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# Colour and *E. Coli* Removals by Riverbed Filtration – A Physical Modelling Study at Different Filter Bed Depths and Inflow Rates

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**Abstract:** Riverbed filtration system (RBeF) is a simple, efficient and cost-effective alternative method of extracting water for drinking water purpose. The contaminants present in the surface water were attenuated biochemically where the aquifer acts as a natural filter. This study involved a physical model work for riverbed filtration (RBeF), where the depth of filter media and the flow rate of surface water were manipulated to improve the removal percentage of true colour and *E. Coli* (media depth: 60 and 90 cm, flow rate: 1, 3 and 5 L/min). River water samples from Lubok Buntar, Kedah were used to simulate the effectiveness of RBeF for colour and *E. Coli* removal. Readings were tested at the inlet and outlet of the filter with specified flow rates. Results from the physical model study showed the colour and *E. Coli* removal increased as the media depth increased from 60 to 90 cm, from 23-57.28% to 14.82-78.45% (p-value 0.008) and 69.45-98.34% to 76.15-99.69% (p-value 0.027), respectively. Besides that, from the study, results showed that the colour and *E. Coli* removal were not significantly affected by the flow rate.

**Keywords:** True colour, *E. coli*, riverbed filtration, media depth, inflow rate

## 1. Introduction

The presence of colour in drinking water can be caused by several factors such as coloured organic matter associated with humus fraction of soil, the presence of iron and other metals, and contamination due to industrial effluents [1]. People usually do not accept the presence of colour in their drinking water as this portrays low water quality. On the other hand, the presence of faecal coliform bacteria that are commonly found in the lower intestine of warm blooded organisms shows the sign that a water source has been contaminated by human or animal waste because of their ability to survive outside the bowel of warm-blooded organisms for a long time. According to Rock and Rivera, *E. Coli* can be washed from land into the rivers, streams or lakes during rainfall besides natural wildlife, failing septic systems, recreational activities and local land use practices. Even though not all *E. Coli* are pathogens, some cause sickness such as nausea, vomiting, abdominal cramps, diarrhea and fever [2].

Many water utilities have come up with advanced technology in treating water such as membrane filtration, soil aquifer treatment and advanced oxidation. Recently, many countries have been using riverbank/bed filtration (RBF or RBeF) to improve water quality which is a simple, low-cost, and efficient method in producing high quality drinking water as compared to the conventional water treatment system. It was first used in Malaysia in water treatment plants in

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Jeli (Kelantan), Jenderam Hilir (Selangor), Kuala Kangsar (Perak), and Lubuk Buntar (Kedah) since 2013 while it has been practiced in Europe for more than 150 years [3]-[5].

Riverbed filtration (RBeF) is a process in which natural filtration takes place through a riverbed. It is composed of a single well connected to one or several collectors dug in the riverbed. RBeF is identical with the horizontal riverbank filtration (RBF) with similarities in physical and chemical principles [6]. These horizontal wells or RBeF are efficient in collecting groundwater in aquifers of limited saturated thickness and can also be installed in shallow unconfined aquifers [7]. Currently in Malaysia, a few sites have been explored and RBF have been installed to extract water for water treatment plants [8], [17]-[19]. A preliminary study in Langat River Basin, found that the studied area was hydraulically suitable to establish RBF system for river water extraction. The Langat river was predicted to be able to contribute 95% of extracted water during North East Monsoon season, where it will predominantly be from surface water [8]. From test carried out from samples extracted, the improvement on selected water quality parameters (turbidity, $HCO_3^+$, Cl, $SO_4^-$, $NO_3^-$, Al, As, and Ca) were between 5 – 98%, and microorganism such as total coliform bacteria and *E. coli* were reduced up to 99% [8]. Whereas in China, the horizontal wells are often applied to area which have lower hydraulic conductivity and with smaller exploitation quantity. Many of the United States (US) water facilities implemented riverbed filtration and this technique is famously used in the US [9]. More than 50 collector wells are under operation along the Rhine River, Netherland whereas 12 horizontal collector wells have been operated by Düsseldorf Waterworks in Germany. Meanwhile, more than 200 collector wells are functioning in the Danube province. Besides that, there are also collector wells along the Save, Main, Maas, Ruhr, Enns, Elbe and Oder Rivers [10]. In South Korea, there are about 10 horizontal collector wells under operation and 20 more were constructed in 2012 [11].

The general principle of the RBF or RBeF is dependent on natural phenomena to produce clean water, where a limited number of additional steps of sanitation is needed. The refinement process is obtained by the natural infiltration of water passing through the riverbed or riverbank and at the same time, the slow-sand filtration effect occurred. According to Umar et al. and Gutiérrez et al., the purifying process takes place mainly within the first 60 cm depth of the riverbed surface where a sediment layer known as Schmutzdecke (biologically active layer) is formed [11], 12]. Throughout the purifying process, river water will undergo a combination of physical, chemical, and biological processes, such as filtration, dilution, sorption, precipitation, redox reaction, leaching, and biodegradation, which boost the quality of raw water [13]. The filtration process will retain the biggest particles present in the water while the smaller particles will be trapped on the riverbank/bed particles surfaces by Van der Waals forces and thus increase the quality of produced water.

Since Malaysia has about 189 river basins, it is an advantage for us to apply the RBeF technique [14]. Considering RBeF only uses natural riverbed and aquifer material as the filter media, hence the capability of the media to remove the contaminant plays an important role in the efficiency of this technique. Suitable thickness of riverbed material will also influence the quality of water produced. Thus, this study was conducted in a laboratory by using a physical model with the aim to analyse the quality of filtered water in terms of colour and *E. Coli* removals naturally without using any chemical substances, at different filter media depths and different inflow rates.

## 2. Methodology

A physical model with a dimension of 1.5 m x 0.6 m x 1.5 m (h) was filled-up with 60 cm and 90 cm depths of soil from Tanah Merah, Kelantan and the initial flow rate was set-up at 1 L/min, 3 L/min and 5 L/min. The media depth was chosen at 60 cm and 90 cm based on a preliminary round which applied 30 cm depth and was found to be not efficient in removing higher turbidity level (161 NTU) at higher flowrate (>3 L/min). The soil type was classified according to Unified Soil Classification System (USCS). Apart from that, the permeability of the soil was determined following constant head method, to BS: Part 5: 1990 (BSI, 1990b) [15] for every meter depth. Other than that, the liquid limit, plastic limit and plasticity index were also determined according to the British Standard [15].

River water sample from Lubok Buntar, Kedah was used to simulate the effectiveness of RBeF in colour and *E. Coli* removal. Water samples at the inlet and outlet of the model were collected, where water sample at the inlet represented river water and water sample at the outlet represented RBeF filtrate water. In this study, the true colour was measured and the reading was recorded in True Colour Unit (TCU). The test was conducted according to Method 8025 by using Hach DR 3900 Spectrophotometer. Water sample must be filtered first by using 0.45 µm filter paper and then 10 ml of the filtered sample was filled in the sample cell. The sample cell was inserted in the cell holder and the reading was read from the display. *E. Coli* test was conducted according to IDEXX Colilert ® Test Method by using Quanti-Tray enumeration procedure [16]. This method is recognised as an ISO standard 9308-2:2012 for detecting total coliforms and *E. coli* in water. In this method, water sample was collected for 100 ml in a sterilised vessel and one packet of Colilert reagent was added into the sample. The mixture was then shaken vigorously until the reagent dissolved completely. After that, the mixture was poured directly and cautiously into the Quanti-Tray, avoiding contact with the foil tab. The sample-filled Quanti-Tray was then sealed and incubated for 24 hours at 35 ± °C. The Quanti-Tray was put under UV light in order to determine the presence of *E. Coli.* The wells appeared fluorescence in the presence of *E. Coli.* The number of wells with positive *E. Coli* was counted and referred to the Quanti-Tray MPN table to determine the Most Probable Number (MPN).

## 3. Results and Discussion

### 3.1 Soil Classification, Porosity and Permeability

From the soil classification test, it was found out that roughly the soil can be classified as poorly graded sand, where the uniformity coefficient, $C_u$, falls within the range of 3.67-8.7 whereas the value of gradation coefficient, $C_c$, is within the range of 0.73-1.22. The overall soil sample from Tanah Merah can be classified as poorly graded sand (Table 1). The grain size distribution indicated that the soil sample consisted of high percentage of sand which was between 80.46 -94.5%, whereas the percentage of gravel was between 4.90-15.00% and the percentage of silt was in the range of 0.71-8.71%. It was comparable to the study of RBF at Kuala Kangsar [19] and Lubuk Buntar [5] which also involved high percentage of sand and gravel. Meanwhile, the porosity value was recorded in the range of 0.28 – 0.33 which can be classified as poorly graded soil and the porosity is within the range of 7.95 x $10^{-3}$ to 5.35 x $10^{-2}$ cm/s. From the result is can be concluded that the water is expected to be able to flow through the media effectively as it contains mostly sand and gravel with small amount of silt.

**Table 1 - Grain size distributions, uniformity coefficient ($C_u$) and gradation coefficient ($C_c$) of the soil sample**

| Depth (m) | % Gravel | % Sand | % Silt | % Clay | $C_u$ | $C_c$ | Soil Type (USCS) |
|---|---|---|---|---|---|---|---|
| 0 | 5.76 | 82.34 | 8.71 | 0 | 4.29 | 1.22 | Poorly graded sand with silt (SP-SM) |
| 1 | 9.64 | 80.46 | 2.81 | 0 | 8.7 | 1.22 | Well graded sand (SW) |
| 2 | 4.90 | 94.5 | 0.65 | 0 | 5.29 | 0.76 | Poorly graded sand (SP) |
| 3 | 14.37 | 85.34 | 0.15 | 0 | 4.75 | 0.84 | Poorly graded sand (SP) |
| 4 | 11.68 | 88.22 | 0.10 | 0 | 4.44 | 0.8 | Poorly graded sand (SP) |
| 5 | 11.35 | 88.51 | 0.15 | 0 | 3.67 | 0.82 | Poorly graded sand (SP) |
| 6 | 7.39 | 92.21 | 0.40 | 0 | 3.67 | 0.76 | Poorly graded sand (SP) |
| 7 | 8.72 | 91.03 | 0.25 | 0 | 4.29 | 0.8 | Poorly graded sand (SP) |
| 8 | 15.00 | 84.71 | 0.30 | 0 | 5.14 | 0.73 | Poorly graded sand (SP) |

### 3.2 Colour Removal

Generally, the graphs in Fig. 1 and Fig. 2 show fluctuated results for all experiments where the removal was higher at the beginning of the experiments. In the figures, the black lines represent the first round, purple is the second round and the red lines are the third round of sampling. The hydraulic retention time (HRT) was lower at the start of the experiment and after the development of the Schmutzdecke layer (approximately 3 weeks), the HRT was lower. The layer acted as a filter and slowed the filtration process, thus increasing the HRT. In some cases during the first round of experiment (Q = 1 L/min), the removal increased after the first hour of experiment. This might be due to the absent of water initially in the media, and on the one hour sampling the flow has been stabilised.

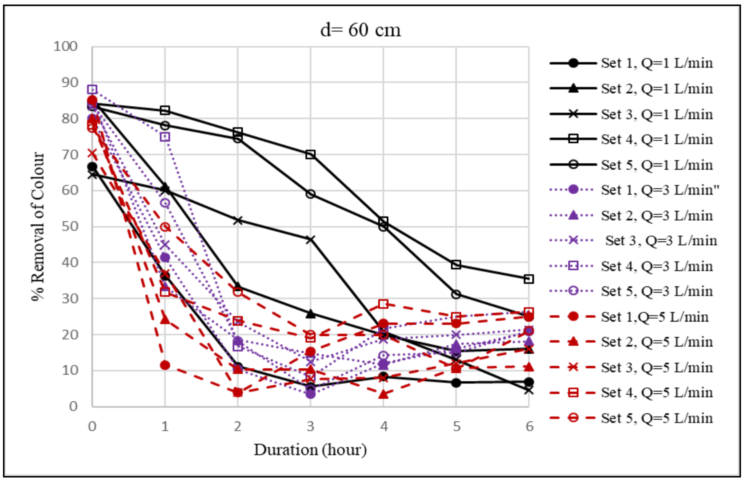


**Fig. 1 - Colour removal results at inflow rates ± 1, 3 and 5 L/min for 60 cm filter media depth**

According to a study conducted by Zahrim and Hilal [18] in treating highly concentrated dye solution by using sand filtration, the colour removal of the dye showed the same decreasing pattern. In their experiment, the dye was removed within 20 minutes and the concentration of the dye increased again after that. The rapid removal of the dye might be due to the attachment to the deposit (ripening process). After ripening, the dye concentration in the filtrate water increased slowly until it reached steady concentration. This would explain why the graph lines in both past and current experiments show a decreasing pattern in removal percentage for the earlier hours and then increased again later in the experiments.

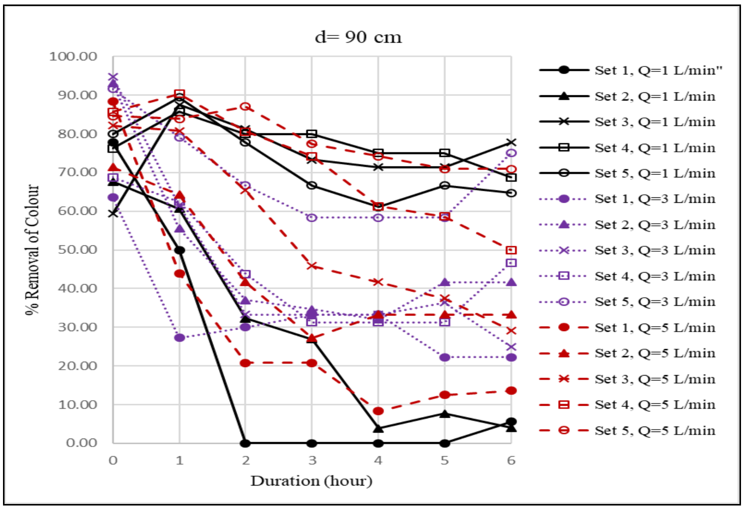


**Fig. 2 - Colour removal results at inflow rates ± 1, 3 and 5 L/min for 90 cm filter media depth**

Meanwhile, a study of riverbank filtration by Othman et al. [19] at Kuala Kangsar, Perak showed that colour removal was increased from 48.35% to 73.56% as compared to the raw water at the first day of the pumping test. The colour removal decreased to 35.78% and 0% on the second day of pumping test and increased to 50% on the third day and then decreased again to only 38.46% until the end of the pumping test. The colour of filtered water in the pumping well was in the range of 16-70 TCU as compared to the river water at 22-109 TCU.

From the summarised result in Table 2, it is clearly shown that the removal of colour was better when the media depth was 90 cm. Besides, the percentage of removal was enhanced at flow rate of 1 L/min for 60 cm media depth and at flow rate of 5 L/min for 90 cm media depth. The interaction plot of colour removal between depth and flow rate is shown in Fig. 3. As can be seen in Fig. 3, analysis of variance by factorial regression for media depth and inflow rate gave the p-value 0.008 ($< 0.05$) and 0.508 ($> 0.05$), respectively. This implies that the media depth significantly affected the filter efficiency in colour removal whereas the inflow rate did not contribute to the filter efficiency in colour removal. Meanwhile, the interaction between depth and flowrate gave p-value of 0.557 (p-value $> 0.05$) which showed that there was no interaction between the two factors. This indicates that the factor of media depth and flow rate, if manipulated simultaneously, will not have a significant effect on the percentage of colour removal. Hence, it can be concluded that the maximum colour removal was at 90 cm media depth and the flow rate did not affect the colour removal.

**Table 2 - Summary results of colour removal at different filter media depths and different inflow rates**

| Depth of filter media (cm) | Inflow rate (L/min) | Colour before filtration (TCU) | Colour of filtered water (TCU) | Removal Percentage (%) |
|---|---|---|---|---|
| | 1 | 30-45 | 6-28 | 20.23-62.69 |
| 60 | 3 | 24-30 | 3-28 | 26.29-37.29 |
| | 5 | 22-30 | 4-27 | 22.14-33.26 |
| | 1 | 18-34 | 2-25 | 14.82-77.24 |
| 90 | 3 | 11-29 | 1-17 | 33.14-69.64 |
| | 5 | 14-39 | 3-22 | 26.82-78.45 |

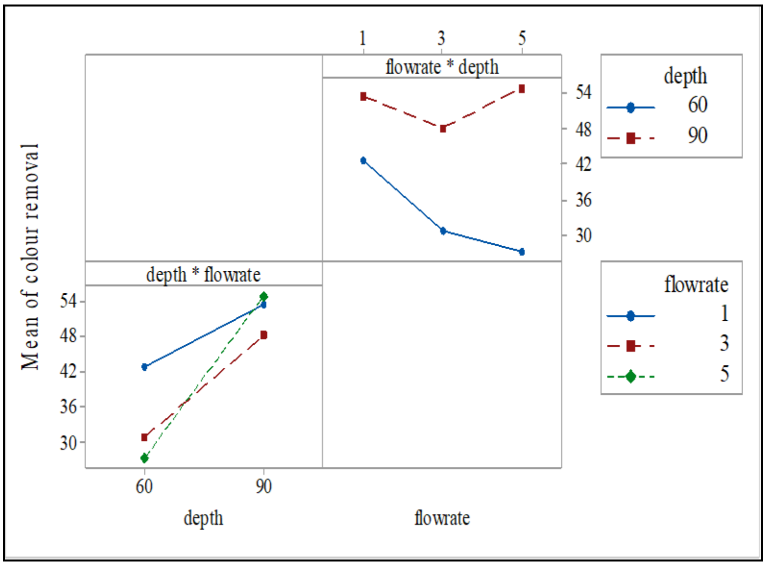


**Fig. 3 - Interaction plot for colour removal between media depth and flow rate.**

### 3.3 *E. Coli* Removal

Fig. 4 (media depth 60 cm) shows that, when the initiated flow rate was 1 L/min, the removal percentage was higher after 1 hour of the experiment which was in the range of 92 - 99% (48.1 - 1299.7 most probable number (MPN) to 1 - 75.9 MPN) in filtered water. However, only 50% of *E. Coli* could be removed at the end of the experiment for the first set as compared to the other four sets that were conducted at a later date where the removal was above 90% (14.4-152.9 MPN to <1-2 MPN) in the filtered water. When the inflow rate of 3 L/min was used, after 1 hour, above 90% removals were recorded (59.4 - 920.8 MPN to 4.1 - 18.3 MPN), whereas the removals were between 58% - 87% from 9.8 - 124.6 MPN to 2 - 26.2 MPN at the end of the experiment. The removal percentage at 1 hour of experiment for the inflow rate of 5 L/min showed an increasing pattern from 70% to above 90% in comparison to the first to the last sets of experiment. The initial reading ranged from 142.1 - 517.2 MPN whereas the reading of *E. Coli* in the filtered water was in the range 5.2 - 145 MPN. The removal percentage at 6 hours of experiment showed above 85% removal, from 50.4 - 201.4 MPN to 2 - 16 MPN, except for the second set which was below than 70% with the reading of 111.2 MPN to 35.9 MPN in filtered water.

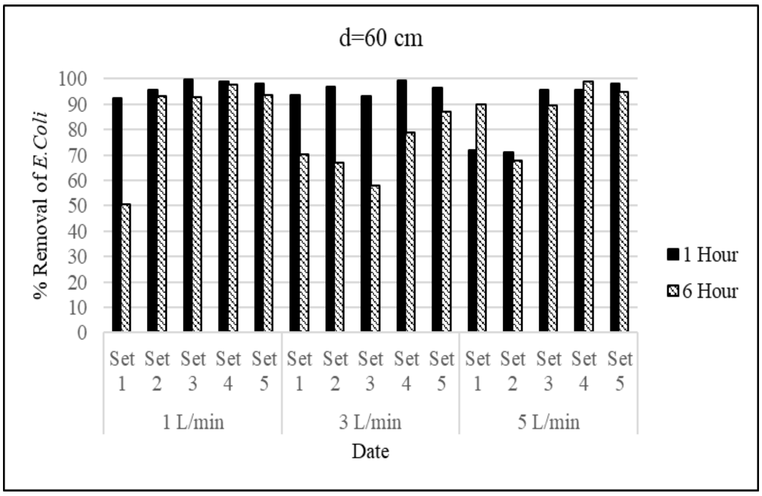


**Fig. 4 - *E. Coli* removal results at inflow rates ± 1, 3 and 5 L/min for 90 cm filter media depth**

Basically, the removal percentages of *E. Coli* were improved in the later experiment rounds as compared to the first set of experiment for all inflow rates for both filter media depths. This may be due to the maturity of the Schmutzdecke or algae layer above the filter bed as the time passed, which enhanced the efficiency of the filter. A column study by Kandhar et al. [20] reported that the reduction of total coliform bacteria was minimum at the first four weeks of the experiment and the removal was maximum at the 8$^{th}$ week of the experiment. This indicates that the biofilm development started after the 4$^{th}$ week.

According to Bagundol et al. [21] in the study of slow sand filtration, the Schmutzdecke layer could probably be the mechanism of *E. Coli* removal in water. Verma et al. [22] also stated in their study of slow sand filtration that biologically active Schmutzdecke layer hosts bacteria, diatoms, protozoans and metazoan to retain pathogens and produce microbiologically safe water. Besides, the effluent quality was usually poor during the ripening process of Schmutzdecke layer. Hence, the result obtained as reported in the subtopic above showed that the filter was efficient to remove *E. Coli* at later dates, even though the inflow rate was higher, where at that time the algae layer was fully matured.

Based on the summarised results in Table 3, the removal percentage of *E. Coli* showed a slight improvement as the depth of filter media increased. Besides that, the removal was improved at flow rate 1 L/min for 60 cm media depth and at flow rate 5 L/min for media depth of 90 cm. The analysis of variance by factorial regression gave a p-value of 0.027 for media depth factor and p-value of 0.291 for flow rate factor. That means the media depth did affect the removal of *E. Coli* in the filtered water and flow rate did not contribute to the filter efficiency in *E. Coli* removal. The interaction plot for *E. Coli* removal between media depth and flow rate is shown in Fig. 5 with p-value 0.737, which shows that there is no interaction between the two factors. It can be concluded that the maximum removal percentage of *E. Coli* was at media depth 90 cm. However, *E. Coli* were still present in the filtered water which did not follow the drinking water standard of the maximum acceptable value of 0 MPN in 100 ml. Thus, further treatment was needed to make sure the filtered water is safe for drinking water purposes.

**Table 3 - Summary results *of E. Coli* at different filter media depths and different inflow rates**

| Depth of filter media (cm) | Inflow rate (L/min) | *E. Coli* before filtration (MPN) | *E. Coli* in filtered water (MPN) | Removal percentage (%) |
|---|---|---|---|---|
| 60 | 1 | 48.1-1299.7 | <1-75.9 | 71.44-98.35 |
| | 3 | 59.4-920.8 | 2-26.2 | 75.63-91.71 |
| | 5 | 142.1-517.2 | 2-145 | 69.45-97.27 |
| 90 | 1 | 47.5-1413.6 | 1-14.3 | 89.6-99.55 |
| | 3 | 160.7-547.5 | 1-58.3 | 76.15-97.73 |
| | 5 | 93.3-1299.7 | 0-72.3 | 92.5-99.69 |

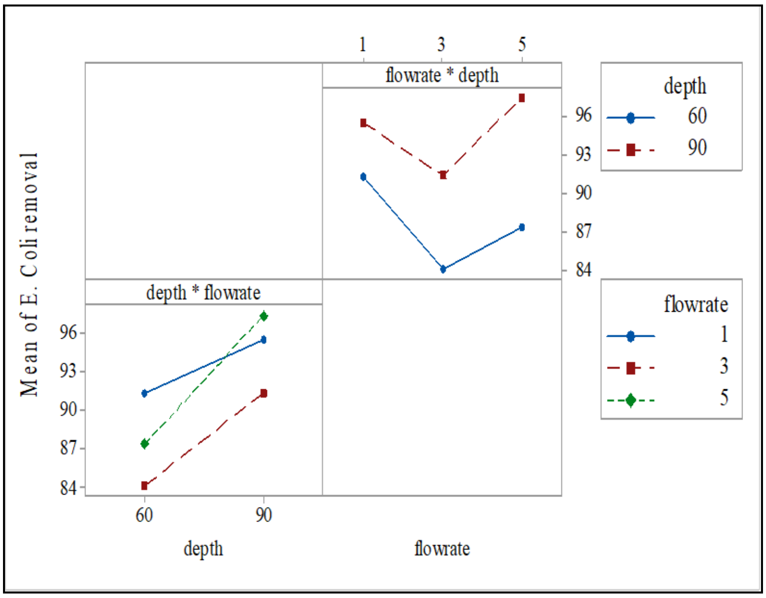


**Fig. 5 - Interaction plot for E. Coli removal between media depth and flow rate**

Since this physical modelling study has a similar concept with the slow sand filtration study, hence the result of *E. Coli* obtained will be compared to the previous study of slow sand filtration. According to a study conducted by Nancy et al. [23], the removal efficiency of the bacteria groups did not fully depend on the sand bed depth. Even though the removal of coliform organisms achieved 98% when the sand depth was 0.5 m as compared to depths of 0.7 and 1 m, the study showed that there was no significant difference in bacteria removals in effluent water at different filter media depths. This statement is supported by a study conducted by Bagundol et al. [21], which stated that the development of the Schmutzdecke layer was responsible for the removal of *E. coli* regardless of filter depths and flow-through rates. This was because most of the biological treatments occurred on top of the filter media and increasing the filter depth would have only little effect on the bacteria removal.

## 4. Conclusion

Both colour and *E. Coli* removals showed that the media depth has affected the removal percentage while inflow rate did not affect the removals. The removal percentages of colour were enhanced when the flow rate was 1 L/min for filter media depth of 60 cm and at 5 L/min for filter media depth of 90 cm, which was in the range of 20.23 - 57.28% and 26.82 - 78.45%, respectively (p-value for inflow rate; 0.508, and p-value for media depth; 0.008). The removal percentage of *E. Coli* was significantly increased as the depth increased (p-value of 0.027), where the removal percentages were in the range of 69.45 - 98.35% and 76.15 - 99.69% for media depths 60 cm and 90 cm, respectively. Meanwhile, the flow rate did not have a significant effect on the removal percentage of *E. Coli* (p-value of 0.291). However, the *E. coli* in final drinking water must have 0 MPN values (no (*E. coli* detected). Therefor it can be concluded that even though RBF can provide until 99% removal of bacteria, chemical disinfectant is still needed to make sure that residual chlorine is present at the user's end. Without residual chlorine present in water, the remaining unfiltered bacteria will continue to grow.


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