Research on Hydraulic method of Urban River re-aeration restoring

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Abstract: Nowadays, in our country urban rivers have been contaminated in different degree, river re-aeration has good effect on eliminating black water and bad smell, this has been proved by large amount of facts. According to different characters of urban river, by the way of using existing hydraulic structure and do some simple reformation such as: dam surface roughened, adding steps on dam surface, set re-aeration facilities etc, or building new hydraulic structure for water re-aeration on the basis of having no influence on sail and fishway, such as rubber low dam dropping-water re-aeration, contact oxidization dank bank etc. These have full use of water self-purified capability, have low investment, simple operational management and have good engineering application future.

Key words: Re-aeration, aeration, hydraulic structure, roughened surface, flow-separated bank

At present, river pollution is the most important environmental problem, attracting more and more attention. In the fast movement of our country's urbanization, the contamination degree of the rivers flow through the prosperous districts is deteriorated day by day. By some statistics data, now, the urban river whose water quality is lower than the V type water defined in national standard' Ground water environmental quality standard' takes 38%[1] in all that of our country, the black and bad smell urban river influences the living quality of inhabitants' living on both banks of the river and city scenery greatly. How to solve the black water and bad smell problem of urban river as soon as possible is the urgent duty of urban environmental work.

In the process of urban river manual treatment, the popular physics measures are: sewage block and treatment, sediment dredging up, bank and revetment renovating etc, Biochemical measures are: casting purifying medicament, man-made micro-biological germ, river wetland restoring, but all these measures have been restrained by investment and possible second pollution. We should decrease the pollution load greatly by the time taking urban river's self-purified capability as a great of environmental treasure, make it restored as possible as we can and make full use of it.

The content of dissolved oxygen is an important coefficient of evaluating water organic pollution. The re-aeration process of water influences the transfer, diffusing, dispelling of organic pollutant in water even the whole self-purified process of water directly. River re-aeration has good effect on eliminating the black water and bad smell, this has been proved by laboratory test and river re-aeration experiment. The theory is the dissolved oxygen in water take redox reaction with the black and bad smell substances(such as H_2S、F_eS etc.)

furthermore, it has the character of reaction fast. Simultaneously, the

experiment has discovered that river re-aeration can also make anaerobic and loose surface sediment to be aerobic and close-grained surface sediment, so as to reduce the process of pollutant in deep-seated sediment diffusing to upper water.

Artificial re-aeration technology can improve the urban river environment rather quickly, it become prevalent method to treat pollution in middle and small type contaminated river even in bay and lagoon water, in some developed countries and regions such as, America, Germany, England, Australia, Korea, China HongKong, some native cities also try this method. Man-made re-aeration technology mainly used to mend contaminated seriously urban river environment or reply for paroxysmal pollution impact load. It can be sorted in two forms according to technical measure, such as fan-fine bubble re-aeration system, pure oxygen re-aeration system, impeller inspiration push-flow re-aeration machine, re-aeration ship, underwater jet flow re-aeration machine etc [3]. However, related costs still restrain the spread of these technologies. Relatively, use the hydraulic structure to re-aeration in river should be more economic.

Hydraulic sluice structure has obvious effect on dissolved oxygen restoring in oxygen-consumed contaminated river, because it has large flux, good oxygen restore effect and low investment and operational cost, latter-day time, when people construct hydraulic structures, they all attach high importance on this problem. England, America, Japan, Germany etc nation always take gate and weir and so on hydraulic structures as measure of re-aeration. In urban river water system, for the need of flood block, sand block, water level regulation and scenery, people always construct all sorts of sluice structure (such as weir, gate, dropping-water and so on), obviously, making use of sluice structure for re-aeration, putting the process of re-aeration into the natural flow of river, has great economic benefit and extend value.

1.Re-aeration Theory

Researching on water re-aeration regulation has important value on forecasting and evaluating the dissolved oxygen content in water, verifying the organic pollutant self-purified process so as to find the optimum re-aeration measure. Dissolved oxygen in water mainly comes from air re-aeration, hydrobiology photosynthesis, upstream water entrapped re-aeration, however air re-aeration is the most important of all. According to the observation of England water quality pollution institute on Thames estuary, air re-aeration take more than 80% of all re-aeration amount, hence, research on air re-aeration is the most important too.

Re-aeration of water is a complicated mass transfer process between air and water, so far, though there are many research and put forward all kinds of theories, such as molecule diffusing theory, double film theory, permeating theory, film renovation theory and so on, but these all put forward on the basis of different assuming of air transfer into water, they all lack of experimental proof. For popular consideration, static water re-aeration conforms with molecule diffusing theory model in theory, large amount experiments all prove this. As to turbulent water re-aeration, though molecule diffusing can not be neglected (especially for low speed water, such as reservoir, lagoon and so on), the surface diffusing on the interface of water and air is the main control factor, its essential can be understood as the energy

exchange process of oxygen molecule on the interface of air and water, the molecule diffusing effect and turbulent diffusing effect should both be taken into account at the same time.

Double film theory was put forward by Whitman and Lewis in 1924, and used much in practice. This theory considers that on upper and bottom interface of the air phase and water phase there are air and water two layers of films. No matter how strong the turbulence of water is, air film and water film always exist, but the turbulence can make the thickness of water film l change. Because the diffusing resistance of water film molecule is much greater than the resistance of air film, the speed of air transferring to water film is controlled by molecule diffusing between water films. There are always enough oxygen content on the surface of water film clinging to air, it can be considered that the dissolved oxygen on the water surface is always at saturated concentration status Os, however, the water lower than the water film lower surface, because of the turbulence blend action, its concentration is uniform, the major concentration O is on the lower surface, according to the molecule diffusing regulation the speed of water dissolves in water is:

$$\frac{dm}{dt} = AD_m \frac{O_s - O}{l}$$

In this formula, m stands for the oxygen mass dissolved in water volume v at t time; D_m stands for the oxygen molecule diffusing coefficient in water film; l stands for the thickness of water film; A stands for the surface area of re-aeration.

Under natural condition, we can set average water depth approximately: H=V / A, that is:

$$\frac{dO}{dt} = \frac{D_m}{lH}(O_s - O)$$

$$\text{set}: k_2 = \frac{D_m A}{lV} = \frac{D_m}{lH} = \frac{k_l}{H}$$

In this formula: k_2 is called re-aeration coefficient; $k_l=D_m / l$ is called oxygen molecule transfer coefficient or mass transfer coefficient.

So, we can get the water air re-aeration equation that contemporary used abroad.

$$\frac{dO}{dt} = k_2(O_s - O)$$

We can see that the re-aeration speed of air to water has direct ratio to oxygen deficiency (Os-O).

This formula still has some vice: one is that the assumption of double film is hard to proved, the other is that the thickness of film can not measure in practice.

The quantitative coefficients of evaluating the re-aeration speed mainly have: re-aeration coefficient and surface mass transfer coefficient, there are many experienced and half experienced formula about re-aeration coefficient and surface mass transfer coefficient, the majority is to set correlativity of coefficient with time averaged flow character such as time averaged speed, water depth, hydraulic sloping and so on. The re-aeration model and re-aeration coefficient formula is set on the ground of this, for the reason of neglecting the boundary condition that influence the re-aeration coefficient or its theory is too rough on the description of flow character, that cause accuracy of this model is not very high, and the universality is rather bad, we should take several methods for calculation and take water temperature and other factors into account synthetically.

2. Free spillway re-aeration

Sluice weir is a common hydraulic sluice structure, the sluice weir in urban river has the main function of regulating water level so that fulfill the ecological water and scenery water need of urban river. The substance of sluice weir re-aeration is air and water interfacial mass transfer of oxygen and downstream stilling basin bubble interfacial mass transfer. Because of the strong air entrainment in downstream stilling basin, and the pressure that the bubble burden in water is rather high, the time detaining is rather long, so that the bubble interfacial mass transfer is the main reason of sluice weir re-aeration.

The factors that influence the sluice weir re-aeration mainly have: runoff per width, depth of stilling basin, turbulence intensity and so on. Under the condition that other condition is certain, the more the per width runoff is, the more the bubble volume cavitational efficiency is, that the bubble interfacial mass transfer is bigger, re-aeration capability is boost up; Accompany with the water depth in stilling basin is getting higher and higher ,the bubble can get to the deeper space in water, it makes the static pressure that the bubble burden higher ,the released oxygen is manifold, the bubble transferratio is higher, however when the water depth get to a critical depth, the oxygen transfer ratio will decrease, the turbulence intensity cause that many different sides of eddies and countless different sides of bubbles are brought out on the water surface. The strong turbulence can also break the bubble having large diameter into many bubbles having smaller diameters so that they can get into water easily. The bubble interfacial mass transfer ratio has direct ratio with turbulence viscosity coefficient, water turbulence intensity can be reinforced by water tongue collision and increasing the drop height of water level and so on common hydraulic methods.

In order to accurately design and proper using the hydraulic sluice structure, so as to fulfill the different re-aeration need of different water, make the hydraulic sluice structure air re-aeration regulation clear is required. Overseas country studied the free sluice weir re-aeration beginning at the late 1950's. There are some research production on the free sluice structure re-aeration capability, such as waterfall, dropping-water and so on. In our country there are also some investigators put forward several re-aeration capability evaluation formulas on the basis of indoor experiment, prototype observation. Popularly, oxygen deficient ratio r is used to define the effect of re-aeration. The definition is showed as follow:

$$r = \frac{C_s - C_1}{C_s - C_2}$$

In this formula C_s is the saturated concentration of dissolved oxygen, C_1 and C_2 stands for upstream and downstream dissolved oxygen concentration of sluice structure separately. Large amount research data shows that when the in flow oxygen deficient water aerates greatly by the hydraulic sluice structure, the dissolved oxygen concentration of water is always tend towards saturation data, downstream water is always at the status of re-aeration.

It is need to demonstrate that under some conditions, the hydraulic sluice structure will cause super-saturated re-aeration problem, it can make the concentration of air dissolved in water beyond saturated value, this will cause fish get "bubble disease", it will do harm to the growth of fish [7]. However, as for urban river, because of the low flux and drop-height, the research production before, did not find the situation that when urban

river flow through the hydraulic structure, the dissolved oxygen concentration will increase and beyond the super-saturated value, so the super-saturated problem can be neglected.

3 under gate submerged flow re-aeration

For the need of flood block and regulation of water resources, the culvert and gate are used commonly in urban river. The under gate submerged flow re-aeration is mainly realized by water spring, .Its re-aeration capability is rather strong. The research on under gate flow re-aeration problem in relatively late mainly began after 1970’s. In these researches the oxygen deficiency ration r is represent for the re-aeration effect commonly.

As common consideration, under gate submerged flow re-aeration capability is mainly influenced by entraining character of jet flow and turbulence character of eddy region, it is related with water spring submerged degree. Because of the different type and application mode of hydraulic sluice structure, it has different influence on flow re-aeration. When the in flow dissolved oxygen content is very low, it belongs to non-saturated re-aeration, after the water flow through the gate vulva, the flow becomes leap flow, dissolved oxygen trend towards saturated value. If the dissolved oxygen content of in flow is rather high itself, after the strong entrainment and turbulence of spring, perhaps the flow will become super-saturated re-aeration. The indoor experiments indicates that the submerged degree S=15％ can be looked as the distinguish criterion to separate the re-aeration of flat bottom spring. If S<15％, it is surface re-aeration and air entrainment re-aeration, at this time, except surface re-aeration ,there is re-aeration that caused by bubble entrainment in water, the flow has the capability of super-saturated re-aeration. If S>15％, the air entrainment phenomenon is not very obvious, it is non-air entrainment re-aeration it is pure surface re-aeration, it belongs to non-saturated re-aeration[4].Therefore, how to design and apply the hydraulic sluice structure according to the different need of oxygen content of water, serving as encourage benefit and eliminate harm is a problem that need consideration. Usually, for II、III type water, in order to prevent the “bubble disease” of fish, the highly submerged degree S>15％ under gate flow should be took; for IV、V type water, the low submerged degree under gate flow that have higher re-aeration capability should be took ,in order to increase the oxygen content and enhance the self-purified capability in water.

The under gate submerged flow is helpful to improve the influence that the low dissolved oxygen concentration of down layer water in reservoir on downstream ecological environment. Because the dissolved oxygen and water temperature distribution is not uniform on the vertical direction of water depth, the notable character of the deep-seated water of reservoir is low temperature and low dissolved oxygen. If not treat properly, it is easy to cause the low dissolved oxygen concentration of downstream, and influence the downstream hydro ecological environment. The deep-seated water of reservoir that has low dissolved oxygen can be re-aerated by discharging through the mid vulva or deep vulva. When downstream water level is too high or too low, in order to improve the dissolved oxygen level of downstream, we can take the way of adding air entrainment slot or air entrainment ridge

on the water pass through section of mid vulva or deep vulva. Air entrainment is a measure of avoiding cavitation in high-speed flow before, and it has been applied widely. After adding the air entrainment slot, the content of bubble in flow is increased, because of the mixture of bubble in water again and again, the downstream dissolved oxygen level can be improved greatly.

4. Dropping-water aeration

On urban stagnant flow water area, such as the narrow and long conjunct segment between lagoon, under the condition that there is no influence on sail and fishway, we can design stepped rubber section block flow and sluice water by segment according to the character along river, to make water level get to a certain depth, use rubber dam to operate dropping-water aeration. Rubber dropping-water aeration is a special form of surface aeration, when water drop from dam, the oxygen in air is engulfed, so aeration is made, it is has the character of operation and manage convenient.

In the process of dropping-water aeration, the air entrainment character of leap flow is applied, when water is drop freely from a high space, during the period of dropping, some certain air is engulfed in bottom water, the air engulfed in water keep full contact with deep-seated water at the form of bubble, after the bubble is broken, the deep-seated water is aerated. The dissolved oxygen effect of dropping-water aeration is related with of flux per width, dropping height, and dropping steps of dropping-water. In order to increase the total transfer coefficient of oxygen, increasing the contact time and contact area of air and water is in need. It can be realized by two ways: one is increasing drop-height, the other is dispersing flow, delaying the drop speed of flow.

Dropping aeration theory is applied more often in sewage treatment plant, usually work with contact oxidation pool. Take advantage of the drop height between the two border upon contact oxidation pools, make the sewage drop stepped from a higher space, when dropping the water can contact air fully and re-aeration naturally, so as to satisfy the demand of dissolved oxygen of contact oxidation pool. This model of re-aeration can decrease the operation cost.

Applying rubber dam dropping-water aeration has the character of operation and manage easily, low engineering cost. Segment sluice and dropping-water can also increase some city sceneries, by the way, the use of rubber dam is easily removed and restored. The capability and techniques of dropping-water aeration has been fully proved and applied by sewage treatment plant at home and abroad.

5.The bodily form of sluice weir and surface roughened dam

The urban contaminated river always has low flux, low speed, and the existing sluice weir is usually low dam, many of them are rubber dams. Though at the time water flow through dam surface the turbulence is increased, the engulfed oxygen of air can increase the dissolved oxygen in water, but the increased dissolved oxygen is insufficient to make water fulfill the demand of water quality standard. If paste some artifical roughness on the dam surface existing, the dissolved oxygen will increase obviously, it has notable effect on urban river ecological restoring. Commonly, when

the flux is fixed, the higher the dam is, the bigger the roughness is , the more obvious re-aeration effect of sluice weir will be [9]. In order to increase the re-aeration capability deeply, when the sluice weir is constructing in urban riverway, the selection of slop ration of 45°（the contact area of water and air is the biggest）,the form of stepped dam has the best re-aeration effect.

After the sluice weir surface is artificially roughened, the turbidity of water strengthened, air is engulfed into water and become dissolved oxygen. Under the condition of stepped dam, when water encounters steps, it colliding with step violently, and make different sides of vortexes caused on water surface, meanwhile, water surface is distorted, the surface area of air and water interface is increased. According to turbulence diffusing theory, the air volume that engulfed into water surface from water and air interface has some relation with water turbulence energy. On the smooth dam surface there is no turbulence caused by water, however, on the roughened surface dam, the turbulence energy is large, furthermore, on the action of turbulence, a part of oxygen on the air enriched layer will combine with water and become dissolved oxygen, then diffuse to downstream, so as to increase the dissolve oxygen concentration of downstream.

Because the biological film that inserted on dam surface having the function of purifying water, the selection of dam surface material should be take into account. On the precondition that the roughness on dam surface is as large as possible, select the dam surface material that new biological film can easily inserted and older biological film can easily shelled, can bring the self-purified capability into full play.

Currently, the surface roughened dam is not used very wide, but take advantage of the existing urban low dam, make some reformation, adding roughness on dam surface or setting stepped dam surface, will be a economic and efficient re-aeration method, furthermore it is convenient for application.

6.contact oxidation dank bank

In the middle of river and on the direction of water flow, construct a contact oxidation dank bank made of hole enriched material, separate the river into two parts, at the same time construct 4 gates on upstream and downstream of the two rivers, by the operation of gates, make the water level drop-height of the two sides. That is open upstream one side and downstream the other side gates, close the other two gates, make one side river flow to the other side through the contact oxidation dank bank, purifying water. Then, change the open and close group of gates by turn, to make the water change the dank direction, this can not only prevent hole block of bank, but also is benefit for the back swimming of the small fish. The re-aeration theory of this method is similar with the techniques setting block board in contact oxidation single pool in sewage treatment plant.

Related experiment had been did in Japan, tested the river water dank through the sand river bed in field, the result showed that the purifying effect of dank between sand was very high, the elimination ratio of SS(Suspend Solid) get to 96%, and the purifying effect of BOD(Biochemical Oxygen Demand) and Turbidity were rather good too.

The direct purifying in natural river flow, because of flowing through the clearance of sands in one direction for a long time, it is too ease to be blocked that

will decrease the oxidation effect. Make use of the contact oxidation dank bank manual constructed in river, make water flow through the oxidation bank back and forth, can prevent the block of e sands clearance, so as to improve the oxidation effect of water in river that flowing through the contact oxidation dank bank. It is a good technique measure that can bring the natural purifying function of water into play, and it is city scenery too.

7.conclusions

In the process of solving the urban pollution problem, river re-aeration has good effect on eliminating black water and bad smell. But in practice，many artificial re-aeration techniques are hard to spread out because of the restriction of cost and management. Make use of natural energy that created in the natural flow of river, adapt the hydraulic method, take some special designed hydraulic structure, to make more oxygen in air engulfed in water to become dissolved oxygen, and diffusing and transfer in water properly, will be a more economic and efficient method of restoring and maintain the water quality.

Using hydraulic structure for re-aeration, there are some research outcomes at home and abroad. But there are still some fields that need more research, such as the model of gate and dam, the property of contamination concentration, the selection of optimum dam body and best dam surface material, the site direction of dam body, the speed that the river flow should controlled and the influence of water temperature of river, these are also the research directions of tomorrow.

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