Hydraulic Behavior and Copper Ions Treatment for Flow Over Modified Gabion Stepped Weir

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Abstract
In this research; attempt to modify the traditional gabion stepped weir (TGSW) was investigated. Gravel was replaced by new available locally and inexpensive media which is Porcelnite and lime stone. The efficiency of dissipating flow energy, classify the flow types and its efficiency in removal copper (Cu) from simulated wastewater. Six of different discharges values were carried out for investigate hydraulics behavior, water surface profile, the energy dissipation for modified gabion stepped weir (MGSW) and TGSW. Three flow rates (2.5, 5 and 15) L/m is chosen for testing the weir efficiency in removal of Cu with initial concentration of 3 mg/L. The results showed the maximum energy dissipation occurred with lime stone (MGSW), for small (nappe) and high (transition) flow rates, whereas the increase of relative energy dissipation (R.E.D) at high flow rate (Q=18 L/m) equal 26.35 % compared with flat sloped weirs, 16.35 % compared with stepped weir without any addition and 10% more than (TGSW), While the R.E.D of porcelnite rock was low and equal to 10 % at high flow rates (transition flow). For environmental result show porcelnite rocks (MGSW) has a good ability for removing of copper metal (Cu), whereas the removal efficiency was 90% at initial of system operating and 58% after 6 hours from operating, while the gravel media (TGSW) was inefficiency for removal of (Cu) even for low flow rates whereas (RE% = 23.59, 15.56 and 10.13 %) at three flow rates respectively.
Keywords: energy dissipation, modified gabion, stepped weir, Porcelenite, lime stone removal efficiency, copper ions.

1. Introduction

In general, the major functions of weirs are to regulate river flow and to reserve water. Impermeable weirs prevent transportation of chemical and physical substances in water and the movement of aquatic life. Nowadays, alternative hydraulic structures of solid concrete weirs which made of porous media such as gravels or stones called gabion weirs, these types of weir preferred since can meet the natural, ecological, and environmental requirements better. Stepped weirs can also be made in gabion style, whereas stepped gabion weirs have many applications in dam structures, river engineering, hydraulic work; soil conservation works (small earth dams). They are more stable, easy to build and flexible than their rigid (impervious) counterparts, in areas where plenty of stones are available, this type of structure will be an economical alternative. Gravel and rocks are used in porous dams to create a porous body which the water crosses through it (Salmasi et al.2012, Gonzalez et al.2008). The wire mesh of the gabion basket serves to restrain any significant movement. Also, gabion weirs offer an alternative design that could be adopted for flash flood mitigation (Mohamed 2010).

Many researchers have investigated and study the hydraulics behavior and the effect of many parameters such as dimensions, types of crest and number of stepped on the energy dissipation and hydraulic characteristics of different type of gabion stepped weirs. (Peyras et al. 1991, Peyras et al. 1992) studied the flow patterns and energy dissipation of gabion stepped chutes. Kells discussed the interactions between of seepage and free-surface flows (Kells 1995). Chanson reviewed the design of gabion stepped spillways(Chanson 2001); (Chinnarasri et al. 2008) maintain that energy loss ratios in the gabion-stepped weirs are greater than those in the corresponding horizontal stepped weirs by approximately 7, 10, and 14% for weir slopes of 30, 45, and 60 degrees, respectively.

Streams and rivers play an essential role in water supply. Moreover, they are considered the main source for water supply used in drinking, irrigation, industrial and municipal water supply and disposal, navigation, and fishing (Water Quality Assessments 1992) .Streams and rivers receive lots of point source and non-point source pollutants in addition to receiving residual waste daily produced by the community. Some of these pollutants could be inorganic silt derived from surrounding lands, organic particles of dead plants and animals sinking down the water column leading to oxygen depletion in the streams (Velz 1984). Many countries are encountering polluting problems in their water. For Instance, the United Kingdom is suffering from the pollution of its rivers and streams due to the disposal of chemical contaminants; Key Largo in Florida has growing oil. The Damodar River where there are large concentrations of heavy metals arising mainly from electroplating, tanning and metal industries (Water Quality Issues 2005). Barbooti et al. and Kadhem concluded that concentrations of metals ions for samples taken from Tigris river at Baghdad city were higher than guidelines of standards specification of Water Pollution Control Regulation of Iraqi Authorities 1989 and WHO 2004.(Barbooti et al. 2010, Kadhem 2013)

Deyah et al. used cascade weir filling with limestone media and trickling the wastewater on it, for removal some of pollutants includes, Phenols, Surfactants and Polychlorinated biphenyls (PCBs) (Abbood 2015].

The present research is to integrate two objectives in single system, first, study the efficiency of replacing traditional gabion steeped weir (gravel) by new media such as porcelenite and limestone for removal of (Cu) by taking many samples of water before and after the weir which is Finally; treatment irrigation water from hazardous industrial pollutants, second, the energy dissipation at traditional or modified gabion stepped weir are higher than of these in rigid (impervious) stepped spillways due to the extra resistance offered by both the surface and the through-flow, thus reducing the cost of the stilling basins constructed.

2. General Theoretical In Stepped Spillway

The following general relationships for the flow energy dissipation were applied at upstream and downstream of each stepped spillway [15]:

$$E_0 = y_0 + \frac{\alpha v_0^{\ 2}}{2g} \tag{1}$$

$$E_0 = y_1 + \frac{\alpha v_1^{\ 2}}{2g} \tag{2}$$

$$\frac{\Delta E}{E_0} = \frac{(E_0 - E_1)}{E_0} \tag{3}$$

where y_0 is depth of water at upstream, cm, y_1 is depth of water at toe of stepped weir, cm, v_0 is velocity at upstream, m/sec, v_1 is velocity at downstream at toe of spillway, m/sec, α is kinetic correction coefficient for turbulent flow and it is generally equal to 1.1 according to (Chen et al., 2002), *g* is acceleration due to gravity, m/s^2, E_0 is upstream energy, m, E_1 is downstream energy, m, and ($\Delta E/E_O$) is relative energy dissipation (R.E.D) between upstream and downstream of stepped and flat sloped spillway, %.

3. Materials and Method

3.1 preparations of media

Porcelnite and lime stone rocks are widely available in the Western Desert of Iraq. They were selected due to availability, inexpensive in cost and their durability. Part of porcelnite has been used it purchased from the General Company of Geological Survey while lime stone medium was bought from Iraqi market. The rocks was broken in the construction material laboratory using a crushing machine then sieved for two suitable size with diameter ranges of 2.36 to 4.75mm and 4.75 to 9.5 mm the two different size are mixing with ratio of 65% and 35% for each size respectively then washed using distilled water and drying in oven for 24 hours at 105^o and keeping in plastic container to used later. The samples of Porcelnite and lime stone mediums which used in stepped weir are presented in figure (1) respectively.

Figure 1. Images of filtration media **a)** porcelenite (P) **b)** Limestone (LS)

3.2 Laboratory Flume and Mold of Stepped weir

The experimental work was performed using a flume with armfield bench at the lab of hydraulics in the faculty of Engineering as show in figure 2. The flume is rectangular with a length of 1.5 m, width 5.2 cm and depth 13 cm. Discharges were measured by armfield bench using the volumetric method. The armfield bench is fabricated from plastic material with dimension 1m Height, 1.13 m width and 0.73 depth. The flume installed above the bench. The technical details of bench accessories are Centrifugal pump type with max water head 21m and max flow rate 1.35 l/s, the rating of motor 0.37 kw, capacity of sump tank 250 L, high flow volumetric tank 40L and low flow volumetric tank 6 L and Height of working surface 1m above floor level. The mold of stepped weir which used in the study is made from stainless steel material the first part of mold is block of broad crested weir with curvature of 10 mm at the top of front face to prevent the separation of flow at entrance. Broad weir height 9 cm this height equal to about 69 % from flume depth to ensure upstream head without water spills from both sides of the channel and the width of the model is 5.2 cm equal to width of flume. The length of crest and radius of curvature of upstream face are from the following equations (Chow 1959, Henderson 1966), respectively.

$$\frac{L_{crest}}{H_T - h_e} > 1.5 - 3 \tag{4}$$

$$R = 0.2(H_T - h_e) \tag{5}$$

Where: $Lcrest$ is the length of broad crested weir length, cm, H_T is upstream total head above the channel bed, cm, he is the height of weir above the flume bed, cm, and R is the radius of curvature at top of upstream face.

Figure 2. Indoor flume with stepped weir model at the hydraulics laboratory.

The second parts of mold are three steps with length of 10 cm for each one; rectangular plates steel strainer are used for separating each step from the other beside, the height of plate 1, plate 2 and 3 are (6.5, 4 and 1.5 cm) respectively whereas the height of the fall for each step is 2.5 cm and the diameter of the openings of the metal plate is 1 mm that suitable for the diameter of the stone granules which will beused in the experiments in order to prevent the mixing of media or washing out. The figure (3) explains the mold of stepped weir in details.

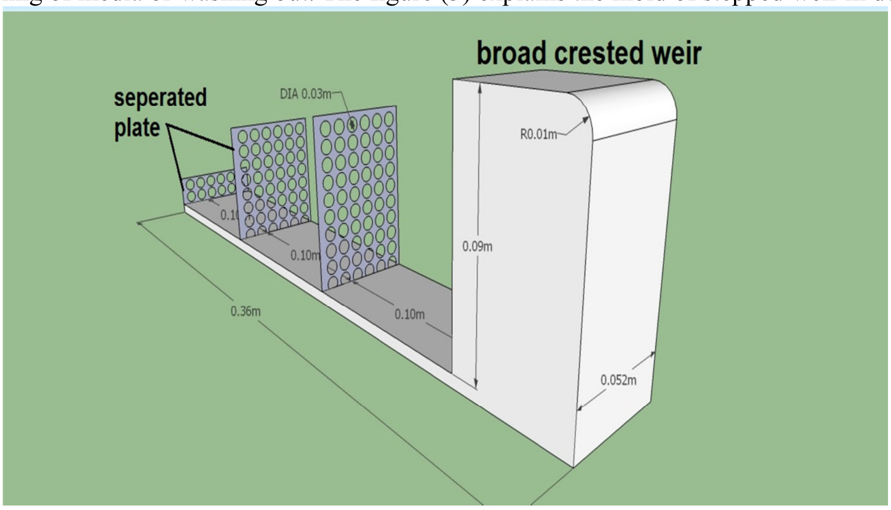

Figure 3. Sketch show the details of steeped weir mold.

3.3 Experimental method

The model was installed in a flume at a distance equal to 0.75 m from the entrance of it (according to standard location of accessories of arimfield flume), at the first set of experiments the steel mold filled with gravel as traditional gabion stepped weir (gravel), second it filled with Porcelnite media that was prepared as mentioned in item 3.1 above as modified gabion stepped weir, next operating the system to feed the water to the flume. For each model six runs were utilized to measure the following parameters: the discharge (Q), the upstream flow heads were measured at different location upstream of the model (y_1, y_2, y_3, y_4, y_5 and y_6), critical flow depth over the mid of broad crested weir (y_c), the depth over each step (ys_1, ys_2 and ys_3) and finally the flow depth downstream of model (y_{d1} and y_{d2}), figure (4) shows locations where the water depth has been measured along the longitudinal section of the flume.

To investigate the performance of the gabion stepped weir as filter system, operating and feeding the contaminant water at constant flow rate to the flume, the water was pumped at initial concentration equal 3 mg/l of copper (Cu) and after 10 minutes from start of operation, samples are takes at different interval time (10, 20, 30, 45, 60, 90,120,150,180,240,300,360 min) the samples for each time are taken from two locations upstream stepped gabion weir and downstream it. The experiments were repeated for each media (porcelenite and lime stone) at three different flow rates (2.5, 5and 15) L/m. The experiments are conducted at laboratory temperature ranging from (20-29) ^{o}C and continued for about 6 hr and the pH was adjusted to be 7.

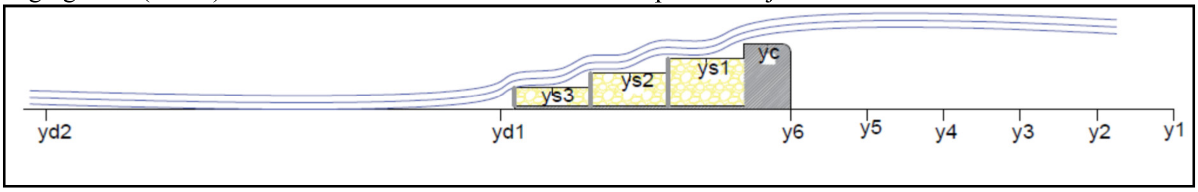

Figure 4.Schematic show water surface profile over modified gabion steeped weir

4. Results and Discussion

4.1 Types of water surface profile

Generally, there are three types of flow regimes on stepped weirs. These are nappe, transition, and skimming flows, in the present research achieved two types of flow for all models nappe flow at low discharges was less than 12.5 L/m and transition flow at flow rates ranges (12.5 – 18 L/m).the images in **Figure (5)** shows the two flow types which was obtained for flow over modified stepped weir for each of Porcelnite and Limestone media also schematic in figure 4 is confidence with image in Figure 5.

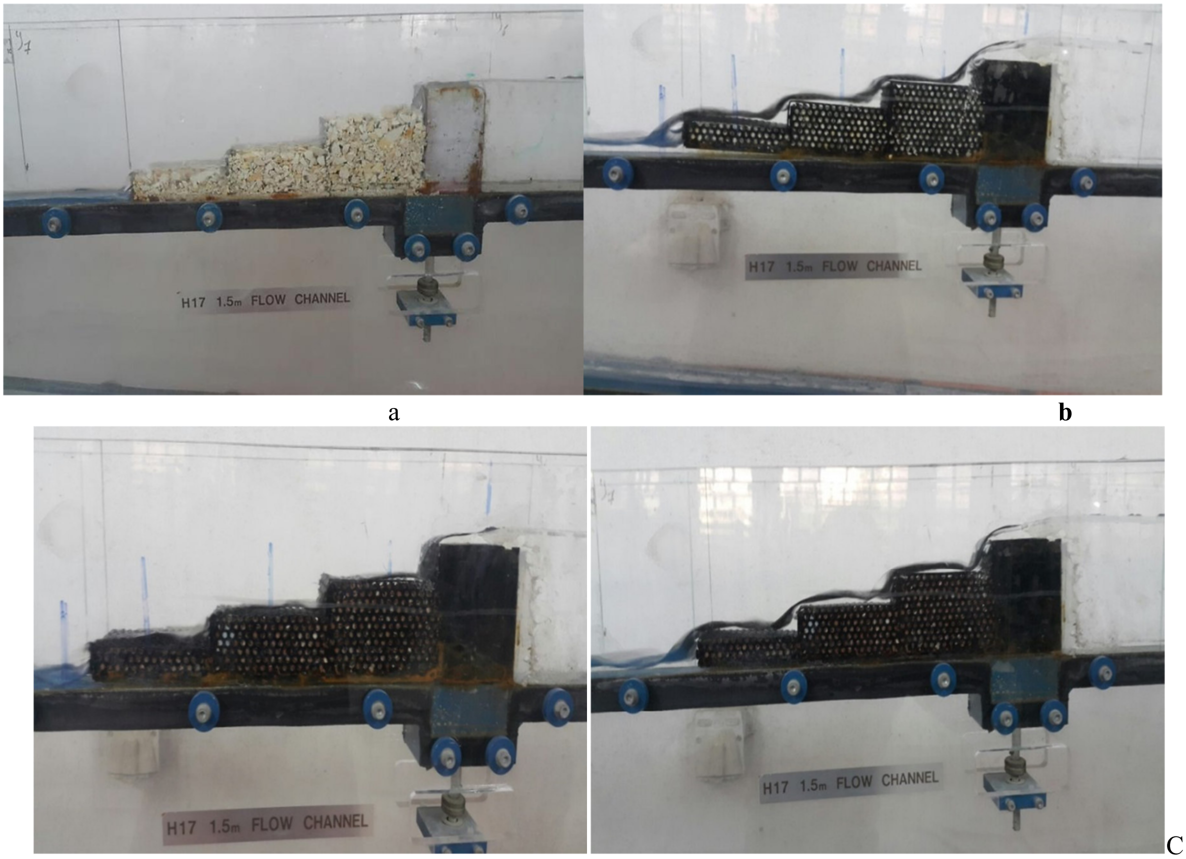

Figure 5. a) Nappe flow over porcelnite weir. b) Transition flow over porcelnite weir.
c) Nappe flow over limestone weir. d) Transition flow over limestone weir.

mentioned earlier, absenteeism and turnover are identified as the two major problems leading to workforce Figure 6 represent the water surface profiles that were obtained experimentally at flow over limestone weir at different flow rate for two types of regimes. Figure shows that, the longitudinal section of flow has been divided into three zones, the first zone is upstream the weir , In this region, we note an increase in the height of water surface when approaching the steeped weir this type of flow is known gradually varied flow as shown in figure 4 ,The second zone represented by flow through the area enclosed by the stepped weir in which water runs from one step to another we notes when the discharges increase the depths of water increasing above the steps of weir . The third zone represented by the region downstream of the weir. Figure 7 show the water surface profile of flow over (MGSW). As indicated in figure the nappe flow presented at low discharge Q = 2.5 L/m for while transition flow occurred at high discharge Q = 15 L/m for each of porcelnite and limestone media. Therefore, the efficiency of relative energy dissipation was increasing at low discharges (nappe flow) for two media.

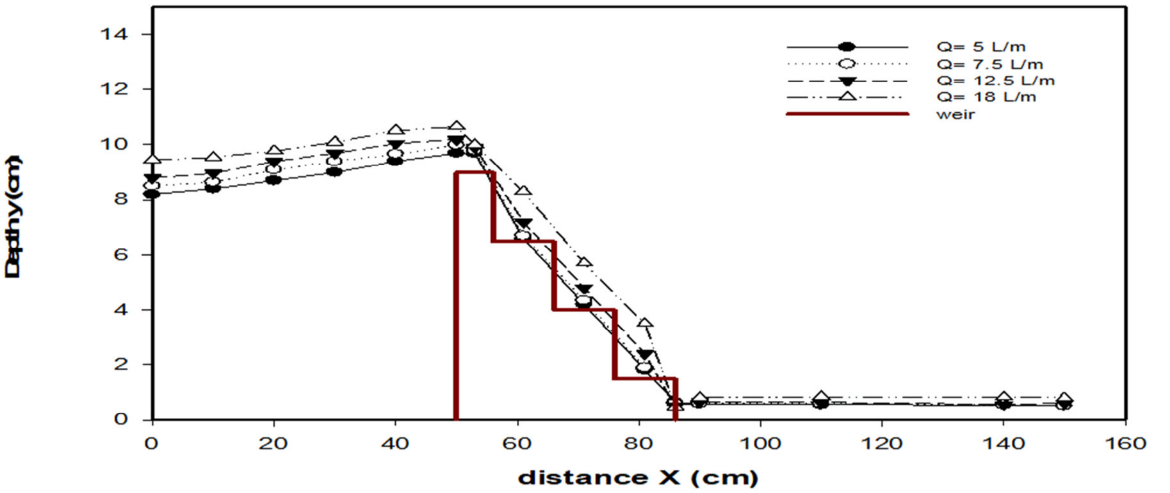

Figure 6. Water surface profile for (MGSW) lime stone media at different flow rates

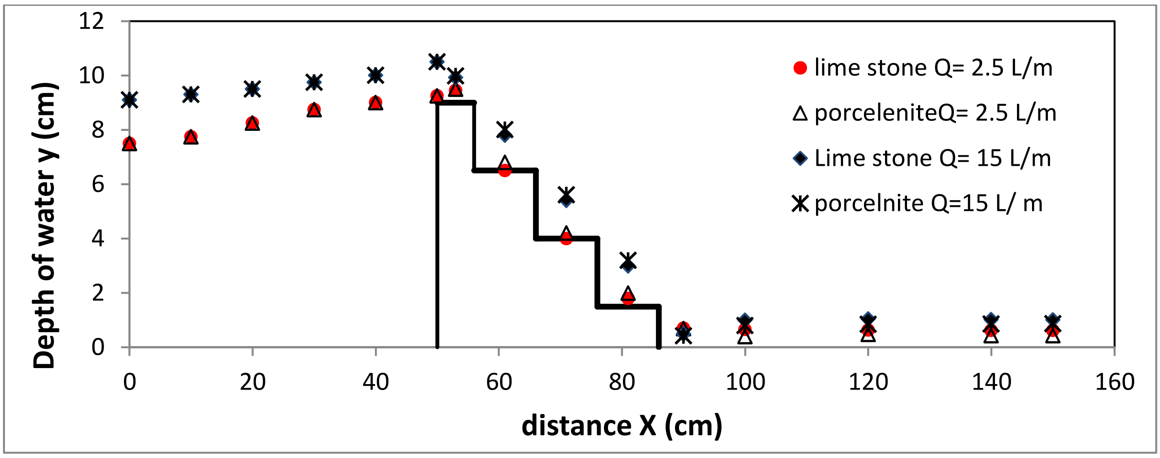

Figure 7. Water surface profile for lime stone and porcelnite at nappe and transition flow

4.2 Result and analysis of Energy dissipation

The first aim of this research was increase the relative energy dissipation (R.E.D) of impermeable weirs using traditional gabion stepped weir (gravel) (TGSW) and modified gabion stepped weir (MGSW) that filled with lime stone and porcelnite rocks. The energy dissipation for flow over each of (TGSW) and (MGSW) are calculated at six different flow rates. As expected the (R.E.D) was decreased when the discharge increased for all cases utilized in this research, Figure (8) show the values of relative energy dissipation (ΔE/Eo) for three media (gravel, limestone and porcelnite) are identical and very close at the few discharges (2.5, 5 and 7.5) L/s, which represent a nappe flow. While at higher discharges transition flow the highest (R.E.D) was through limestone equal to 36.5 %, While for gravel (TGSW) equal to 26.5 % and 10% for porcelnite medium.

Al- Talib 2007 found that stepped weirs were more efficient than flat sloped weirs and the relative energy dissipation (R.E.D) for flow over stepped weirs was about 10 % higher than in flat sloped weirs due to roughed surface by stepped sloped in stepped spillway compared to flat one of flat sloped [18]. Therefore, in this study the MGSW with limestone were more efficient by 26.5% than the flat sloped spillway of pervious researches. **Figure** showed the relationship between discharge and relative energy dissipation with fit of goodness R^2=0.8933 and R^2 = 0.9286 for each of (TGSW) and (MGSW) respectively and inverse relation of (R.E.D = 120.8 $e^{-0.061Q}$) and (R.E.D = 132.08 $e^{-0.077Q}$) for each of (TGSW) and (MGSW) respectively.

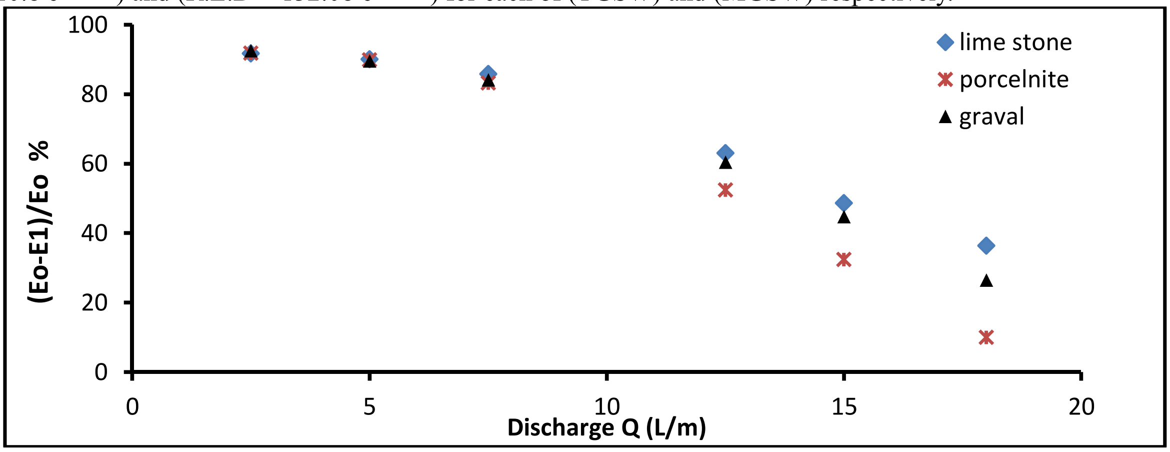

Figure 8. Relation between energy dissipation ratio and discharges for three media.

4.3 Environmental results

For testing the efficiency of (TGSW) *and* (MGSW) *in removal of copper ion (Cu) three different discharges (2.5, 5 and 15 L/m) are flowing through the laboratory flume.* The experiments start at initial concentration of (Cu) was equal to 3 mg/L. *Figures 9, 10 and 11 shows the removal efficiency of (Cu) against different interval time for each of porcelnite and limestone media as* (MGSW) and gravel as (TGSW). As expected clear from these figures that, as flow rate increases, RE% decrease at all times. This is due to decrease in the residence time of solute in the bed as the flow rate increases and therefore there is no enough time for adsorption equilibrium to be reached which results in lower bed utilization and the adsorbate solution leaves the stepped weir before equilibrium. *Fig. 9 and 10 shows that* (MGSW) *have good removal efficiency at nappe flow type (Q=2.5 and 5L/m) for each of porcelnite and limestone, whereas porcelnite have maximum removal efficiency RE%= 90 %*

at initial of operating then the removal efficiency decreased when time of operation increase, Therefore, the removal efficiency after 6 hours is equal to 65%. While for (TGSW) the results show the efficiency of gravel media is very low in removing of copper metal for all flow rates as indicated in Figure 11.

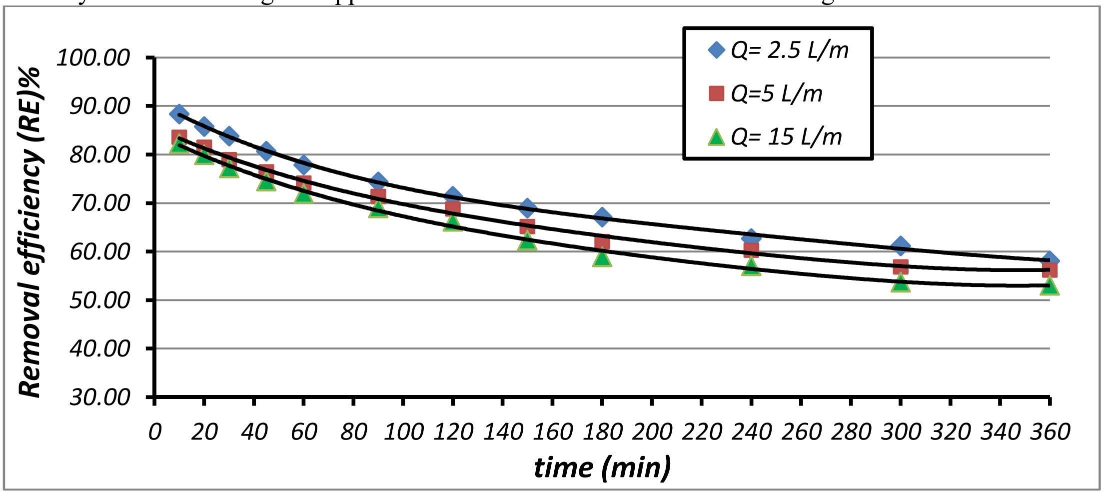

Figure 9. Experimental curves of removal efficiency of copper ion (Cu) through MGSW, porcelnite media

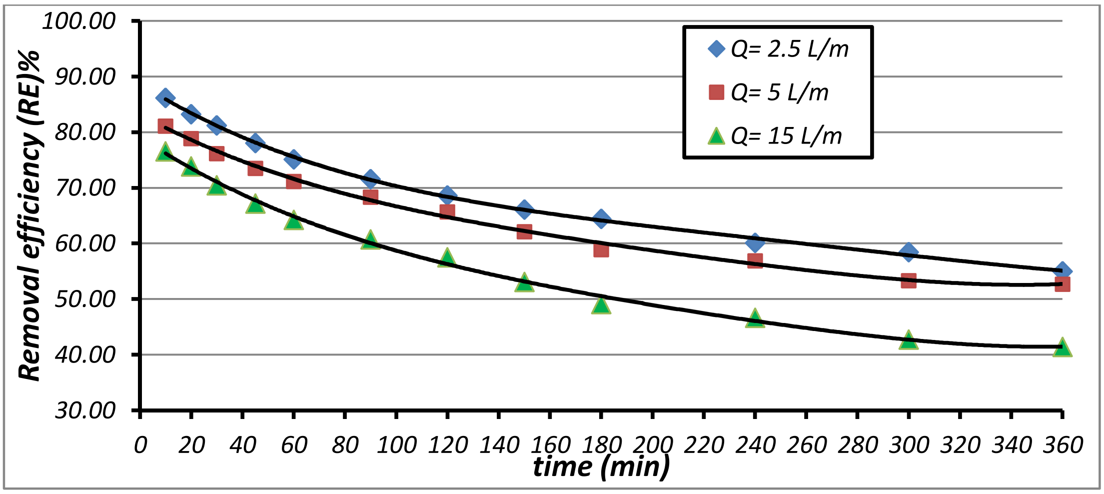

Figure 10. Experimental curves of removal efficiency of copper ion (Cu) through MGSW, Limestone media

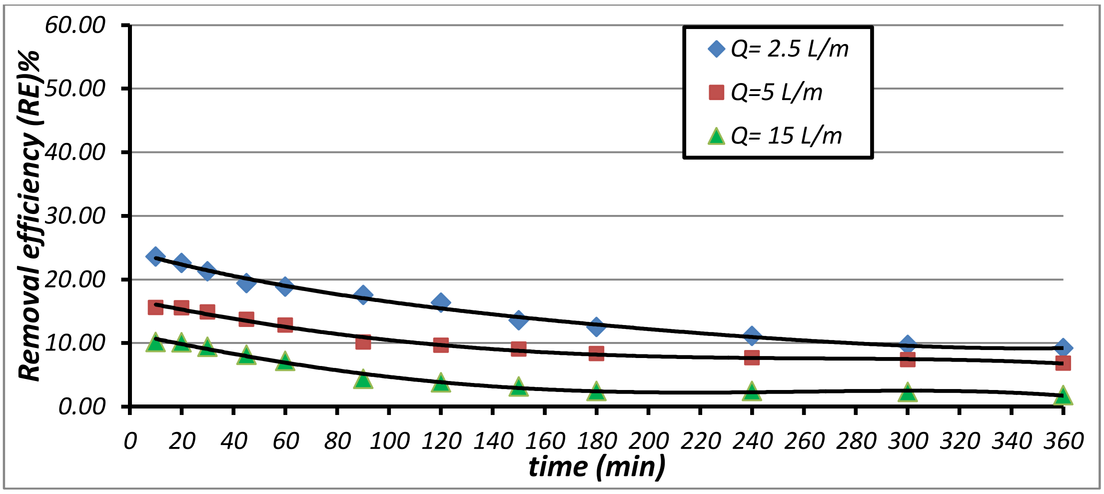

Figure 11. Experimental curves of removal efficiency of copper ion (Cu) through MGSW, Gravel media.

5. Conclusion

In this experimental study the hydraulic behavior, relative energy dissipation and removal efficiency for flow over traditional gabion stepped weir (gravel media) and modified gabion stepped weir (lime stone and porcelnite) The conclusions can be withdrawn from this study as:

- The results showed the maximum energy dissipation occurred with lime stone (MGSW), for small (nappe) and high (transition) flow rates, and that led to increase relative energy dissipation (R.E.D) by 26.35 % compared with flat sloped spillway and 16.35 % compared with stepped spillway without any addition. While the R.E.D of porcelnite rock was low and equal to 10 % at high flow rates (transition flow)
- The porcelnite steeped weir has a good ability for removing of copper metal (Cu), whereas the removal efficiency was 90% at initial of system operating and 58% after 6 hours from operating.
- The gravel media (TGSW) was inefficiency for removal of copper metal (Cu), RE%= 20 % at low flow.

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