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Analysis of Tubewell Performance as an Evaluation of the Physical Aquifer Model Being Developed

S. A Sulaiman[*,1,a], *M. A. M. Zawawi*[1,b] *and E. H. Mohamed*[2,c]

[1]Department of Biological and Agricultural Engineering
[2] Department of Civil Engineering
Faculty of Engineering, Universiti Putra Malaysia,
43400 UPM, Serdang Selangor, Malaysia.
[a,*]*shazeliashikin@gmail.com*, [b]*azwan@eng.upm.edu.my*, [c]*azzadin2003@yahoo.com*

Abstract – *Physical aquifer model is used as a tool for further understanding of groundwater concept. Demonstration and observation activities on water level drawdown in the observation well, performance of pumping well, groundwater flow and solute transport of groundwater contamination can be carried out on this aquifer model. The objective of this study is to evaluate the physical aquifer model developed in the laboratory, used as a teaching tool and research material through the analysis of well performance. Well efficiency is an indicator in determination of the performance of pumping well developed in the aquifer model. Using stepdrawdown pumping test technique, the optimum pumping discharge rate for the pumping well is determined at 0.0612m^3/hr and its efficiency is calculated to be 99%. This technical evaluation helps to study further of the aquifer hydraulic properties which accomplished on this artificial aquifer model.*

Keywords: Aquifer model, Well performance, Well efficiency

1.0 INTRODUCTION

Groundwater flow is a movement of water beneath the earth's surface in fracture of soils and rocks. The difficulty associated with the study of real groundwater aquifers as it cannot be observed physically with bare eyes and needs a lot of manpower and machinery, which makes the artificial aquifers or small scaled models in the laboratory to be the best way to study and to understand the groundwater flow. Aquifer model is a physical structure consists of a tank filled with artificial or real aquifer materials and water tank on each side to control the hydraulic head inside the model to represent the real aquifer conditions. Further explanation of the aquifer model operating will be addressed later in this article.

The intangible process of groundwater is most likely a reason why misconceptions of groundwater theory among students occurred [1]. They are unable to imagine what actually happens in the aquifer due to the limited opportunity for hands-on learning activities [2]. Besides that, researches on groundwater are facing time and cost constraints due to uncertainty factors on determining the aquifer conditions [3]. This is why the physical aquifer model plays the important role. The understanding on groundwater theory can be enhanced by allowing students to do the exploration activities by themselves on the aquifer model. The research constraints can be solved by representing the real aquifer condition in the model to study the groundwater flow and solute transport of groundwater contamination.

Previous studies [4] demonstrated a mobile physical model in hydrogeology class to give deeper understanding on the concepts and processes of groundwater. A laboratory sandbox experiment was used to predict and interpret the drawdown response under heterogenous unconfined aquifer [5]. Another large sandbox of two layers of aquifer system was used to study an airflow induced by pumping test [6]. Contaminant transport was studied previously under controlled boundary and initial condition in three-dimensional artificial aquifer too [3].

However previous studies on aquifer model only described the major elements of the research, without describing further the technical details on the development of the model. How to know if the aquifer model is really functioning as a representation of the aquifer? How to know if the water flowing in the aquifer model does flow according to the real theory? Is there any way to evaluate this aquifer model?

This paper will elaborate on how to evaluate the aquifer model developed in terms of the performance of the pumping well. Pumping well is one of the major elements in the groundwater extraction. The performance of the pumping well shows the effectiveness of the aquifer in delivering the water out of the aquifer. Well performance test are conducted to estimate the energy losses in the aquifer and the pumping well developed during the groundwater extraction [7].

The aims of this study are i) to determine the optimum pumping rate for the aquifer model being developed, ii) to evaluate the well efficiency of the pumping well on the aquifer model using step-drawdown pumping test technique. The evaluation and the analysis are carried out by the Aquifer Test software.

2.0 METHODOLOGY

2.1 Experimental setup

The aquifer model was developed at the Soil and Water Conservation Laboratory, Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM). The aquifer model was constructed using hollow structural steel with thick prospect visible glass at an outer dimension of 5.00 m x 2.00 m x 2.00 m, where the central part of the model has an inner dimension of 3.72 m x 1.88 m x 2.00 m and two water tanks with an inner dimension of 0.5 m x 1.88m x 2.00 m, each attached on both sides of the model. Figure 1 shows the structure of the physical aquifer model with homogenous three layers aquifer system developed.

The geological condition of the artificial aquifer resembled the real condition of aquifer as it was designed accordingly to the ratio of 1:13, of a groundwater research area in Jenderam Hilir, Dengkil, Selangor [8]. Layer 1 of the artificial aquifer consists of silty sand with 0.23m depth, layer 2 is sandy clay with 0.15m and layer 3 is silty sand again with 0.83m depth.

The artificial aquifer is fully saturated with water and the level of the water table is controlled by the height of water level in water tanks. This is done by raising the water level in the inlet water tank, supplied by pump slowly from below and let the water flow into the central part of the aquifer. Pipe connectors with diameters of 0.381m., made by polyvinyl chloride (PVC) connect the centre part of the model with the water tanks by allowing water transfer between them. The connectors are filtered with nylon weave to avoid the soil mix and passing through the water tank.

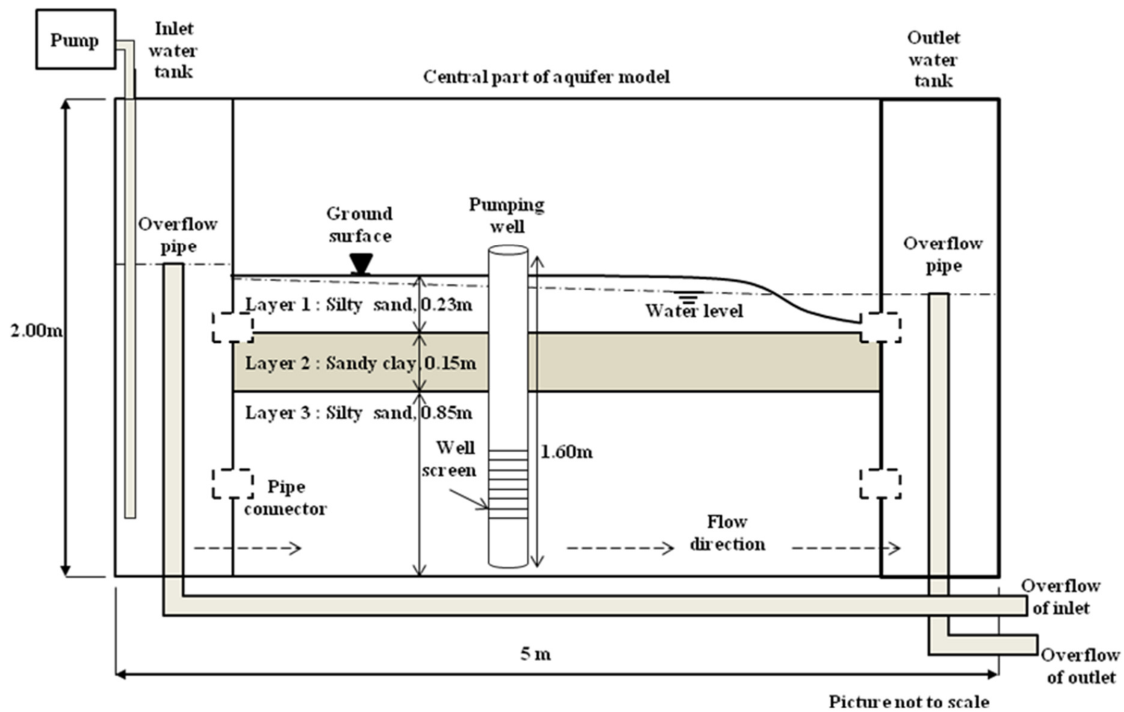

Figure 1: Schematic figure of the aquifer model

Water flows throughout the aquifer and excess water flow into the outlet water tank. The overflow pipes made of PVC are placed in both water tanks to circulate overflow water and maintain the water level in water tanks at certain heights. The height of the overflow pipe in the inlet tank is fixed at 1.05m while the height of the overflow pipe in the outlet tank is 0.96m, both from the floor of the model. The difference of water level in water tanks, known as the hydraulic head is the force which makes the water flows from a higher pressure to lower pressure.

The pumping well with 10.16cm (4 inch) diameter of PVC pipe is 1.60m length, placed at the centre of the model. The penetration screen of well with 0.46m lengths located along the layer 3 of the aquifer, is to filter the water when it is entering the well. The screen size of 0.01mm is provided based on sieve analysis tests of both silty sand and sandy clays soils. Gravels of 5mm diameter in size are put along the screen to assist better filtering of water in the aquifer.

2.2 Experimental procedure

A submersible pump with a maximum head of 1.2m and maximum flow of 1200L/hr is chosen to carry out the pumping test. The pump is installed inside the pumping well at a depth of 1.10m from the top of the well and hose pipe is connected to flow the discharge from the pump out of the model. Since the discharge rate is small, measuring cylinder and stopwatch is used as manual measurement of discharge. A PVC pipe valve is put between the pump and pipe hose. The valve prevents the backflow of the discharge as well as controlling the volume discharge of water.

The automatic water level recorder, Troll 500 level logger is used to measure and record the water level in the well automatically. The connection cable which holds the logger hanging inside the pumping well also attached the logger to the computer for in situ water level monitoring during the test. The configuration of the equipment installed for the experiment can be seen in Figure 2.

2.2.1 Determination of Optimum Pumping Discharge Rate

The well should operate optimally with the well design given to ensure it worked at its best performance. The high flow rate might cause an error during analysis, in which sand clogging around the screen occurred due to the high entrance velocity through the screen [9].

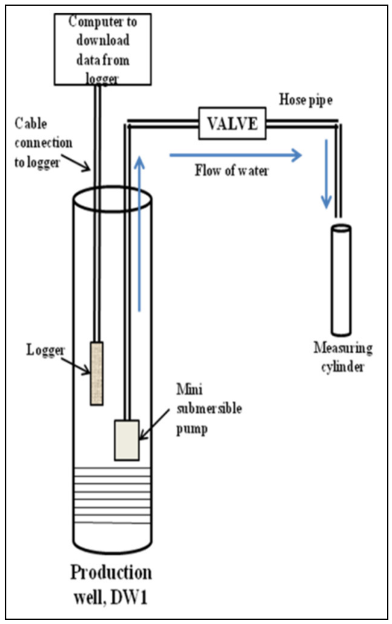

Figure 2: Configuration of equipment for pumping test

Measurement of static water level in the pumping well is taken initially using level logger. The first pumping rate is to lower the water in the pumping well about one-third of the maximum drawdown. The drawdown is monitored and pumping test is continued until the drawdown stabilized at a constant level. Then without stopping the pump, the pumping rate is increased to produce about two-thirds of the maximum drawdown. Another drawdown measurement is monitored until it remained constant. This increment in flow rate procedure is similar to the pumping test of step-drawdown technique.

The increasing of the pumping rate procedure is repeated until the well produced about 90 percent of the maximum capacity of the pump. The optimum pumping discharge rate determined in the test will be used in further pumping test on the aquifer model.

2.3 Step-drawdown pumping test

The aquifer model was left at rest for recharge process after the pumping test for determination of optimum pumping discharge rate. Static water level is measured initially before proceeding to the next step-drawdown pumping test. The water level during pumping test is measured at time intervals as shown in Table1.

Table 1: Time intervals for water level measurements during pumping test activities [10]

Starting time after pumping	Time intervals
0 – 5 minutes	0.5 minutes
5 – 60 minutes	5 minutes
60 – 240 minutes	30 minutes

The step-drawdown pumping test consists of four consecutive steps of discharge rate. The optimum pumping discharge rate chosen will be put on the third step. The pumping test starts with the lowest discharge rate and continuously conducted until the highest discharge rate.

2.3.1 Determination of well performance

Total well loss defined as the difference of drawdown between the observed pumped well and theoretical aquifer. It is a useful indicator to describe well performance. The relationship of well performance's factors is explained by Equation (1) [12]:

$$s_w = BQ + CQ^2 \tag{1}$$

in which sw is the drawdown in the well, BQ (representing laminar flow) is referred as the aquifer loss while CQ^2 (representing the turbulent flow) referred as well loss. Hantush-Bierschenk graphical method is proposed to determine coefficient B and C [. The aquifer loss and well loss were interpreted and determined by presenting a diagnostic plot of specific capacity (sw/Q) versus discharge (Q) on linear scale graph [13]. The well loss coefficient, C was given by the slope from the straight line plotted while aquifer loss coefficient B was the interception of the line.

Well efficiency is one of the indicators of well performance [11]. The efficiency of pumping well is defined by Equation (2):

$$E_w\,(\%) = \frac{\text{Aquifer Loss}}{\text{Aquifer Loss + Well Loss}} \times 100 = \frac{100E}{BQ+C} \tag{2}$$

in which it is defined as the ratio of the aquifer head loss to the total head losses. Total head loss is the total of aquifer loss and well loss.

3.0 RESULTS AND DISCUSSION

3.1 Analysis of optimum pumping discharge rate

The discharge rate of pumping test started with 21.6L/hr and conducted until drawdown is stabilized and remained constant at level 0.0225m. The discharge rate was then increased to 39.6L/hr and again conducted until (the drawdown) is stabilized. The increment processes are repeated at discharge rates of 49.6L/hr, 6.86L/hr and 85.6L/hr. The total drawdown and difference in drawdown is recorded in Table 2.

The discharge rate versus difference in drawdown is plotted as in Figure 3. It can be seen that when discharge rate is increased gradually, the specific drawdown in the pumping well is increased too. However after one point of the discharge rate, the difference in drawdown is slowly decreased even though the discharged rate is increased. This point indicates the well has reached its maximum specific drawdown. The potential optimum pumping discharge rate is selected right at the point mentioned. Due to the pump capacity, 61.2L/hr is selected as the optimum pumping discharge rate.

Table 2: Total drawdown and difference in drawdown for each discharge rate

Discharge rate, Q (L/hr)	Discharge rate, Q (m3/hr)	Difference in drawdown, Δs (m)	Specific drawdown Δs/Q
21.6	0.0216	0.0225	1.042
39.6	0.0396	0.0431	1.088
49.6	0.0496	0.0570	1.149
68.6	0.0686	0.0780	1.137
85.6	0.0856	0.0669	0.782

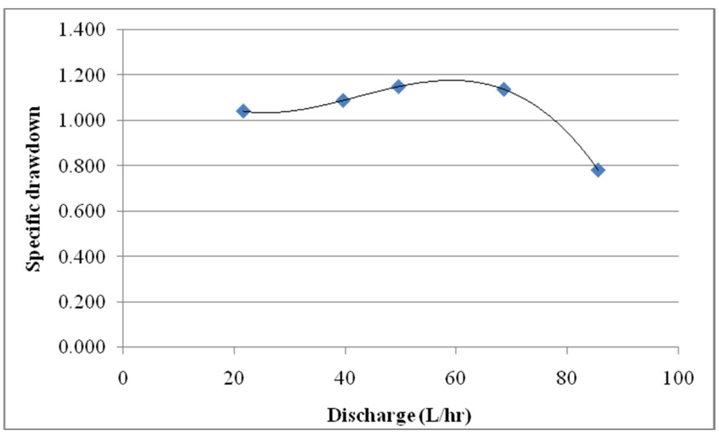

Figure 3: Plot of specific drawdown versus discharge rate

3.2 Analysis of well efficiency

Table 3 summarizes the data of step-drawdown pumping test conducted in the pumping well. The total drawdown increased accordingly for each increment of discharge rate. Drawdown increased up to a total of 0.1219m after four different steps of discharges. The time drawdown data result of the step-drawdown pumping test is presented in semi-log scale as shown in Figure 4.

Table 3: Summary of step drawdown pumping test data

Step	Discharges, Q (L/hr)	Increment of drawdown, Δsw (m)	Total drawdown, Δs (m)
1	29.2	-	0.0426
2	45.4	0.0246	0.0661
3	61.2	0.0237	0.0905
4	84.6	0.0321	0.1219

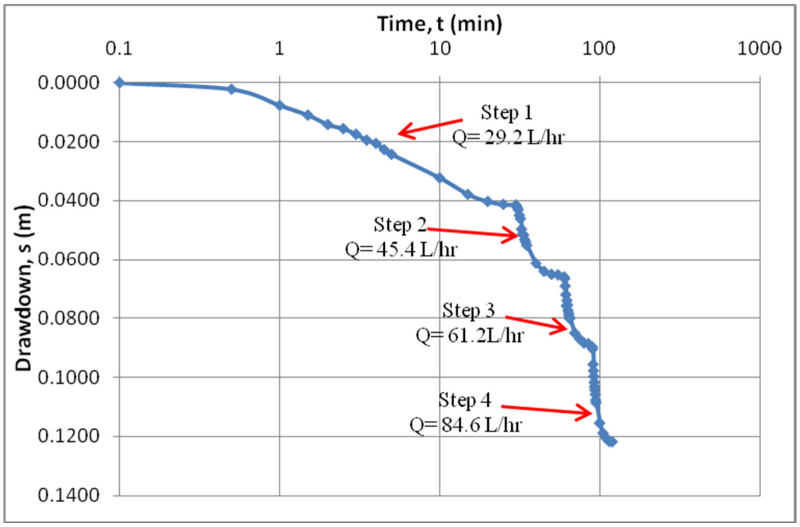

Figure 4: Time drawdown data of step drawdown pumping test in semi-log scale

Aquifer Test software is used to determine the coefficient of aquifer loss, B and coefficient of well loss, C which will be used in Equation (2) to obtain well efficiency. The software then computed a Hantush-Bierschenk well loss analysis graph, from time drawdown data in Figure 5.

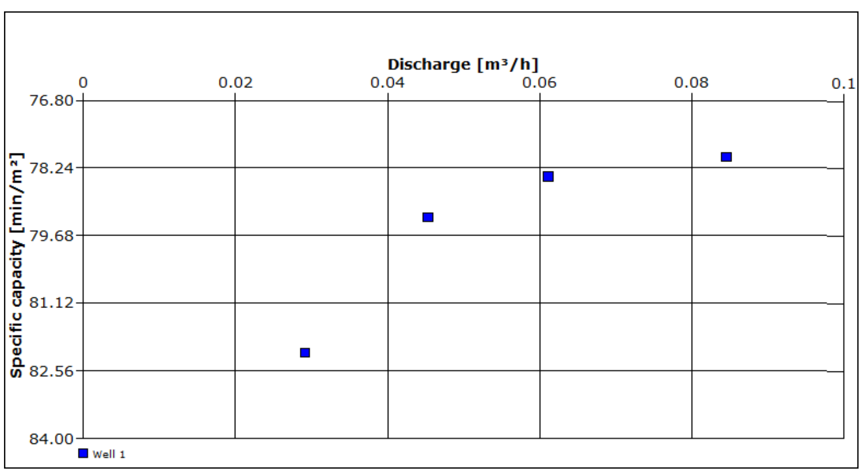

Figure 5: Hantush Bierschenk well loss analysis (From Aquifer Test software)

The well loss coefficient, C was given by the slope from the straight line plotted in the Hantush-Bierschenk well loss analysis as in Figure 5, while aquifer loss coefficient B was the interception at Q = 0. A linear fit of the values of specific capacity versus discharge gives a value of 1.42hr/m^2 for coefficient B and value of 2.74x10^{-04}hr^2/m^5 for the well loss coefficient C. The efficiency of well for each discharge is calculated using Equation (2) and presented below in Table 4.

Table4: Efficiency of well determined from aquifer loss and well loss using Aquifer Test

Discharge, Q (m^3/hr)	Aquifer loss, BQ	Well loss, CQ^2	Efficiency (%)
0.0292	0.0415	2.34 x10^{-07}	99
0.0454	0.0645	5.57 x10^{-07}	99
0.0612	0.0869	1.01 x10^{-06}	99
0.0846	0.1201	1.93 x10^{-06}	99
Average	0.0782	9.32 x 10^{-07}	99

Well loss is the difference between the head in the aquifer instantly outside the well to the head inside the casing during pumping test. One of the causes of well loss is decreasing in permeability at the well or around the well due to the clogging at well screen [14]. Well loss coefficient obtained describes the condition of well developed [15]. According to the relationship mentioned in [16], the pumping well developed in the artificial aquifer is having mild deterioration and probably facing clogging of the well screen.

In this study, the pumping well efficiency achieved 99%. During the pumping test, a small pressure in the pumping well is observed to be caused by the aquifer.

The aquifer model holds small pressure in that confined structure, compared to the large and boundless aquifer in real condition. The well faced turbulent losses through the screen, which caused a minimal loss of efficiency.

To achieve 100 percent efficiency level, the total dynamic head needs to lift the water to the initial water level must be equal to the total resistive losses in the aquifers [16]. Except for unscreened wells in fractured rock aquifers, this perfect kind of well rarely exist in reality.

4.0 CONCLUSION

Many groundwater processes and exploration activities can be shown on the aquifer model being developed. Besides determining the hydraulic properties of the aquifer, evaluation of pumping well performance is one of the analyses to be carried out from groundwater pumping test. A properly designed well can work efficiently for a long time with a low operational cost.

It can be concluded that the pumping well developed on the aquifer model is working optimally at 0.0612m^3/hr. Further analysis of the aquifer properties, can be obtained by using the constant rate pumping technique with given optimum pumping discharge rate.

It is impossible to obtain 100 percent well efficiency rate due to the unavoidable clogging of the well screen.

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