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Performance of Rotating Biological Contactor (RBC) under Different Hydraulic Loading Rates and Rotational Speeds on Ammonia Removal in a Recirculating System

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Air-drived rotating biological contactor (RBC) system, which is effective method in filtering performance, was tested for the nitrification capacity in a recirculating system. At ammonia concentrations between 0.029 and 0.528 mg/ℓ, the effect of ammonia loading rate on ammonia removal rate at three different hydraulic loading rates could be defined by the following first-order regression models: Hydraulic loading rate of 14.8 m^3/m^3/day: $y=39.2x+3.4$ ($r^2=0.9137$), Hydraulic loading rate of 26.5 m^3/m^3/day: $y=53.3x+4.0$ ($r^2=0.8686$), Hydraulic loading rate of 37.3 m^3/m^3/day: $y=58.4x+4.2$ ($r^2=0.7755$), where, x is ammonia loading rate (mg/ℓ), y is ammonia removal rate (g/m^3/day), The equations showed the optimal ammonia removal rate at the hydraulic loading rate of 26.5 m^3/m^3/day. Below the ammonia concentration of 2.72 mg/ℓ, first-order regression models between ammonia loading rate and ammonia removal rate at three different rates of speed are defined as follows: Rotational speed of 0.75 rpm: $y=28.5x+4.7$ ($r^2=0.9143$), Rotational speed of 1.0 rpm: $y=33.6x+8.4$ ($r^2=0.9534$), Rotational speed of 2.0 rpm: $y=28.9x+3.6$ ($r^2=0.9488$), where, x is ammonia loading rate (mg/ℓ), y is ammonia removal rate (g/m^3day). The equations show the ammonia removal rate at the rotational speed of 1.0 rpm is significantly higher than that at the rotational speed of either 0.75 rpm or 2.0 rpm ($P<0.05$).

Key words: RBC, hydraulic loading rate, rotational speed, ammonia removal rate

Introduction

The marine fish culture in Korea has been developing rapidly since the early 1970's mainly around the Chungmu and Yeosu areas. Initially yellowtail was mainly cultured. However, because of the difficulties of rearing this fish during the winter and getting seedling supplies, fish farmers replaced yellowtail with olive flounder and black rockfish. These species can be cultured all year round and their seedlings are readily available. They are mainly cultured in either marine floating netcages or land-based flow through culture systems. Recently, the marine floating netcage cultures are confronted with the problems of red tides and oil spills. And the land-based flow through culture systems were suffered difficulties of getting suitable water supply due to the prevailing water polluting. As a solution to these problems, water recirculating systems have been developed, which, however, require proper biological filters to treat waste materials.

The effectiveness of submerged filter systems has been studied for the culture of flounder (Honda et al., 1993), trickling filter systems for European eel (Otte and Rosenthal, 1979) and African catfish (Bovendeur et al., 1987), and rotating biological contactors (RBC) for stripped bass (Libey, 1994) and tilapia (Losordo and Westerman, 1994).

The RBC systems were originally developed by environmental engineers for the treatment of domestic and industrial wastes and studies on its effectiveness have so far been mainly focused on its environmental applications. Disks of RBC are

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driven either by a motor or an air-driven mechanism. The latter is preferable because it also aerates the rearing water. Rogers and Klemetson (1985) compared the RBC system to several other biofilters for their effectiveness in removing ammonia from recirculating systems. Miller and Libey (1985) and Westerman et al. (1993) found that the RBC system is superior in nitrification efficiency to fluidized beds and trickling filters as used in channel catfish culture.

In this study, two experiments were conducted to determine optimal operating conditions of the RBC system loaded with black rockfish, *Sebastes schlegeli*, at different hydraulic loading rates and rotational speeds.

Materials and methods

In this study, the recirculating system was consisted of a rearing tank (1 m^3), a reservoir tank (150 ℓ), and six rotating polyvinyl film disks. RBC was consisted of a 60 cm shaft and 23 round disks with 32 cm diameter, which provided 12 m^2 of total effective surface area in 0.075 m^3 of volume (Fig 1).

At first experiment, for optimal hydraulic loading rate of the RBC system, recirculating rates were adjusted at 353 ℓ, 636 ℓ and 896 ℓ per hour, i.e. hydraulic loading rates were controlled at 14.8, 26.5, and 37.3 $m^3/m^2/day$, respectively. At this time, rotational speed was adjusted to 1.0 rpm. The rearing tank was stocked with 10~20 kg of black

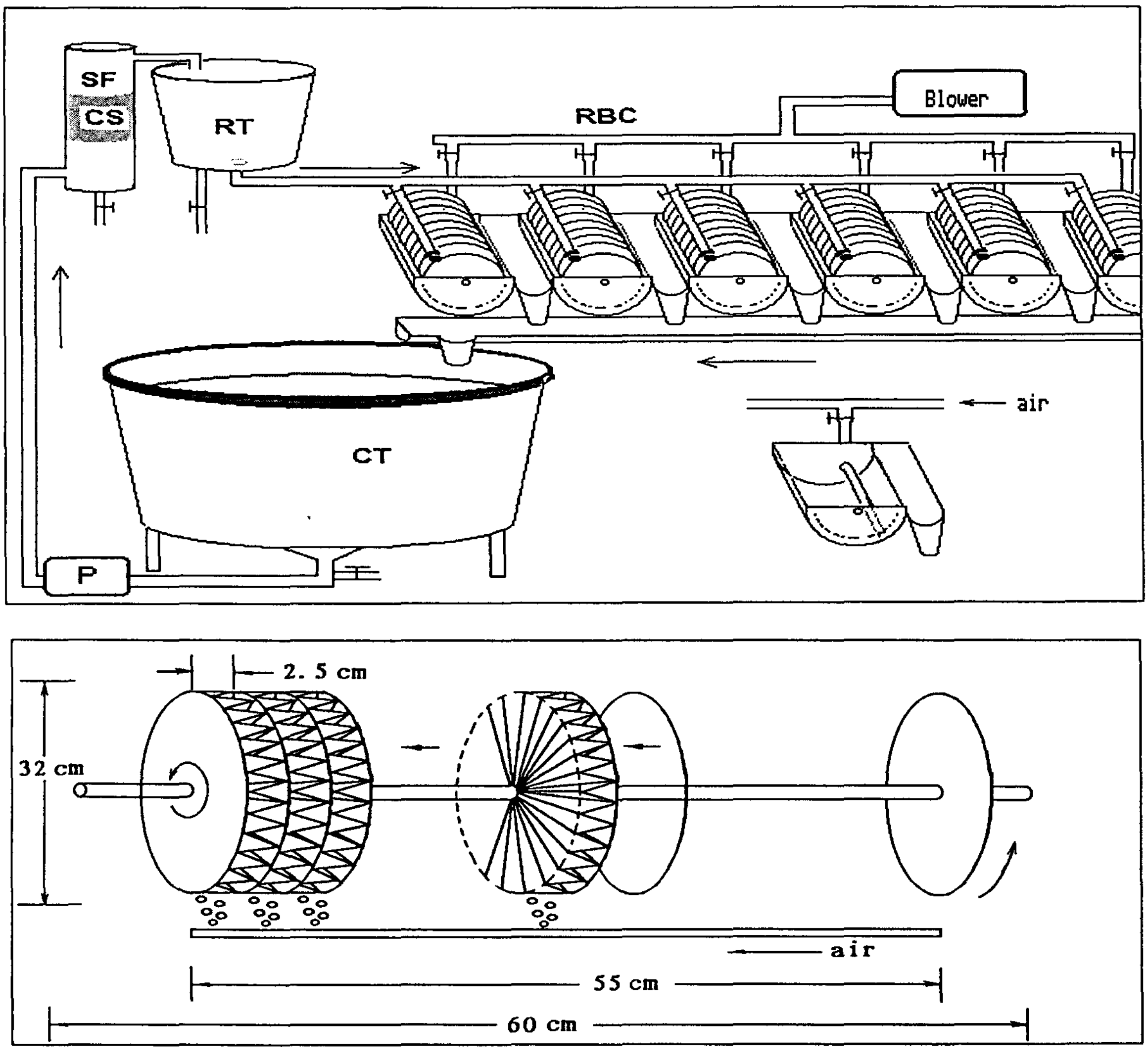

Fig. 1. Diagram of experimental system for the test of nitrification in the RBC system. (CT) culture tank; (P) pump; (RT) reservoir tank; (RBC) rotating biological contactor; (SF) submerged filter; (CS) coral sand.

rockfish (mean weight 500 g) to provide ammonia nitrogen.

At second experiment, for optimal revolution of the RBC system, rotational speeds were adjusted at 0.75 rpm, 1.0 rpm, and 2.0 rpm using air blower (60 ℓ per minute), respectively. At this time, hydraulic loading rate was controlled at 25.0 m^3/m^3/day. The rearing tank was stocked with 10~20 kg of black rockfish (mean weight 235 g).

The experimental fish were fed moist pellets (commercial compound feed : frozen horse mackerel = 1 : 1) enough to satisfy themselves during 6 days per week. Filtering water and rearing water were sampled every 3 hours interval. Dissolved oxygen, water temperature, specific gravity, pH, ammonia, nitrite and nitrate concentration were measured daily throughout the experiment.

For the measurement of ammonia, the samples were added by sodium nitroprusside in phenol and tricitrate desodium containing NaOH and trichlorocyanuric acid. Then, the solution was placed in the dark room for 6 hours for the formation of color before measured the concentration using spectrophotometer (DMS 80, Varian Co.) at a wavelength of 630 nm. For the quantification of nitrite, the samples were mixed with sulfanilamide and N-(1-naphthyl)-ethylene diamine dihydrochloride, formed color over 10 minutes, and measured the concentration using spectrophotometer (DMS 80, Varian Co.) at a wavelength of 543 nm. Nitrates in the samples were passed through Cu-Cd column to be reduced into nitrites (APHA, 1989).

Statistical differences were determined using Duncan's multiple range test (Duncan, 1955).

Results and discussion

Capacity of filter in the RBC system was examined at three different hydraulic loading rates. The ammonia concentration in the rearing water containing 10 kg black rockfish was maximized to 0.24 mg/ℓ at 8 hours after feeding. At this time ammonia removal efficiency (%) were fluctuated according to ammonia loading rate at three hydraulic loading rates. Higher hydraulic loading rate induced low ammonia removal efficiency (Fig. 2), but ammonia removal rate (g/m^3/day) was substantially increased with high hydraulic loading rate (Fig. 3).

The ammonia concentration in the rearing water containing 20 kg black rockfish was maximized to 0.53 mg/ℓ at 14 hours after feeding. The ammonia removal efficiency and ammonia removal rate showed similar tendency to the RBC system containing 10 kg black rockfish (Fig. 4).

In general, ammonia excreted from cultured fish in a closed system is peaked at several hours after feeding. Several researchers have studied diurnal ammonia excretion in fed and unfed fish and then have developed relationships to describe ammonia excretion over a twenty-four hour period based on several feeding regimes (Paulson, 1978; Brett and Zala, 1975; Poxton and Allouse, 1987; Gunther et al., 1981).

The peaks of ammonia excretion in present study showed at 9~14 hours after feeding (Fig. 3 and Fig. 4).

Figure 5 shows ammonia removal rates at

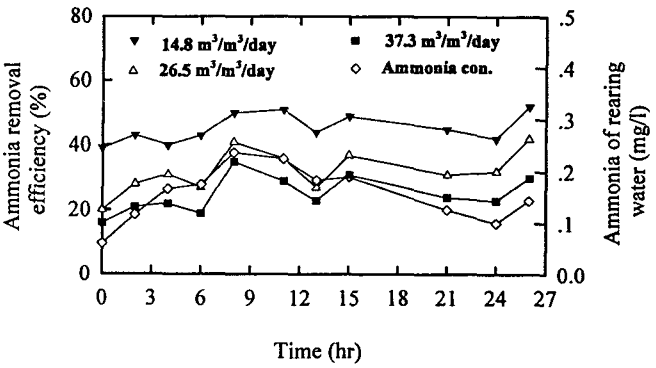

Fig. 2. Relationship between ammonia concentration and ammonia removal efficiency at different hydraulic loading rates in the RBC system loaded with 10 kg of black rockfish.

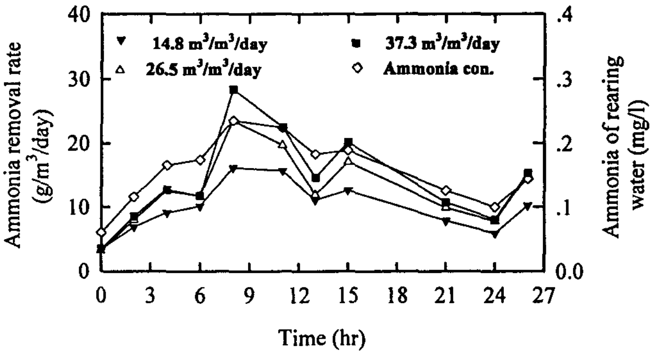

Fig. 3. Relationship between ammonia concentration and ammonia removal rate at different hydraulic loading rates in the RBC system loaded with 10 kg of black rockfish.

different hydraulic loading rates stocked 20 kg of black rockfish. In 37.3 m^3/m^3/day of hydraulic loading rate, the highest ammonia removal rate was 40 g/m^3/day at 14 hours after feeding, at the controlled water temperature of 20℃. The ammonia concentration of rearing water was maintained at 0.53 mg/ℓ.

At ammonia concentrations between 0.029 and 0.528 mg/ℓ, the effect of ammonia loading rate on ammonia removal rate at three different hydraulic loading rates can be defined by the following first-order regression models (Fig. 6):

Hydraulic loading rate of 14.8 m^3/m^3/day :
$y=39.2x+3.4$ ($r^2=0.9137$)
Hydraulic loading rate of 26.5 m^3/m^3/day :
$y=53.3x+4.0$ ($r^2=0.8686$)
Hydraulic loading rate of 37.3 m^3/m^3/day :
$y=58.4x+4.2$ ($r^2=0.7755$)

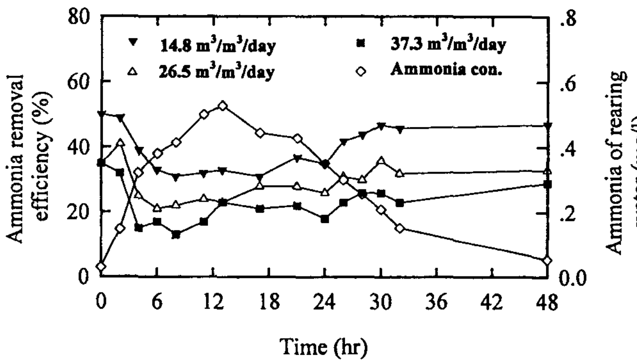

Fig. 4. Relationship between ammonia concentration and ammonia removal ratio at different hydraulic loading rates in the RBC system loaded with 20 kg of black rockfish.

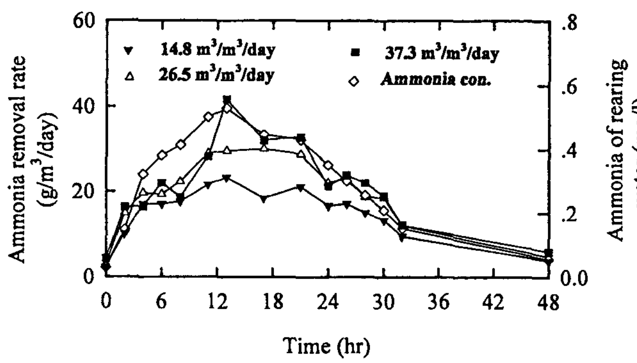

Fig. 5. Relationship between ammonia concentration and ammonia removal rate at different hydraulic loading rates in the RBC system loaded with 20 kg of black rockfish.

where, x is ammonia loading rate (mg/ℓ), y is ammonia removal rate (g/m^3/day)

Ammonia removal efficiency were gradually reduced with increasing of ammonia loading rate. Those were lowered with higher hydraulic loading rate (Fig. 7).

At water temperature of 20℃, rotational speed of 1.0 rpm and ammonia concentration of rearing water ranges from 0.029 to 0.528 mg/ℓ, ammonia removal rates were linearly increased with ammonia concentration in the RBC system rearing the similar amount of fish.

Below ammonia concentration of 0.53 mg/ℓ, ammonia removal rate was the lowest at 14.8 m^3/m^3/day of hydraulic loading rate ($P<0.05$). However,

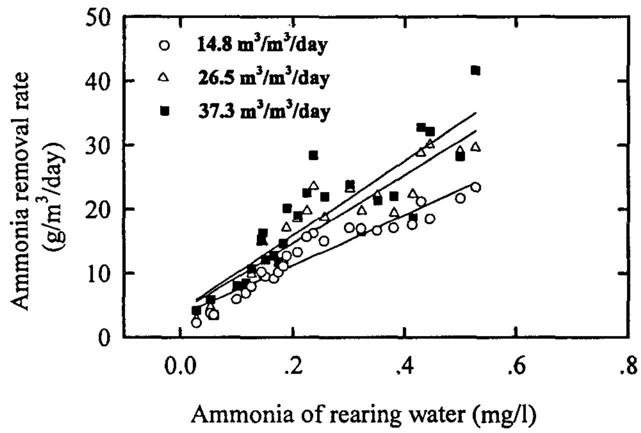

Fig. 6. Relationship between removed ammonia rate and ammonia concentration of rearing water at different hydraulic loading rates in the RBC system.

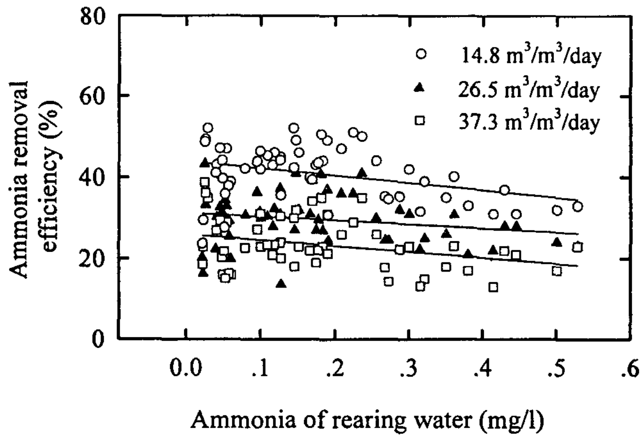

Fig. 7. Relationship between ammonia removal efficiency and ammonia concentration of rearing water at different hydraulic loading rates in the RBC system.

26.5 and 37.3 m^3/m^3/day of hydraulic loading rates showed no significant difference. Therefore, 26.5 m^3/m^3/day of hydraulic loading rate could be beneficial to reduce operation cost.

Nijhof and Bovendeur (1990) reported a maximum ammonia removal rate was 56 g/m^3/day (0.28 g/m^2/day×200 m^2/m^3) in trickling filter sea-water system at 24℃, when the ammonia concentration was maintained at 2.0 mg/ℓ. As ammonia concentration may be actually maintained below 0.5 mg/ℓ in the culture system, ammonia will be removed 10 g/m^3/day (0.05 g/m^2/day×200 m^2/m^3). On the other hand, in fresh-water system ammonia will be removed 60 g/m^3/day (0.3 g/m^2/day×200 m^2/m^3). Ammonia removal rate of the RBC system, it was known superior to trickling filter system at similar ammonia loading rate and water temperature.

The use of the nitrification rates for engineering purposes is obvious; for instance, 1 kg of pelleted feed, fed to fish in a recirculation system, induces an ammonia excrection of about 40 g (Heinsbroek, 1987). In present experiment, an ammonia removal rate 40 g/m^3/day in the RBC system can be considered. This means that 1 m^3 RBC per kg feed should be regarded as the absolute minimum amount of volume to be installed per kg daily feed supply. In practice, the recommended amount will be highly dependent on the effectiveness of the engineering and management of the system.

Second, filter capacity was examined at three different rotational speeds in RBC system containing 10~20 kg black rockfish.

Rotational speed of the RBC had a great influence on nitrification in the recirculating system. Generally, the treatment efficiency of waste water had a trend to increase with the increase of revolution.

Below the ammonia concentration of 0.38 mg/ℓ, first-order regression models between ammonia loading rates and ammonia removal rates at different rates of speed are defined as follows (Fig. 8):

Rotational speeds of 0.75 rpm: $y=57.9x+0.7$ ($r^2=0.9201$)
Rotational speeds of 1.0 rpm: $y=62.9x+1.8$ ($r^2=0.9186$)
Rotational speeds of 2.0 rpm: $y=33.7x+2.2$ ($r^2=0.7732$)

where, x is ammonia loading rate (mg/ℓ), y is ammonia removal rate (g/m^3/day)

Ammonia removal rates were increased with the ammonia concentration of rearing water at three different rotational speeds in the RBC system containing 10 kg black rockfish (Fig. 8). It was highest in the 1.0 rpm of rotational speed, followed in the 0.75 rpm and the 2.0 rpm of rotational speed in the RBC system.

Below the ammonia concentration of 2.72 mg/ℓ, first-order regression models between ammonia loading rates and ammonia removal rates at different rates of speed are defined as follows (Fig. 9):

Rotational speeds of 0.75 rpm: $y=28.5x+4.7$ ($r^2=0.9143$)
Rotational speeds of 1.0 rpm: $y=33.6x+8.4$ ($r^2=0.9534$)
Rotational speeds of 2.0 rpm: $y=28.9x+3.6$ ($r^2=0.9488$)

where, x is ammonia loading rate (mg/ℓ), y is ammonia removal rate (g/m^3/day)

Ammonia removal rate was highest in the at 1.0 rpm of rotational speed, but 0.75 and 2.0 rpm of rotational speed were no significant difference in the RBC system. And ammonia removal rates were similar tendency to hydraulic loading rates in same system. That is, ammonia removal rates were linearly increased with ammonia hydraulic loading rate in the RBC system stocked 20 kg black rockfish (Fig. 9).

Ammonia removal rate was the highest at 1.0 rpm

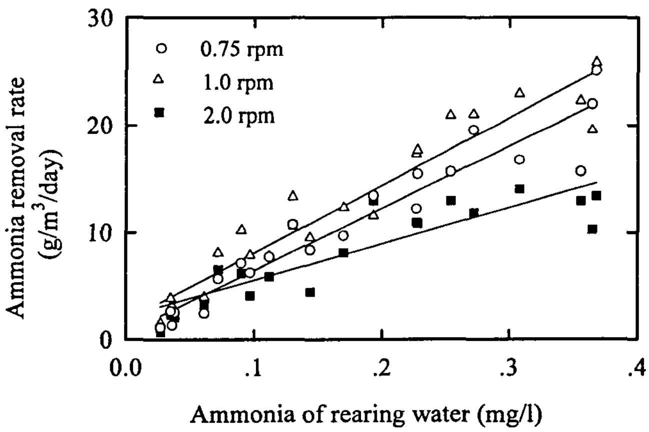

Fig. 8. Relationship between ammonia removal rate and ammonia concentration at three different rotational speeds in the RBC system loaded with 10 kg of black rockfish.

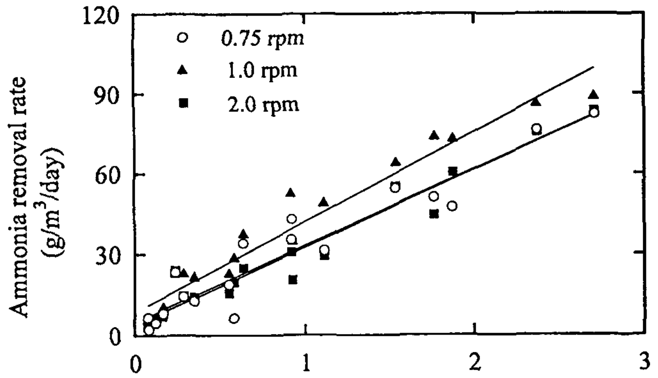

Fig. 9. Relationship between ammonia removal rates and ammonia concentrations at three different rotational speeds in the RBC system cultrured 20 kg of black rockfish.

of rotational speed; this phenomenon could be endogenous characteric of filter microbes, that was already operated to 1.0 rpm of rotational speed in the previous experiment.

In conclusion, this study was demonstrated importance of proper operating conditions in the RBC for effective filter performance in seawater recirculating culture system. Therefore, the results of this study will be provided a guide of effective design in RBC system to engineer and aquaculturist.

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