WASTEWATER TREATMENT MEASURES FOR HSUEHSHAN TUNNEL CONSTRUCTION

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ABSTRACT

Hsuehshan Tunnel, 12.9Km long including three tube tunnels (two main tunnels, one pilot tunnel), is downgrade as 1.255% from north to south. According to the original construction plan of Hsuehshan Tunnel, three tunnels will be driven through exclusively by TBM. Therefore, most of wastewater treatment plants (WWTP), a dominant part of wastewater treatment measures（WWTM）, will site at the southern portal and be easy not only to save running cost but also to deal with a contingency or emergency. Due to many serious geological and groundwater influx disasters resulting in much delay to the progress of this project, constructor has to develop more break points along with the tunnel. Each break point follows normally with one set of WWTP. Owing to violation of gravity flow, raw water derived from construction need to be pumped upwards to WWTP. The major constituent of wastewater coming from tunnel construction is suspended solids (SS) derived from broken strata, shotcrete and grout particles. Application of coagulation-flocculation sedimentation principle in design of WWTP has been proved to handle SS successfully. Separating clean groundwater and wastewater into different routes is a good way to reduce loading of WWTP. Reuse effluents of WWTP for TBM cooling system, tunnel construction and sanitary activity can save a lot of cost and improve environment. Both of them, there are a few successful applications in this project.

Keywords: WWTM, WWTP, HTC, SS, BOD, COD, NH3-N, Coagulation, Flocculation, Sedimentation, Phosphate, ERM.

INTRODUCTION

According to the Water Pollution Control Act of EPA, ROC, the wastewater produced from Hsuehshan Tunnel construction（HTC）or any other civil jobsite must be treated as the criteria of Effluent Standards of EPA before discharging to surface water bodies (river, stream, creek or ocean) in the neighborhood; otherwise, the penalty from local competent authority will be put on the relevant polluter or constructor. If circumstances are so serious to endanger human health, agricultural or aqua cultural production or drinking water sources, the partial or complete suspension of work will be executed immediately by local competent authority until those circumstances has been improved. Therefore, it is no doubt to establish wastewater treatment measures at right time, right place and to run it to meet the criteria of Effluent Standards are necessary for Hsuehshan Tunnel smooth construction.

The Hsuehshan Tunnel is a 12.9km long tunnel that penetrates through the Hsuehshan Mountain Range which covers part of Taipei County and I-lan County. The effluents of wastewater produced from HTC have to discharge to Beishih Stream which is one upstream of FeiTsui Reservoir in Taipei County and to Bei-Mon-Ken creek via Ho-Don creek to Pacific Ocean separately. On requirement of being adjacent to the origin of wastewater, some of wastewater treatment measures（WWTM）are built on the plain and the top of mountain, the others have to be built in the tunnel inevitably.

During 14 years' period of Hsuehshan Tunnel construction, the criteria of Effluent Standards had been remediating for several times. For examples, Biochemical Oxygen Demand（BOD）（50mg/l →30mg/l）, Chemical Oxygen Demand （COD）

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（200mg/l→100mg/l）, Suspend Solids（SS）（50mg/l→30mg/l）, it makes some wastewater treatment plants (WWTP) must be modified to meet the new criteria of Effluent Standards. In fact, some minor particles required either or both of BOD, COD stick and form SS more or less with inorganic matters. By experiences, most of the times, the less BOD and COD always follow with the less SS. Sometimes, E. coli, true color unit, phosphate, Ammonia Nitrogen（NH3-N）and pH come down with the less SS, it depends on the composition of SS.

This literature is attempted to be written systematically as a basic guideline of wastewater treatment measures in long tunnel construction and expected to be assistances to Tunnel Engineers and planners of future long tunnel construction. This literature commences with basic concept of coagulation and flocculation wastewater treatment, then steps with treatment process and design criteria, geographical distribution and treatment capacity, reuse of groundwater and effluents, reduction of wastewater, operational strategy and emergency response measures of WWTM for HTC.

BASIC CONCEPT OF WWTM FOR HTC

Wastewater can be deemed as the combination of waste plus water, water is main body while waste is foreigner. In spite of visual panic to wastewater, be calm down to analyze the constituents of foreigner and to take the most efficient method to remove it to get clean water back are the basic concept of WWTM for HTC. The characteristic of wastewater produced between HTC and general tunnel construction are similar. The major constituent of wastewater produced from HTC is suspended solids（SS）which are derived from minor particles of broken strata under construction, tiny cement or sand particles under shotcrete and pouring concrete, little cement or chemical grout material particles seepage under grouting process.

Water（H_2O, H-O-H）is a polar molecule with V type structure and an included angle 105^o between two O-H chemical bonds. Oxygen（O）possess more strong electronegativity than hydrogen（H）,that make unequal charge distribution（O^{2-}, H^+）in chemical bond O-H and cause H^2O to be a polar molecule. Most of SS in wastewater produced from HTC are provided with negative charge, it is easy to form stable hydration with water molecules by hydrogen bond to keep SS floating in wastewater. In case, the buoyancy of SS is much less than the gravity of SS itself, then SS will settle rapidly and be removed easily; otherwise, it is necessary to add some coagulant and flocculant to expedite sedimentation of SS for subsequent treatment.

Coagulant used in wastewater treatment, an electrolyte, will hydrolyze to create metallic cation which is opposite to SS surface charge and to form metallic hydroxide floccules furthermore. These phenomena enable not only to convert the status of SS from stable hydration to instable discrete particle but also to neutralize the negative charge of SS and to bridge, adsorb, capture or sweep those dispersing SS particles to come into floc. If the buoyancy of floc is just right less than the gravity of floc itself, then this floc will settle within detention time and be removed easily; otherwise, it is necessary to add some flocculant to expedite sedimentation of floc for subsequent treatment. Poly Aluminum Chloride（PAC）known as general chemical formula「$Al_2(OH)_nCl_{6-n}$」m is the most popular coagulant used in WWTM for HTC.

Flocculant used in wastewater treatment, a polyelectrolyte, a high organic polymer, will hydrolyze to create plenty of functional groups with opposite charge to floc and to neutralize, adsorb, capture, bridge or sweep just like an octopus does those floating, loose floc to come into dense floc aggregates. Finally, the gravity of floc aggregates is much heavier than the buoyancy of floc aggregates itself and these floc aggregates settle down to the bottom of sedimentation basin very fast within confined detention time. The most popular flocculant used in WWTM for HTC is a kind of polymer powder with long chain structural organic macromolecular compounds of anionic type.

Sulfuric acid known as chemical formula H_2SO_4 play an important role in WWTM for HTC, not only to neutralize the influent pH of wastewater to adapt the best reaction range of coagulant and flocculant to save cost, but also to neutralize the effluent pH of treated wastewater if it needs, to meet the criteria of Effluent Standards to avoid penalty from local competent authority.

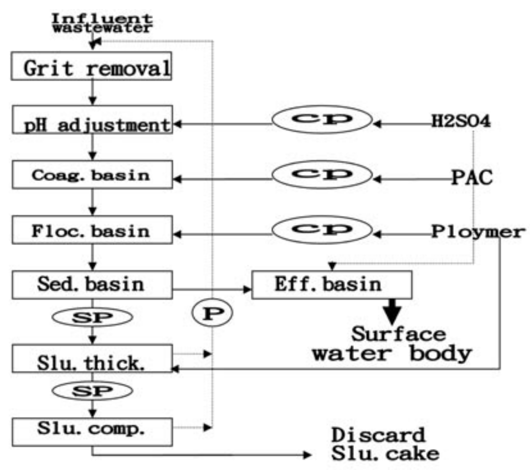
Sedimentation basin, its shape has rectangular or circular, it could be made of concrete or steel structure, its major function is to provide the volume to check and accept removal efficiency of floc aggregates produced from coagulation-flocculation process. Furthermore, for enhancing settling velocity and removal efficiency of floc aggregates, an inclined tube settlers with the effect of rectifying turbulent flow to laminar flow and providing the second time to do coagulation-flocculation process are installed in sedimentation basin.

According to the statements of Newton' law and Stokes' law, we know the more increasing mass gravity in SS the faster settling terminal velocity and removal efficiency of SS. Based on this concept, to enlarge the size of SS and to make it more heavier through above mentioned coagulation-flocculation sedimentation principle are essential for promoting removal efficiency of SS, increasing treatment capacity of WWTP and saving land cost or land requirement which is sometimes ignored in planning of tunnel construction.

PROCESS FLOWSHEET & DESIGN CRITERIA OF WWTM FOR HTC

Based on coagulation-flocculation sedimentation principle, a simplified treatment-process flowsheet digested from 30240 CMD WWTP which is located at south portal of Hsuehshan Tunnel will be introduced as follows to explain the process flowsheet and design criteria of WWTM for HTC.

Pretreatment of chemical coagulation-flocculation process include basins or chambers for influent wastewater, primary precipitation of grit, sand and large matters, ridding of oil and adjusting pH to adapt the optimum range of coagulant, flocculant. To neutralize the negative charge of SS in HTC wastewater by sulfuric acid（H_2SO_4）occur instantaneously, so the hydraulic detention time for neutralization might be omissible. Normally, if land is shortage, grit removal chamber and pH adjustment basin are combined in one; if not, it is advised to separate them for saving the usage of H_2SO_4. The design criteria of hydraulic detention time（effective volume of basin / flow rate of wastewater）for grit removal（more than 50%） and pH adjustment, we adopt 3~10 minutes by experiences. It is for sure,



the longer hydraulic detention time, the better treatment effect and the less cost of subsequent chemical treatment.

Coag. basin is the basin to provide with effective volume for detention, reaction time to do coagulation between SS in wastewater and added coagulant. An experienced operator of WWTP will recognize whether coagulation is successful or not by appearance of minor floc to some extent. We adopt Poly Aluminum Chloride（PAC）, liquid type with 10~11% concentration, as coagulant which is used and proved to be successful in WWTM for HTC. In addition to the essential 1~5 min hydraulic detention time as design criteria for coagulation basin, the size of mixer installed in coagulation basin shall refer to the design criteria of velocity gradient G=200~300/s, power formula $p=\mu G^2V$, 120 rpm of mixer blades rotation speed to choose the optimum mixer. If the quality of influent wastewater has a lot of variation, to do analysis of wastewater quality and jar test immediately are necessary for remediation of coagulant add.

Floc. basin is a basin to provide with effective volume for detention, reaction time to do flocculation among floc, SS in wastewater and added flocculant. An experienced operator of WWTP will recognize whether flocculation is successful or not by appearance of floc aggregates to some extent. We adopt a kind of polymer powder with long chain structural organic macromolecular compounds of anionic type which is normally diluted by clean water to 0.1% concentration to adapt chemical feed pump system. This kind of polymer has been proved to be successful in WWTM for HTC. In addition to the essential 5~10 min hydraulic detention time as design criteria for flocculation basin, the size of mixer installed in flocculation basin shall refer to the design criteria of velocity gradient G=20~80/s, power formula $p=\mu G^2V$, 6 rpm of mixer paddles rotation speed（to avoid breaking floc aggregates to small floc） to choose the optimum mixer. If the quality of influent wastewater has a lot of variation, to do analysis of wastewater quality and jar test immediately are necessary for remediation of flocculant add.

Sed. basin is a basin to provide with effective volume for detention time to precipitate the floc aggregates produced through coagulation-flocculation process. For enhancing 3~8 times precipitation of the floc aggregates, an inclined tube settlers with the effect of rectifying turbulent flow to laminar flow and providing the second time to do coagulation-flocculation process are installed in sedimentation basin. In addition to the essential 1~2 hrs hydraulic detention time as design criteria for sedimentation basin, we shall refer to some hydraulic

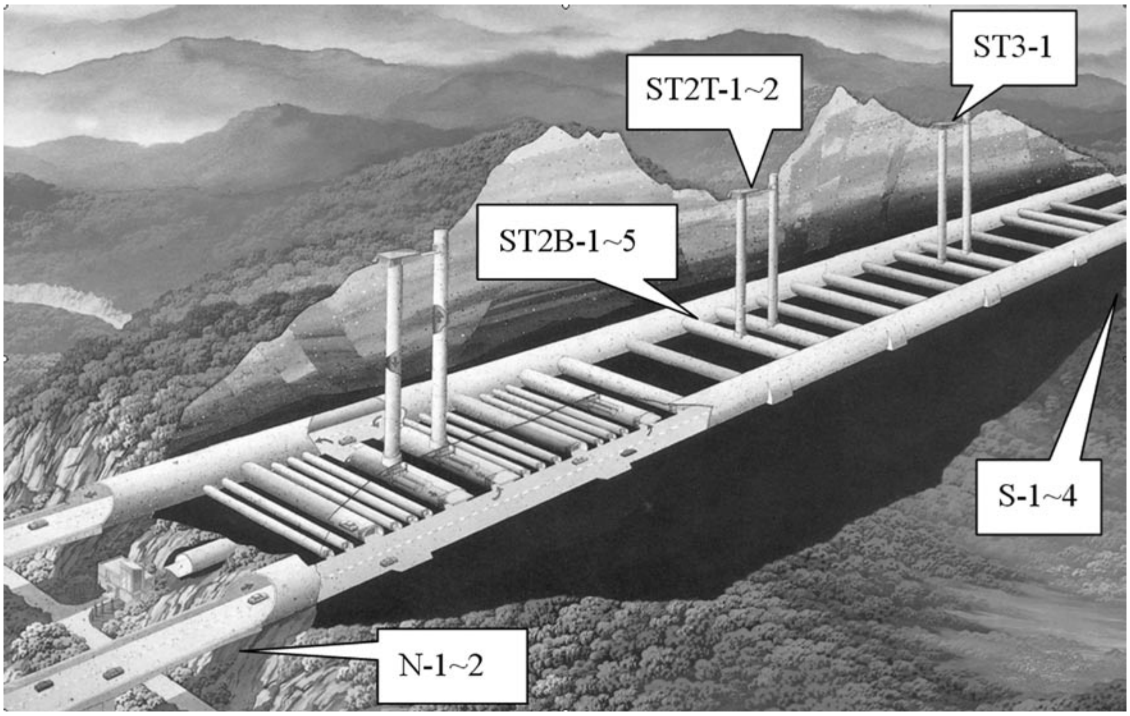


Fig. 1 Geographical Distribution of WWTM for HTC

design factors: surface-loading rate< 400 m^3/m^2.day, weir loading< 300 m^3/m.day, solids loading rate≦ 100 kg/m^2.day as design criteria for sedimentation basin. The effluent, upper portion of sedimentation basin, contain SS less than 30 mg/L under a good control of WWTP. The sludge, lower portion of sedimentation basin, will go to sludge thickening process by sludge pump.

Slu. thick. means a basin to provide with effective volume for detention time to do sludge thickening by adding some polymer (flocculant) and sludge itself gravity compression. The purpose of sludge thickening is to remove excess water from sludge and to reduce the volume of sludge for subsequent sludge cake production. A good design of sludge thickening basin has to include enough surface area and depth of basin too in order to achieve the effect of sludge thickening and clarification, hence we shall refer to hydraulic detention time> 3 hrs and surface loading rate 10~20 m^3/m^2.day as design criteria of sludge thickening basin. The upper clarified portion of sludge thickening basin must be pumped back as influent wastewater to do treatment again instead of discharging directly to pollute effluent. The thickened sludge, lower portion of sludge thickening basin, will go to sludge cake production by sludge pump.

Slu. comp. is a mechanical equipment built with high efficiency filter cloth or belt driven by mechanical roller or hydraulic power to force free water away from thickened sludge and to promote solids content in sludge cake for saving disposal cost of sludge cake. There are two kind of mechanical compression equipment used in sludge dewatering of WWTM for HTC, one is plate and frame filter press driven by air cylinders, the other is horizontal belt filters driven by mechanical rollers. The former which is able to increase the solids content in sludge from 5~10% to 50~60% is preferred. The seeping wastewater under mechanical compression process must be pumped back as influent wastewater to do treatment again instead of discharging directly to pollute effluent.

GEOGRAPHICAL DISTRIBUTION AND TREATMENT CAPACITY OF WWTM FOR HTC

Hsuehshan Tunnel cuts through the Hsuehshan Mountain Range which is located in north-eastern portion of Taiwan and is deemed as a water reservoir owing to abundant annual average rainfall about 3500㎜ and very fractured geologic structures. Hence, where tunnel constructions go, where the water drops and the requirements of WWTM step after right away. Unless tunnel is complete penetration,

Table 1 Treatment Capacity of WWTM for HTC

Name of WWTM	Location of WWTM	Treatment Capacity of WWTM (L/S)	Type of WWTM
N-1	NP of Pilot Tunnel	100	Std. RC WWTP
N-2	NP of Southwards Tunnel	250	Std. Steel-Structure WWTP
S-1	SP of Southwards Tunnel	83	Std. RC WWTP
S-2	SP of Northwards Tunnel	115	Std. RC WWTP
S-3	SP of Northwards Tunnel	115	Std. RC WWTP
S-4	SP of Northwards Tunnel	347	Std. Steel-Structure WWTP
ST3-1	Top of #3 Vent. Shaft	46	RC+ Steel-Structure WWTP
ST2T-1	Top of #2 Vent. Shaft	46	RC+ Steel-Structure WWTP
ST2T-2	Top of #2 Vent. Shaft	28	WET Type
ST2B-1	Bottom of #2 Vent. Shaft	88	WET Type
ST2B-2	Bottom of #2 Vent. Shaft	100	Chem.-add Rectangular Sed. Basin
ST2B-3	Bottom of #2 Vent. Shaft	100	Chem.-add Rectangular Sed. Basin
ST2B-4	Bottom of #2 Vent. Shaft	100	Chem.-add Rectangular Sed. Basin
ST2B-5	Bottom of #2 Vent. Shaft	194	Std. RC WWTP

any trial to centralize all wastewater and WWTM are impracticable. Fig. 1 and Table 1 show geographical distribution and treatment capacity of every WWTM for HTC. Some of WWTM are built on the top of mountain, inner available portion of tunnel while the others are sitting at portal of tunnel as normal.

In general, the historical establishment process of WWTM for HTC shall be divided into three stages:

The first stage began from the commencement of south portal of Pilot Tunnel in July, 1991. Pilot Tunnel is one and locates at the lowest position of the group of Hsuehshan Tunnel. Pilot Tunnel is scheduled to be the pioneer of HTC, to do more accurate geological investigation and to release water pressure for smooth construction of main tunnel by discharging water into invert space of Pilot Tunnel. At the very beginning, a small sedimentation basin, the predecessor of S-1, was built at the south portal of Southwards Tunnel for handling the wastewater from Pilot Tunnel. Due to increasing wastewater as the advancement of Pilot tunnel and the commencement of main tunnel at south portal in July, 1993, the predecessor of S-1 had been developed to S-1, a standard RC WWTP in spring, 1995. Based on such experience, N-1 in Pinglin, a standard RC WWTP, was built directly in 1995 to follow the 150m D&B commencement of north portal of Pilot and main tunnel which were served as waiting room for three TBM.

#3 Ventilation Shaft which is composed of one fresh air shaft as deep as 438.2m and one exhaust air shaft as deep as 458.9m was scheduled originally to do raise-boring method to make Pilot Tunnel supposed to be penetrated in 1995 as its dumping area of muck and wastewater produced from construction. Because of the serious delay of Pilot Tunnel progress, the construction method of #3 Ventilation Shaft had been converted to sinking method which need its own de-mucking system, dewatering system and WWTP instead. ST3-1 on the top of mountain, a RC+ Steel-Structure WWTP, was established in 1995 inevitably. A few years later, #2 Ventilation Shaft encountered the same situation as #3 Ventilation Shaft too.

The second stage of historical establishment process of WWTM for HTC covers the proposal and execution periods of [Integral Improvement and Response Program of HTC and Its Amendments]. As a result of adverse geological structures of Hsuehshan Tunnel, a number of disasters, which contain the biggest collapse in the Northwards Tunnel in Dec., 1997 and commit the double-shield TBM (11.74mϕ) to the fate of being dismantled, occur and cause the client, Taiwan Area National Expressway Engineering Bureau (TANEEB), to review and propose [Integral Improvement and Response Program of HTC and Its Amendments] through the board meeting of consults to reset the deadline of completion of HTC in Dec., 2005 instead of 1999 and 2003. For recovering the progress loss in TBM, this program and its amendments prolong the construction length from 150m to 3800m+475~845m of Pilot and main tunnel in the north of Hsuehshan Tunnel and increase new work points toward the north and south in the Northwards Tunnel from the bottom of #2 Ventilation Shaft.

For response to the full speed construction derived from this program and its amendments, to modify N-1 to handle some extent of wastewater increment which comes along with tunnel advancement temporally and to establish without hesitance the subsequent, permanent, large treatment capacity (250 l/s) WWTP named as N-2, a standard steel-structure WWTP, right under the free space of RC bridge at the north portal of Southwards Tunnel. By the way, several ascendant (1.255% slope) pipelines and interchange pump stations are installed along the tunnels from excavation face to WWTP for pumping wastewater upstream. N-2 (see Fig. 2) commences normal operation in Mar., 2001.

#2 Ventilation Shaft which is composed of one fresh air shaft as deep as 237.9m and one exhaust air shaft as deep as 248.7m encountered the same situation as #3 Ventilation Shaft too. Sinking method with the following costly vertical lift de-mucking system, vertical upstream dewatering system and WWTP is the only choice to the construction of #2 Ventilation Shaft and its subsequent activities for integral HTC progress. In addition to ST2T-1, a RC+ Steel-Structure WWTP, was built at early stage of #2 Ventilation Shaft construction, ST2T-2(WET Type), ST2B-1(WET Type, see Fig. 3), ST2B-2, ST2B-3, ST2B-4 (Chem.-add Rectangular Sed. Basin, see Fig. 5) and ST2B-5(Std. RC WWTP, see Fig. 4) are built in succession to respond to the increasing wastewater quantity produced from abundant groundwater strata which always release a lot of water with the advancement of tunnel progress. It is not so easy to look after both sides of finding available space to install above mentioned WWTM and keeping minimum interference to tunnel construction, especially at the bottom of a deep shaft.

#1 Ventilation Shaft which is composed of one fresh air shaft as deep as 480.2m and one exhaust air shaft as deep as 500.9m is lucky to take raise boring construction method due to the dumping area and disposal way for muck and water produced from #1 Ventilation Shaft construction are ready through the passage of Pilot and main tunnel. Therefore, it is no need of any WWTP in #1 Ventilation Shaft construction.

Based on the penetration of Pilot Tunnel can be expected soon, the third stage of historical establishment process of WWTM for HTC keeps an eye on the successive collection and exclusive treatment of all HTC wastewater at the south portal of Hsuehshan Tunnel. Upon a deliberate evaluation, in addition to S-1, S-2 and S-3(Standard RC WWTP built at the second stage, see Fig. 6), the team of HTC decides to establish S-4, a Standard Steel-Structure WWTP with 347 l/s treatment capacity, within six months. As scheduled, S-4 (see Fig. 7) commenced operation in Jun., 2003.

Dismantlement sequence of WWTM for HTC is related to whether the relevant tunnel or shaft are penetrated, accessible or not and the passage of wastewater is ready or not. When the TBM of Pilot Tunnel passed through the bottom of #3 Ventilation Shaft in Feb., 2002 and opened it in a few months later, the wastewater produced from #3 Ventilation Shaft construction is able to be discharged to S-1~3 without any problem. However, ST3-1 is useless and must be dismantled for successive construction activities.

As the TBM of Pilot Tunnel marched through the crossover of Pilot Tunnel and Northwards Tunnel excavated from the bottom of #2 Ventilation Shaft, #15 pedestrian cross connection was opened from the top of Pilot Tunnel and installed a mechanical device for disposing most of muck and wastewater produced from Northwards Tunnel construction by the passage of Pilot Tunnel to S-1~4. When the Pilot Tunnel was complete penetration in Oct., 2003, all WWTM in relation to #2 Ventilation Shaft and its successive construction, ST2T-1~2 and ST2B-1~5, were arranged to be dismantled one after another.

At the north portal of Hsuehshan Tunnel, N-1 had been treated as a spare WWTP since N-2 commenced operation in Mar., 2001. After the Pilot Tunnel was complete penetration in Oct., 2003, all wastewater produced from the north of HTC could be discharged downstream directly to S-1~4 by the passage of Pilot Tunnel. N-1 was removed right away. N-2 handled car washing wastewater only and was supposed to be dismantled as the completion of Hsuehshan Tunnel.

At the south portal of Hsuehshan Tunnel, S-1 had been listed as a spare WWTP since 2002 and the first one to be dismantled, due to the expensive power charge and maintenance cost of pumps used to lift influent wastewater up to pH adjustment basin and the following treatment process at higher water level. S-2, S-3 and S-4 are in cooperation to handle all wastewater produced from HTC now and will be supposed to be dismantled as the completion of Hsuehshan Tunnel.

Each WWTM plays a supporting role to relevant tunnel or shaft construction and has to show fully enough treatment capacity in spite of much difficulty to do exact estimation of the quantity and quality of influent wastewater

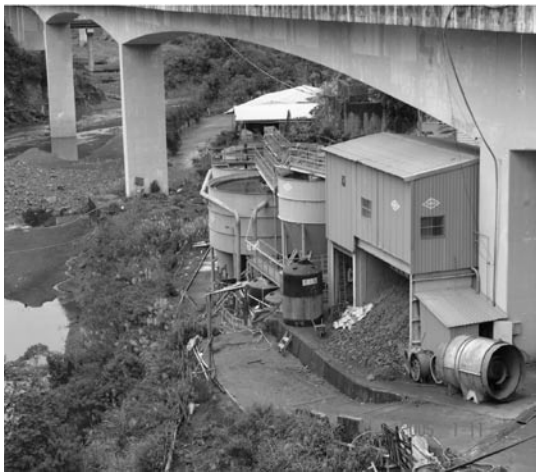


Fig. 2 N-2 WWTP

Fig. 3 ST2B-1 WWTP

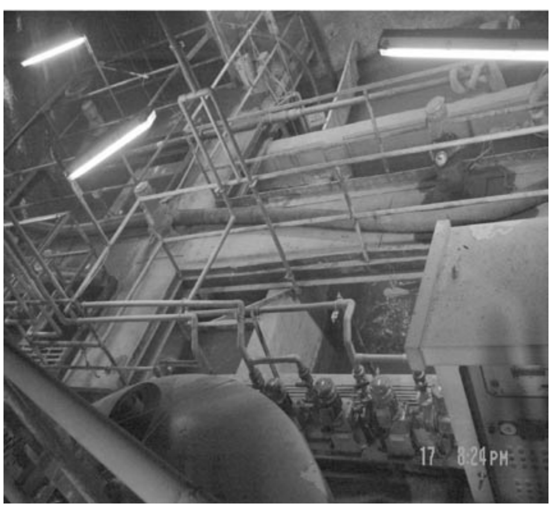


Fig. 4 ST2B-5 WWTP

Fig. 5 ST2B-2 Sed. Basin (Left side)

Fig. 6 S-2&S-3 WWTP

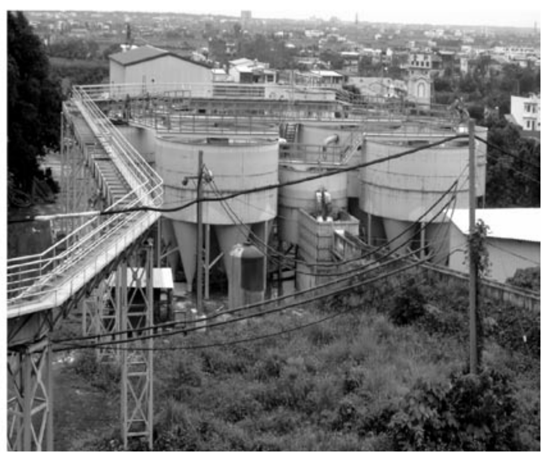


Fig. 7 S-4 WWTP

derived from groundwater influx in relation to adverse geological structures so far. To review the entire process of establishment and dismantlement of WWTM for HTC, even though some of penalties were issued by local competent authorities for violating Effluent Standards occasionally, the people involved in decision, design, establishment, operation and dismantlement of WWTM for HTC at right time, right place and right manner are worthy to be praised at all.

REUSE OF GROUNDWATER, EFFLUENTS & REDUCTION OF HTC WASTEWATER

As known, Hsuehshan Tunnel is full of groundwater everywhere. Most of groundwater influx with the advancement of tunnel construction are clean water, if not, high silt content in groundwater that give us a warning of geological deformation on excavation face is coming up, will cause collapse finally in serious condition. When clean water drop onto ground, it becomes highly cost-needed wastewater which must be treated in WWTM before discharging directly to surface water body as above mentioned. Hence, Tunnel Engineers are always trying to save cost of wastewater treatment by the separation of clean water and wastewater. To reuse clean groundwater has side effect of reducing quantity of wastewater into WWTM.

In fact, blasting processes and mechanical equipments used in D&B always damage very easily the piping systems installed on or nearby to excavation face for separating clean water and wastewater, unless tunnel excavation is ceased to make the separation succeed. So does TBM making tunnel process.

One successful reuse of groundwater and reduction of wastewater was located in the south of Pilot Tunnel; its position was about 1km far behind TBM boring face. The plastic piping system was connected to outlets of clean groundwater through one grab hole of erected segment and conveyed the water about 800m long by existing groundwater pressure and designed tunnel descendent slop into two receiving tanks for pumping upwards to TBM as construction water. Another successful reuse of groundwater and reduction of wastewater was located in the north of Pilot Tunnel; its position was at some safe distance behind D&B excavation face and about 3km far away from the north portal of Pilot Tunnel. The plastic piping system was connected to outlets of clean groundwater through several drilled holes on completed shotcrete face and conveyed the water 3km long by relay-pumping upwards to discharge mostly into Beishih Stream.

The service life of piping systems installed as above mentioned were counted about one year for TBM side and half a year for D&B side. The common reason of both sides is no more groundwater influx which is caused by ground deformation and re-formation to seal inlets of groundwater. Pilot Tunnel construction is scheduled as the pioneer of HTC; it excavates or bores firstly and disturbs the ground firstly too. Main tunnel construction step right after Pilot tunnel construction, they disturb or affect indirectly ground of Pilot Tunnel secondly. This situation makes ground deform and re-form to seal the inlets of groundwater.

To recycle, reuse the cooling water of hydraulic and electric power system of two TBM is the other way to reduce quantity of wastewater into WWTM. Even if the quantity of cooling water is not so much, it is worthy to do it because the service life of cooling water recycling system is able to last for several years to the termination of TBM, the cost of this system is cheap and the most concern is TBM can not do any production without cooling water supply.

To reuse, recycle effluents of WWTM as construction water supply in HTC is a very good substitute for surface water source, it also has the advantages of environment-protection, cost-saving, power-saving and stable quantity, quality water supply with regardless of weather change. There are several successful, wide- spread cases in HTC.

At the south portal of Hsuehshan Tunnel, two sets of powerful submersible pump are installed in a common effluent basin of S-2&S-3 WWTP for conveying qualified effluent to FRP tanks and its pumping system built beside the outlet of Southwards Tunnel, by relay-pumping, the qualified effluent is lifted upwards about 90m to the top of mountain where a receiving RC tank with 450m3 storage capacity is ready to send the qualified effluent to Pilot and main tunnel as construction water of TBM and D&B. This system has been operated so far so good.

At the north portal of Hsuehshan Tunnel, two sets of powerful submersible pump are installed in effluent basin of N-2 WWTP for conveying qualified effluent directly to Pilot and main tunnel as construction water of D&B. So do ST2-1&ST3-1 WWTP sited on the top of #2&#3 Ventilation Shaft.

OPERATIONAL STRATEGY OF WWTM FOR HTC

According to Government Procurement Act, ROC, RSEA, a government-owned enterprise and a main contractor of Hsuehshan Tunnel Engineering Lot 4&5, shall conduct any procurement of WWTM in accordance with this Act. Hence, based on the fundamental requirements of each WWTM, several qualified, experienced WWTM suppliers which include RSEA environmental professional division are invited case by case to participate in tendering procedures and are awarded the contracts under the government estimate. Basically, WWTM will be no problem in operation and its effluents shall meet the Effluent Standards of EPA by further strict inspection and acceptance procedures before closing the contracts.

The number of operator in each WWTM is not necessary to be in proportion to the scale of WWTM. In general, two Chinese and six Thai in one WWTM organization are enough at the early stage of WWTM and it is possible to be reduced to one Chinese and 3~4 Thai through complete training. The remaining personnel work somewhere in normal time and will be called back as firemen for emergency of WWTM. If some of WWTM are sited in the neighborhood, we can assign fewer operators in sum total to cover these WWTM areas instead of fixed operators for each WWTM. For instance, S-2 and S-3 are closed together, S-4 is about 200m far from them, all of them have simple nearby dormitory individually, it need only two Chinese and 4 Thai to cover full time and all the year operation in these WWTM areas so far so good. For better maintenance and operation of WWTM, the operator provided with mechanical and electrical background will be chosen in the first priority.

To offer cheap, high quality and stable supply of chemicals (H_2SO_4, PAC and Polymer) is a key way to save operation cost of WWTM for HTC. For stable supply, RSEA awards long-term contract under the govern of Government Procurement Act once a year to chemicals supplier instead of frequent tendering procedures on each requirement of different chemicals. RSEA may effect an inspection on each delivery during the supplier's performance of the contract to maintain high quality of chemicals as contracts said. A fair and beneficial principle set forth in tender documentation for purchasing Polymer is to award the contract by the lowest product which equals to the unit price of polymer multiply by the effectiveness of polymer. To obtain the effectiveness of polymer, we ask all tenders bring their polymer samples to S-3, dilute each sample to 0.1%, add it slowly into the fixed amount of wastewater sample taken from coagulation basin of S-3 and stir slightly until apparent flocs are observed, record the amount of diluted sample and return it to the original weight of sample, this amount of weight is called as the effectiveness of Polymer. These procedures of purchasing chemicals have been carried out for several years so far so good.

Every operator of WWTM is required strongly to step with check list to check the function of all listed systematic components in WWTM once on his duty and record the status of each system on check list. If any component is found to be damaged or going to be damaged, the experienced operator has to change it right away for keeping in good function of system or examine the spare parts on stock list, tracing the procurement process of the spare parts, analyze the damage frequency of these spare parts to do further decision of changing the supplier of these spare parts or modifying the design of relevant system. If the problem is so complicated or out of the scope of operator work, manager of WWTM has to gather up operators and the contractor of this WWTM to find solution at once. These operation and maintenance strategy have been proved to be effective for several years except a few violations caused by ignorance of operators to Effluent Standards.

For enhancement of wastewater treatment knowledge of managers and operators of WWTM, We introduce some short-training programs from some professional constructors, material suppliers of wastewater treatment and RSEA environmental professional division. We also award the research contract to Graduate Institute of Environmental Engineering of National Central University for integral evaluation of WWTM for HTC and solution program of removing LW (Labile Waterglass) grout seepage from WWTM. In addition to essential training programs, to require manages to patrol and investigate operation of WWTM frequently, to maintain high alertness of operators on proper function of WWTM and fluctuation of quantity, quality of influent wastewater are very important too.

According to the accumulated self-monitoring results of effluents of WWTM for HTC and the analyses of several penalties issued by local competent authorities, we conclude the phenomena of these shortcomings into two respects; one of them is the pH value of WWTM effluents is leaning toward acid and lower than the criteria (pH=6~9) of Effluent Standards. Improper function of pH meter and H_2SO_4 feed piping system are the reasons to make these violations as we investigate. The other of them is the SS value of WWTM effluents is higher than the criteria ($SS \leqq 30$ mg/L) of Effluent Standards. Ignorance to clean all basins of WWTM on a regular time schedule which will shorten the hydraulic detention time of every basin and result in worse wastewater treatment effect, improper function of PAC, Polymer feed piping system which will lead to insufficient density of floc aggregates formation and result in worse wastewater treatment effect, are the reasons to make these violations as we investigate. In addition to strengthen again the measures of preceding paragraph, one of the solution is to prepare a number of NaOH（strong base）tablet on sites for emergency to neutralize the effluents leaned toward acid.

EMERGENCY RESPONSE MEASURES OF HTC WASTEWATER TREATMENT

When an abrupt change in quantity or quality of wastewater during HTC or a combination of it which is obvious to exceed the designed wastewater treatment range of corresponding WWTM so many times and will cause violation of Effluent Standards and pollution of nearby surface water body, a serious breakdown of any WWTM occurs, takes a long time to be repaired and is very possible to cause violation of Effluent Standards and pollution of nearby surface water body, in such cases, emergency response measures（ERM）must be turned on immediately. ERM is not a permanent solution to wastewater treatment problem; on the contrary, ERM is a temporary measure for response to emergency only. In addition to protect environment and reduce harm of people and property, to take ERM also means appearances of abnormal situation which show some special difficulties in tunnel construction or insufficient wastewater treatment capacity of present WWTM. We shall realize the implicit meaning of taking ERM and not hesitate to do further effective improvement measures for not taking ERM any more.

In general, the basic design criteria of WWTP for HTC is set from influent wastewater with the quality of SS=1000~1500 mg/L, pH=10~12 and the relevant quantity evaluated by HTC team in accordance with geologic investigation and successful experiences, to effluent quality which has to meet the latest Effluent Standards no doubt. Hereinafter, three categories of abnormal condition of influent wastewater: abrupt change in quality but keeps quantity constant, abrupt change in quantity but keeps quality constant, abrupt change in both quality and quantity, will be stated individually by HTC experiences and explained why it happens, what measures they take to respond to such emergency.

There are two cases with abrupt change in quality but keeps quantity constant of influent wastewater of WWTP are used to be found in tunnel construction work. A characteristic of the first case is SS value raised up very quickly to 9000~10000 mg/L at early stage of TBM boring, shotcrete and de-mucking process of D&B by mechanical equipments, but to lower SS value is quite different, it depends on the ratio of coarse particles to fine particles and the distance from SS source to WWTP. If it is high ratio to allow most of SS to settle down in a short time and long distance to allow the most remaining of SS to precipitate along the passage, then the final SS value will drop into the design range of WWTP, it becomes a normal condition; on the contrary, the final SS value will be controllable higher than the design range of WWTP except the excavation face of tunnel or shaft is going to collapse. Under this slightly abnormal condition, the operator of WWTP shall add more chemicals to all reaction basins and keep an eye on floc aggregates formation to ensure the quantity of chemicals is proportional to the fluctuation of SS value of influent wastewater.

A characteristic of the second case is SS value produced from LW and cement grouting process but not from normal construction process. Water（H_2O）is a good solvent to hydrophilic molecules which are used to be constituents of strata, by long-term erosion-corrosion effects, strata shall decompose to a number of small pieces, loose its original binding structure and its capability of self-support which is very important in making tunnel process, especially in adverse geological structure sections. The more water content in strata is found, the more caution in tunnel construction is essential absolutely. Therefore, the experienced tunnel engineers usually adopt LW, pure cement or other chemical grouting before and after making tunnel to take the place of water in strata by grout material, not only to get rid of erosion-corrosion effects by water, but also to glue strongly nearby strata together than before by grout material for temporary or permanent safety of tunnel. The problem is very hard to block completely the seepage during LW and cement grouting process in fractured, abundance of groundwater influx, geological structure sections. If Waterglass and cement can’t mix well in LW grouting process, then some of them will be flushed out with groundwater from fissures of strata into wastewater and increase SS value rapidly, raise pH value simultaneously as high as 12, or remix here to form a number of white floating SS in different size. To handle such phenomena, the operator of WWTP normally adds more chemicals to precipitate SS increment and to neutralize abnormal pH. If it is still in vain, the operator must take ERM, report immediately to manager of WWTP and request to stop all grouting activities until it is under control. The cases above mentioned happened several times in #2, #3 Ventilation Shaft grouting periods but not in the south of HTC. To analyze it, we find abundance of groundwater influx to dilute SS increment and long conveying passage to allow more SS particles to settle down along the way to WWTP are important reasons, in addition to different skills in grouting.

Abrupt change in quantity but keeps quality constant of influent wastewater of WWTP means already to meet underground waterway or water pocket in making tunnel process but the present structure of tunnel is safe by self-support of surrounding strata. Normally, groundwater influx in this case is clean or a little SS inside. If the water pocket is small and the waterway is re-sealed in a few days, the operators of WWTP add merely more chemicals into all reaction basins will be enough to solve this problem. If not, a long-term, huge amount of water shall disturb and flush the precipitated SS particles back into wastewater to raise SS value up. For instance, TBM of Pilot Tunnel bored and met this situation in Feb., 2003. At that time, all rail at the south portal of Pilot Tunnel were submerged in flood which lasted for one month, it is funny to see muck cars, locomotives and other carrying devices to move in and out of Pilot Tunnel just like boats moving on the water. The groundwater influx is too enormous to grout and the structure of surrounding strata are good enough to be bored, the manager of Pilot Tunnel gave the exact order to keep TBM boring instead of helpless waiting. The manager of S-1~S-3 WWTP take ERM right away: not only to give the order to run all WWTP in full speed, in maximum treatment capacity to reduce the quantity of wastewater discharged to Bei-Mon-Ken creek which is used as a flood discharging channel for nearby mountains only, but also to do negotiation and explanation actively with local people to obtain their understanding and promise some further improvement measures for promoting friendly relationship with local people. Finally, no one gets hurt in this event and no accusation is lodged against this event.

Abrupt change in both quality and quantity means most of small natural infill materials which are essential components of structural strength of strata are flushing out by continuous, pressurized, huge amount of groundwater into wastewater and strata are going to loose their self-support capability, in short, collapse is inevitable. By many observations on several collapses of Pilot Tunnel before 2000 and the terrible collapse （maximum groundwater influx reaches to 750 l/s） to bury TBM worked in the Northwards Tunnel in Dec., 1997, it is so clear not only the quantity of wastewater is abrupt change and much higher than the sum total of S-1+S-2+S-3=308 l/s treatment capacity, but also the quality of wastewater is abrupt change to about 30000 mg/L looked like slurry water and much higher than 1500 mg/L the design criteria of WWTP. Under such circumstances, stopping immediately all tunnel or shaft construction work, waiting the collapsed ground to be stable for safety and preparing materials, equipments used for geological treatment in succession are the first priority to do. In the meantime, the managers of WWTM take ERM in different way to correspond to the situation of job sites.

In the north of Hsuehshan Tunnel, the manager of WWTM takes whole Pilot Tunnel space as a temporary storage volume for abrupt quantity and quality of wastewater during the collapse and waiting period. There are two reasons for the manager of WWTM to adopt this measure; one is the ascending（1.255%）design up to the portal of tunnel, it is easy to store wastewater in Pilot Tunnel, the other is the location of N-1 and N-2 are very closed to Beishih Stream which is one upstream of FeiTsui Reservoir, if untreated wastewater discharged directly into Beishih Stream to cause serious pollution of FeiTsui Reservoir, then predictable accusations to be lodged by local people or local competent authority against this event shall be unavoidable. So do the difficult time of #2 and #3 Ventilation Shaft construction. In the south of Hsuehshan Tunnel, the manager of S-1~S-3 WWTP takes the same ERM as preceding page says. There are two reasons for the manager of S-1~S-3 WWTP to adopt this measure; one is the descending（1.255%）design down to the portal of tunnel, it is impossible to store wastewater in Pilot Tunnel, the other is Bei-Mon-Ken creek which is deemed as the receiving water body of effluents of S-1~S-3 WWTP is used as a flood discharging channel for nearby mountains only, the discharged, non-poison, construction wastewater will not affect anything except the slurry appearance of Bei-Mon-Ken creek which must be quickly cleaned by constructor as this event is over. However, to establish S-4 is imperative under the circumstances.

CONCLUSION

The historical establishment process of WWTM for HTC has been closely linked to the complicated and multivariational HTC historical process since the commencement at the south portal of Hsuehshan Tunnel fourteen years ago. By the efforts of all members of HTC team, Hsuehshan Tunnel was fully penetrated through in Sep., 2004. Especially, the people who worked in #2 Ventilation Shaft and its successive Northwards Tunnel did their best to overcome tough and difficult environments, to utilize all available space in tunnel to build ST2B1~5 and to operate it well approximately, shall be praised here again.

In addition to main topical subjects of SS and pH, lightly excessive concentration of phosphate and Ammonia Nitrogen in effluents of N-1, N-2, ST3-1 and ST2T-1 WWTP were raised to be issues regarding to eutrophication of Beishih Stream. Eventually, it was proved to be nothing to do with HTC wastewater but in relation to seeping fertilizer（phosphate inside）from tea farm, washing and cleaning agent（phosphate inside）,and domestic wastewater（Ammonia Nitrogen inside）. Isolation and substitution of pollution sources are the final solutions.

Normally, construction manager can’t tolerate extremely to take ERM and to stop tunnel construction work owing to the breakdown or malfunction of WWTM. Therefore, all operators and managers of WWTM must always keep alert on doing whatever they are supposed to do for the normal operation of WWTM.

During 14 years’ struggled period of HTC, we have realized deeply it is very difficult to forecast exactly the quantity of groundwater influx with the advancement of tunnel or shaft, even though most of the latest detective methods are carried out frequently. If some simulated programs or high technical machines for predicting better information of groundwater are developed in the future, then not only tunnel engineer can use it to do something good for safety and prevention prior to the collapse of tunnel, but also environmental engineer can use it to do better planning for the scale and location of WWTM.

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