water wash. The third method (SAW) is simultaneous air scouring and sub-fluidized water wash. These methods were evaluated by four parameters; turbidity of backwash waste, mass of suspended solids in backwash waste, head loss development, initial turbidity breakthrough. According to this study results, simultaneous air scouring and sub-fluidized water wash (SAW) was the most effective backwash in seawater filtration and water wash alone (W) was the least effective. Subsequent analysis of computational fluid dynamics (CFD) confirmed the effectiveness of the SAW method. Calculation of shear rate and fluid velocity around the media showed that values of these parameters were the highest when a filter was backwashed by simultaneous air scouring and sub-fluidized water wash.

Keywords: Seawater filtration; Backwash; Air scouring; CFD

1. Introduction

The backwash by water wash alone is unable to clean a dirty filter sufficiently due to limited media contact [1], while air scouring can increase media contact during backwash [1]. Undesirable effect of air scouring is media loss. Air bubble can carry the filter media above wash trough. Subsequently, the water wash rate is usually reduced below fluidization velocity when air and water are provided simultaneously. Air scouring is known to be the most effective when used simultaneously with sub-fluidized backwash due to collapse pulsing effect [2,3]. Air alone or separate air scouring and water wash is less effective than simultaneous air scouring and water wash at sub-fluidization velocity [1].

Most studies concerning backwash has been conducted in fresh water, and no information is available about optimum backwash method for a granular media filtration of seawater. Subsequently, this study has an objective to find the optimum backwash method in seawater filtration. For this purpose, effectiveness of three different backwash methods were evaluated; water wash alone at fluidization velocity, air scouring followed by fluidized water wash, simultaneous air scouring and sub-fluidized water wash. Since backwash performance is affected by shear stress, computational fluid dynamics (CFD) technique is used to evaluate shear stress around the filter media during backwash.

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2. Materials and methods

2.1. Raw water and filter column

Experiments were conducted using seawater of Masan bay. Characteristics of raw seawater during the study period are summarized in Table 1. This seawater is more contaminated than typical seawater in Korea. Turbidity is high and particle number is large. The COD concentration is also relatively high. The chlorophyll-a concentration is low.

A filter column (0.05 m × 2 m) was used in this study. Dual media of sand and anthracite was installed in depth of 0.5 m, respectively. Effective sizes of sand and anthracite were 0.7 mm and 0.9 mm, respectively so that the ratio of depth to size becomes 1,270. The concept of the ratio of bed depth to media diameter L/d is supported by Ives and Sholji [4]. For ordinary find sand and dual media beds, the ratio is recommended to exceed 1,000 [5]. Their uniformity coefficients were less than 1.4. Ferric chloride was added at 4 mg/L before raw water was fed into a filter for in-line filtration. The dual media filter was operated at 5 m/h. A filtration cycle was 24 h and a filter was backwashed every day without chlorine.

2.2. Backwash method

Three columns were operated in parallel in order to compare the performance of three backwash methods, as shown in Fig. 1. The first method (W) is water wash alone at fluidization velocity. The second method (AW) is air scouring followed by fluidized water wash, at which air scouring and water wash was provided separately. The third method (SAW) is simultaneous air scouring and sub-fluidized water wash. At the W method, a filter was washed at 0.8 m/min for 5 min. The wash rate of 0.8 m/min was determined from preliminary experiments, which showed that 10% expansion occurred at 0.8 m/min. According to the Wen and Yu equation [6], the minimum fluidization velocity of the media used in this study at 20°C was calculated to be 0.71 m/min. When the backwash rate exceeded 0.8 m/min, media loss occurred. Consequently, the wash rate of 0.8 m/min was selected. At the AW method, backwash was initiated by air scouring, at which air was supplied at 0.5 m/min for five minutes. Then, air scouring was terminated and fluidized water wash followed at 0.8 m/min for five minutes. At the SAW method, after air scouring was provided at 0.5 m/min for two minutes, water wash joined air scouring so that simultaneous air scouring and water wash could occur. The water wash rate was held at 0.5 m/min so as not to cause fluidization. After three minutes, simultaneous air scouring and sub-fluidized water wash was terminated by stopping air supply. The water wash rate was then increased to 0.8 m/min and continued for five more minutes. Two different water wash rates were employed at the SAW method. The rate of 0.5 m/min was employed during simultaneous air scouring and sub-fluidized water wash in order to prevent media loss. During the final water wash, the rate was increased to 0.8 m/min.

Table 1
Characteristics of Masan bay seawater during the study period

Parameter	Concentration
Temperature, °C	16–22 (20)*
Conductivity, mS/cm	49.4–50.2 (49.8)
pH	7.7–7.9 (7.8)
Turbidity, NTU	1.87–6.76 (3.43)
Particle number (> 2μm), #/mL	4,902–6,908 (5,996)
COD, mg/L	2.4–6.8 (4.2)
UV-254, 1/m	0.69–2.30 (1.23)
Chlorophyll-a, mg/m^3	1.6–7.5 (5.2)

*Values in parentheses indicate average value

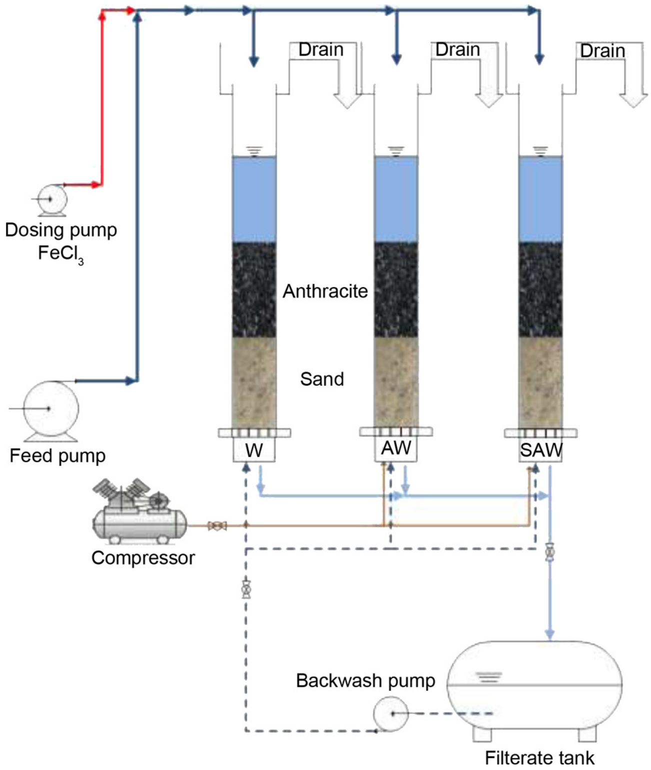

Fig. 1. Schematic diagram of experimental set-up (W: water wash alone at fluidization velocity; AW: air scouring followed by fluidized water wash; SAW: simultaneous air scouring and sub-fluidized water wash).

2.3. Evaluation of backwash

The backwash efficiency was evaluated by four parameters. The first parameter is turbidity of backwash waste, which is related to effectiveness of backwash performance. The more effective the backwash is, the more particles will be dislodged from the media. Consequently, turbidity of backwash waste will be high after effective backwash. Turbidity of backwash waste was measured every thirty seconds. A limitation of this parameter is that turbidity is affected by wash water volume. Turbidity decreases when wash water volume increases and vice versa. In order to eliminate an effect of wash water volume, mass of dislodged particles was measured, which is the second parameter. Suspended solids (SS) concentration of backwash waste was measured every thirty seconds like turbidity during initial five minutes of backwash. Mass of SS was then calculated by multiplying wash water volume by the SS concentration. The third parameter is head loss development. When a filter is backwashed effectively, no particles remain in the media and the head loss of a backwashed filter develops at the same rate as a clean filter. Similarly, backwash affects initial breakthrough. Ineffective backwash would result in severe initial turbidity breakthrough [7–10], while effective backwash would reduce initial turbidity.

2.4. Computational fluid dynamics technique

Since backwash effectiveness is influenced by hydrodynamics around the filter media, CFD technique was employed in this study. The velocity and shear stress of fluids were calculated using CFX version 11, which is developed by ANSYS (ANSYS, 2006). All simulations were conducted under the steady state conditions. The numerical simulations were conducted by splitting the geometry of interest into a large number of elements, collectively known as grid or cell. Then, the continuity [Eq. (1)] and momentum equation [Eq. (2)] were formulated for each grid under the given boundary conditions and iteratively solved by using the finite volume method. The time-averaged Navier-Stokes equations for the continuity and the momentum were solved for steady, incompressible, turbulent and isothermal flow.

$$\nabla \cdot (U) = 0 \tag{1}$$

$$\nabla \cdot (\rho U \otimes U - \mu \nabla U) = B + \nabla P - \nabla \cdot (\rho u \times u) \tag{2}$$

In the above equations, ρ and μ are the fluid density and dynamic viscosity, P the pressure, U the fluid mean velocity, B a body force and u the fluctuating velocity. A turbulence modeling method was also employed in order to investigate the eddy flow and the energy dissipation in detail. The standard k–ε model was used for modeling the turbulence transport of momentum. In addition, the wall shear stress was obtained from the logarithmic law of wall [11].

It was assumed that column with diameter of 100 mm and height of 100 mm was filled initially with water and the spherical filter media. The number of media with 10 mm diameter aligned to three layers is 15. The space among media is 5 mm. The cylinder is constructed with 230,231 nodes and 1,274,162 elements. To simulate air scouring and water wash, 172 holes of 4 mm in diameter were generated at the column bottom. The size of air bubble is assumed to be 1 mm in diameter. As boundary conditions, the outflow and wall conditions are imposed to the upper part and side of column, respectively.

3. Results and discussion

3.1. Comparison of three backwash methods

Effectiveness of three backwash methods is compared in Figs. 2–5. According to these figures, better performance was obtained when backwash was augmented by air scouring. Air supply method was important for backwash performance. When air scouring and water wash at sub-fluidization velocity was provided simultaneously, the best backwash performance was obtained. According to Fig. 2, the average turbidity of backwash waste was initially about 400 NTU when a filter was washed by water alone at fluidization velocity (W), while that was around 900 NTU when air scouring was followed by fluidized water wash (AW). Highest turbidity (1,000 NTU) was obtained when simultaneous air scouring and sub-fluidized water wash (SAW) was provided. It took five minutes for turbidity of backwash waste to stabilize at approximately 10 NTU. During five minutes, turbidity of backwash waste resulting from the method SAW was consistently higher than that from the method AW. This result indicates that simultaneous air scouring and sub-fluidized water wash is more effective than air scouring followed by fluidized water wash for cleaning in granular media filtration of seawater.

Effectiveness of backwash with air scouring was also confirmed by the mass of SS in backwash waste. Total mass of SS in backwash wastes resulting from three mehods is compared in Fig. 3. According to Fig. 3, total mass of SS from the method W was in the range of 300–1,400 mg (average of 650 mg), that from the method AW was 600–1,650 mg (average of 800 mg), and that from the method SAW was 800–2,750 mg (average of 1,400 mg). Based on average value, total mass of SS from the method SAW was higher than that from the method W by more than twice. This result confirms that simultaneous air scouring and sub-fluidized water wash is the most effective backwash.

Fig. 4 shows head loss development of three filter columns after backwash. According to Fig. 4, initial head of a filter column backwashed by wash water alone at fluidization velocity (W) was the highest and that by the method SAW was the lowest. Initial head of a filter is related to effectiveness of backwash. Effective backwash will reduce initial head. Since simultaneous air scouring and sub-fluidized water wash effectively dislodged particles captured during filtration, initial head of a filter colum backwashed by the method SAW remained low.

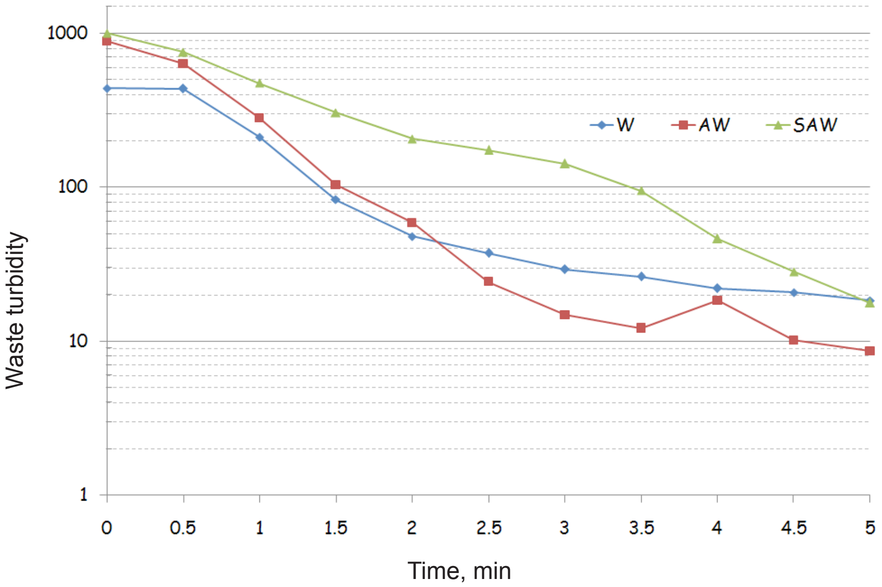

Fig. 2. Comparison of waste turbidity by three backwash methods.

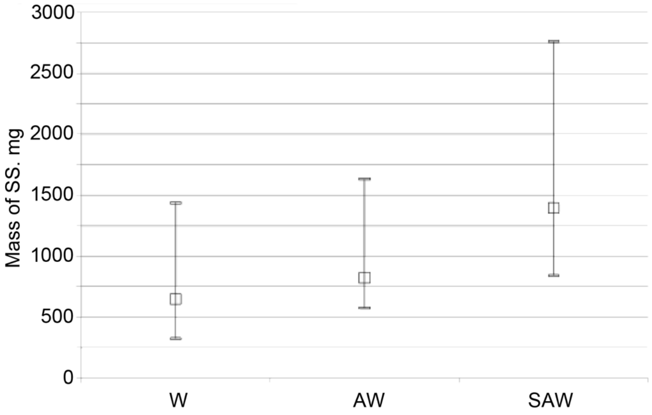

Fig. 3. Comparison of total suspended solids mass by three backwash methods.

This result confirms that the SAW is the most effective backwash method and the method W is not effective. Although initial head was different, head loss development of all columns were similar. This result indicates that effectiveness of backwash affects initial head of a filter rather than head loss development during filtration.

Fig. 5 shows variation of filtrate turbidity of three columns receving different backwash methods during initial filtration period of 120 min. For the filtrate turbidity immediately after backwash, the highest value was recorded for a column receiving the backwash method W, while the lowest for a column receiving the backwash method SAW. Initial turbidity breakthrough occurs due to backwash remnants in the filter media and above the media [9]. Effective backwash will reduce the amount of backwash remnants, while ineffective backwash will increase the backwash remnants. Subsequently, initial filtrate turbidity will be low ater an effective backwash. Low initial turbidity after the method SAW in Fig. 5 indicates that little remnants remained after backwash of simultaneous air scouring and sub-fluidized water wash. This result also confirms the effectiveness of backwash method SAW.

3.2. *CFD analysis*

The CFD analysis was conducted in order to find the rationale why simultaneous air scouring and sub-fluidized water wash was effective in dislodging particles captured in the filter media. Shear rate around the media is related to backwash efficiency. Shear rate will be high for effective backwash, while it will be low for ineffective backwash. Therefore, velocity and shear rate around the media was examined using the CFD technique. Fig. 6 shows the shear rate around the media for each backwash method.

Fig. 6 clearly shows that shear rate is different depending on the backwash method. For the method W, shear rate is relatively weak, which suggests that backwash of water wash alone at fluidization velocity will be ineffective for cleaning. Shear rate at the method SAW was greater than that at the method AW. This result suggests that the backwash performance of SAW will be better than that of AW. Although data are not shown here, higher velocity was obtained for backwash with air scouring than for backwash without air scouring. High velocity led to high shear rate, resulting in effective backwash.

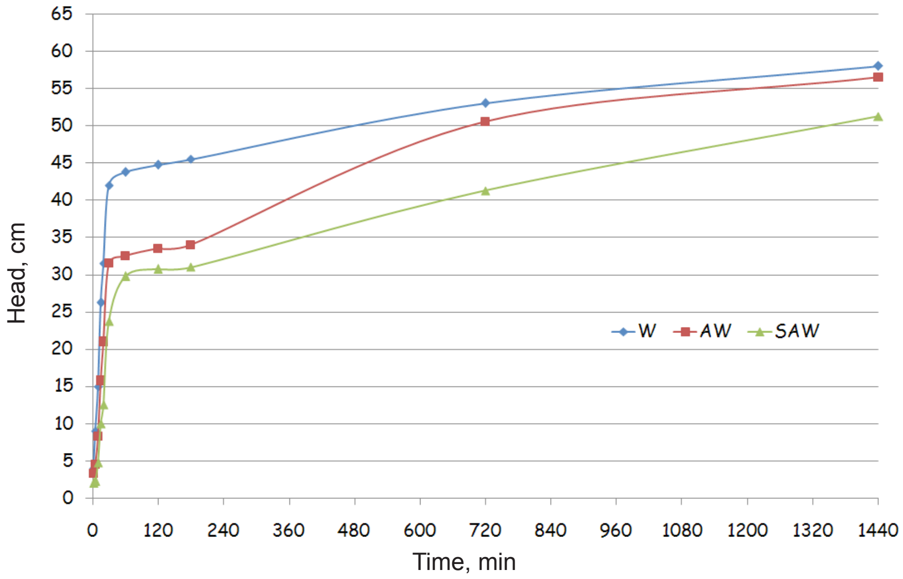

Fig. 4. Comparison of head loss development by three backwash methods.

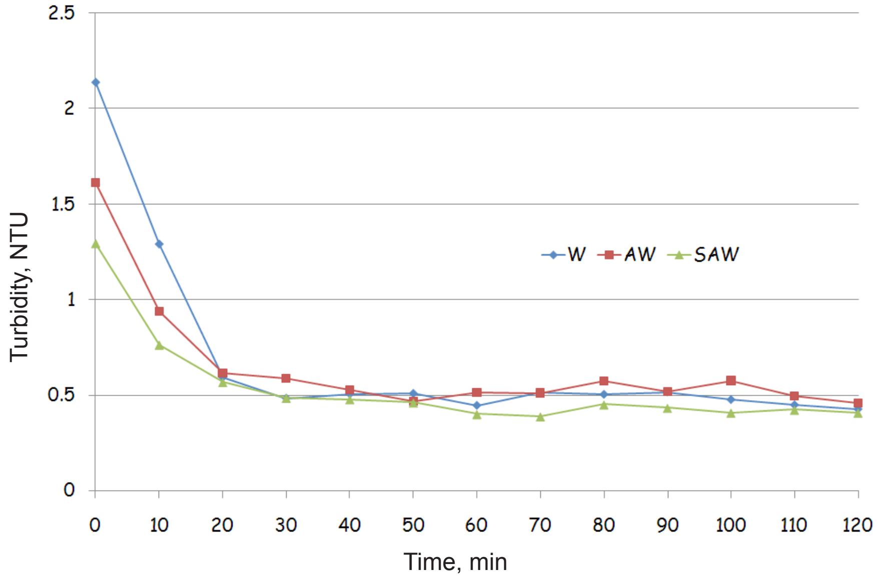

Fig. 5. Comparison of initial turbidity breakthrough by three backwash methods.

4. Conclusions

It is attempted to find the optimum backwash method in granular media filtration of seawater in this study. Three backwash methods were employed for this purpose. The first method is water wash alone at fluidization velocity. The second method is air scouring followed by fluidized water wash. The third method is simultaneous air scouring and sub-fluidized water wash. These methods were evaluated by four parameters; turbidity of backwash waste, mass of suspended solids in backwash waste, head loss development, initial turbidity breakthrough. According to this study results, simultaneous air scouring and sub-fluidized water wash was the most effective backwash, while water wash alone at fluidization velocity was the least effective. This result is in line with other study results conducted in fresh water. Subsequent CFD analysis showed that shear rate around the media was the highest when a filter was backwashed by simultaneous air scouring and sub-fluidized water wash, while it was the lowest when a filter was backwashed by wash water alone at fluidization velocity. Advantage of air scouring was reduced when air scouring was not provided simultaneously with water wash.

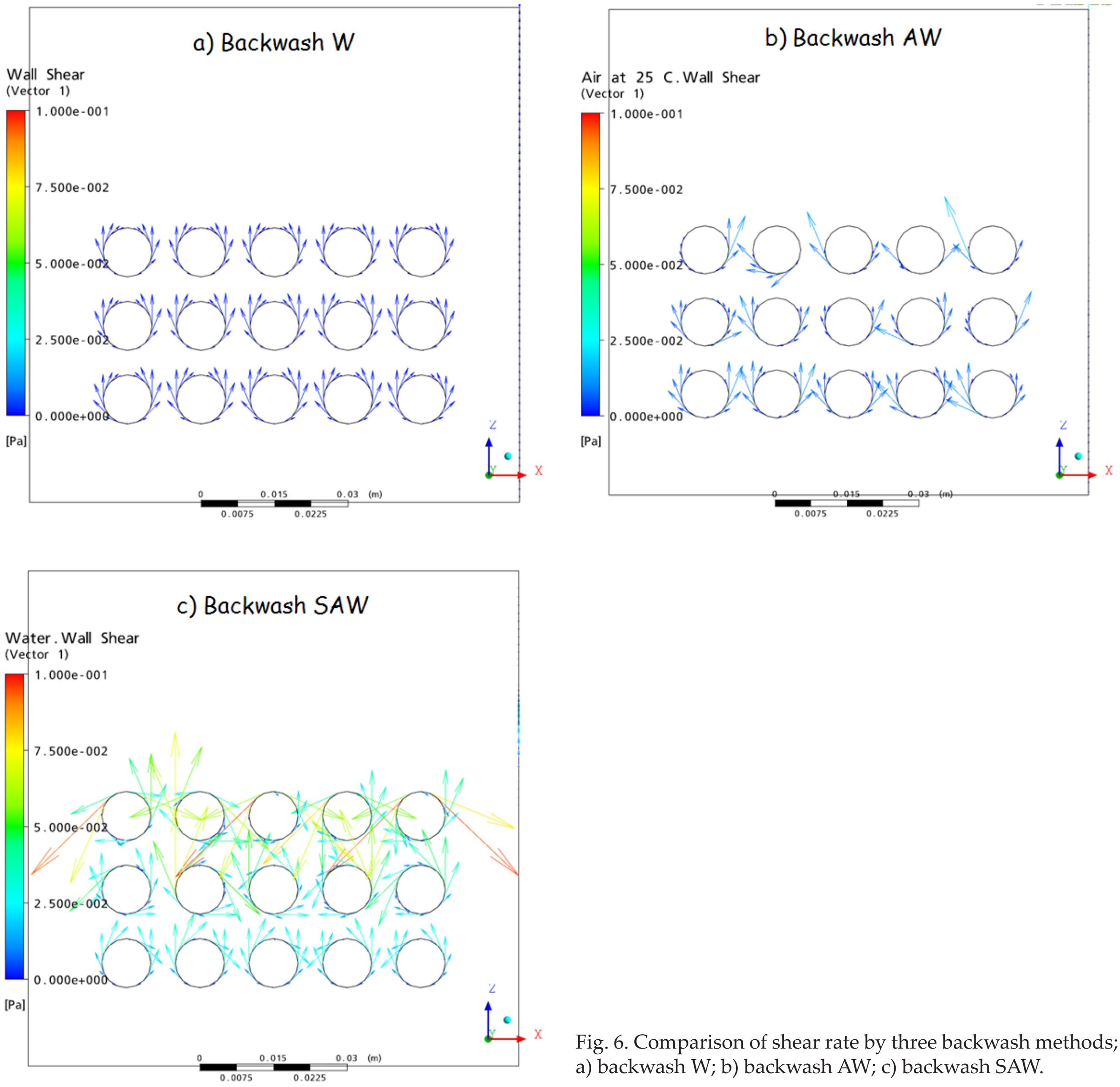

Fig. 6. Comparison of shear rate by three backwash methods; a) backwash W; b) backwash AW; c) backwash SAW.

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