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ORIGINAL ARTICLE

High-pressure Air Impulse Technique for Rehabilitating Well and Its Application to a Riverbank Filtration Site in Korea

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Abstract

Rehabilitation work is required to increase well productivity, which decreases with the elapsed time of pumping owing to the clogging of the water well. Clogging causes not only a reduction in the well productivity but also a deterioration of the water quality. For unclogging and rehabilitating wells, several techniques are used such as brushing, air surging, surge blocks, and gas impulse. In this study, the high-pressure air impulse technique, which effectively and economically rehabilitates wells, was applied to a riverbank filtration site in Korea for the same objective. At most of the wells, the hydraulic parameters (transmissivity, storage coefficient, and specific capacity) were increased by the application of the high-pressure air impulse technique. The well loss change values also indicate an increase in the hydraulic parameters by the air impulse implementation. Thus, the high-pressure air impulse technique can be efficiently and economically applied to water and riverbank filtration wells for rehabilitating the decreased productivity.

Key words : Riverbank filtration, Air impulse technique, Rehabilitation, Well clogging, Nakdong river

1. Introduction

Riverbank filtration is an indirect intake method for obtaining cost-effectively high-quality groundwater by natural filtration through the river-bed alluvial deposits in the vicinity of rivers and lakes, compared to conventional municipal purification systems. Riverside filtration has been revealed to remove disinfection byproducts and protozoan pathogens like Cryptosporidium and Giardia (Weiss et al., 2005). In addition, the effects of riverbank filtration are natural removal of suspended particles, organic matters including decomposing biodegradable organic matter, and pathogenic microorganisms. Thus, riverbank filtration is a good measure of securing water quantity and quality irrespective of floods or dry seasons as well as in the scenario of surface-water pollution accidents, while reducing the cost of water purification. However, despite the various advantages of the riverbank filtration, during the intake of riverbank filtered water, there is worsening of the water quantity and quality owing to the precipitation of inorganic matters like iron (Fe) and manganese (Mn) on the intake pump, screen, and intake pipe. Other reasons are

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the turbidity increase of the raw surface water and clogging phenomena occurring around the pumping well by physical and biological actions.

Several techniques like brushing, air surging, surge blocks, and impulse are applied for the rehabilitation of wells. Brushing removes the clogged materials by the up-and-down movement of rod pistons inside the wells, and it discharges the materials by an air lift or bailing. Brushing is particularly effective for eliminating surface biofouling in wells. Air surging can be of three types (surging with surge block, compressed air surging, and surge pumping and backwashing) and is widely used for effective chemical treatment in wells. A surge block is a simple, inexpensive, and generally well-known approach for the rehabilitation of wells. For a surge block, a packer disk is loosely installed inside a well and is moved up and down. The downward movement of the packer disk discharges the water inside the well, whereas the upward movement of the packer disk sucks the water around the well and releases the loosely filled materials inside the pores.

The clogging of riverbank filtration wells causes a reduction in the well productivity as well as a deterioration of the water quality and then causes economic losses by shortening the lifetime of the production well (Houben and Treskatis, 2007). Clogging is mainly classified into two categories: physical clogging (McDowell-boyer et al., 1986) and chemical and biological clogging (van Beek et al., 2009). Numerous studies have been conducted on physical clogging, including the formation process of the clogging materials inside a well (McDowell-Boyer et al., 1986; van Beek et al., 2009), deposition of the drilling mud inside and around a well, and clogging due to the groundwater movement through aquifer particles and filter packs (Hurst et al., 1969; Saucier, 1974; Muckenthaler, 1989; Howsam and Hollamby, 1990; Timmer et al., 2003). Prins(2003) revealed a significant relationship between the physical clogging of moving particles and groundwater flow rate.

Screen clogging by chemical and biological reactions produces slimes of iron oxide and manganese oxide (Smith, 1995). The causes and types of chemical corrosion can vary depending on the vertical depth and chemical environment in the well (Driscoll, 1989; McLaughlan et al., 1993; Appelo and Postma, 1996). Maogong(1988) applied the forced oxygen injection method for removing iron from an aquifer. These results of mineralogical and geochemical corrosion/clogging provide crucial information for determining the rehabilitation and aging degree of a well (Walter, 1997; Houben et al., 1999; Mettler et al., 2001; Houben, 2003). Choo et al.(2012) characterized clogging materials as amorphous iron hydroxides (goethite, ferrihydrite, and lapidocrocite), with less amounts of Fe, Mn, Zn metals, and silicates (quartz, feldspar, micas, and smectite), based on the wells located in a mountain in Korea.

Since the 1900s, unclogging techniques for eliminating the clogged materials around the wall of a production well have been studied in many countries like EU and USA; however, in Korea, the research on the clogging occurring around the wells of riverbank filtration has a relatively short history. Timmer et al. (2003) published a study on the mechanism of well clogging in Australia. Houben and Treskatis(2007) studied the formation of clogged materials by physical, chemical, and biological reactions inside groundwater and riverbank filtration wells as well as the removal techniques of the clogged materials. The German Technical and Scientific Association for Gas and Water (DVGW, 2019, https://www.dvgw.de/) reported that from a total of 12,000 wells in Germany, 3,080 wells have been rehabilitated because of a reduced discharge rate and well clogging. This figure indicates that approximately 5% of the wells are required to be rehabilitated every year. In Korea, a few methods like brushing, air surging, and surge blocks have been used for the unclogging of groundwater and riverbank filtration wells (Lee at el., 2011). Lee et al.(2012) applied the method of oxygen water injection to a riverbank filtration site for reducing iron and manganese. Kim et al.(2009) reported well improvement by manganese reduction using air surging and a surge block at a riverbank filtration site. In the 1990s, in Korea, a feasibility study of riverbank filtration was conducted in major river basins, including the Han river and Nakdong river basins. Based on the result, in the downstream of the Nakdong river, riverbank intake facilities in Changwon city, Haman county, and Kimhae city have been built and operated.

This study aims to apply a high-pressure air impulse technique for rehabilitating a riverbank filtration well and to demonstrate its application to the riverbank filtration site in Daesan-Myeon, Changwon city, Korea. The latter is achieved by comparing the changes in the groundwater quantity and hydraulic characteristics before and after the execution of the air impulse technique on the vertical wells of the riverbank filtration.

2. Methods

The impulse technique uses a high-pressure shock from a compressed gas or fluid, which disassembles and removes incrusted particles on a casing, screen, and filter pack. The high pressure (approximately 10-300 bar) of the compressed gas instantaneously generates a vibration pulse and maximizes the inflow to the well from the surrounding aquifers by removing the physical, chemical, and biological clogging materials. The pulse effects include (1) the separation and abrasion of the particles due to the elasticity of the casing, screen, filter pack, and sediments, (2) resonance oscillation, and (3) the thixotropy of the deposits (Houben and Treskatis, 2007). In Europe in the 1950s, the impulse technique was applied to the cleaning of wells for seismic exploration or oil production, and it is currently widely used in the US, Germany, Israel, and other countries for removing clogged materials and enhancing the abstraction of water wells. The well habilitation technique by a high-pressure impulse utilizes the pulse generated by the compressibility of water. An ultrasonic wave produces a long-duration pulse with a frequency of approximately 20,000-25,000 Hz, which is much higher than the frequency of approximately 20-40 Hz with a shorter-duration pulse by the explosion method (Houben and Treskatis, 2007).

The high-pressure air impulse technique is used for effectively and economically rehabilitating clogged wells. Similar to the well cleaning technique using explosives, the air impulse generator generates a shock wave by instantaneously discharging compressed air of 100 bar in a container of 300 cc volume, while controlling the pressure of the shock wave. This method has an advantage of generating a shock wave continuously. Fig. 1 shows the components of the air impulse generator. Physical unclogging technologies such as brush or air surging can only remove the clogged materials on the inner wall of water wells but cannot eliminate those in the filter pack outside the well. By contrast, the high-pressure impulse technique removes the clogged materials inside pores by a shock wave that reaches 3-7 m from the well (Fig. 2).

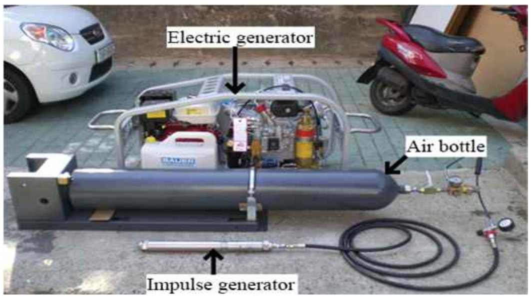

Fig. 1. Air impulse generator components.

Among the 43 vertical wells (DS1-1 to DS1-7, DS6-1 to DS6-36) in the study area, the high-pressure air impulse technique was applied to 36 wells for rehabilitating and increasing the productivity by removing the clogged materials (Table 1). The high-pressure generator was operated by moving an automatic reel 2-3 times up and down along the screen section of the object well, while applying an impulse once every 3-5 seconds at 20-cm intervals at a pressure of 150-200 bars.

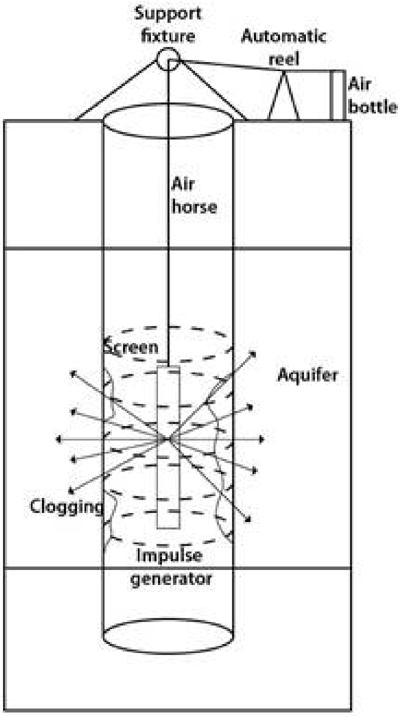

Fig. 2. Installation of air impulse generator.

To verify the efficiency of the high-pressure air impulse technique, pumping tests were performed before and after the air impulse technique was applied to the 33 wells. The hydraulic parameters (transmissivity, storage coefficient) were estimated by the Hantush (1960) leaky confined aquifer model. Subsequently, the transmissivity (*T*), storage coefficient (*S*), specific capacity (*Q*/*s*), and well loss values were compared for the cases of before and after the execution of the air impulse technique (Table 1). Drawdown s [L] for an unsteady flow in a homogeneous, isotropic leaky confined aquifer assuming upper aquitard storage is as follows (Hantush, 1960):

$$s = \frac{Q}{4\pi T} H(u,\beta) \tag{1}$$

where Q and T are the pumping rate [L^3/T] and transmissivity [L^2/T], respectively.

$$H(u,\beta) = \int_{\beta}^{\infty} \frac{e^{-y}}{y} erfc\left\{ \frac{\beta u^2}{y(y-u)^{1/2}} \right\} dy \tag{2}$$

where $u = \frac{r^2 S}{4Tt}$, $\beta = \frac{r\lambda}{4}$ and $\lambda = \left[\left(\frac{K'}{Tb'} \right) \left(\frac{S'}{S} \right) \right]^{1/2}$

with *r* the radial distance from the pumping well to the observation well [L], *S* [dimensionless] the storativity, *t* [T] the elapsed time since the start of pumping, b' [L] the thickness of the upper aquitard, K' [L/T] the vertical hydraulic conductivity of the upper aquitard, and S' [dimensionless] the storativity of the upper aquitard.

3. Study area

In the study area, 43 vertical wells (DS1-1 to DS1-7, DS6-1 to DS6-36) are located and are arranged along the Nakdong river, which flows from the west to the east, showing a meandering (Fig. 3). From the north and south, small tributaries flow into the Nakdong river in a trellis drainage pattern. According to the drilling data, alluvial deposits are divided into four layers: ground surface-sand layer, silty/clayey sand layer, sand gravel layer, and weathered zone. The variability of the thicknesses of the layers depend on the location, owing to the change in the sedimentation caused by the change in the stream velocity and discharge as well as because of spatially different sedimentary phases. The silt, clay, or silty sand layers are intercalated between the sand layers. According to the borehole (BH-1 to BH-7) data, the average

Table 1. Result of hydraulic parameters change before and after air impulse implementation

Well no.	Before			Well no.	After		
	T (m^2/s)	S	Q/s (m^2/d)		T (m^2/s)	S	Q/s (m^2/d)
DS6-2	2.44E-03	0.3457	738.6	DS6-2	2.45E-03	0.2994	750.9
DS6-3	2.73E-03	0.3200	860.5	DS6-3	3.00E-03	0.2953	907.9
DS6-6	-	-	-	DS6-6	9.81E-04	0.4247	380.1
DS6-7	1.43E-03	0.6804	471.6	DS6-7	1.71E-03	0.3615	526.6
DS6-8	8.10E-04	0.4354	358.8	DS6-8	9.06E-04	0.3030	399.2
DS6-10	6.34E-04	0.3889	266.6	DS6-10	9.42E-04	0.3774	381.7
DS6-11	4.81E-04	0.3548	259.3	DS6-11	8.50E-04	0.5059	424.9
DS6-12	2.58E-04	0.2416	122.6	DS6-12	9.75E-04	0.5079	467.9
DS6-14	6.02E-04	0.3466	237.0	DS6-14	7.98E-04	0.3136	303.4
DS6-15	5.83E-04	0.3370	239.5	DS6-15	7.31E-04	0.3356	290.9
DS6-16	5.63E-04	0.4102	244.2	DS6-16	7.17E-04	0.4093	306.7
DS6-17	2.19E-04	0.3723	150.2	DS6-17	2.37E-04	0.3606	157.6
DS6-18	2.09E-04	0.2676	111.1	DS6-18	2.37E-04	0.2513	161.0
DS6-19	8.28E-04	0.3321	360.7	DS6-19	9.04E-04	0.3194	372.6
DS6-20	1.16E-03	0.4428	488.5	DS6-20	1.40E-03	0.4002	533.6
DS6-22	5.70E-04	0.3497	267.3	DS6-22	6.07E-04	0.3382	286.5
DS6-23	7.20E-04	0.3554	355.0	DS6-23	1.10E-03	0.3220	416.5
DS6-24	-	-	-	DS6-24	1.02E-03	0.7024	347.7
DS6-25	1.04E-03	0.4288	410.8	DS6-25	1.11E-03	0.4130	448.2
DS6-26	4.74E-05	0.0563	49.2	DS6-26	6.13E-04	0.3668	283.4
DS6-27	3.52E-05	0.0304	24.5	DS6-27	1.11E-03	0.3381	343.6
DS6-28	6.73E-04	0.3918	270.7	DS6-28	9.46E-04	0.3343	360.0
DS6-29	3.63E-05	0.0416	32.3	DS6-29	1.18E-03	0.4707	490.2
DS6-30	5.77E-06	0.0057	4.3	DS6-30	1.00E-03	0.4196	394.7
DS6-31	-	-	-	DS6-31	1.02E-03	0.4369	393.2
DS6-32	3.60E-05	0.0551	30.0	DS6-32	1.67E-04	0.2069	116.6
DS6-33	4.77E-05	0.0657	44.0	DS6-33	2.57E-04	0.1937	148.7
DS6-34	4.60E-05	0.0747	42.3	DS6-34	6.83E-04	0.4343	260.7
DS6-35	1.40E-04	0.1236	88.5	DS6-35	4.85E-04	0.3082	216.3
DS6-36	4.21E-05	0.0484	33.6	DS6-36	5.26E-04	0.3695	233.1
DS1-2	1.30E-04	0.2512	74.8	DS1-2	1.41E-04	0.2418	90.8
DS1-3	3.38E-04	0.4286	201.1	DS1-3	4.53E-04	0.4146	266.0
DS1-4	3.43E-04	0.3841	195.4	DS1-4	5.84E-04	0.1362	336.0
DS1-5	3.04E-04	0.3317	190.3	DS1-5	4.01E-04	0.4281	238.3
DS1-6	8.59E-05	0.2529	77.7	DS1-6	2.23E-04	0.4224	153.5
DS1-7	3.03E-04	0.4083	179.3	DS1-7	4.36E-04	0.3812	260.4
Max	2.73E-03	0.6804	860.5	Max	3.00E-03	0.7024	907.9
Min	5.77E-06	0.0057	4.3	Min	1.41E-04	0.1362	90.8
Mean	5.42E-04	0.2836	226.5	Mean	8.59E-04	0.3651	345.8
Median	3.38E-04	0.3370	195.4	Median	8.24E-04	0.3642	339.8
Std. dev.	6.40E-04	0.1612	200.6	Std. dev.	5.90E-04	0.1012	165.2
Kurtosis	5.13E+00	-0.2493	2.6	Kurtosis	5.00E+00	2.7779	3.2
Skewness	2.16E+00	-0.2075	1.5	Skewness	1.88E+00	0.6230	1.3

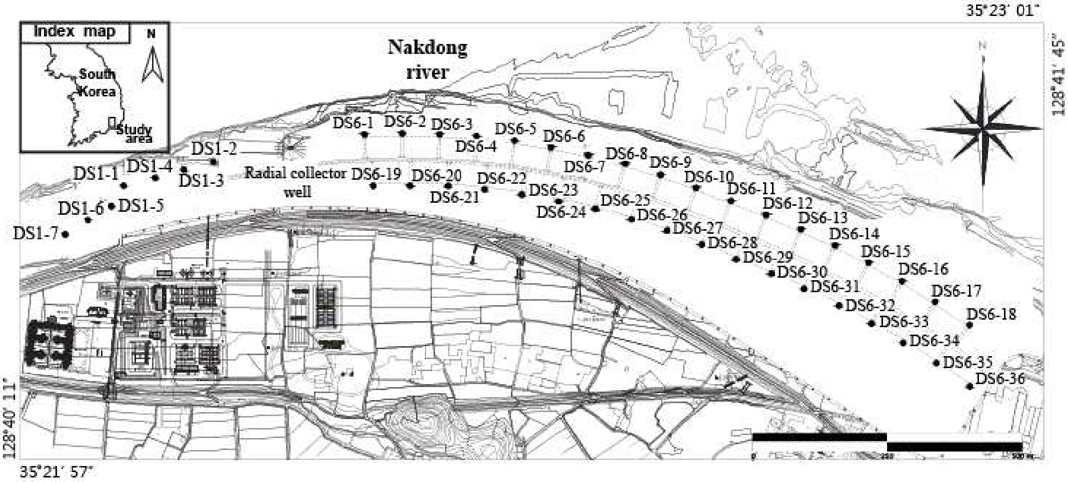

Fig. 3. Location of the wells at the riverbank filtration site in Daesan-myeon area.

thicknesses of the sand gravel layer (the main aquifer) is ~13.4 m.

The vertical and horizontal heterogeneities of these alluvial deposits also affect the groundwater flow characteristics of the riverside filtration sites. Because the inflow of the groundwater from the Nakdong river to the riverside filtration sites mostly occurs through the sand gravel aquifer, the main aquifer, the time to reach the intake well is actually related to the time for passing through the sand gravel layer (Table 1).

4. Results

4.1. Changes in the hydraulic parameters by the air impulse technique

On the air impulse implementation, the *T* values increased at all the 33 wells (Fig. 4). The *T* values before cleaning the water wells by implementing the air impulse technique ranged from 5.77×10^{-6} to 2.73×10^{-3} m^2/s, with a median value of 3.38×10^{-4} m^2/s and an arithmetic mean of 5.42×10^{-4} m^2/s. By contrast, the *T* values after cleaning the water wells increased from 1.41×10^{-4} to 3.00×10^{-3} m^2/s, with a median value of 8.24×10^{-4} m^2/s and an arithmetic mean of 8.59×10^{-4} m^2/s (Table 1).

After the air impulse implementation, the *S* values increased at 14 wells from the 34 wells, which account for 41.2% of the wells, indicating that the air impulse rehabilitation influenced the permeability more significantly than the storage of the wells (Fig. 5). Before cleaning the water wells, the *S* values ranged from 0.0057 to 0.6804, with a median of 0.3370 and an arithmetic mean of 0.2836. In comparison, after cleaning the water wells, the *S* values increased in the range from 0.1362 to 0.7024, with a median of 0.3642 and an arithmetic mean of 0.3651 (Table 1).

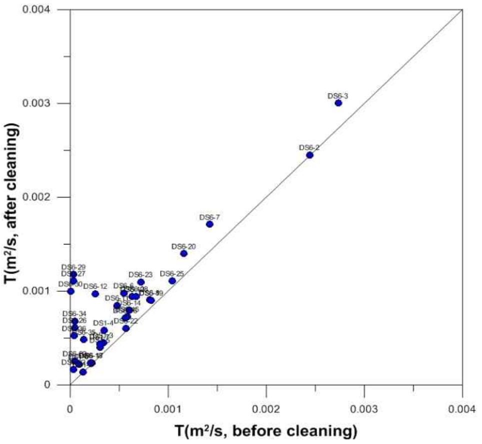

Fig. 4. Transmissivity (*T*) values after and before the execution of the air impulse implementation.

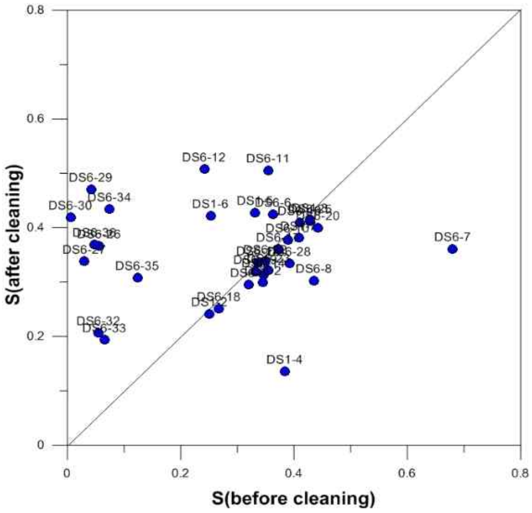

Fig. 5. Storage coefficient (S) values after and before the execution of the air impulse implementation.

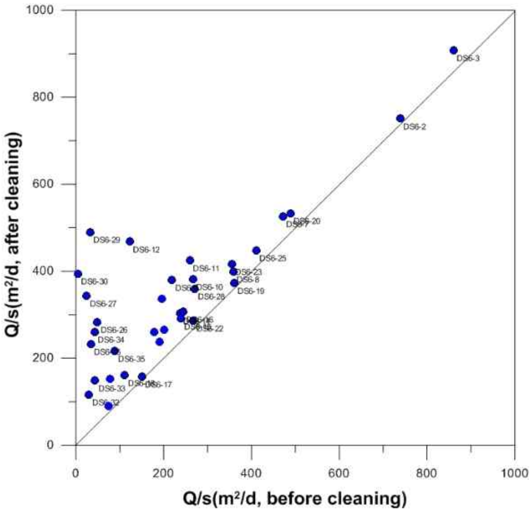

Fig. 6. Specific storage (Q/s) values after and before the execution of the air impulse implementation.

The specific capacity (Q/s) values that represent the ratio of the discharge to the drawdown, increased at all the 34 wells by the air impulse implementation, similar to the case of the T values (Fig. 6). Before cleaning the water wells, Q/s values ranged from 4.3 to 860.5 m^2/d with a median of 195.4 m^2/d and an arithmetic mean of 226.7 m^2/d while after cleaning the water wells, the Q/s values increased in the range of 90.8 to 907.9 m^2/d with a median of 339.8 m^2/d and an arithmetic mean of 345.8 m^2/d (Table 1). Resultantly, the Q/s values after the cleaning increased 102 to 9179% comparing to the state before the cleaning, with an increase of average 543%.

4.2. Changes in the well loss by the air impulse technique

Well loss is the groundwater level that is due to the resistance of the flow originating from the clogged materials and/or precipitation of chemicals as well as turbulence in the suction pipe inside the well. Hantush (1964) and Bierschenk(1963) independently found that the total drawdown on the pumping well could be expressed as the sum of the aquifer loss component (BQ) and well loss component (CQ^2), i.e.,

$$s_w = BQ + CQ^2 \tag{3}$$

where s_w is the total drawdown, B is the aquifer loss coefficient, C is the well loss coefficient, and Q is the pumping rate. From Eq. (3), the difference in the total drawdowns on the pumping well before and after the impulse technique is expressed by Eq. (4):

$$s_{w1} - s_{w2} = (B_1Q + C_1Q^2) - (B_2Q + C_2Q^2) \tag{4}$$

where B_1 and B_2, C_1 and C_2, and s_{w1} and s_{w2} are the aquifer loss coefficient, well loss coefficient, and total drawdown by the pumping tests before and after the impulse implementation, respectively. The difference in the well loss coefficients before and after the impulse implementation can be calculated by using Eq. (5):

$$C_1 - C_2 = \frac{s_{w1} - s_{w2}}{Q^2} - \frac{B_1 - B_2}{Q} \tag{5}$$

The well loss change (ΔC, $\frac{s_{w1} - s_{w2}}{Q^2}$) can be calculated because it is proportional to $C_1 - C_2$. By the

Table 2. Well loss change of the wells through groundwater rehabilitation

Well no.	Q (m^3/d)	s_{w1} (m)	s_{w2} (m)	s_{w1} - s_{w2} (m)	ΔC (s/m^2)	Well no.	Q (m^3/d)	s_{w1} (m)	s_{w2} (m)	s_{w1} - s_{w2} (m)	ΔC (s/m^2)
DS6-2	4306	5.83	5.73	0.10	5.17E-09	DS6-29	387	11.99	0.79	11.20	7.48E-05
DS6-3	3614	4.20	3.98	0.22	1.68E-08	DS6-30	59	13.63	0.15	13.48	3.87E-03
DS6-6	-	-	-	-	-	DS6-31	-	-	-	-	-
DS6-7	3240	6.87	6.15	0.72	6.83E-08	DS6-32	501	16.71	4.30	12.41	4.95E-05
DS6-8	3427	9.55	8.58	0.97	8.22E-08	DS6-33	691	15.70	4.65	11.05	2.31E-05
DS6-10	1541	5.78	4.04	1.74	7.34E-07	DS6-34	661	15.64	2.54	13.10	3.00E-05
DS6-11	3010	11.61	7.08	4.53	4.99E-07	DS6-35	1181	13.34	5.46	7.88	5.65E-06
DS6-12	1613	13.16	3.45	9.71	3.73E-06	DS6-36	459	13.68	1.97	11.71	5.56E-05
DS6-14	3110	13.12	10.25	2.87	2.97E-07	DS1-2	1235	16.51	13.60	2.91	1.91E-06
DS6-15	3686	15.39	12.67	2.72	2.00E-07	DS1-3	2765	13.75	10.40	3.35	4.39E-07
DS6-16	1426	5.84	4.65	1.19	5.85E-07	DS1-4	1555	7.96	4.63	3.33	1.38E-06
DS6-17	2635	17.54	16.72	0.82	1.19E-07	DS1-5	2866	15.06	12.03	3.03	3.69E-07
DS6-18	2002	18.02	14.75	3.27	8.15E-07	DS1-6	1325	17.06	8.63	8.43	4.80E-06
DS6-19	3528	9.78	9.47	0.31	2.51E-08	DS1-7	2909	16.22	11.17	5.05	5.97E-07
DS6-20	3874	7.93	7.26	0.67	4.46E-08	Max	4306	18.02	16.72	13.48	3.87E-03
DS6-22	3427	12.82	11.96	0.86	7.30E-08	Min	59	4.20	0.15	0.10	5.17E-09
DS6-23	3326	9.37	7.99	1.38	1.25E-07	Mean	2182	12.01	7.11	4.90	1.30E-04
DS6-24	-	-	-	-	-	Median	2635	12.82	7.08	3.03	5.85E-07
DS6-25	3701	9.01	8.26	0.75	5.49E-08	Std. dev.	1301	3.87	4.30	4.48	6.72E-04
DS6-26	529	10.75	1.87	8.88	3.17E-05	Kurtosis	-1	-0.89	-0.62	-1.07	3.29E+01
DS6-27	270	11.00	0.79	10.21	1.40E-04	Skew.	0	-0.33	0.32	0.70	5.73E+00
DS6-28	3154	11.65	8.76	2.89	2.90E-07						

air impulse implementation, the ΔC values ranged from 5.17×10^{-9} to 3.87×10^{-3} s/m^2, with a median value of 5.85×10^{-7} s/m^2 and an arithmetic mean of 1.30×10^{-4} s/m^2 (Table 2).

4.3 Correlation between the hydraulic parameters by the air impulse technique

The correlation between the specific capacity (Q/s), transmissivity (T), storage coefficient (S), and well loss change (ΔC) was analyzed by the air impulse rehabilitation (Figs. 7-11). The T vs. Q/s values showed a slightly higher correlation coefficient (R), 0.9812, after the air impulse rehabilitation, compared to the R value of 0.9806 before the rehabilitation, with slopes of 0.253 and 0.243 before and after the rehabilitation, respectively (Fig. 7). Similarly, the S vs. Q/s values demonstrated a positive correlation with slopes of 9.32×10^{-4} and 8.40×10^{-4} before and after the execution of the air impulse technique, respectively (Fig. 8).

The T vs. ΔC values exhibited a correlation coefficient (R) of -0.9235 before the air impulse rehabilitation, compared to the R value of -0.0700 after the rehabilitation (Fig. 9). The S vs. ΔC values presented an R of -0.8353 before the air impulse rehabilitation, compared to the R value of 0.0330 after the rehabilitation (Fig. 10). The Q/s vs. ΔC values exhibited an R value of -0.9026 before the air impulse rehabilitation, compared to the R value of -0.7699 after the rehabilitation (Fig. 11). The lower R values

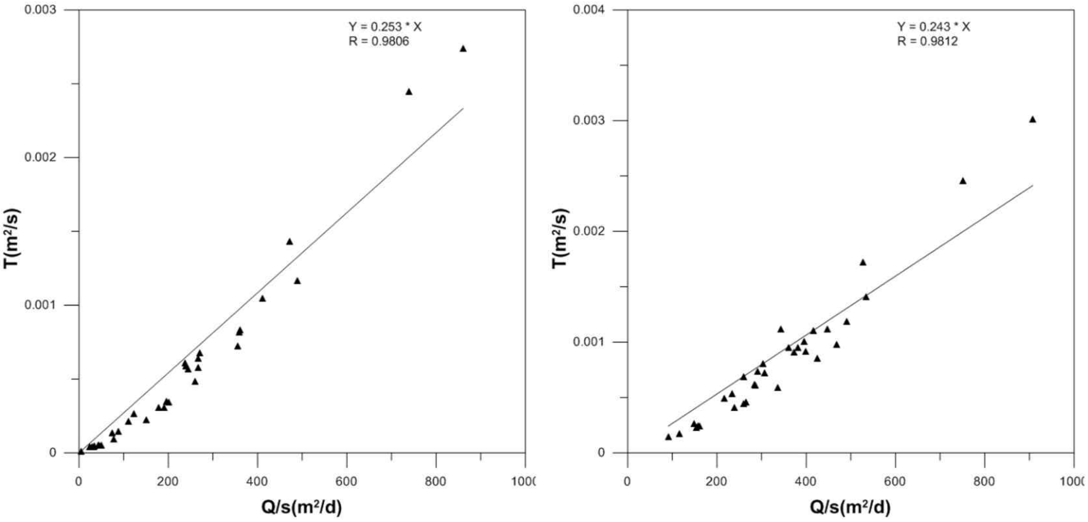

Fig. 7. Transmissivity (*T*) vs. specific capacity (*Q/s*) before rehabilitation (left graph) and after rehabilitation (right graph) by the air impulse implementation.

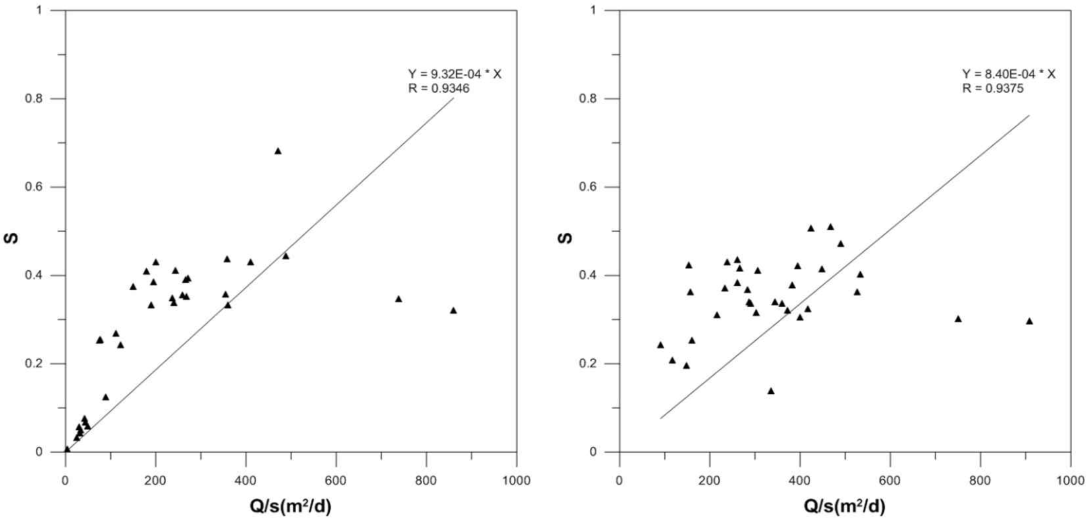

Fig. 8. Storage coefficient (*S*) vs. specific capacity (*Q/s*) before rehabilitation (left graph) and after rehabilitation (right graph) by the air impulse implementation.

between the hydraulic parameters and ΔC values after the rehabilitation than those before the rehabilitation indicate an increase in hydraulic parameters caused by the rehabilitation.

5. Conclusions

This study examined high-pressure air impulse technique for well rehabilitation in the 43 vertical wells located near the Nakdong river in Daesan-myeon area, Changwon city, Korea. The removal effect of the

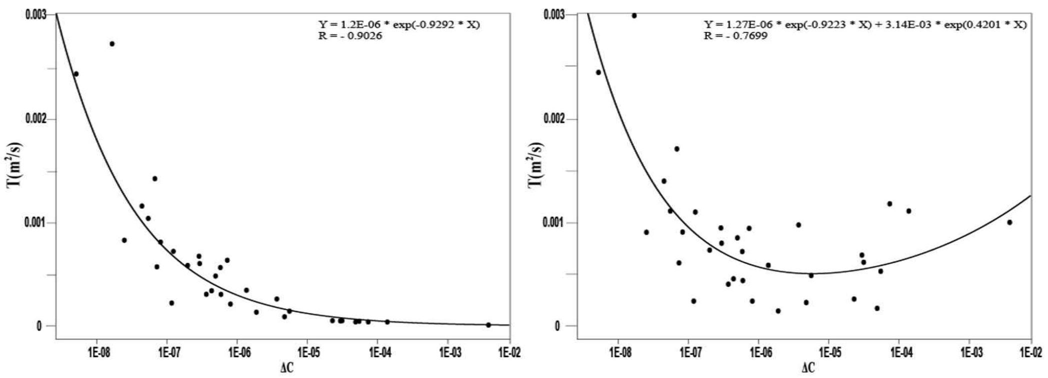

Fig. 9. Transmissivity (*T*) vs. well loss change (Δ*C*) before rehabilitation (left graph) and after rehabilitation (right graph) by the air impulse implementation.

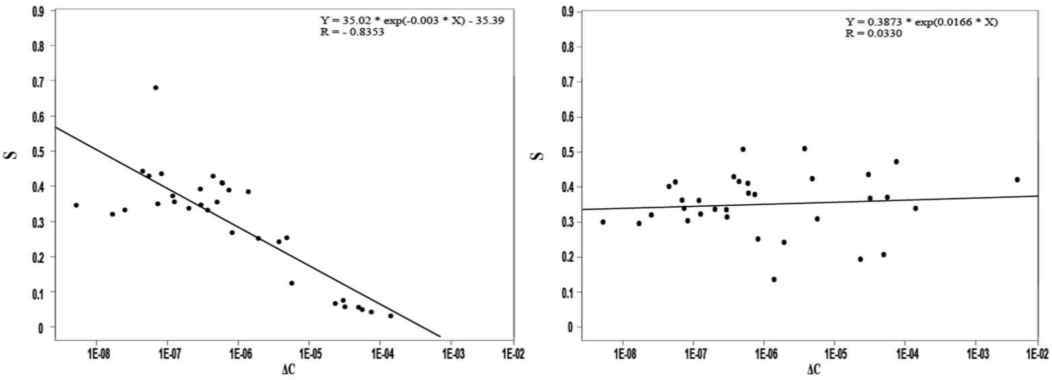

Fig. 10. Storage coefficient (*S*) vs. well loss change (Δ*C*) before rehabilitation (left graph) and after rehabilitation (right graph) by the air impulse implementation.

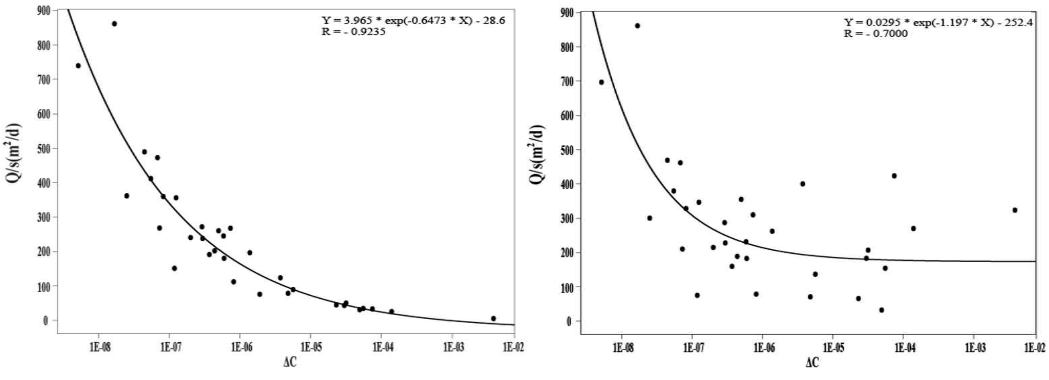

Fig. 11. Specific capacity (*Q/s*) vs. well loss change (Δ*C*) before rehabilitation (left graph) and after rehabilitation (right graph) by the air impulse implementation.

clogged materials in 33 wells was verified by comparing the changes in the hydraulic parameters (transmissivity, storage coefficient, specific capacity, and well loss change) before and after the effective execution of the high-pressure air-impulse technique. After cleaning the wells, the transmissivity (*T*) values mostly increased in the range from 1.41×10^{-4} to 3.00×10^{-3} m^2/s, with a median value of 8.24×10^{-4} m^2/s and an arithmetic mean of 8.59×10^{-4} m^2/s. In comparison to the state before the cleaning, the *T* values varied from 5.77×10^{-6} to 2.73×10^{-3} m^2/s, with a median value of 3.38×10^{-4} m^2/s and an arithmetic mean of 5.42×10^{-4} m^2/s. By the execution of the high-pressure air-impulse technique, the *S* values also increased in the range of 0.1362 to 0.7024 with a median of 0.3642 and an arithmetic mean of 0.3651. By comparison, the *S* values changed from 0.0057 to 0.6804, with a median of 0.33370 and an arithmetic mean of 0.2836. The specific capacity (*Q/s*) values after the well rehabilitation increased from 102 to 9,179%, with an average of 543%.

The *T* vs. *Q/s* values exhibited a positive relationship correlation coefficient (*R*) of 0.982 with a slope of 0.253 after the cleaning; in comparison, before the cleaning, the R value is 0.969 with a slope of 0.243. The *S* vs. *Q/s* values also demonstrated a positive R value of 0.938 with a slope of 8.44×10^{-4} after the cleaning, comparing to the R value of 0.935 with a slope of 9.32×10^{-4} before the cleaning. The well loss change (ΔC) values indicated an increase in the hydraulic parameters by the air impulse implementation.

Thus, the high-pressure air impulse technique could be efficiently applied to groundwater and riverbank filtration wells for rehabilitating the decreased productivity.

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