International Conf. on Water Resources & Arid Environment (2004)

Relationship between Excessive Pressure Drawdown and Groundwater Quality

Musaed N. J. Al-Awad

Petroleum Engineering Department, College of Engineering, King Saud University

Abstract

Ground water is a vital source for fresh water in Saudi Arabia and the surrounding gulf countries. It is well known that fresh water density is lower than that of fresh water containing appreciable amounts of dissolved salts. Therefore, water quality in the top of the aquifer is superior to the water in the bottom of the aquifer due to the effect of density and gravity segregation. Normally, there is a margin of separation between fresh and saline water is known as the fresh water-saline water contact.

Producing fresh water (from the top of aquifer) by excessive pressure drawdown forces the saline water to move faster towards the producing wellbore in a process called coning. The top of the cone (maximum height) is function of pressure drawdown. Several incidences have been reported indicating that the quality of many groundwater wells in the Kingdom of Saudi Arabia are decreased perhaps due to saline water coning caused by high pressure drawdown. Therefore, pressure drawdown must be carefully selected so that good quality fresh water is produced without coning the saline water into the producing wellbore.

In this study, a general equation governing water coning process in groundwater wells is presented. Water coning process is examined on a Saudi groundwater aquifer. Furthermore, a comparison study is made for pressure drawdown using vertical and hypothetical horizontal wells producing from the same groundwater aquifer.

Thus, optimum pressure drawdown reduces the degree of fluid disturbance (coning and saline water intrusion) that may occur due to high pressure drawdown caused by excessive water production from groundwater aquifers.

Keywords: Groundwater, Aquifer, Coning, Horizontal well, Pressure drawdown, Water quality, Saline water.

Introduction

Saudi Arabia (225 million square kilometers) in general is one of hottest and most arid countries in the world, with an average summer temperatures of 46^{o}C and an average rainfall of 120 mm per year. Water resources in Saudi Arabia are conventional which includes groundwater and surface water, and non-conventional such as desalinated seawater and treated waste water. About 88 percent of the water consumption in Saudi Arabia is met by groundwater. The western coastal plain (Tihama) receives 60 percent of the country's total rainfall. Rainfall in this region provides an average supply of approximately 1.85 billion cubic meters of water, accounting for approximately nine percent of the total annual water consumption. Desalinated water production is approximately two and a half million cubic meters per day, constituting approximately 2.5 percent of annual water consumption [1]. Table 1 lists the major groundwater aquifers in Saudi Arabia [2]. All wells drilled in these formations for groundwater production are vertical [3]. Groundwater aquifers listed in Table 1 are formed millions of years ago. Most of these aquifers are non-rechargeable leading to depletion and water quality deterioration with time [4]. Water deterioration can be attributed to saline water natural intrusion or saline water coning caused by excessive drawdown.

Drinking Water Quality

Water fit for human consumption should not contain any substances, which would affect its color, odor or appearance. It should be free from foreign bodies such as soil, sand and other substances and impurities which are visible to the naked eye with total hardness less than 500 ppm [5].

Incidences have been reported indicating that the quality of many groundwater wells in several parts of the Kingdom of Saudi Arabia are decreased perhaps due to saline water coning caused by high pressure drawdown. For example, the quality of groundwater produced from Neogene groundwater aquifer in Al-Hassa in the eastern province was decreased sharply due to saline water intrusion [6]. Similar situations were observed in Ha'il groundwater aquifers [7] and in the central province in Minjur groundwater aquifer [4] due to excessive pressure drawdown.

Objective Of The Study

The objective of this study is to present an engineering method that can be utilized for the prediction of optimum fresh water production rates with no saline water intrusion (coning). This method is presented in the following section.

Water Coning Theory

Coning is a term used to describe the mechanism underlying the upward movement of high salinity water into the producing well. Coning can seriously impact fluids distribution caused by density and gravity action over millions of years in the groundwater aquifers. Once this equilibrium is disturbed, it needs very long time for these fluids to reach there initial equilibrium.

Coning is primarily the result of movement of high density water (saline water) in the direction of least resistance towards the production well as shown in Figure 1 [8 and 9]. Water coning is highly dependent on specific gravity difference ($\Delta\gamma$, dimensionless) between fresh water (γ_{w1}) and saline water (γ_{w2}), formation permeability (k, Darcy), radius of the drainage area (r_e , ft), wellbore radius (r_w , ft), depth of wellbore penetration into the fresh water zone (d, ft), fresh water viscosity (μ_w , cp) and fresh water zone thickness (h , ft). By the combination of the above parameters, critical production rate (Q_c , m^3/day/well) above which saline water coning occurs, can be calculated as follows:

$$Q_c = 0.2441 \frac{k\,\Delta\gamma\,(h^2 - d^2)}{\mu\ \ell n(r_e / r_w)} \qquad \ldots(1)$$

From equation 1, it can be observed that the height of saline water cone (h minus d) is directly proportional to the magnitude of the production rate (i.e. pressure drawdown) as shown in Figure 2. Equation 1 is used to predict water coning in Wasia groundwater aquifer based on the technical data presented in Table 2. It must be noticed that fresh water-saline water contact (interface) and densities must be measured accurately using well logging tools and chemical analysis respectively in order to get realistic predictions using the above equation.

Results And Discussion

Water coning analysis for Wasia groundwater aquifer is performed based on the technical data presented in Table 2. Figure 3 shows the relationship between fresh water production rate and wellbore penetration into the fresh water zone and fresh water zone thickness ratio (d/h). It can be seen that as the penetration of the wellbore into the fresh water zone increased more saline water will cone into the production wellbore and mix with the fresh water causing poor water quality production. Therefore, for good water quality production, the wellbore penetration into the fresh water zone should be kept minimum.

During fresh water production, saline water coning effect will be small if the permeability of the groundwater aquifer is high enough to allow for fast fresh water recharging from the surrounding drainage area. By doubling the value of the permeability, the critical fresh water production rate with no coning is also doubled as shown in Figure 4. Thus, high fresh water production rats can be applied in high permeability groundwater aquifers. Similar effect on fresh water production rate can be noticed due to the difference between the specific gravities of the fresh water and the saline water as shown in Figure 5. Higher saline water specific gravity yields higher gravity (weight). Therefore, higher fresh water production rates can be applied when high specific gravity saline water exists below the fresh water.

It is well known that a horizontal well yields similar production rate as four vertical wells or more based on h/L ratio yield from identical drainage areas for the same pressure drawdown as shown in Figure 6 [3]. Therefore, higher fresh water production rates with no saline water coning can be applied in horizontal water wells. More details about the utilization of horizontal well technology in groundwater projects are documented in reference 3.

Conclusions

Based on the analysis conducted in this study, the following conclusions are obtained:

- Fresh water quality is highly affected by undersigned production rates.
- Minimum well penetration into fresh water zone should be applied in groundwater aquifers.
- The utilization of horizontal wells provides higher water production at minimal disturbance of water level and formation properties.
- Saline water coning in groundwater aquifers is highly affected by formation permeability and saline water specific gravity and height.
- Groundwater aquifer permeability and fresh water-saline water interface must be evaluated carefully.

References

Homepage of the International Cooperation and Development Fund, Republic of China, Taipei, 2003. http://www.icdf.org.

Homepage of the Ministry of Water and Agriculture, Riyadh, Saudi Arabia, 1421H. http://www.agrwat.gov.sa.

Musaed N. J. Al-Awad, Omar A. Almisned and Abdulrahman A. Alquraishi, 2003. "Application of Horizontal Drilling Technology in Groundwater Projects" The WASTA 6th Gulf Water Conference in Concurrence with the 2nd Symposium on Water Rationalization in the Kingdom.", March 8-12, 2003, Riyadh, Saudi Arabia.

Slider, H. C. ,1976. "Practical Petroleum Reservoir Engineering Methods, An Energy Conservation Science.", 1st Edition, Petroleum Publishing Co., Tulsa, OK.

Tarek Ahmed, 2001. "Reservoir Engineering Handbook.", Gulf Publishing Company, Huston, Texas, U.S.A.

"Unbottled Drinking Water.", 1993. Standardization and Metrology Organization for G.C.C. Countries, Gulf Standard No. 149.

إبراهيم عبدالعزيز الصعقبي و محمد علي معلم ، 1421 هـ. "دراسة الموارد المائية بمدينة موقق بمنطقة حائل." ، الندوة الأولى لترشيد إستهلاك المياه وتنمية مصادرها ، 12-15 محرم 1421 هـ ، وزارة الزراعة والمياه ، الرياض، المملكة العربية السعودية.

خليفة عبدالله الكويتي ، صلاح سيد أحمد و عادل خضر بوزيد، 1421 هـ. "الحالة الراهنة لملوحة المياه الجوفية بمنطقة مشروع الري والصرف بالإحساء والعوامل المؤثرة عليها." ، الندوة الأولى لترشيد استهلاك المياه وتنمية مصادرها ، 12-15 محرم 1421 هـ ، وزارة الزراعة والمياه ، الرياض ، المملكة العربية السعودية.

رائد سليمان المديهي، 1421هـ. "تأمين مياه الشرب – التحدي المستمر." ، المؤتمر الهندسي السعودي الثالث ، 18 -21 جمادى الأولى 1421 هـ ، الرياض ، المملكة العربية السعودية.

Table 1 Major groundwater aquifers in Saudi Arabia [3].

Aquifer name (Rock type)	Water depth, m	Thickness, m	Productivity, 10^3 m^3/day	Location
Saq (Sandstone)	150 – 1500	650	8640	Central-North
Wajid (Sandstone)	150 – 900	600	3456 – 6912	Southern
Tabuk (Sandstone and Shale)	60 – 2500	1072	1296 – 1728	Central-North
Minjur (Sandstone)	1200 – 2000	315	5184 – 10368	Central
Dhruma (Sandstone and Limestone)	100	375	5184 – 10368	Central
Biyadh (Sandstone)	30 – 200	425	2160 – 4320	Northern
Wasia (Sandstone and Shale)	100 – 800	150	7344 – 9504	Central-East
Umm-Er-Radhuma (Limestone)	100 – 400	330	4320 – 8640	Eastern
Dammam (Limestone)	160 – 200	80	605 – 1900	Eastern
Neogene (Sandstone and Limestone)	50 – 100	100	4320 – 8640	Eastern

Table 2 Technical data for Wasia groundwater used in coning calculations.

Permeability (k) = variable (0.5, 1.0 and 1.5 Darcies).
Fresh water zone thickness (h) = 1200 ft.
Wellbore penetration into fresh water zone (d) = variable with maximum value of 1200 ft.
Single vertical well drainage radius (r_{ev}) = 1388 ft.
Single horizontal well drainage radius (r_{eh}) = 2776 ft.
Length of horizontal well (L) = h, 5h and 7h, ft.
Wellbore radius (r_w) = 0.375 ft.
Fresh water viscosity (μ_w) = 1 cp.
Fresh water specific gravity (γ_{w1}) = 1.0.
Salt water specific gravity (γ_{w2}) = variable with maximum value of 1.04.

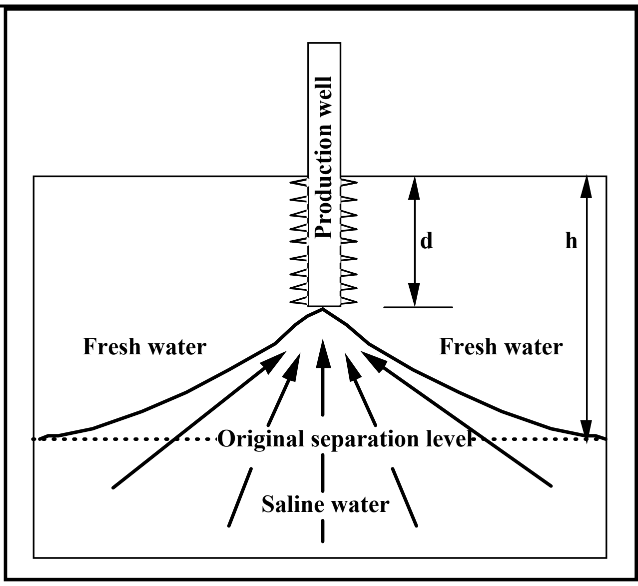

Figure 1 A schematic diagram of coning phenomenon.

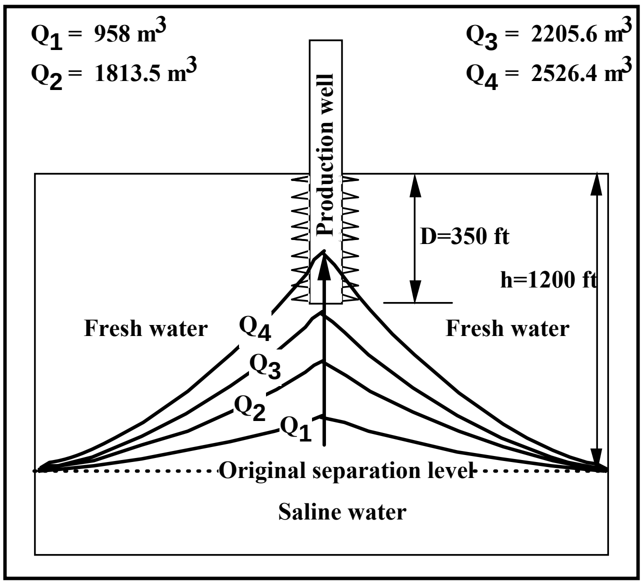

Figure 2 Coning process caused by water production in the studied Saudi groundwater aquifer.

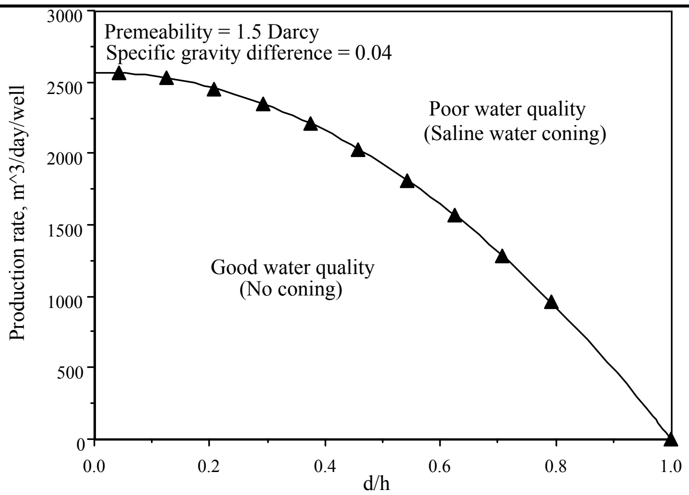

Figure 3 Relationship between d/h and critical production rate from a vertical well in the studied Saudi groundwater aquifer.

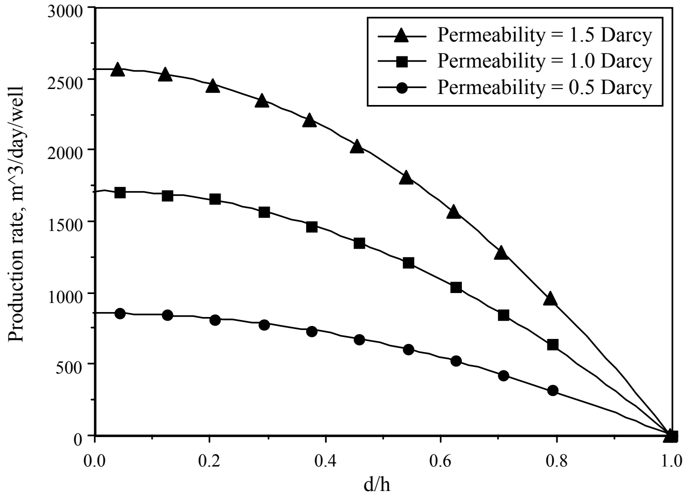

Figure 4 Relationship between d/h and critical production rate from a vertical well in the studied Saudi groundwater aquifer at various permeabilities.

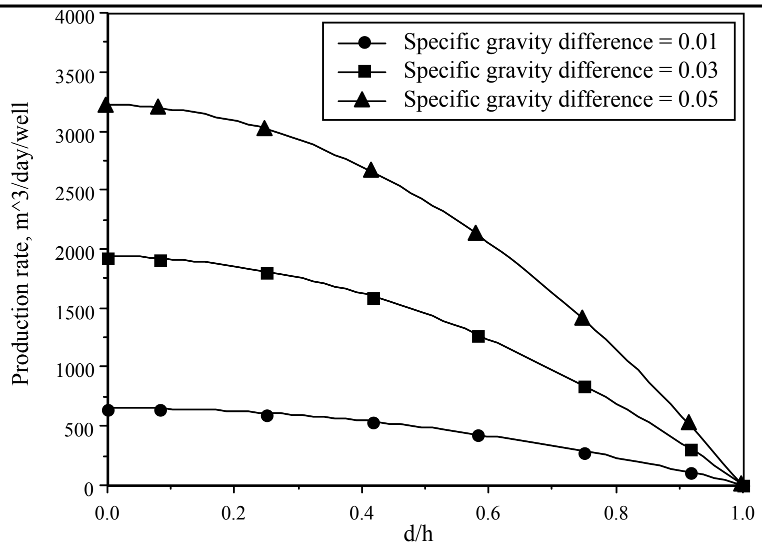

Figure 5 Relationship between d/h and critical production rate from a vertical well in the studied Saudi groundwater aquifer at various specific gravity difference.

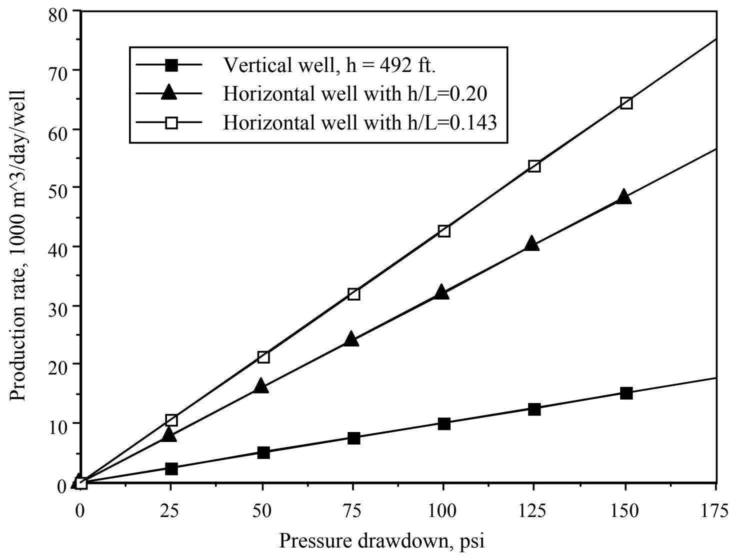

Figure 6 Relationship between pressure drawdown and production rates from vertical and horizontal wells.

العلاقة بين التناقص في قيمة ضغط السحب و جودة المياه المنتجة من مكامن المياه الجوفية

مساعد ناصر جاسم العواد
قسم هندسة النفط – كلية الهندسة – جامعة الملك سعود– المملكة العربية السعودية

الملخص تعتبر المياه الجوفية مصدر حيوي للمياه العذبة في المملكة العربية السعودية ودول الخليجي العربي. ومن المعروف أن كثافة الماء العذب أقل من كثافة الماء المحتوي على كميات من الاملاح الذائبة. ولذلك فأن عذوبة وجودة الماء الموجود في أعلى المكمن الجوفي للماء أكبر من الماء الموجود في قاع المكمن بسبب قانون الأنفصال بين السوائل نتيجة الجاذبية و إختلاف الكثافة. وعادة ما يكون هناك خط وهمي يفصل بين مستوى الماء المالح والماء العذب.

إن إنتاج الماء العذب من أعلى المكن بتناقص عالي في ضغط السحب سوف يؤدي الى حركة الماء المالح من اسفل المكمن الى الأعلى بحركة تسمى الحركة المخروطية. ويعتمد ارتفاع مخروط الماء المالح على قيمة التناقص في في ضغط السحب. ولقد تم تسجيل عدد من الحالات التي تشير الى تناقص في عذوبة المياه المنتجة من بعض آبار المياه الجوفية في المملكة العربية السعودية قد تكون ناشئة عن الحركة المخروطية للماء المالح من اسفل المكن الى الأعلى بسبب التناقص في ضغط السحب نتيجة معدلات الأنتاج العالية للماء. ولذلك يجب الحرص عند إختيار مقدار التناقص في الضغط للحصول على مياه عذبة ذات جودة عالية دون حصول حركة مخروطية للمياه المالحة.

تم في هذه الدراسة بيان القانون العام الذي يربط الحركة المخروطية للماء المالح مع قيمة التناقص في الضغط بسبب الإنتاج وتم تطبيق ذلك على مكمن مياه جوفي للمياه العذبة في المملكة العربية السعودية. ومن ثم تم عمل مقارنة بين مقدار التناقص في ضغط السحب الناشئ عن إنتاج الماء من بئر عمودي وآخر أفقي في نفس المكمن.

وعلى ذلك فأن اختيار مقدار تناقص مناسب في ضغط السحب المتولد عن إنتاج الماء سوف يقلل من الاضطرابات الناشئة عن الحركة المخروطية للمياه المالحة بسبب الإنتاج الجائر وبالتالي يحافظ على جودة الماء المنتج.