

## Preliminary Field Study of a Model Plant for Sewage Water Treatment Using Gravel Bed Hydroponics Method

*Ismail M.I. Shalaby, Abdulla D. Altalhy and Hosny A. Mosallam*

Department of Biology, Faculty of Science, Taif University, Saudi Arabia

**Abstract:** The importance of water for life cannot be denied. Water forms the most important for all life activities. So keeping available water from being polluted and thinking of new sources of water are the most important issues for all. One of the most popular ways for that is the reuse of treated sewage and agricultural drains. There are many methods of water treatment for reuse. Of that there are chemical, mechanical and biological methods. The biological methods are regarded the most suitable, safe and cheap ones. The gravel Bed Hydroponics (GBH) method is one of the newest biological treatment methods. It has been used in many countries with a great success. It is characterized with being the less polluted method for the treatment of sewage water. It is also very economical in terms of construction and running cost. The GBH depends on using gravel and plant roots and the associated bacteria, which play an important role in clearing water. The present work can be briefed by the construction of a pilot field plant in the city of Taif, with the following specifications: 50X5X0.35 m, with a total area of 250 square meters and total volume of 15 cubic meters. The daily treatment capacity reached 75 cubic meters. The total load measured was 5 cubic meters and the retention time of waters reached 1.6 cubic meters per day. The basin was used as an experimental plant for the treatment of sewage waters and make some tests for the removal efficiency of the plant. Physicochemical and microbiological parameters were measured. It was proved from these measurements for 12 months from January to December 2007 the efficiency removal rate of pathogens from the sewage waters collected from some houses in Taif city. The highest removal rate measured was 99.4% for the removal of Ammonia on July. The lowest rate was 56% for the removal of total dissolved solids on March. The removal rate of bacteria showed the highest rate of removal during July and it was 89% for faecal streptococci, while the lowest rate was 65% for total faecal coliform bacteria on October.

**Key words:** Gravel Bed Hydroponics • Microbiology • Physicochemical • Parasites • Sewage • Biological treatment

### INTRODUCTION

Hydroponics is the science of growing plants without soil. The plants thrive on the nutrient solution alone. The medium merely acts as support for the plants and their root systems and perhaps to hold moisture around the roots. The growing medium, if any, is totally inert. Constructed wetlands have been used world-wide especially for wastewater treatment. In temperate and tropical areas, wetland systems have proved to be an effective, low cost technology for removing nutrients and organic material from wastewater. However, treated effluents satisfying physico-chemical consents for discharge may still contain large numbers of pathogens. The removal of pathogens, particularly parasite eggs, is an important health-related treatment

objective for sewage treatment systems when wastewater is used to supplement limited water resources especially for irrigation purposes. However, information on parasite egg removal in wetland systems is limited [1-3]. The removal of parasite eggs in wetland systems in semi-arid climates has been investigated using GBH reed beds in Ismailia, Egypt. Stott *et al.* [3] demonstrated that GBH system has practical application for secondary wastewater treatment and reuse with the removal of a variety of pathogens including eggs of human intestinal parasites from domestic wastewater. Although levels in raw sewage rarely exceed 1000 eggs/l, very high concentrations can occur. Diurnal and daily variation in egg numbers have also been recorded in raw and partially treated wastewaters [2]. The capability of GBH constructed wetlands to treat "shock loading" from

influent wastewater containing high numbers of parasite eggs and to consistently produce effluents meeting microbial guidelines for reuse is investigated [4]. The capacity of GBH system for parasite egg removal was evaluated with particular reference to [5] of less than 1 nematode egg per litre for safe reuse of treated wastewater [4]. The use of Gravel Bed Hydroponics (GBH) constructed wetlands for wastewater treatment and reuse in semiarid climates has been evaluated in Egypt with respect to the removal of parasite eggs from domestic wastewaters [4]. Influent and effluent from established 100m (GBH) reed beds receiving partially treated wastewater, were analyzed to establish daily parasite loading rates and removal performance of the system under normal operating conditions (20l/min; intermittent 12h on/off flow regime.) The system was then challenged with high numbers of parasite eggs (*Ascaris* sp., *Hymenolepis* sp. and *Toxocara* sp.) equivalent to an influent of 100–500 eggs/l and a daily loading rate of  $1.0\text{--}7.2 \times 10^6$ , representing up to a 110-fold increase over typical mean daily loading rates. This system was designed by the University of Portsmouth, UK and based on previous experience with the Gravel Bed Hydroponics (GBH) constructed wetland system. The steep topography of the site posed constraints on the design and a modular system composed of a rock filter in gabions for primary treatment, (GBH) beds for secondary treatment and a pond for tertiary treatment was selected. This system was designed to follow the contours of the site and maximize treatment [6]. Monitoring of the system has shown large BOD removals from more than 350 to less than 20 mg/l. Initial results have also suggested 4 log cycle reductions in indicator bacteria [6]. This survey indicates that (GBH) beds have the capacity to remove pathogens from wastewaters. Improvement in wastewater quality after (GBH) treatment satisfied WHO microbiological quality guidelines for restricted irrigation. With a retention time of 6h, (GBH) constructed wetlands have practical applications for wastewater treatment for safe reuse in Egypt [4]. Gravel Bed Hydroponics (GBH) is a constructed wetland system for sewage treatment which has proved effective for tertiary treatment in the UK and secondary treatment in Egypt. Significant improvements in effluent quality have been observed in 100 m long field scale beds planted with *Phragmites australis*, resulting in large reductions in BOD, suspended solids and ammoniacal N. For such (GBH) beds, operating optimally with a residence time of about 6 hours, 2 to 3 log cycle reductions in the counts of indicator bacteria, certain bacterial pathogens

and viruses are typically obtained. However, the efficiency of mineralization was strongly influenced by flow-rate and the prevailing temperature. In addition, in the UK, overloading of the treatment system reduced the efficiency of removal of faecal coliforms, probably due to decreased adsorption to bio-films. Faecal coliform counts were also more strongly correlated to BOD than suspended solids. As a secondary treatment process, pathogen removal was consistently better in Egypt than the UK. Although (GBH) constructed wetlands do not fully satisfy the WHO guidelines for unrestricted irrigation, they can make a significant contribution to the control of pathogens in developing countries [7]. Experimental microcosms using macrophytes were set up to determine the role of the plants and their rhizosphere in the removal of nutrients and fecal indicators from rural wastewater. *Scirpus lacustris* was grown in hydroponics culture and in siliceous gravel to compare them with the efficiency of gravel beds without macrophytes [8]. Chow *et al.* [9] stated that their study looks into the potential cultivation of butter head lettuce (*Lactuca sativa*) and Chinese cabbage (*Brassica chinensis*) using municipal wastewater in deep flow technique. Stott *et al.* [3] stated that parasite removal and low cost systems for wastewater treatment have become increasingly important requirements in developed and developing countries to safeguard public health from wastewater-associated intestinal diseases. Pilot and field-scale ponds and wetlands in Brazil and Egypt have been investigated for the fate and removal of eggs of human intestinal parasites from domestic wastewater. Stott *et al.* [4] concluded that GBH wetland systems have great potential as water treatment technology for pollution control and are a robust and economical technology capable of treating wastewater for compliance with health related objectives for the agricultural reuse of treated effluents. El-Shatoury *et al.* [10] studied the biodiversity of some microorganisms in GBH system.

## MATERIALS AND METHODS

**GBH Site Description:** The GBH wetland system under investigation was situated in Taif city just nearby the sewage water treatment plant and consisted of a subsurface horizontal flow system with a single channel (50 m length and 5 m wide) (Fig. 1) lined with poly vinyl sheet and filled with gravel about 3 – 5 cm diameter and planted with local emergent helophytes. The reed bed received primary settled sewage transferred to the site by tanks from retention reservoir at a flow rate of about

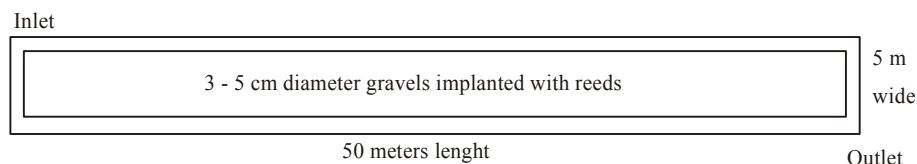


Fig. 1: Diagrammatic scale of the GBH basin

20 l/min under an intermittent 12 h on: off flow regime equivalent to a hydraulic loading of 72 mm/d. Under these conditions, wastewater has a reported residence time of approximately 3 hours in the bed. The final effluent from the reed bed was gravity discarded nearby. The full data of the GBH basin are mentioned in Table 5.

Water sampling was performed on a monthly basis from the inlet and the outlet of the Gravel Bed Hydroponics (GBH) basin for at least one year. Ten samples were collected till now, five from the inlet and five from the outlet of the GBH basin. Sampling was started on March 2007 equivalent to Safar 1428. The following parameters were determined in each sample:

**Physicochemical Parameters of Water Samples:** pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Turbidity (T), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Ammonical Nitrogen (Amm), Oxidized Nitrogen (OX N), Total Nitrogen (TN). All above parameters were determined according to the standard methods for the examination of water and wastewater [11]. Flow rate, detention rate, day time water temperature (°C), hydrogen ion concentration (pH) and dissolved oxygen (DO) were determined immediately in the field at the time of sampling. Parameters such as (BOD), (COD), (TSS), Total dissolved solids (TDS), Ammonical Nitrogen (Amm), Oxidized Nitrogen (Ox N) and Total nitrogen (TN) were monitored monthly in all water samples collected from the inlet and outlet of the (GBH) basin. For comparison of physicochemical parameters removal, inlet concentrations were subtracted from outlet concentrations for each parameter  $\delta \log[\text{mg/l in/mg/l out}] = \log \text{mg/l in} - \log \text{mg/l out}$  [12].

**Microbiological Parameters of Water Samples:** Total Viable Bacteria (TVB), Total Coliforms (TC), Faecal Coliforms (FC), Faecal Streptococci (FS). All the above microbiological parameters were performed according to the standard methods for examination of water and wastewater [11]. Serial dilutions were prepared immediately after sample collection. The proper dilutions

for various bacterial groups were selected so that number of colonies on plate will be between 30 and 300 using the pour plate method.

For comparison of bacterial removal, inlet concentrations were subtracted from outlet concentrations for each bacterial type  $\delta \log[\text{CFU in/CFU out}] =$

$$\log \text{CFU in} - \log \text{CFU out} \quad [12]$$

**Parasitological Analysis of water samples:** Cysts of Protozoa (CP) and Ova of Helminthes (OH) parameters were performed using direct thin smear technique. In which a thin smear from the precipitant of the centrifuged sample was made on a glass slide and stained with Lugol's Iodine method.

## RESULTS

**1-Physicochemical Parameters:** Table 1: shows the monthly values of the physicochemical parameters measured in the 24 samples collected. It is obvious the differences between the inlet and outlet samples which indicate the efficiency of the system.

Table 2 shows the log values of the removal of physicochemical parameters and the removal percentage in GBH basin: The highest percentage removal in Table 2 is 99.4% which represents the removal rate of Ammoniacal Nitrogen in September. While the lowest rate is 56% which represents the removal rate of total dissolved solids during March.

**2-Microbiological and Parasitological Parameters:** Table 3 shows the monthly values of the microbiological and parasitological parameters measured in the samples collected:

Cysts of *Giardia lamblia* and *Entamoeba histolytica* as well as ova of *Ascaris lumbricoides* and *Hymenolepis nana* were observed in influent water. Few ova of *Ascaris lumbricoides* and *Hymenolepis nana* were seen on effluent water. It is shown that the efficiency of parasite removal is high, however, the number of parasitic stages were small in influent wastewater.

Table 1: shows the monthly values of the physicochemical parameters measured in the 24 samples collected

Sample	pH mg/l	DO mg/l	TSS mg/l	TDS mg/l	BOD mg/l	COD mg/l	Amm. mg/l	OX. N. mg/l	T-N mg/l	C°
Inlet January	7.68	0.10	477.00	65.00	199.00	755.00	81.00	0.40	86.52	18
Outlet January	7.20	1.90	61.00	25.00	34.00	175.00	0.58	0.86	3.65	19
Inlet February	7.86	0.20	575.00	58.00	201.00	843.00	80.00	0.10	85.77	20
Outlet February	7.00	2.50	79.00	21.00	36.00	172.00	0.56	0.83	3.35	21
Inlet March	7.84	0.13	468.00	61.00	205.00	766.00	89.00	0.60	86.33	24
Outlet March	7.35	2.80	70.00	27.00	31.00	167.00	0.59	0.90	3.80	25
Inlet April	7.60	0.14	587.00	72.00	208.00	847.00	88.00	0.30	86.55	29
Outlet April	7.30	3.40	63.00	17.00	29.00	162.00	1.30	0.77	2.90	30
Inlet May	7.76	0.22	681.00	67.00	210.00	837.00	83.00	0.50	86.76	30
Outlet May	7.24	3.80	65.00	18.00	30.00	153.00	1.20	0.69	5.80	32
Inlet June	7.72	0.11	469.00	71.00	203.00	839.00	85.00	0.20	87.45	34
Outlet June	7.18	3.00	63.00	23.00	32.00	159.00	1.00	0.72	6.90	36
Inlet July	7.67	0.10	478.00	66.00	197.00	754.00	80.00	0.47	86.50	36
Outlet July	7.22	1.90	60.00	23.00	33.00	173.00	0.56	0.88	3.60	37
Inlet August	7.88	0.20	576.00	59.00	202.00	841.00	82.00	0.20	85.75	36
Outlet August	7.20	2.50	77.00	23.00	38.00	174.00	0.54	0.85	3.33	36
Inlet September	7.87	0.13	469.00	60.00	200.00	768.00	88.00	0.61	86.36	27
Outlet September	7.33	2.80	72.00	25.00	30.00	165.00	0.57	0.92	3.83	26
Inlet October	7.65	0.14	589.00	70.00	205.00	843.00	86.00	0.33	86.57	25
Outlet October	7.32	3.40	61.00	19.00	26.00	166.00	1.10	0.78	2.92	26
Inlet November	7.78	0.22	683.00	66.00	212.00	834.00	82.00	0.52	86.74	24
Outlet November	7.25	3.80	70.00	17.00	32.00	156.00	1.30	0.68	5.82	23
Inlet December	7.73	0.11	467.00	73.00	205.00	836.00	87.00	0.21	87.47	20
Outlet December	7.19	3.00	60.00	25.00	30.00	157.00	1.20	0.73	6.94	20

Table 2: The log values of the removal of physicochemical parameters in GBH basin

Sample	TSS	TDS	BOD	COD	Amm.	OX. N.	T-N
January log removal (%)	0.89 (78.0)	0.41 (61.0)	0.76 (83.0)	0.63 (77.0)	2.15 (99.0)	-0.33	1.37 (96.0)
February log removal (%)	0.86 (86.0)	0.44 (64.0)	0.75 (82.0)	0.69 (79.0)	2.16 (99.0)	-0.92	1.41 (96.0)
March log removal (%)	0.83 (85.0)	0.35 (56.0)	0.82 (85.0)	0.66 (78.0)	2.17 (99.0)	-0.18	1.36 (96.0)
April log removal (%)	0.97 (89.0)	0.63 (76.0)	0.86 (86.0)	0.72 (81.0)	1.83 (98.0)	-0.40	1.47 (97.0)
May log removal (%)	1.02 (90.0)	0.57 (73.0)	0.85 (86.0)	0.74 (82.0)	1.84 (98.0)	-0.14	1.17 (93.0)
June log removal (%)	0.87 (87.0)	0.49 (68.0)	0.80 (84.0)	0.72 (81.0)	1.93 (99.0)	-0.56	1.10 (82.0)
July log removal (%)	0.90 (79.0)	0.46 (65.0)	0.77 (83.0)	0.64 (77.0)	2.15 (99.3)	-0.27	1.38 (96.8)
August log removal (%)	0.87 (75.0)	0.41 (61.0)	0.73 (81.0)	0.68 (79.0)	2.18 (99.3)	-0.63	1.41 (96.1)
September log removal (%)	0.81 (65.0)	0.38 (58.0)	0.82 (85.0)	0.67 (78.0)	2.19 (99.4)	-0.18	1.35 (95.6)
October log removal (%)	0.98 (96.0)	0.57 (73.0)	0.89 (87.0)	0.71 (80.0)	1.90 (98.7)	-0.37	1.50 (96.7)
November log removal (%)	0.99 (97.0)	0.60 (74.0)	0.82 (85.0)	0.73 (81.0)	1.80 (98.4)	-0.12	1.20 (93.3)
December log removal (%)	0.89 (78.0)	0.47 (66.0)	0.83 (85.0)	0.73 (81.0)	1.86 (98.6)	-0.54	1.10 (92.0)

Table 3: The monthly values of the microbiological and parasitological parameters measured in the samples collected

Sample	Total Viable Bacteria (TVB) cfu/ml	Total Coliforms (TC) cfu/ml	Faecal Coliforms (FC) cfu/ml	Faecal Streptococci (FS) cfu/ml	Cysts of Protozoa (CP) cell/ml	Ova of Helminths (OH) o/ml
Inlet January	37x10 <sup>5</sup>	410x10 <sup>3</sup>	210x10 <sup>3</sup>	28x10 <sup>3</sup>	2	10
Outlet January	24x10 <sup>4</sup>	46x10 <sup>3</sup>	33x10 <sup>3</sup>	88x10 <sup>3</sup>	0	2
Inlet February	39x10 <sup>5</sup>	430x10 <sup>3</sup>	208x10 <sup>3</sup>	20x10 <sup>3</sup>	4	8
Outlet February	30x10 <sup>4</sup>	135x10 <sup>3</sup>	27x10 <sup>3</sup>	97x10 <sup>3</sup>	0	2
Inlet March	44x10 <sup>5</sup>	415x10 <sup>3</sup>	345x10 <sup>3</sup>	27x10 <sup>3</sup>	3	7
Outlet March	42x10 <sup>4</sup>	140x10 <sup>3</sup>	87x10 <sup>3</sup>	79x10 <sup>3</sup>	0	1
Inlet April	65x10 <sup>5</sup>	440x10 <sup>3</sup>	432x10 <sup>3</sup>	40x10 <sup>3</sup>	5	6

Table 3: Continued

Outlet April	26x10 <sup>4</sup>	65x10 <sup>3</sup>	96x10 <sup>3</sup>	85x10	0	1
Inlet June	86x10 <sup>5</sup>	406x10 <sup>3</sup>	525x10 <sup>3</sup>	60x10 <sup>3</sup>	1	9
Outlet June	21x10 <sup>4</sup>	35x10 <sup>3</sup>	99x10 <sup>3</sup>	93x10	0	1
Inlet July	35x10 <sup>5</sup>	408x10 <sup>3</sup>	260x10 <sup>3</sup>	36x10 <sup>3</sup>	2	5
Outlet July	23x10 <sup>4</sup>	50x10 <sup>3</sup>	43x10 <sup>3</sup>	81x10	0	0
Inlet August	36x10 <sup>5</sup>	408x10 <sup>3</sup>	215x10 <sup>3</sup>	25x10 <sup>3</sup>	1	6
Outlet August	25x10 <sup>4</sup>	43x10 <sup>3</sup>	35x10 <sup>3</sup>	83x10	0	0
Inlet September	32x10 <sup>5</sup>	424x10 <sup>3</sup>	207x10 <sup>3</sup>	22x10 <sup>3</sup>	0	4
Outlet September	29x10 <sup>4</sup>	137x10 <sup>3</sup>	25x10 <sup>3</sup>	94x10	0	0
Inlet October	42x10 <sup>5</sup>	425x10 <sup>3</sup>	342x10 <sup>3</sup>	22x10 <sup>3</sup>	0	8
Outlet October	40x10 <sup>4</sup>	149x10 <sup>3</sup>	86x10 <sup>3</sup>	72x10	0	1
Inlet November	66x10 <sup>5</sup>	436x10 <sup>3</sup>	430x10 <sup>3</sup>	41x10 <sup>3</sup>	1	2
Outlet November	23x10 <sup>4</sup>	60x10 <sup>3</sup>	93x10 <sup>3</sup>	86x10	0	0
Inlet December	84x10 <sup>5</sup>	416x10 <sup>3</sup>	521x10 <sup>3</sup>	61x10 <sup>3</sup>	1	3
Outlet December	22x10 <sup>4</sup>	37x10 <sup>3</sup>	95x10 <sup>3</sup>	94x10	0	0

Table 4: The log removal values of bacteria in GBH basin in monthly samples

	Jan. log removal	Feb. log removal	Mar. log removal	Apr. log removal	May log removal	Jun. log removal	Jul. log removal	Aug. log removal	Sept. log removal	Oct. log removal	Nov. log removal	Dec. log removal
	(%)											
Total Viable Bacteria (TVB) cfu/ml	1.18(94.00)	1.11(92.00)	1.20(93.00)	1.10(92.00)	1.00 (90.00)	1.40 (96.00)	1.60(98.00)	1.20(93.00)	1.04(91.00)	1.02(90.50)	1.45(96.50)	1.58(97.40)
Total Coliforms (TC) cfu/ml	0.95(89.00)	0.50(68.60)	0.90(90.00)	0.50(69.00)	0.47 (66.00)	0.83 (85.00)	1.06(91.00)	0.91(88.00)	0.49(67.70)	0.46(65.00)	0.86(86.30)	1.05(91.10)
Faecal Coliforms (FC) cfu/ml	0.80(84.30)	0.88(87.1)	0.80(84.30)	0.88(87.00)	0.59(75.00)	0.65(78.00)	0.72(81.00)	0.78(83.00)	0.92(87.9)	0.60(74.90)	0.66(78.40)	0.74(81.80)
Faecal Streptococci (FS)cfu/ml	1.50(96.90)	1.31(95.10)	1.50(96.90)	1.30(96.00)	1.53 (97.00)	1.67 (97.80)	1.80(98.00)	1.58(97.40)	1.37(95.80)	1.48(96.70)	1.68(97.90)	1.81(98.50)

Table 5: The main design characteristic and operation of the reed gravel bed hydroponics constructed in Taif City

Reed Bed characteristics	
No. of beds	1
Bed dimensions (length, width)	50 mx5m
Depth of bed	35 cm
Total bed area	250 m <sup>2</sup>
Gross capacity	15 m <sup>3</sup>
Operation parameters	
Hydraulic loading	75 m <sup>3</sup> /day
Loading rate	5 m <sup>3</sup> / day
Retention time	1.6 m <sup>3</sup> /day

Table 4: Shows the log removal values and removal percentage of bacteria in GBH basin in monthly samples:

The overall percentage removal as seen in Table 4 ranged from 65-98.5%. 65% was the total coliform bacteria percentage removal in October, 98.5% was the of faecal streptococci bacteria percentage removal in December.

Table 5 show the main design characteristic and operation of the reed gravel bed hydroponics constructed in Taif City.

## DISCUSSION

Sewage treatment any where is a serious environmental problem. Therefore establishing of sewage treatment plants is essential to avoid many environmental problems including: (i) pollution of ground water, which

is the main source of drinking water in Taif city, (ii) pollution of surface water, irrigation canals and drains. Establishment of conventional sewage treatment will cost a lot of money. Non-conventional sewage treatment plants are thought of to overcome this difficulty. Gravel bed hydroponics (GBH) has been developed in research centers in England and Egypt [3,4,6,13-15]. The system was designed to face the economic and environmental challenges facing sewage treatment any where. The system is very cheap; uses the minimum land; simple treatment plant with minimum running costs; no energy consumption; no chemicals used; consistent with regulation levels any where.

The results obtained in the present study proved that GBH provides a good solution for the problem of domestic wastewater treatment any where.

The average removal log values obtained in the present study were at the upper end of the range of removal rates mentioned in the literature (79-88%) for subsurface horizontal flow systems used for secondary treatment [16,17].

The present treatment system results in the elimination of 66 - 98% of the pathogenic bacteria, 85% of BOD, 92% of TTS, 65% of TN. This agreed with the recommendations World Health Organization scientific group in their conclusions that "Municipal wastewater is a valuable resource that should be used wherever possible with adequate health safeguards" [5].

Cost benefit analysis of the present treatment plant shows that it costs less than 30% of the conventional systems. In addition, simplicity of the treatment system makes its operation and maintenance very cheap as it requires unskilled workers instead of expert engineers, as it is the case in most conventional systems.

In respect to the removal of parasite stages the present work results agrees with that of Stott *et al.* [4]. Same results were obtained by Stott *et al.* [18,19].

The results obtained in the present work showed the efficient pathogen removal from sewage waters. The findings are concluded by Stott *et al.* [4].

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