Design Standard

For

Municipal Wastewater Treatment Plants

Second Edition

Japan Sewage Works Association

Preface

The standard issued by Japan Sewage Works Association (JSWA) is the basis for planning and designing of publicly owned municipal wastewater facilities in Japan.

The first edition was issued in 1964, and then revised five times, in 1972, 1984, 1994, 2001, and 2009 respectively.

The standard has been edited by the experienced engineers mainly from major cities.

It is the basis for procurement specification although details are decided by each.

Upon the international request from developed and developing countries, JSWA issued the first English version of the standard in 2012.

In the first edition, the design for conventional activated sludge process was translation.

In this second edition, oxidation ditch process was added.

JSWA hopes this will be of use to professionals in the world.

Contents

1 General

1.1 Fundamentals

Effluent quality shall meet law requirements.

They include minimum requirement for publicly owned wastewater treatment plants and permit derived from receiving wasters' quality standard by the sewerage law.

Treatment process selection shall be made based on the law description of achievable effluent quality by each process, site conditions, and local requirements

Design shall be made to meet the target effluent quality by taking into consideration of influent quality, temperature, and variation of influent load of the hour, day, moth and season.

1.2 Design inflow and influent quality

Design inflow shall be the planned maximum daily flow except for biologically nitrogen removal reactor.　For the tank for nitrogen removal, design inflow shall be the planned maximum daily flow in winter.

Design influent quality shall combine planned raw sewage quality and load of sidestream return from sludge treatment process.

Design inflow and influent quality shall consider variation along the time.
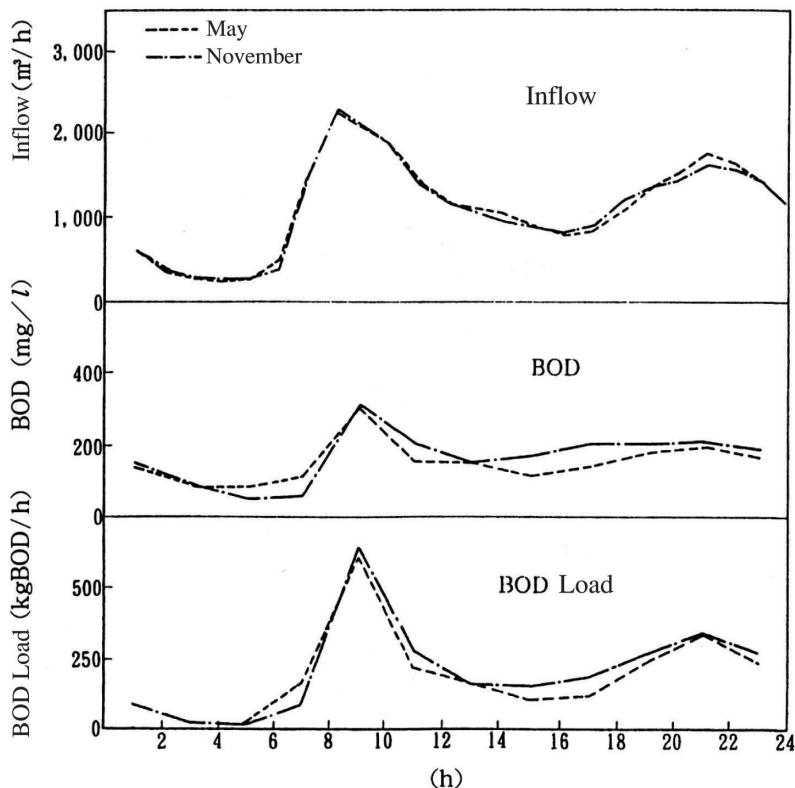
Figure 1.2.1 Diurnal Variation of Inflow and Influent Quality of WWTP at Kobe

1.3 Layout and structure of wastewater treatment facility

Layout, structure, and process shall be designed for the facility to be easily maintained considering locally available resource, human and financial.

The number of process line shall be two or more considering the suspension of individual operational line due to inspection, repair, cleaning, rehabilitation, and replacement.

Construction works shall be made step by step to meet the inflow of sewage to raise investment efficiency and to avoid operational difficulties of little sewage.
If step by step construction work cannot handle little sewage problem at initial stage of operation, special measure shall be made.

Layout and structure shall suit the neighboring environment of WWTP, especially for the residences, by considering emission of odor, noise, radio wave, sunlight cut-off, air pollution, and landscape disturbance. If necessary, cover of clarifiers and reactors and

greenery along the boundary of WWTP site shall be designed.

When the recreational public space is planned over the clarifiers and reactors, layout shall be designed to coordinate recreational use and operation & maintenance work.

Layout shall be designed to include space for rehabilitation of civil and architectural works including temporary works and rehabilitation works. Layout shall include roads around facility so that machines and electrical would be brought in for installation.

When clarifiers and reactors are rehabilitated, they cannot accept wastewater. Therefore, bypass channel or shut off gate shall be designed.

Layout should be designed to place machinery and electronics at easily replaceable positions as they are shorter in useful life than civil and architectural works.

Layout and structure shall be designed to incorporate future upgrade plan from secondary to advanced treatment in master plan.

1.4 Hydraulic Profile

Control point for calculation of hydraulic profile is receiving water surface elevation in master plan. The hydraulic profile shall be calculated through the outfall line and each process unit up to the influent sewer by adding the calculated head loss the receiving water elevation. If elevation difference between units is too small, backflow may occur. If it is too big, uneconomically big pump is needed. Consideration may be needed for sidestream from sludge treatment, return sludge and internal return of activated sludge system, and ,if applicable, stormwater runoff from within the site.

	Type	Description
	Sewer	Separate
	Treatment	Conventional Activated Sludge
	Capacity	39,500 m³/d

Sludge thickener

Sludge Handling Bld

Control Bld

Standby Generator

Primary Sedimentation

Reactor

Secondary Sedimentation

Chlorination

Grit, Pump & Blower Chamber

Outfall Sewer

Influent Sewer

River
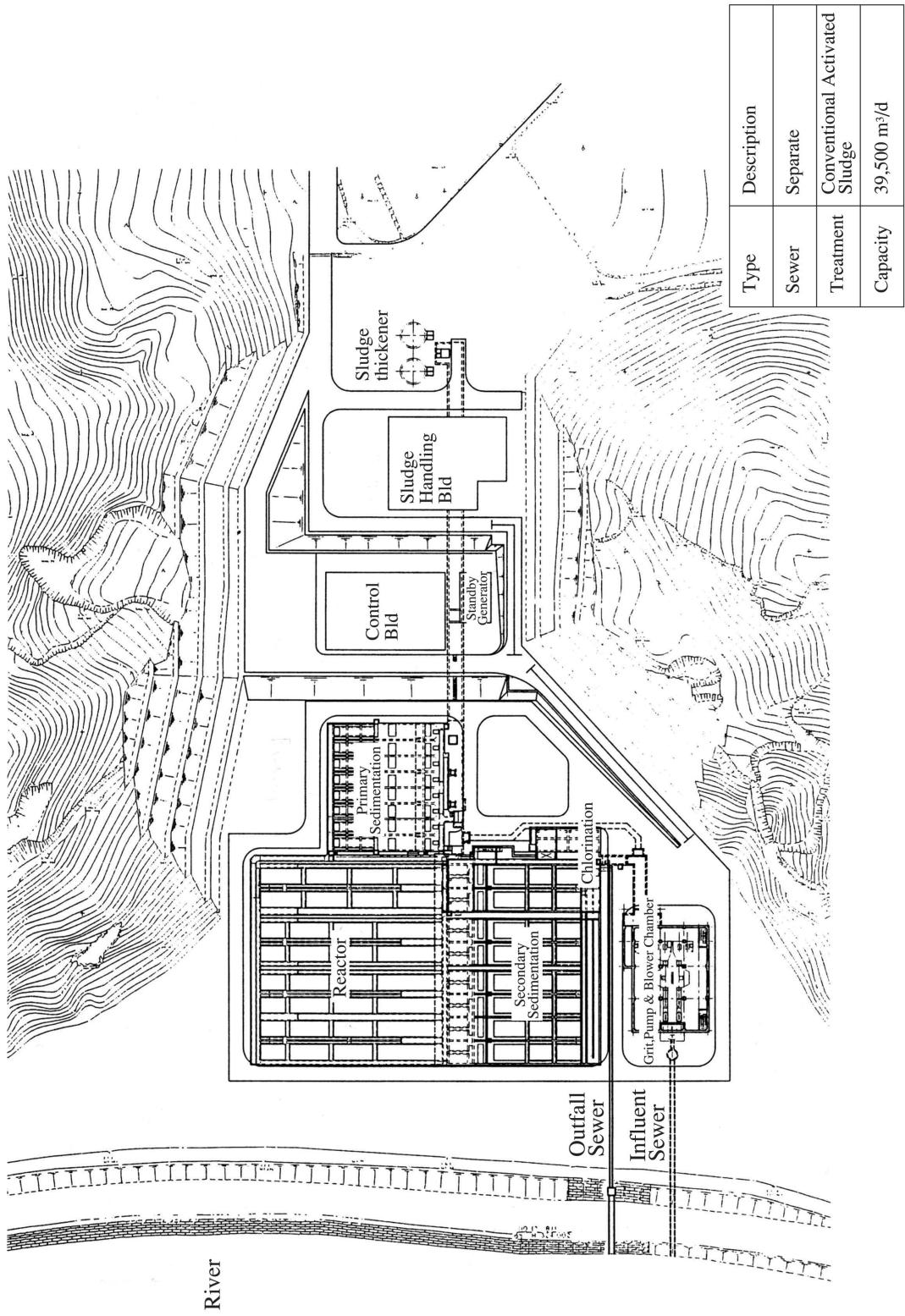
Figure 1.4.1 Layout Plan of WWTP at Shirakawa
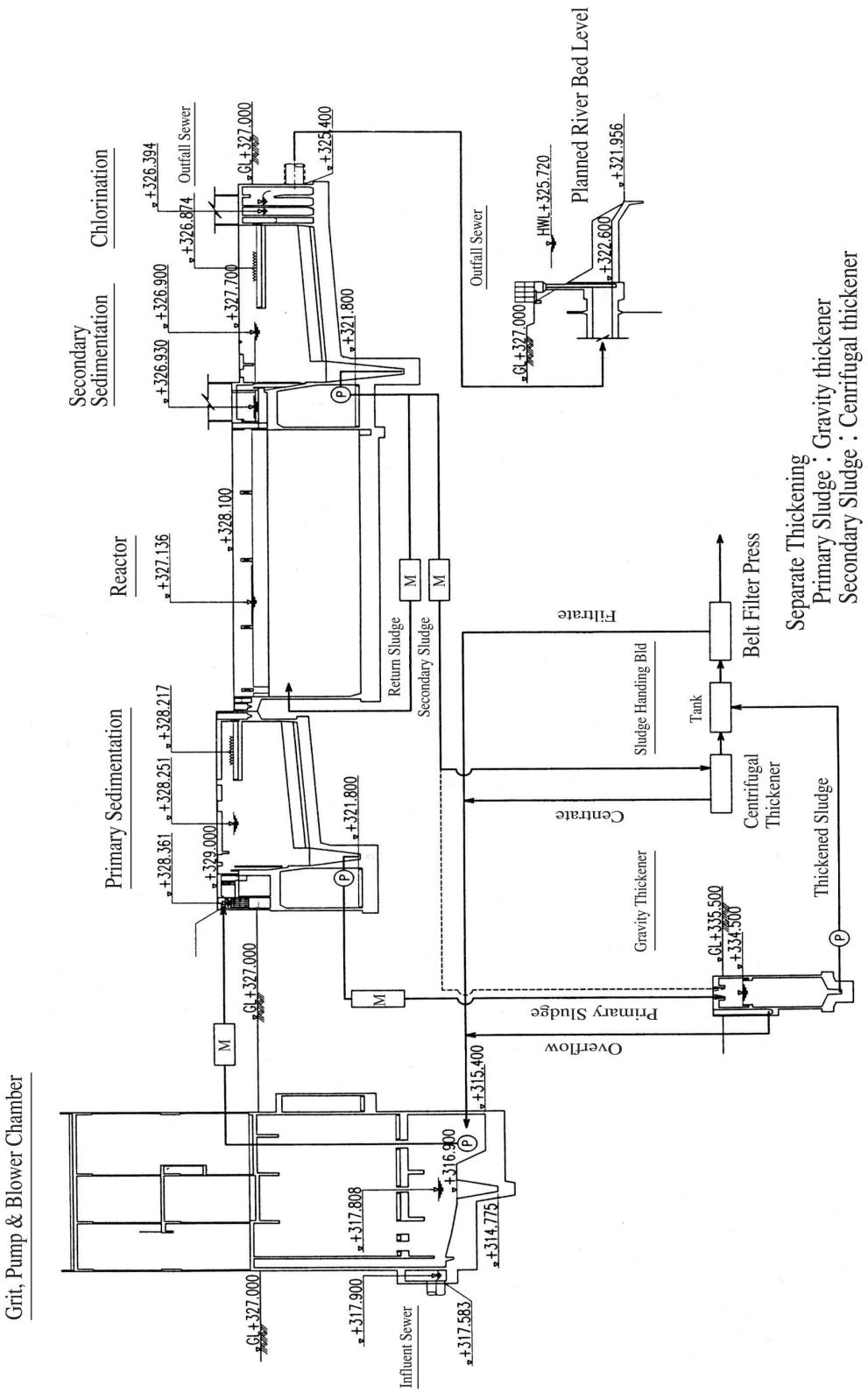
Figure 1.4.2 Hydraulic Profile of WWTP at Shirakawa
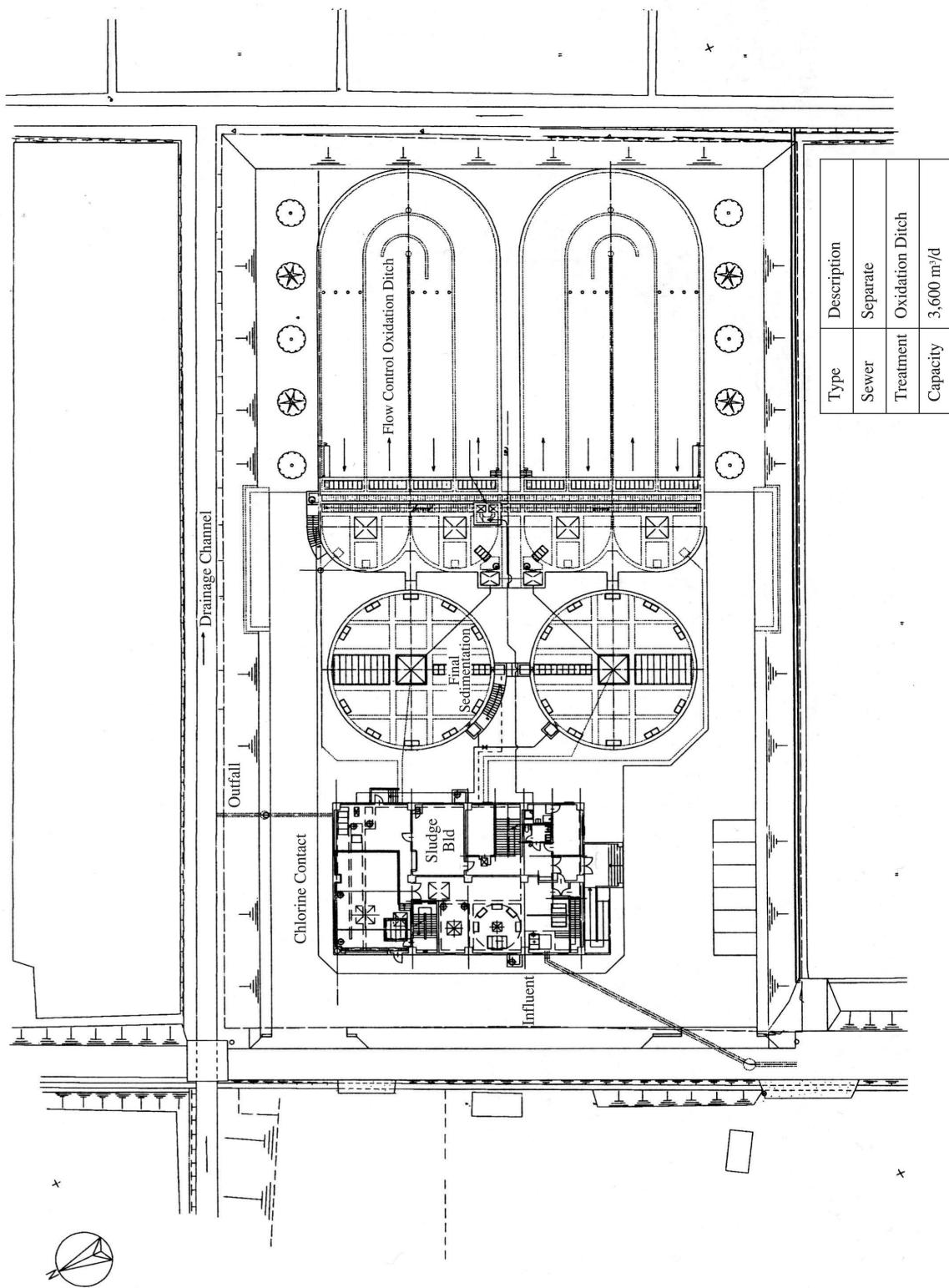
Figure 1.4.3 Layout Plan of WWTP at Iiyama

Type	Description
Sewer	Separate
Treatment	Oxidation Ditch
Capacity	3,600 m³/d
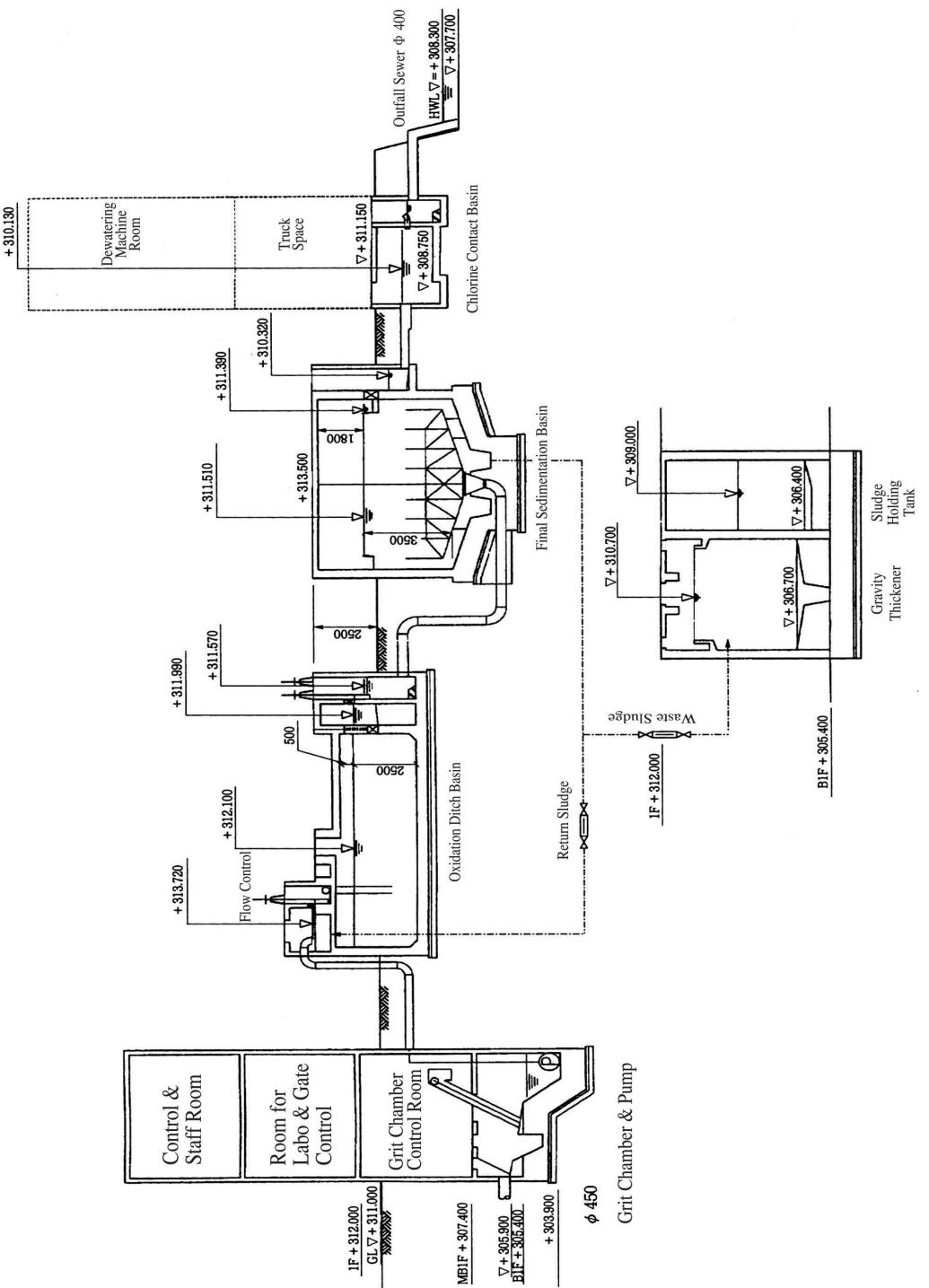
Figure 1.4.4 Hydraulic Profile of WWTP at Iiyama

Control & Staff Room

Room for Labo & Gate Control

Grit Chamber Control Room

Grit Chamber & Pump

φ 450

1F + 312.000
GL ▽ + 311.000

MB1F + 307.400
▽ + 305.900
B1F + 305.400
+ 303.900

Oxidation Ditch Basin

Return Sludge

Flow Control

+ 313.720

+ 312.100

500

2500

+ 311.890

+ 311.570

2500

Final Sedimentation Basin

+ 311.510

+ 313.500

1800

3500

+ 311.390

+ 310.320

Dewatering Machine Room

Truck Space

+ 310.130

▽ + 311.150

▽ + 308.750

Chlorine Contact Basin

Outfall Sewer φ 400

HWL ▽ = + 308.300

▽ + 307.700

Waste Sludge

1F + 312.000

▽ + 310.700

▽ + 309.000

Gravity Thickener

Sludge Holding Tank

▽ + 306.700

▽ + 306.400

B1F + 305.400

2 Selection of treatment process

2.1 Selection of treatment process based on law

Selection shall be made from the list of sewerage law with due considerations in this section.

Table 2.1.1 Treatment Process and Design Effluent Quality by Sewerage Law

Design Effluent / Process Type	0.5 or under	above 0.5 to 1.0	above 1.0 to 3.0	1.0 or under	above 1.0 to 3.0	1.0 or under	above 1.0 to 3.0	3.0 or under	3.0 or under
BOD mg/l	10 or under							above 10 to 15	
TN mg/l	10 or under			above 10 to 20				20 or under	
TP mg/l	(TP values in header above)								
AS/ABF/SFBB									◎
AS/ABF/SFBB+RSF							◎		O
AS/ABF/SFBB+CO								O	O
AS/ABF/SFBB+CO+RSF						O	O	O	O
BN								◎	O
BN+ORG								O	O
BN+RSF				◎			O	O	O
BN+CO						◎		◎	O
BN+ORG+RSF			◎				O	O	O
BN+ORG+CO						O	O	O	O
BN+CO+RSF				◎	◎	O	O	O	O
BN+ORG+CO+RSF		◎	◎	O	O	O	O	O	O
BP								◎	O
BP+RSF						◎	O	O	O
BP+CO								O	O
BP+CO+RSF						◎	O	O	O
BNP						◎	◎	◎	O
BNP+ORG						O	O	O	O
BNP+RSF				◎	◎	◎	O	O	O
BNP+CO						O	O	O	O
BNP+ORG+RSF		◎	◎		O	O	O	O	O
BNP+ORG+CO						O	O	O	O
BNP+CO+RSF				◎	O	O	◎	O	O
BNP+ORG+CO+RSF	◎	◎	O	O	O	O	O	O	O

◎: Recommended
O: Allowed
AS: Conventional Activated Sludge Process, Oxidation Ditch, Extended Aeration, Sequence Batch Reactor, Pure Oxygen
ABF: Aerobic Biological Filtratiton Process with Plastic Media
SFBB: Submerged Fixed Bed Biofilm Process
RSF: Rapid Sand Filtration
CO: Addition of Coagulant
BN: Biological Nitrogen Removal Activated Sludge Process
ORG: Addition of Organics for enhancing denitrofication
BP: Biological Phosphorus Removal Activated Sludge Process
BNP: Biological Nitrogen & Phosphorus Removal Activated Sludge Process

Inflow rate and influent quality shall be designed by totaling future wastewater generation from domestic, commercial, industrial, and institutional sources with addition of inflow and infiltration.

In case of expansion and rehabilitation of the existing WWTPs, record of actual inflow rate and influent quality shall be referenced to correct the initial design values. Hourly and seasonal variation in pollutants load shall be compared to the neighboring similar municipalities. If extreme variation is expected by specific customers such as factories, schools, nursing homes, and hotels, special survey shall be made for the operation of the customers.

When a wastewater reuse and reclamation project is planned, process selection shall be made to meet the requirements of quality and quantity of the project.

Selection of wastewater treatment shall be made considering the sludge treatment. Sidestream return from sludge treatment may influence water treatment. Selection of sludge treatment process depends on how sludge is finally disposed or recycled.

Site characteristics shall be referred for the selection of treatment type. They include are, shape, slope, geology. In case of expansion and rehabilitation, existing plant layout and actual use of site shall be taken into consideration.

Environmental factors of site shall be considered for the selection of treatment process. They include weather condition; temperature, rainfall, snow, location; industrial, preservation area, whether or not of designation of land use, local industry; especially tourism, law restrictions on noise, vibration, odor, nature preservation, and how utility can finally dispose of screenings, grit, and waste sludge.

Locally available resource for operation and maintenance shall be considered. Number of maintenance points and frequency of inspection and repairs, operation easiness/difficulty shall be referred.

Economics shall be calculated. Cost for construction and O&M shall be evaluated on life cycle basis in reference to useful life.

2.2 Selection of advanced treatment

When advanced treatment is designed for nitrogen, phosphorus and BOD removal, selection of the process shall be made in accordance with sewerage law.
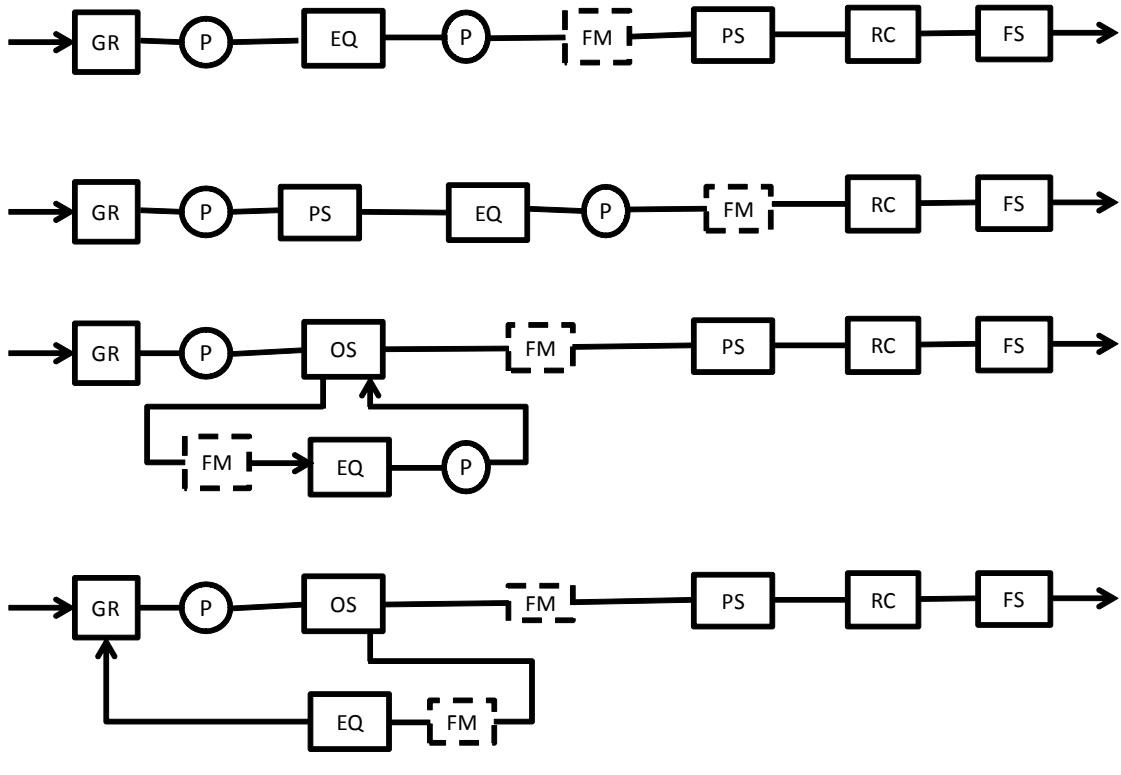
When advanced treatment is designed for other parameters, target quality shall be set for the concerned parameters and necessary process shall be selected.

3 Dry weather flow equalization

3.1 Selection of in-line/on-line

Flow equalization is used to increase efficiency of treatment by accommodating wide variations in flow rates and organic mass loadings.

Selection of either in-line or side-line equalization shall be made based on economy and effectiveness.

Legend

GR: Grit Removal
P: Pump
PS: Primary Sedimentation
EQ:Equalization
FM: Flow Meter
RC: Reactor
FS: Final Settling
OS: Overflow Structure

Figure 3.1.1 Schematic Flow Diagram of Equalization Facilities: in line and side-line

3.2 Equalization capacity

The capacity shall be decided to store the excess wastewater over design flow to the downstream process. It is advisable to have equalization when peak flow exceeds 1.5 times of daily average flow and when biological nutrient removal process is used. When sequencing batch reactor or biofilter system, equalization basin shall be used.
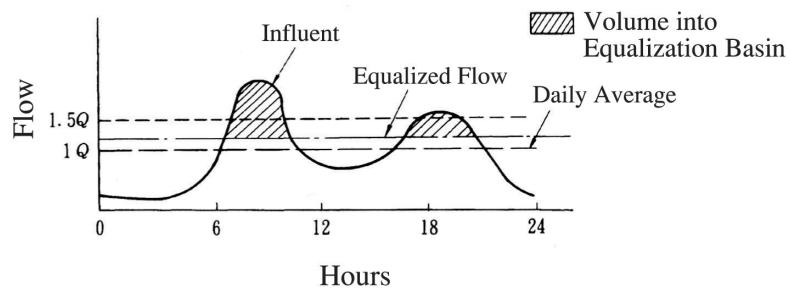
Figure 3.2.1 Necessary Capacity

3.3 Shape and number of basin

The shape of equalization basin shall be rectangular or square. The number of basins shall be two or more for cleanings, inspection, and repair.

Plan

A-A Section
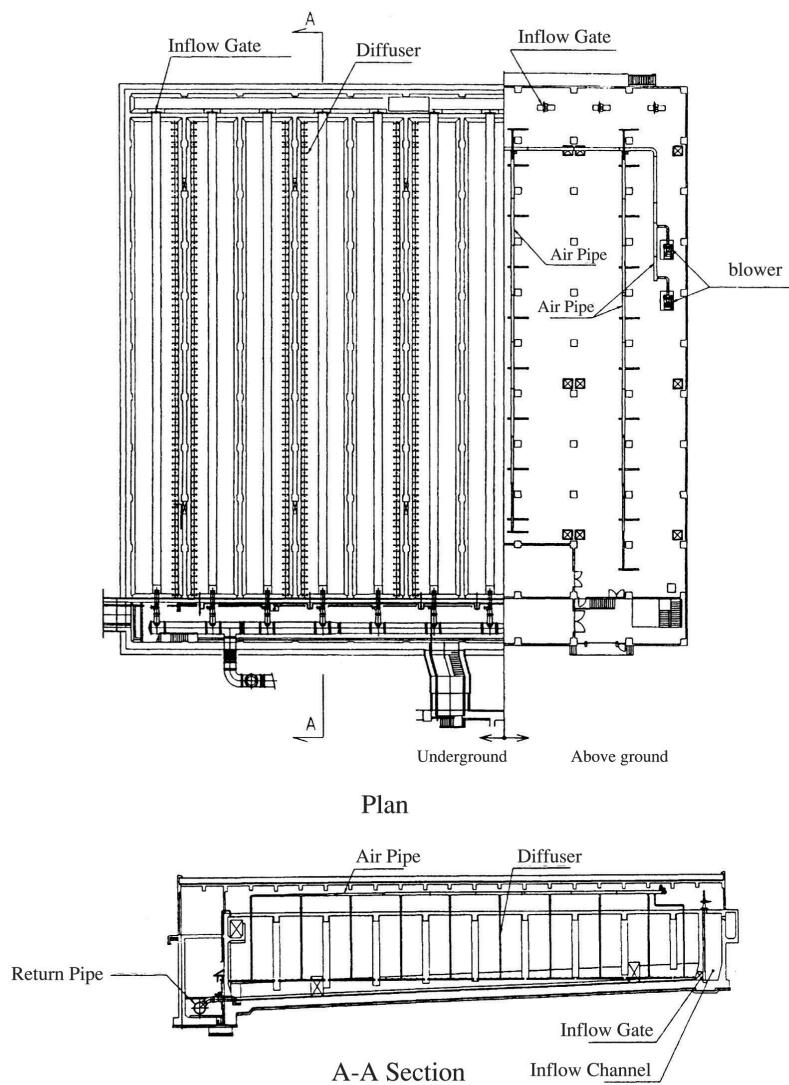
Figure 3.3.1 Equalization Tank at Kobe WWTP

3.4 Structure

The structural material of equalization basin shall be reinforced concrete and watertight. The structure shall be heavy enough for groundwater pressure not to float it.   Top of the basin shall be covered to control odor. Basins and connecting channels shall resist chemical attack.   In case of side line equalization, sum pump should be installed to make the basin dry as remaining wastewater becomes corrosive.

3.5 Mixing

Mixer shall be installed in equalization basin to blend the contents of tanks and prevent deposition of solids in the basin.   The necessity of aerators shall be checked to prevent wastewater from becoming septic.   Mixing method shall be decided to mix the content at low water level.   In case mixing is insufficient to prevent deposition of solids, mechanical collector shall be installed.

3.6 Outflow

Wastewater from equalization shall be returned to grit chamber by gravity or to the first clarifier/reactor tanks by pumps.   In case of the pump use, flow meter and control device of pump shall be installed.

4 Sedimentation
Primary sedimentation
4.1 Shape and Number of basin

The shape shall be either, rectangular, square or circular.
For rectangular basin, influent is fed in parallel to the length.   For square and circular basin, influent is center-fed for flowing in radial.

The ratio of length to width for rectangular basin shall be over 3.
The width of rectangular basin shall be decided considering installation of chain and flights collector.
The ratio of diameter to depth for circular basin shall be from 6 to 12.
The number of basins shall be two or more for cleaning, repair and rehabilitation.

4.2 Structure

The structural material shall be reinforced concrete with water tightness.   The structure shall be heavy enough for groundwater pressure not to float it.

To remove the sludge from the basin, mechanical collector shall be installed to prevent it from becoming septic.

Bottom slope of basin shall be between 5 and 10 to 100 for circular and square type.
Bottom slope of basin shall be between 1 and 2 to 100 for rectangular type.
The slope of sludge hopper shall be 60 degrees or over.

The necessity for the cover of inflow and outflow channels and basins shall be considered to control odor.　When they are covered, corrosion control shall be made.

The necessity of bypass channel to reactor shall be considered for low load problem at the initial stage of commencement of treatment service.　In this case, necessity of screenings shall be considered.

4.3 Design criteria for overflow rates (surface loading rates)

Overflow rates shall be from 35 to 70m^3/m^2/day for separate sewer system and be from 25 to 50m^3/m^2/day for combined system at maximum daily flow.

Table 4.3.1 Typical Removal Rate at Primary Sedimentation Tank

BOD	SS	COD
30-50%	40-60%	30-50%

4.4 Depth

Depth shall be defined as the distance of water surface and the shallowest part of the basin.　The depth shall be 2.5 to 4.0 m.

Table 4.4.1 Design Detention Time on Conventional Activated Sludge Process as Reference

	Separate Sewer	Combined Sewer	
Design Flow Type	Daily Maximum	Daily Maximum	Wet Weather
Detention Time, hr	1.5	3.0	0.5 or over

4.5 Extra depth

Extra depth of primary sedimentation tank shall be around 50 cm.
If it is too big, construction work gets uneconomical and maintenance work is disturbed
If it is too small, overflow may take place.

4.6 Inlet conditions

For rectangular basins with weir inlet, porous baffle shall be installed.

For rectangular basins with the other inlets, porous baffle and baffle plates shall be installed.

For circular and square basins, baffle plates shall be installed surrounding inlet part.
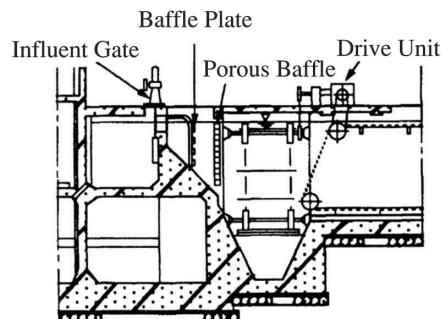

Figure 4.6.1 Inlet Structure
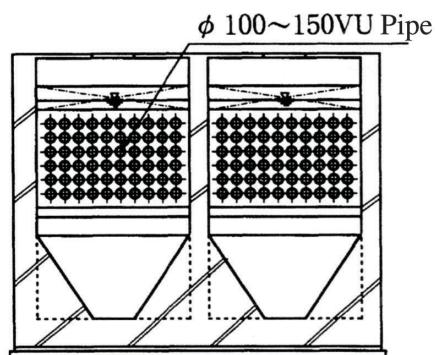
Figure 4.6.2 Porous Baffle Wall
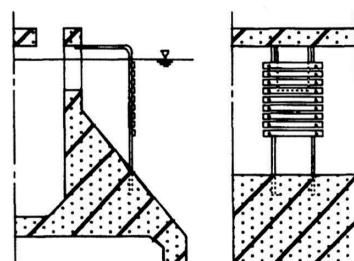
Figure 4.6.3 Baffle Plate

4.7 Scum Collection

Primary clarifier shall have scum collection system.
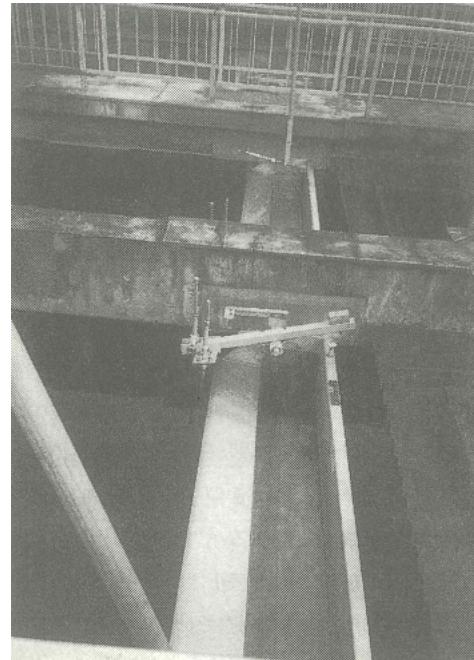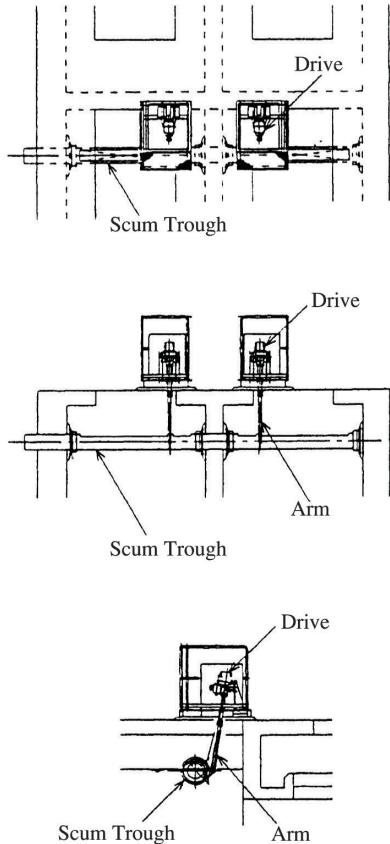
Figure 4.7.2 Power free Scum Collection

Figure 4.7.1 Scum Collection System, Plan & Sections

4.8 Outlet conditions

Outlet structure shall be weir.   Weir rates shall be around 250m³/m/day.   Top shape of weir shall be notched.
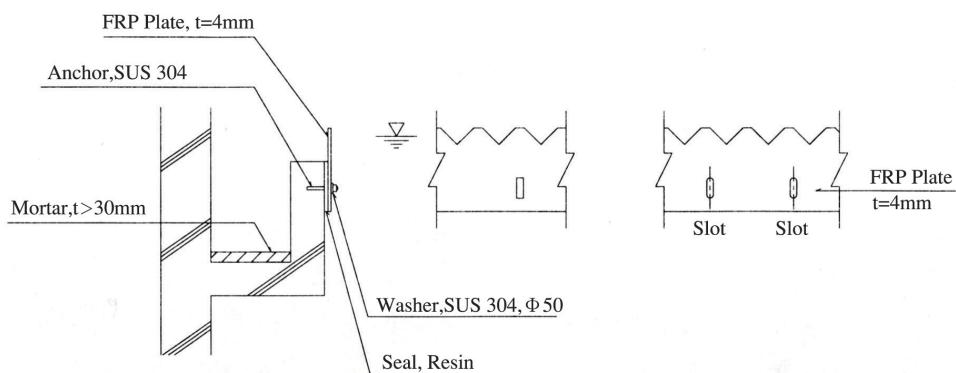

Figure 4.8.1 Weir

4.9 Sludge collection

For rectangular tanks, chain and flights system is advised.

The material of chain was cast iron but is being replaced by plastics and stainless steel

For circular and square tanks, rotating arm collector shall be used.

The speed of chain and flights shall be 0.3 to 1.2 m/min.

The speed of rotation arm shall be 1 to 3 times per hour when axis and drive is centered

The speed of rotation arm shall be 3m/hr or less when drive is outside.
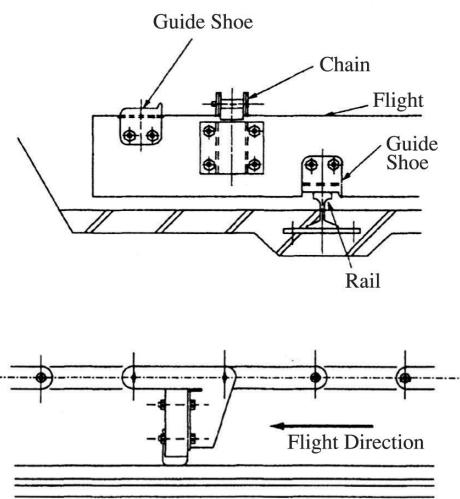
Figure 4.9.1 Flight and Chain Sludge Collection, Diagram
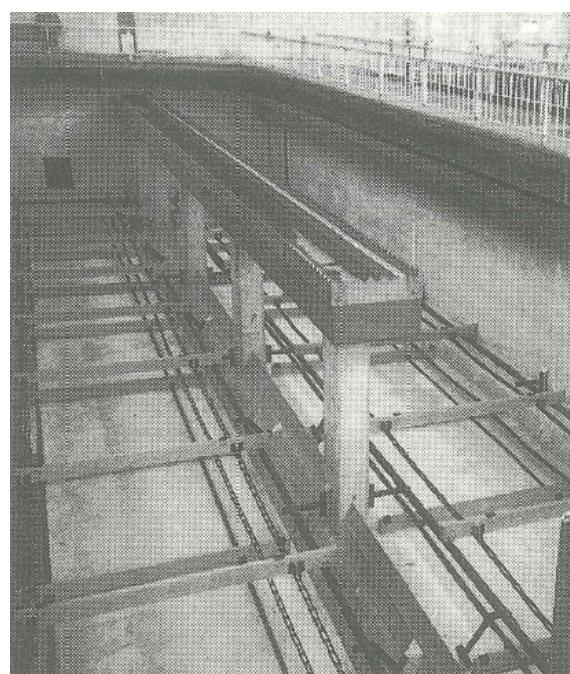

Figure 4.9.2 Flight and Chain Sludge Collection, Figure

Plan

Section B-B
Sludge Collector Drive

Rail

Scum Pit

Sludge Collector

Sludge Collector

Section A-A

Scum Collection Drive

Scum Collection Drive

Sludge Collection Drive

Sludge Collection Drive

Inlet Gate

Inlet to Reactor

Rail
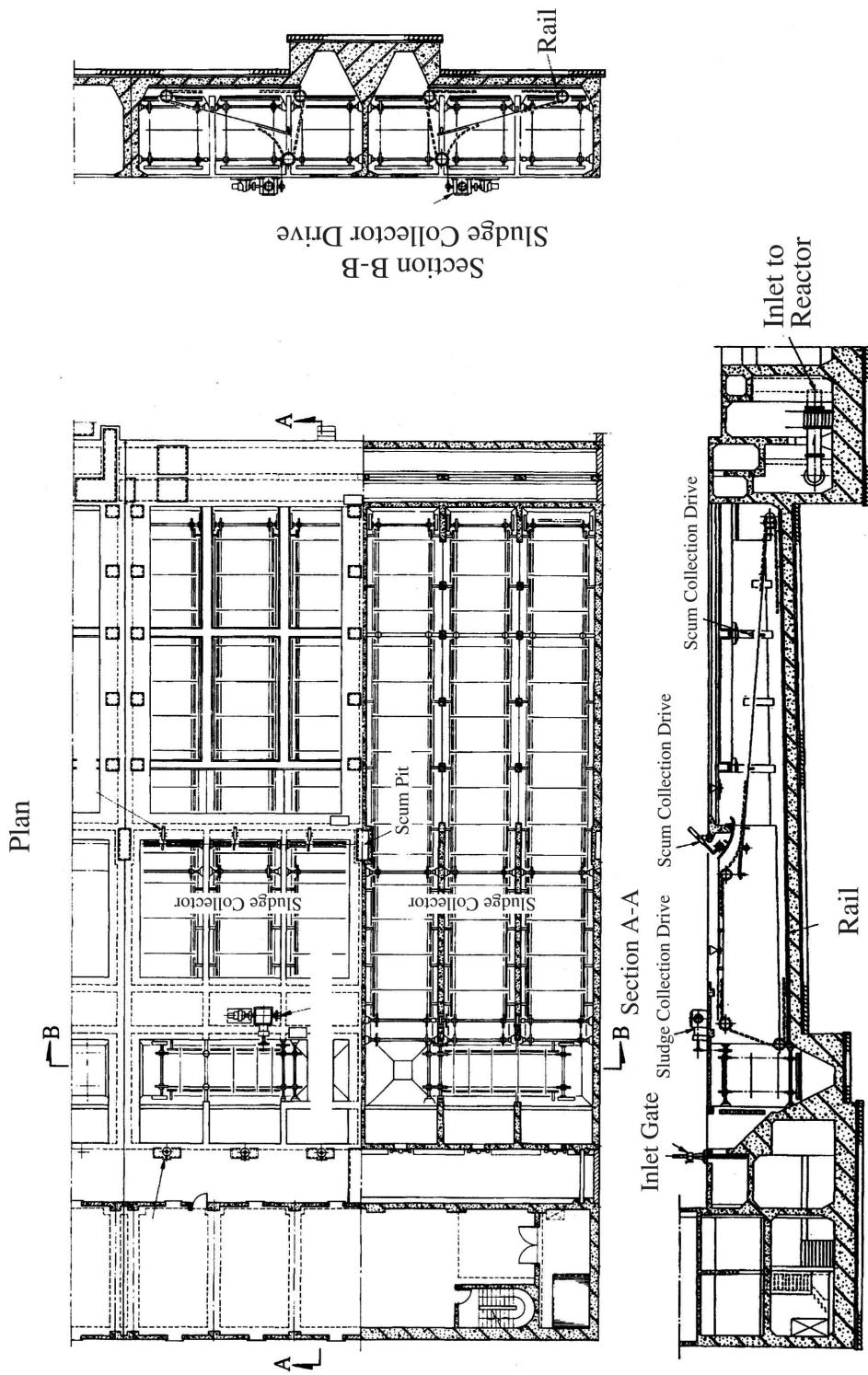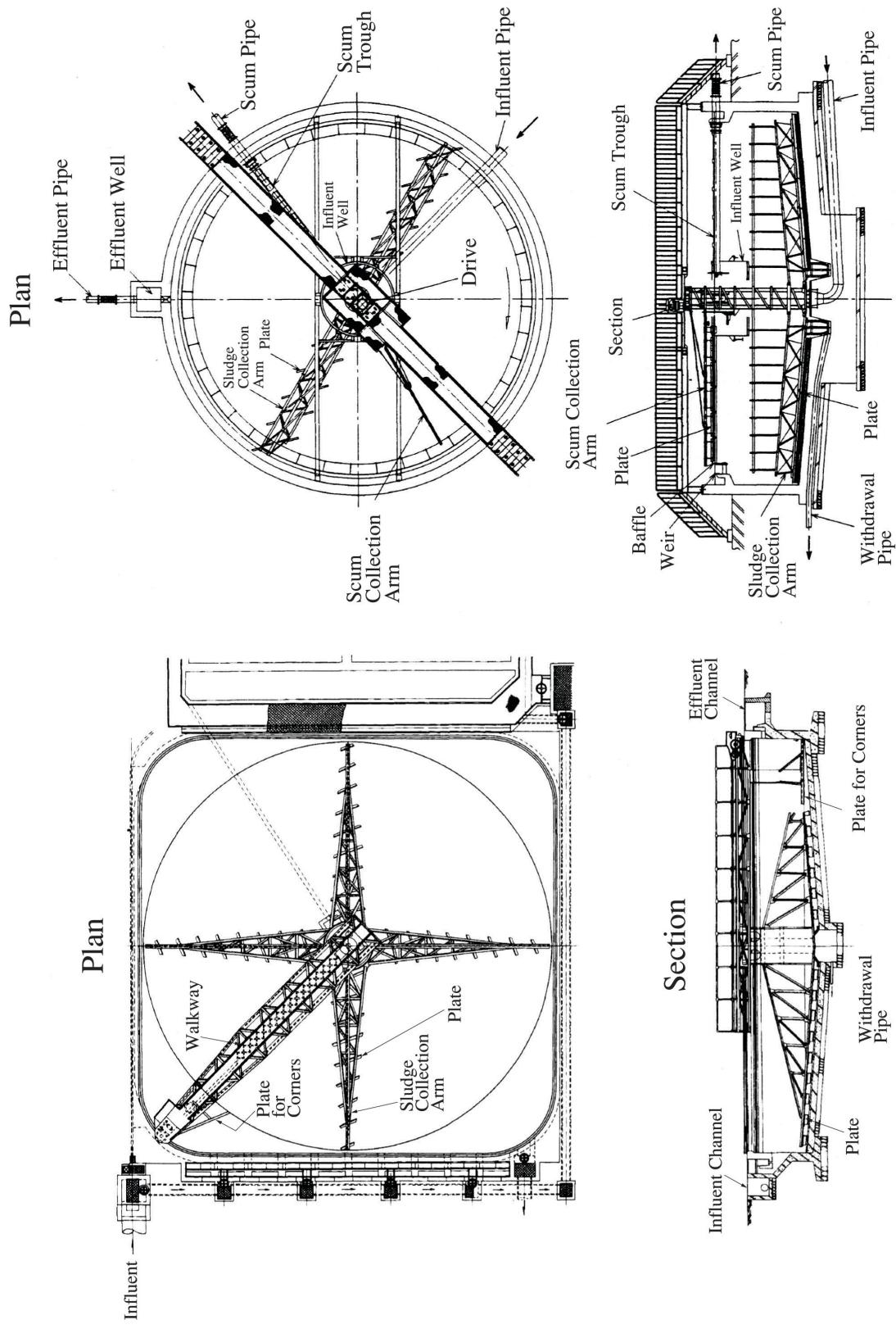
Figure 4.9.3 Flight and Chain Sludge Collection at Yokohama

Plan

Scum Pipe
Scum Trough
Influent Pipe
Effluent Pipe
Effluent Well
Influent Well
Drive
Sludge Collection Arm
Plate
Scum Collection Arm
Scum Collection Arm

Section

Scum Pipe
Influent Pipe
Scum Trough
Influent Well
Plate
Plate
Withdrawal Pipe
Baffle
Weir
Sludge Collection Arm

Figure 4.9.5 Flight and Chain Sludge Collection at Jyonan

Plan

Walkway
Plate for Corners
Plate
Sludge Collection Arm
Influent

Section

Effluent Channel
Plate for Corners
Withdrawal Pipe
Plate
Influent Channel

Figure 4.9.4 Flight and Chain Sludge Collection at Toyohashi

4.10 Sludge withdrawal

The use of pumps is recommended.

The number of pumps shall be two or more.

The sludge withdrawal line shall be at least 150 mm in diameter.

In case of clogging, inspection port and jetting port shall be installed.

Final sedimentation

4.11 Shape and Number of basin

See 4.1.

4.12 Structure

The structural material shall be reinforced concrete with water tightness. The structure shall be heavy enough for groundwater pressure not to float it

To remove the sludge from the basin, mechanical collector shall be installed to prevent it from becoming septic.

Bottom slope of basin shall be between 5 and 10 to 100 for circular and square type.

Bottom slope of basin shall be between 1 and 2 to 100 for rectangular type.

The slope of sludge hopper shall be 60 degrees or over.

4.13 Design criteria for overflow rates (surface loading rates)

Overflow rates shall be from 20 to 30m^3/m^2/day at maximum daily flow

4.14 Depth

See 4.4.

4.15 Extra depth

See 4.5.

4.16 Inlet conditions

See 4.6

4.17 Scum Collection

See 4.7.

4.18 Outlet conditions

Outlet structure shall be weir.

Weir rates shall be around 150m^3/m/day.

The necessity of anti algae growth shall be considered.

Attaching cupper or stainless board is advised

4.19 Sludge collection

For rectangular tanks, chain and flights system is advised.

The material of chain was cast iron but is being replaced by plastics and stainless steel

For circular and square tanks, rotating arm collector shall be used.

The speed of chain and flights shall be around 0.3.

The speed of end of rotation arm shall be 2.5 m/min.

4.20 Sludge withdrawal

The pumps shall be used.

The number of pumps shall be two or more.

The sludge withdrawal line shall be at least 150 mm in diameter.

In case of clogging, inspection port and jetting port shall be installed.
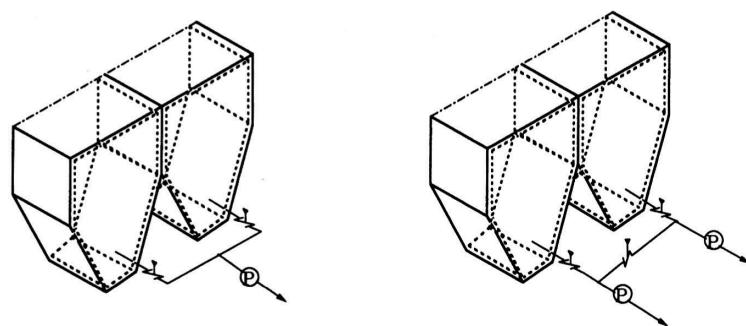
Figure 4.20.1 Withdrawal by Pump

Stacked sedimentation

4.21 Stacked sedimentation

Basin shape shall be rectangular with parallel flow to the length.

Influent shall be distributed in equal amount for each tray.

Effluent structure shall be either weir or porous pipe.

Clog prevention measure shall be taken for sludge withdrawal line.

Total area of each tray shall be used for surface loading rate calculation in 5.3/5.13.
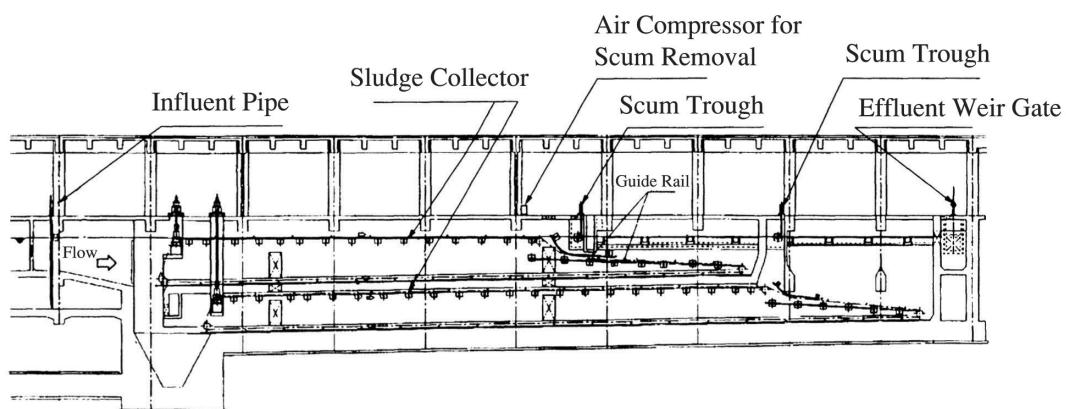
Figure 4.21.1 Two Tray Final Sedimentation at Kyoto
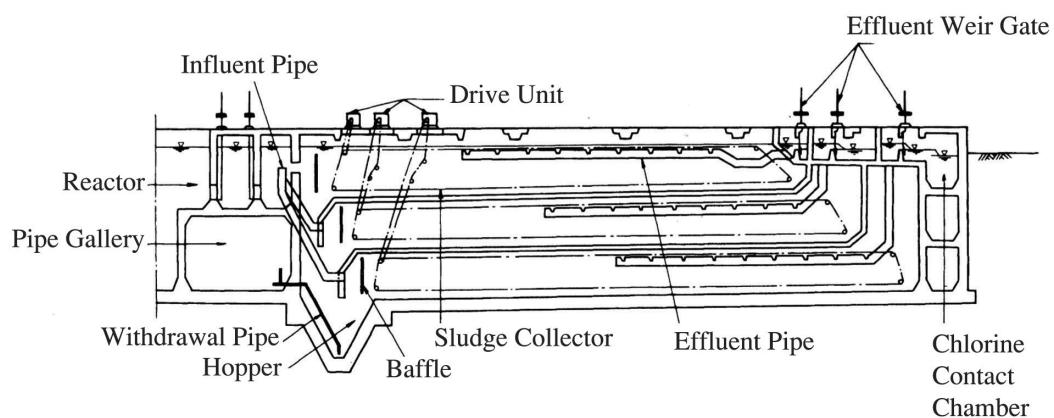
Figure 4.21.2 Three Tray Final Sedimentation at Osaka
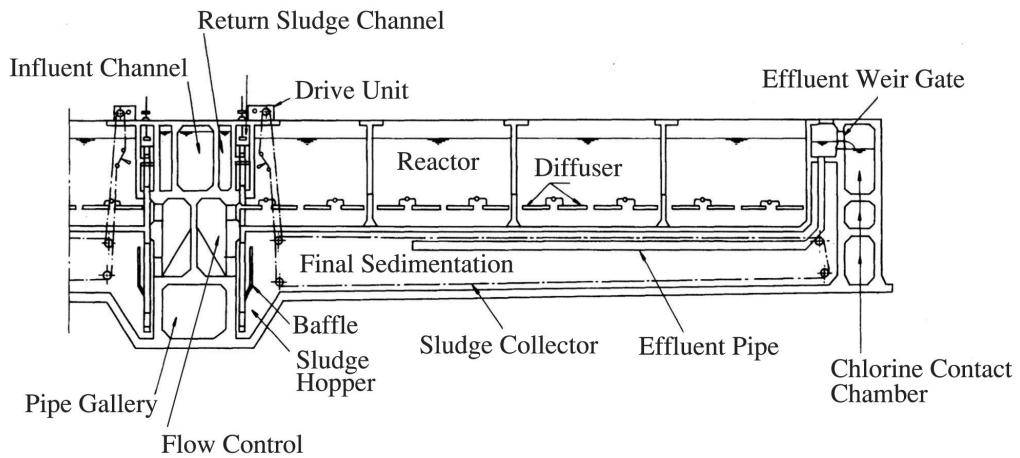
Figure 4.21.3 Stacked Basins of Reactor and Final Sedimentation at Osaka

5 Reactor of Conventional Activated Sludge Process

5.1 Reactor Design

Two flow charts are shown in Figure 5.1.1 and 5.1.2.

In the first flow chart, τ and X shall be decided based on the Table 5.1.1.

By setting $C_{S\text{-BOD, in}}$ and $C_{SS, in}$ and using theoretical and empirical equations below, effluent C-BOD is calculated to see if it meets the design target.

If calculated effluent C-BOD does not meet the target, reactor volume shall be calculated based on the design target C-BOD in the second flow chart.

$V = Q_{in} \tau$

$\theta x = VX/ Q_w X_w$

$Q_w X_w = aQ_{in}C_{S\text{-BOD, in}} + bQ_{in}C_{SS, in} - cVX$

$= (aC_{S\text{-BOD, in}} + bC_{SS, in} - c \tau X)Q_{in}$

$\theta x = \tau X/(aC_{S\text{-BOD, in}} + bC_{SS, in} - c \tau X)$

$\tau = \theta x(aC_{S\text{-BOD, in}} + bC_{SS, in})/(1+c \theta x)X$

Where

V = reactor volume, m3

Qin = inflow, m3/d

τ = HRT, hydrological retention time, day

θx = SRT, sludge retention time, day

X = MLSS, Mixed Liquor Suspended Solids, mg/l

$C_{S\text{-BOD, in}}$ = soluble BOD in influent to reactor, mg/l

$C_{SS, in}$ = suspended solids in influent to reactor, mg/l

a = yield from soluble BOD to MLSS, g-MLSS/g-S-BOD, 0.4-0.6

b = yield from Suspended Solids to MLSS, g-MLSS/g-SS, 0.9-1.0

c = endogenous decay coefficient, 1/day, 0.03-0.05

Qw = waste sludge flow, m3/d

Xw = waste sludge concentration in SS, mg/l

Table 5.1.1 Design Parameters of Activated Sludge Process

	MLSS mg/l	F:M kgBOD/KgSS/Day	Reactor Depth m	Reactor Shape	HRT h	Primary Sedimatation
CAS	1,500–2,000	0.2–0.4	4–6 (10: Deep Aeration)	Rectangular	6–8	yes
OD	3,000–4,000	0.03–0.05	1–5	Racetrack	24–36	no
EA	3,000–4,000	0.05–0.10	4–6	Rectangular	16–24	no
SBR	1,500–2,000 2,000–3,000	0.2–0.4 0.03–0.05	4–5	Rectangular	Varied	no
PO	3,000–4,000	0.3–0.6	4–6	Rectangular	1.5–3	yes

MLSS: Mixed Liquor Suspended Solids
F:M: Food Microorganizm Ratio
HRT: Hydraulic Retention Time
CAS: Conventional Activated Sludge
OD: Oxydation Ditch
EA: Extended Aeration
SBR: Sequence Batch Reactor
PO: Pure Oxygen
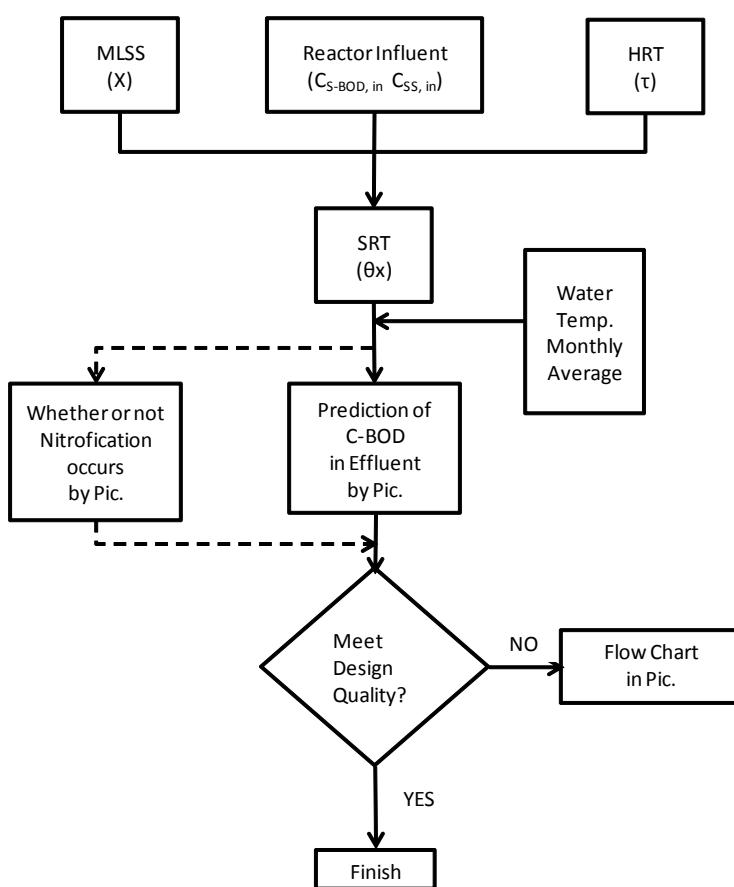
Figure 5.1.1 Design Flow Chart

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┌─────────────────┐
│  Design Effluent │
│     Quality      │
│     C-BOD        │
└─────────────────┘
          │
          │                    ┌──────────────┐
          │◄───────────────────│    Water     │
          │                    │    Temp.     │
┌─────────────────┐            │   Monthly    │
│  SRT prediction │            │   Average    │
│  to meet Target │──────────► └──────────────┘
│     by Pic.     │
└─────────────────┘
          │
┌─────────────────┐
│  SRT Prediction │
│  necessary for  │──────────►
│  Nitrofication  │
│     by Pic.     │
└─────────────────┘
          │
          ▼
┌─────────────────┐
│       SRT       │
│      (θx)       │
└─────────────────┘
          │                    ┌──────────────────────┐
          │◄───────────────────│   Reactor Influent   │
          │                    │  (C_{S-BOD, in}  C_{SS, in}) │
          │                    └──────────────────────┘
          │                    ┌──────────────┐
          │◄───────────────────│     MLSS     │
          │                    │      (X)     │
          ▼                    └──────────────┘
┌─────────────────┐
│       HRT       │
│       (τ)       │
└─────────────────┘
          │
          ▼
┌─────────────────┐
│   Reactor Size  │
│       (V)       │
└─────────────────┘
```
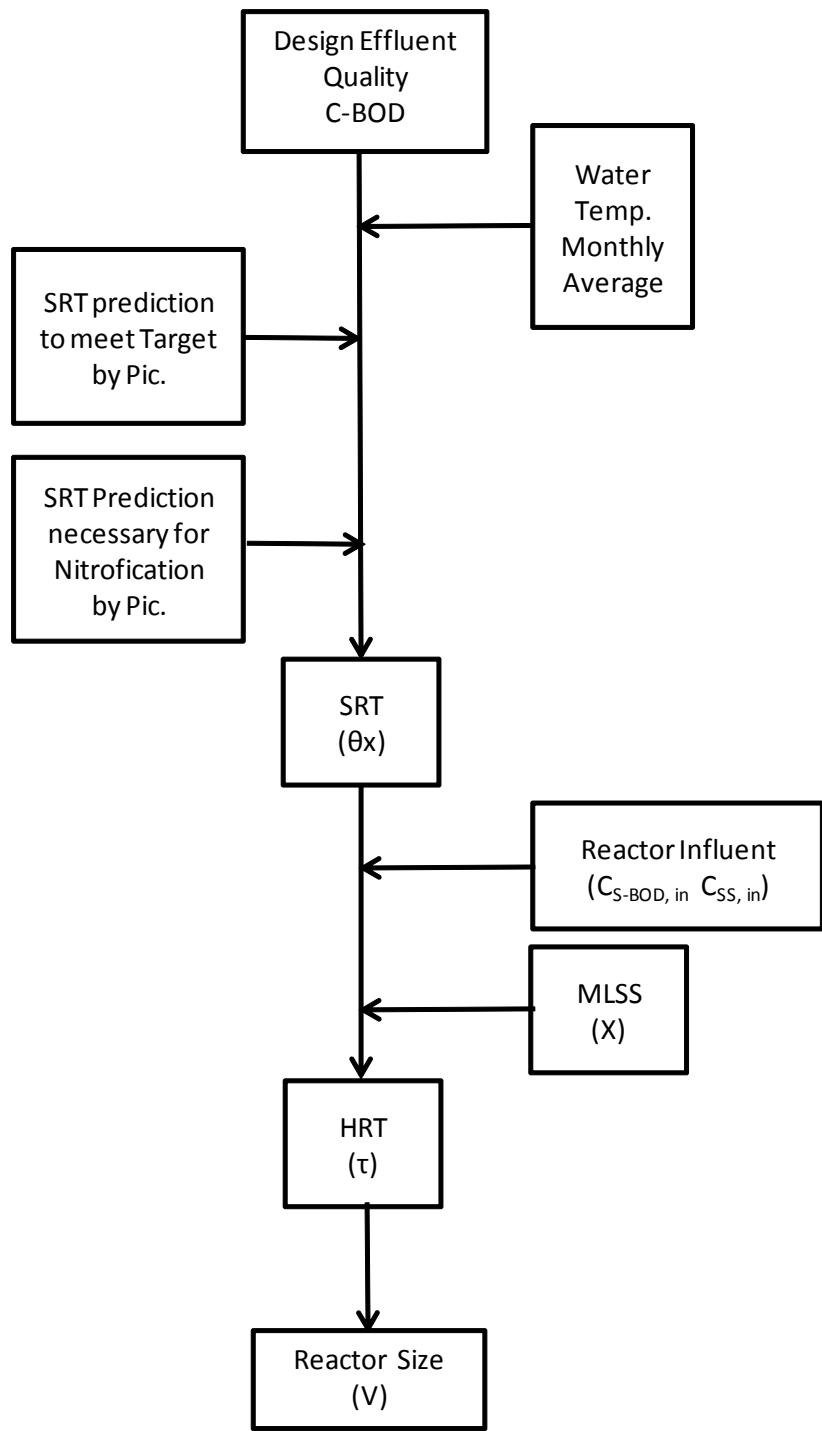
Figure 5.1.2 Alternative Design Flow Chart
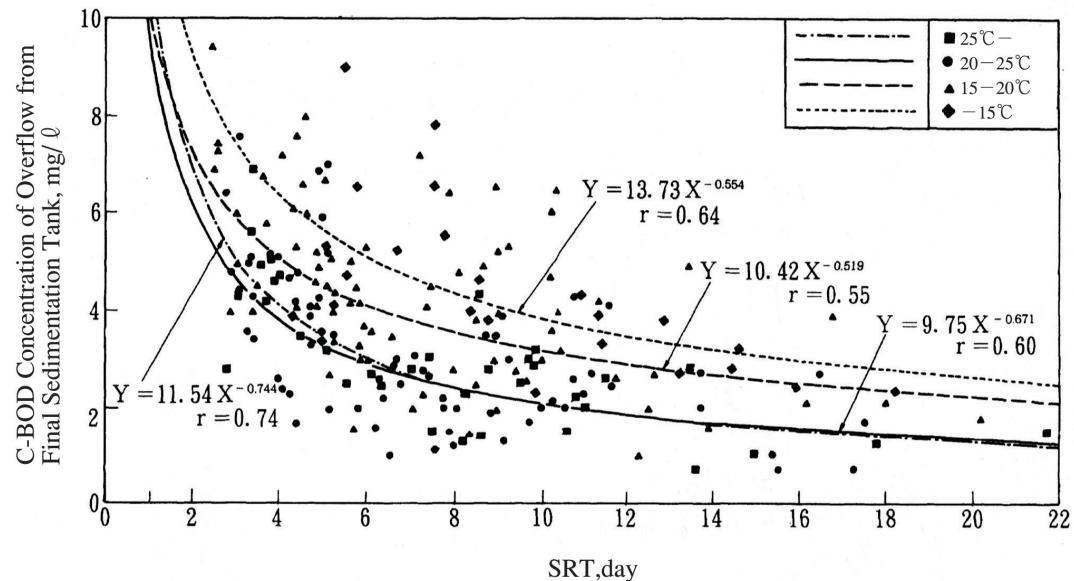
Figure 5.1.3 Effluent C-BOD and SRT at Operational WWTPs
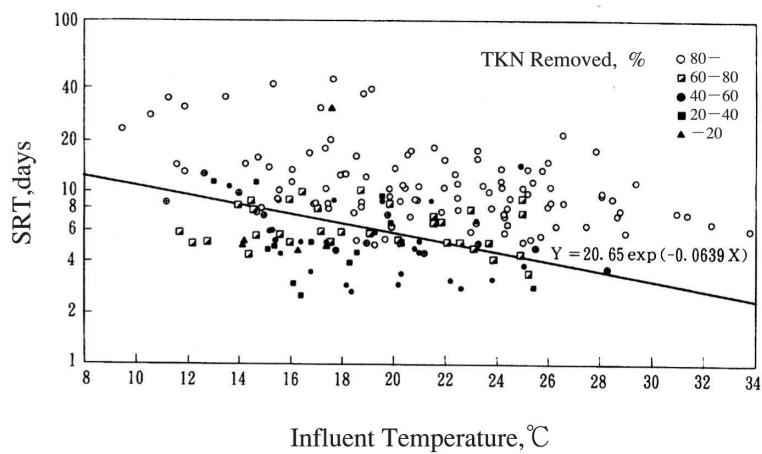
Figure 5.1.4 Necessary SRT for Nitrification and Influent Temp

5.2 Add-on advanced treatment

Add-on advanced treatment shall be rapid sand filtration and addition of coagulant and methanol by law.

Conventional Activated Sludge System

5.3 HRT

HRT shall be between 6 and 8 hours.

5.4 MLSS

MLSS shall be between 1,500 and 2,000 mg/l as norm for stable and economical treatment.

Return sludge concentration shall be assumed.

Return sludge ratio is calculated as follows.

$Rr = X/Xr\text{-}X$

Where

Rr = Return sludge ratio

X = MLSS, Mixed Liquor Suspended Solids, mg/l

Xr = Return Sludge Concentration in Suspended Solids, mg/l

In operation, return sludge ratio is controlled to keep MLSS stable.

5.5 Type of aeration

Selection of aeration type shall be made considering efficiency of mixing and oxygen transfer and location of WWTPs

Aeration types include point injection diffuser system, multiple injection diffuser, jet aerator, and submerged turbine aerator.

Depending on the types of aerator, design parameters shall be in the table.
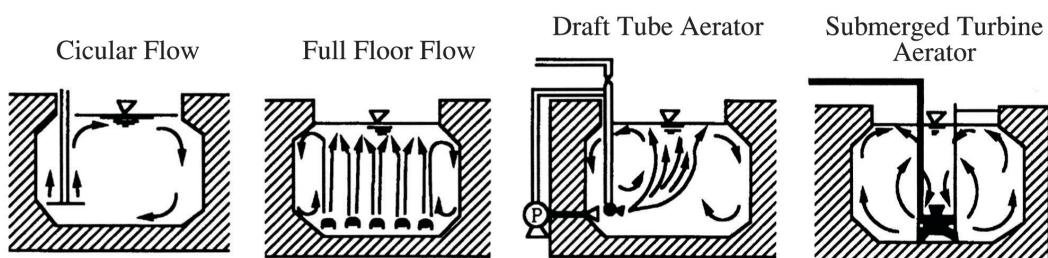
Figure 5.5.1 Type of Aeration

5.6 shape, structure, and number of reactor tank

The shape shall be rectangular or square.

The width shall be 1 to 2 times of depth for standard type.

The width shall be about equal to the depth for deep aeration type.
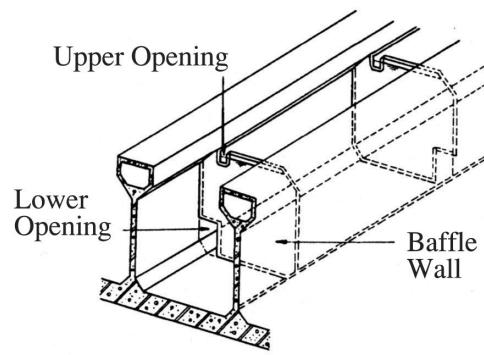
Figure 5.6.1 Baffle Wall in Reactor
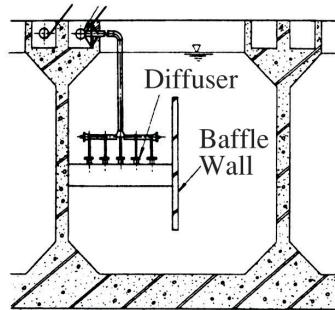
Figure 5.6.2 Aeration System in Deep Aeration Tank

Baffle shall be installed vertically to the flow to prevent short circuiting.

Top and bottom of the baffle shall have minimum openings for maintenance work.

The structural material shall be watertight reinforced concrete and.

The structure shall be stable for groundwater pressure not to float it.

The top of the wall shall be over 15 cm above ground level.

The top of the wall shall have a walkway of width over 90cm and with handrails of over 1.1m in height.

The number of reactor tank shall have two or more.

In the case of deep aeration reactor with point injection aerator system, the tank shall have a baffle for secure circular flow.

5.7 depth and extra depth

The depth shall be 4 to 6m for standard type.

The depth shall be around 10m for deep aeration type.

The extra depth shall be around 80cm for standard type.

The extra depth shall be around 100cm for deep aeration type.

5.8 Instrumentation

Reactor shall be equipped with the meters for inflow, return sludge flow, air flow, DO and MLSS.

5.9 Aeration equipment

Aeration equipment shall enable to provide air uniformly from all the release points.

Aeration equipment shall be physically durable and resistant to chemical attack.
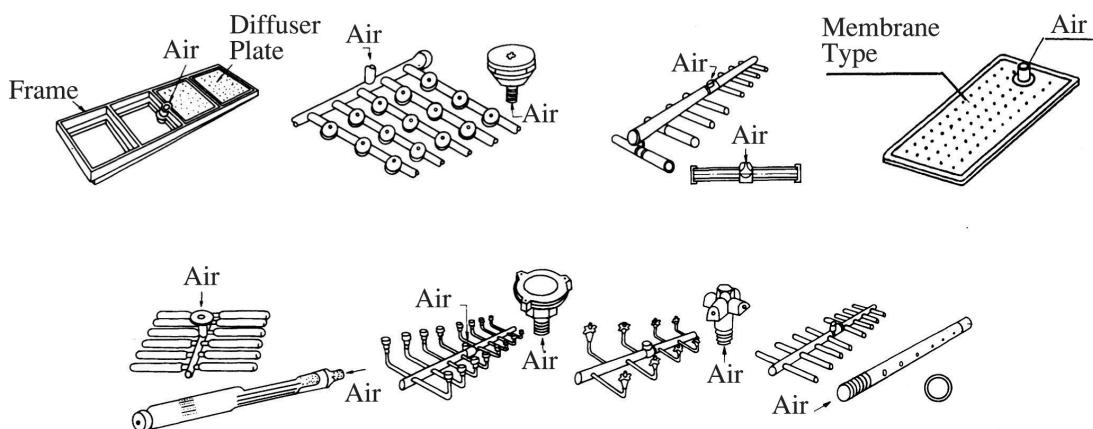
Figure 5.9.1 Type of Diffuser

5.10 Air pipe line

The material shall be steel, either SGP or STPY, with zinc coatings.

The material for droplegs shall be stainless.

The pipeline in the pipe gallery shall be insulated as temperature of blower discharge reaches 80 degrees Celsius.

Air pipeline shall be installed above wastewater level to prevent backflow of wastewater into the pipeline and later corrosion.

Expansion joints shall be installed considering the thermal stress to pipeline.

Flexible joints shall be installed where pipeline passes different structures.

Valves shall be attached for check, flow adjustment, backflow prevention, and waste air discharge.

Air flow meter shall be equipped.

Air flow meter shall be accurate with small head loss and few chances of failure.
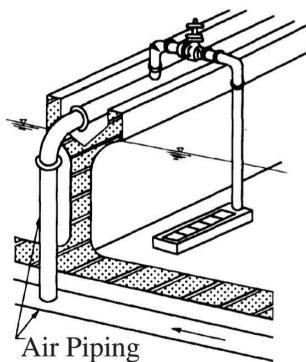
Air Piping

Figure 5.10.1 Air Piping

5.11 Return sludge instruments

Capacity of return sludge pump shall be calculated based on 6.4.

The number of return sludge pump shall be two or more.

Control of return sludge volume shall be made by the number of operational pumps, valve control of discharge, or rotational speed.

The material sludge pipeline shall be ductile iron or polyethylene.

Flow rate shall be 1.0 to 1.5m/s

Diameter shall be 150mm or over.

The pipeline shall have a valve for sampling sludge and a flow meter.

5.12 Instrumentation for inflow, drainage, foam and scum

Inflow structure shall have check valve, gate, or movable weir for shutoff or control of inflow.

Reactor tank shall have drainpipe, catch basin and gutter on the bottom for drainage.

Reactor tank shall have foam removal equipment.

Reactor tank shall have scum control equipment.
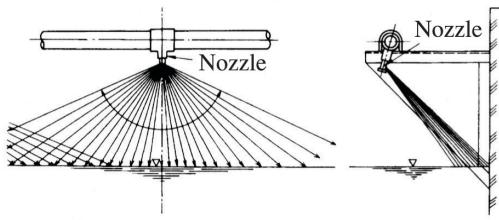
Figure 5.12.1 Sprinkler for Scum Control   **Figure 5.12.2 Nozzle for Foam Removal**
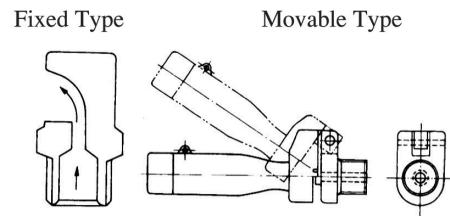
5.13 Selection of blower

Selection shall be made considering flow rate, air pressure, control type, and noise.
Blower shall be durable for long term use.

5.14 Capacity and number of blower

Capacity and number of blower shall be decided plant start-up and future air flow in need considering diurnal variation within a day.

Control of air flow shall be made by number of operational blowers and control of individual blower.

The number of blower shall be two or more.

5.15 Air flow rate

Air flow rate shall meet demand of reactor and other facilities.
Necessary air flow for reactor shall be calculated based on the oxygen demand by considering influent quality and whether nitrification is designed or not and oxygen transfer efficiency of aeration system.

5.16 Air pressure

Air pressure shall total water pressure on diffuser, loss by air filter, pipeline, flow meter, diffuser itself, and extra.
Extra pressure should be 5.0kPa.

5.17 Power of blower and Prime Mover

Power of blower and prime mover shall be set considering necessary air flow and pressure and temperature condition with safety coefficient and overall adiabatic efficiency.

Prime mover shall be electric motor.

5.18 Housing of blower

Blower house shall be fire proof, free of uneven settlement, and free of rainwater and groundwater infiltration.　The house should be soundproof.

Blower house shall have enough space for operation and maintenance of blower, prime mover, and other instrument.

Blower house shall be ventilated.

Foundation of blower and prime mover shall be durable for vibration and weight during operation.

Blower house shall have crane hook for installation, repair, and inspection of blower.
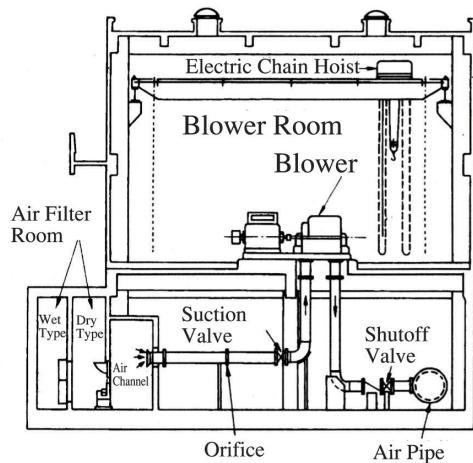
Figure 5.18.1 Blower House　　　　**Figure 5.18.2 Blower House**
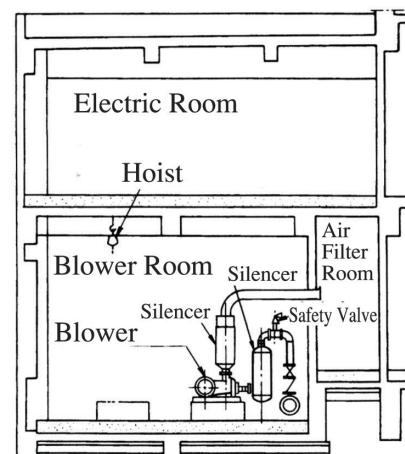
5.19 Support instrument for blower

Air filter shall be installed at blower inlet.

Lubricating oil injector shall be installed for turbo blower.
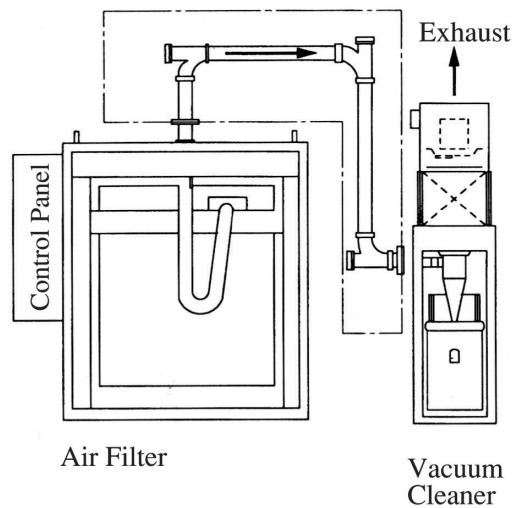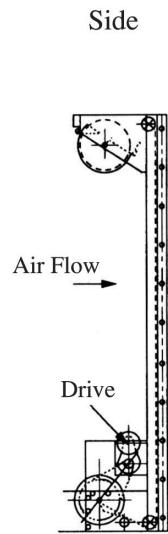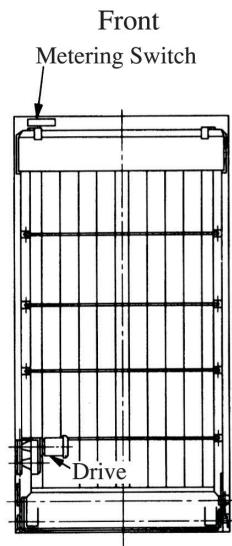
Figure 5.19.1 Dry Air Filter

Figure 5.19.2 Dry Air Filter
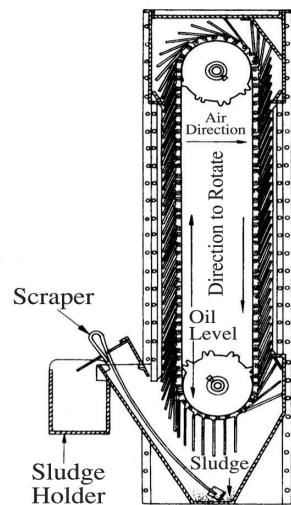
Figure 5.19.3 Wet Air Filter

*Example of Design

In this example, the method in Figure 5.1.1 is used.

Design Conditions

Maximum daily flow, Qin=10,000m3/d for one train of treatment process

Influent BOD=200mg/l

Influent SS=180mg/l

BOD of influent to reactor: $C_{BOD, in}$=120mg/l (40% removal at first sedimentation)

Soluble BOD of influent to reactor: $C_{S-BOD, in}$=80mg/l (67% of total is the soluble.)

SS of influent to reactor: $C_{SS, in}$=90mgl (50% removal at first sedimentation)

Effluent BOD limit: 15mg/l

Effluent SS limit: 10mg/l

Water temperature: 24℃ in summer, 13℃ in winter

Setting MLSS and HRT based on Table 5.1.1

MLSS: X=1,500mg/l

HRT: τ =8/24d

Reactor volume: V

V=Qin・τ =10,000・8/24=3,300m3

Waste sludge amount: QwXw

Use a=0.5, b=0.95, c=0.04

$QwXw= (a \cdot C_{S-BOD, in} + b \cdot C_{SS, in} - c \cdot \tau \cdot X) \cdot Qin$

　　　$= (0.5 \cdot 80 \cdot 10^{-3} + 0.95 \cdot 90 \cdot 10^{-3} - 0.04 \cdot 8/24 \cdot 1,500 \times 10^{-3}) \cdot 10,000$

　　　=1,055kg/d

SRT: θ x

θ x= τ X/(a・$C_{S-BOD, in}$ + b・$C_{SS, in}$ - c・τ・X)

　　=8/24・1,500／(0.5・80+0.95・90-0.04・8/24・1,500)N

　　=4.7d

Expected effluent CBOD in winter to check the meeting effluent BOD limit

See Figure 5.1.3

CBOD=13.73・$4.7^{-0.554}$=5.8mg/l

This CBOD is average value.　But it is well below limit of 15mg/l.　It is accepted.

Nitrification check

Necessary SRT for Nitrification is calculated by referring to Figure 5.1.4.

20.65*EXP(-0.0639*24)=4.5d< θ x: 4.7d

Nitrification goes well

Actual Oxygen Requirement: AOR

Oxygen requirement in summer when nitrification is complete is calculated as follows.

Mass of required oxygen is the sum of oxygen for BOD removal (DB), nitrification (DN), endogenous respiration (DE), and keeping oxygen concentration in the reactor (DO).

DB={(C_{BOD, in}－C_{BOD, eff})・Qin・10^-3－ (L_{NOX,DN}－L_{NOX,A}) ・K}・A

Where,

$C_{BOD, in}$: Influent BOD=120mg/l

$C_{BOD, eff}$: Effluent BOD=3.5mg/l, =9.75*4.7^-0.671, from Figure 5.1.3

Qin: Inflow=10,000m3/d

$L_{NOX,DN}$: NOX-N load to reactor=0kgN/d, ignores denitrification BOD removal for safety

$L_{NOX,A}$: NOX-N mass outflow from reactor=0kgN/d, ditto

K: BOD removal by denitrification=2.86(kgBOD/kgN)

A: Oxygen consumption per removed BOD=0.6(kgBOD/kgN)

Hence,

DB={(120－3.5)Qin・10^-3－0}・0.6

   =0.070・Qin(kgO2/d)

DN=C・(mass of nitrified Kj-N)

   =C・{(inflow Kj-N mass)－(outflow Kj-N mass)－(Kj-N mass in waste sludge)}

   =C・[(C_{KN, in}・10^-3・Qin)－(C_{KN, out}・10^-3・Qin)－{(a・C_{S-BOD, in}・10^-3 + b・C_{SS, in}・10^-3 － c・τ・X・10^-3)・Qin・Nx}]

Where,

C: Oxygen consumption by nitrification=4.57(kgO2/kgN)

$C_{KN, in}$: Kj-N concentration into reactor=35mg/l

$C_{KN, out}$: Kj-N concentration from reactor=5mg/l

a: Yield of activated sludge from soluble BOD=0.5(gMLSS/gS-BOD)

b: Yield of activated sludge from SS=0.95(gMLSS/gSS)

c: Endogenous decay coefficient of activated sludge=0.04(1/d)

Nx: Nitrogen concentration in waste sludge=8%

Hence,

DN=4.57・[(35・10^-3・Qin)－(5・10^-3・Qin)－{(0.50・80・10^-3 + 0.95・90・10^-3 － 0.04・

8/24・1,500・10^-3)・Qin・0.08}]
   =0.099 ・ Qin(kgO2/d)

DE=B・V・MLVSS
   =B・τ・Qin・{X・10^-3・(MLVSS/MLSS)}
Where,
B: Oxygen consumption by endogenous respiration=0.10(kgO2/kgMLVSS/d)
MLVSS/MLSS=0.8
Hence,
DE= 0.10・8/24・Qin・(1,500・10^-3・0.8)
   =0.040・Qin(kgO2/d)

DO=$C_{O.A}$・(Qin+Q_γ+Qc) ・10^-3
Where,
$C_{O.A}$: Dissolved oxygen concentration at reactor end=1.5mg/l
Q_γ: Return sludge flow=0.5・Qin
Qc: Internal recycle flow=0
Hence,
DO=1.5・(Qin+0.5・Qin +0) ・10^-3
   =0.002・Qin(kgO2/d)

AOR in summer when nitrification is complete is calculated as follows.
AOR=DB+DN+DE+DO
   =(0.070+0.099+0.040+0.002) ・Qin
   =0.211・Qin≒0.21・Qin(kgO2/d)
   =0.21・10,000=2,100(kgO2/d)
AOR per BOD when nitrification is complete is;
AOR/(Influent BOD mass)=(0.21・Qin)/(0.12・Qin)=1.75(kgO2/kg influent BOD)

AOR in winter is calculated in the same way as in summer except that nitrification does
not take place and higher effluent CBOD of 5.8mg/l at temperature of 13℃.
AOR=DB+DE+DO
DB={($C_{BOD, in}$－$C_{BOD, eff}$)・Qin・10^-3－ ($L_{NOX,DN}$－$L_{NOX,A}$) ・K}・A
   =(120－5.8)Qin・10^-3－0}・0.6
   =0.069・Qin(kgO2/d)
DE=B・V・MLVSS

$=B \cdot \tau \cdot Qin \cdot \{X \cdot 10^{-3} \cdot (MLVSS/MLSS)\}$

$=0.10 \cdot 8/24 \cdot Qin \cdot (1,500 \cdot 10^{-3} \cdot 0.8)$

$=0.040 \cdot Qin(kgO2/d)$

$DO=C_{O.A} \cdot (Qin+Q\gamma+Qc) \cdot 10^{-3}$

$=1.5 \cdot (Qin+0.5 \cdot Qin +0) \cdot 10^{-3}$

$=0.002 \cdot Qin(kgO2/d)$

AOR in winter when nitrification does not take place is calculated as follows.

AOR=DB+DE+DO

$=(0.069+0.040+0.002) \cdot Qin$

$=0.111 \cdot Qin \fallingdotseq 0.11\ Qin(kgO2/d)$

$=0.11 \cdot 10,000=1,100(kgO2/d)$

AOR per BOD nitrification does not take place is;

AOR/(Influent BOD mass)=(0.11・Qin)/(0.12・Qin)=0.9(kgO2/kg influent BOD)

Required air (Gs)

Gs is calculated after AOR is converted to Standard Oxygen Requirement (SOR).

In this example of design, spiral roll system is supposed for mixing.

SOR in summer when nitrification is complete is calculated as follows.

$SOR=(AOR \cdot Cs1 \cdot \gamma)／\{1.024^{(T2-T1)} \cdot \alpha \cdot (\beta \cdot Cs2 \cdot \gamma - C_A)\} \cdot 101.3/P$

Where,

SOR: Oxygen requirement under clean water condition at T1℃

AOR: Oxygen requirement under process water condition at T2℃

T1: Aerator performance is tested at this temp=20℃

T2: Reactor temp=24℃

Cs1: Saturated dissolved oxygen concentration under clean water condition at T1℃ =8.84mg/l

Cs2: Saturated dissolved oxygen concentration under clean water condition at T2℃ =8.25mg/l

C_A: DO con in reactor=1.5mg/l

α: Process water KLa / clean water KLa=0.83, α is 0.93 in low rate system and 0.83 in high rate. KLa is volumetric mass-transfer coefficient.

β: Process water DO saturation con. / clean water DO saturation con.=0.95, β is 0.97 in low rate system and 0.95 in high rate.

γ: correction factor on aerator depth, $\gamma=1/2 \cdot \{(10.332+h)/10.332+1\}$, where h is aerator depth=4.5m, $\gamma=1/2 \cdot \{(10.332+4.5)/10.332+1\}=1.218$

P: Barometric pressure at WWTP=101.3kPa

By using above, SOR in summer, when nitrification is complete, is,

SOR=0.210Qin・8.84・1.218/{1.024^(24-20)・0.83・(0.95・8.25・1.218 − 1.5)}・101.3/101.3=0.308 Qin=3.080(kgO2/d)

Required air (Gs)

Gs=SOR/(E$_A$・ρ・Ow)・100・(273+T2)/273

Where,

Gs: Required air (m3/d)

E$_A$: Oxygen transfer efficiency=15%

ρ : Air density=1.293kg/m3N, air)

Ow: Oxygen weight in air=0.232(kgO2/kg, air)

Hence,

Gs=0.308・ Qin /(15・1.293・0.232)・100・(273+24)/273

=7.5・Qin=75,000m3/d

Required air, Gs, is 7.5 times as much as influent sewage flow.

SOR in winter, when nitrification does not take place, is,

SOR=(AOR・Cs1・γ)／{1.024^(T2-T1)・α・(β・Cs2・γ − C$_A$)}・101.3/P

AOR: Required oxygen at T2=0.110Qin=1,100kgO2/d

T2: Reactor temp.=13℃

Cs2: Saturated dissolved oxygen concentration under clean water condition at T2℃ =10.20mg/l

The other parameters value are the same as the ones in summer.

Hence,

SOR=0.110Qin・8.84・1.218/{1.024^(13-20)・0.83・(0.95・10.20・1.218 − 1.5)}・101.3/101.3=0.164 Qin(kgO2/d)=1,640(kgO2/d)

Required air (Gs)

Gs=SOR/(E$_A$・ρ・Ow)・100・(273+T2)/273

Gs=0.164・ Qin /(15・1.293・0.232)・100・(273+13)/273

=3.8・Qin=38,000m3/d

Required air, Gs, is 3.8 times as much as influent sewage flow.

Oxidation Ditch Process

5.20 Capacity, shape, structure, and number of reactor

Capacity of reactor shall be calculated using planned maximum daily flow and the table below.　Nitrification and denitrification shall be included in designing.

Table 5.20.1 Design Parameter for Oxidation Ditch Process

Design Paremeter	Range
HRT, h	24-36
MLSS, mg/l	3,000-4,000
Loading, kgBOD/kgMLSS/d	0.03-0.05
Return sludge recycle ratio, %	100-200
Required Oxygen, kgO2/kgBOD	1.4-2.2

Many oxidation ditch processes use racetrack shape tank with no end.

Reactor tank should be 1.0-5.0m in depth and 2.0-6.0m in width.

At corners, installation of partition wall is recommended to have enough inside flow velocity avoiding sludge settling (Figure 5.20.1).
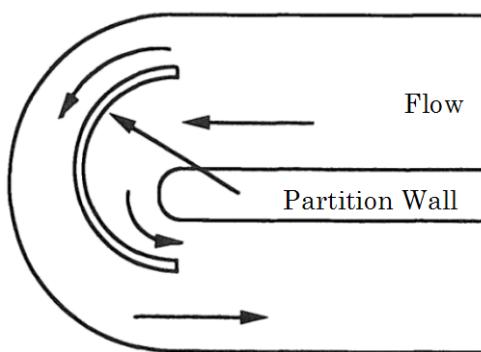
Figure 5.20.1 Partition Wall for Flow Velocity Control

See 3.4 on structure.

For small scale oxidation process, precast concrete products are available.　The plain and section of this precast system is shown in Figure 5.20.2.　Inside the round reactor is secondary sedimentation tank.
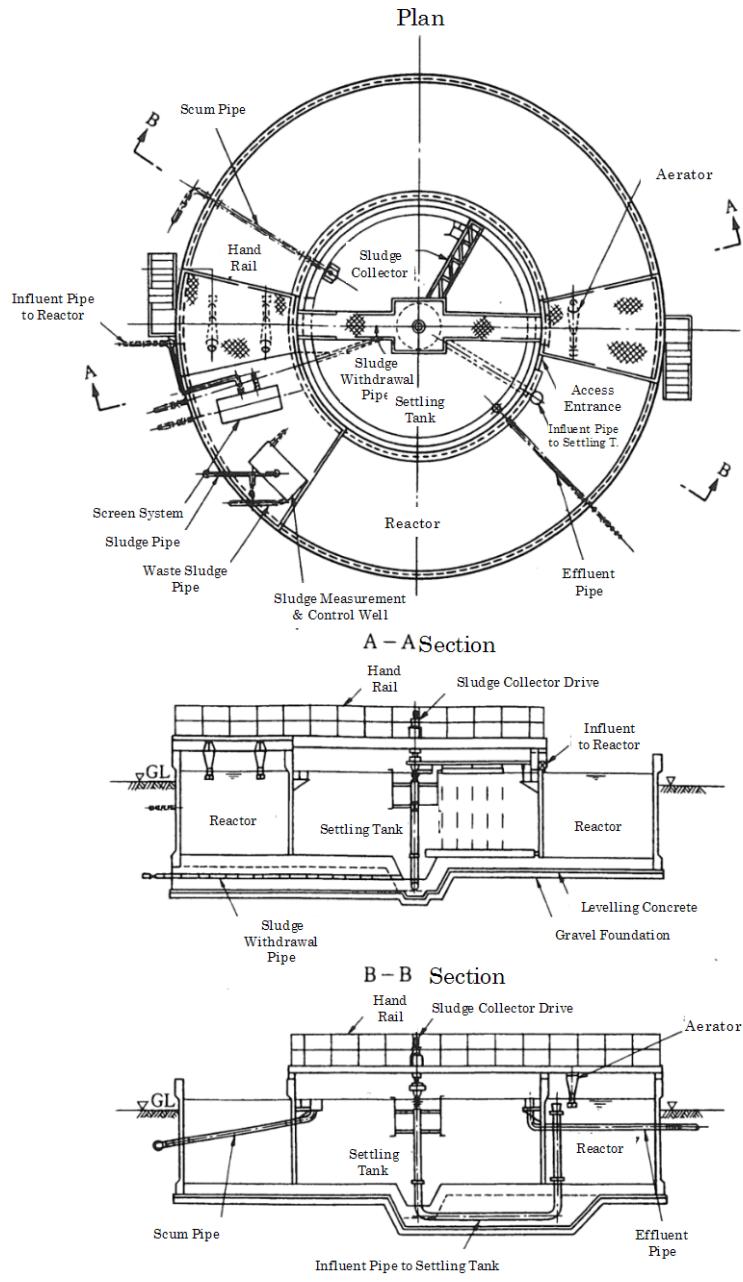
Figure 5.20.2 Precast Oxidation Ditch

The number of tanks for reactor and sedimentation should be two or more for cleanings and repair works. If it is uneconomical to have two tanks, single tank system is accepted.

5.21 Aerator

Aerator for oxidation ditch process should be radial flow, horizontal rotor, aspiring device, or axial flow, or submerged turbine with diffuser.
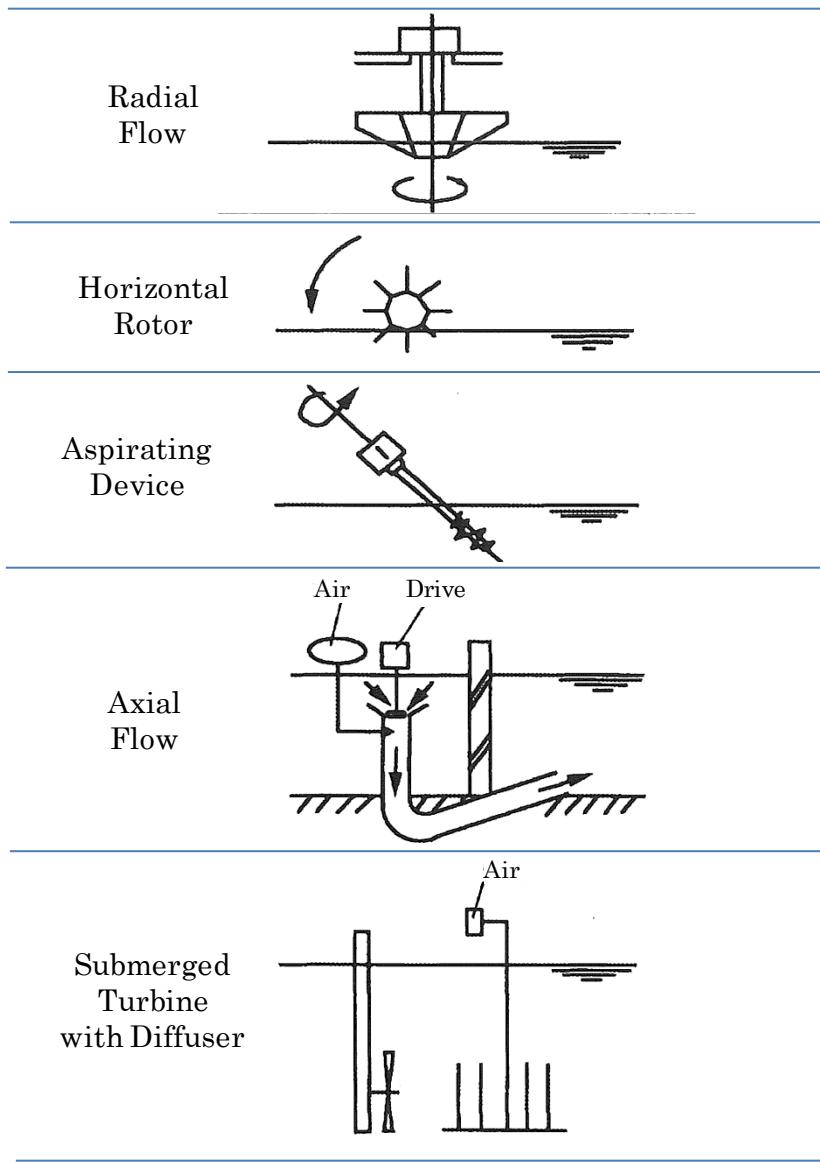
Figure 5.21.1 Types of Aerator

The number of aerator shall be two or more for each reactor to maintain mixing and velocity.

The flow velocity in reactor shall be 0.1m/s or over at the bottom and 0.25m/s or over on average.

Aerator shall ensure provision of oxygen for oxidation of organics, endogenous respiration, nitrification, and keeping oxygen level in the reactor

Aerator shall be able to control oxygen provision capacity by intermittent operation, control of rotation speed and/or depth of air injection position.

5.22 Support equipment for reactor

Influent and effluent structures shall have weir plates or gates to change the water level of reactor.

Aerator should be covered for safety, noise reduction, and prevention of water splashing. Aerator should have access for inspection.

5.23 Final sedimentation

The final sedimentation should be circular center-feed and rim take-off because of easy maintenance and economical installation in case of small scale.

The range of design parameter shall conform to the table bellow.

Table 5.23.1 Range of Design Parameter for Final Sedimentation of Oxidation Ditch

Parameter	Range
Detention Time, hrs	6-12
Side Wall Depth, m	3.0-4.0
Overflow Rate, m3/m2/d	8-12

The number of sedimentation tank should be two or more for cleanings and repair works.   If it is uneconomical to have two tanks, single tank system is accepted.

## 5.24 Support instrument for final sedimentation

Sludge collector shall have pickets to enhance settling by creating paths for water release.

Final sedimentation tank shall have scum skimmer as scum enters final sedimentation without primary sedimentation.

The capacity of return sludge pump shall be 100 to 200% of maximum daily flow.

The number of pumps shall be two or more including standby.

The diameter of sludge pipeline shall be 100mm or over.
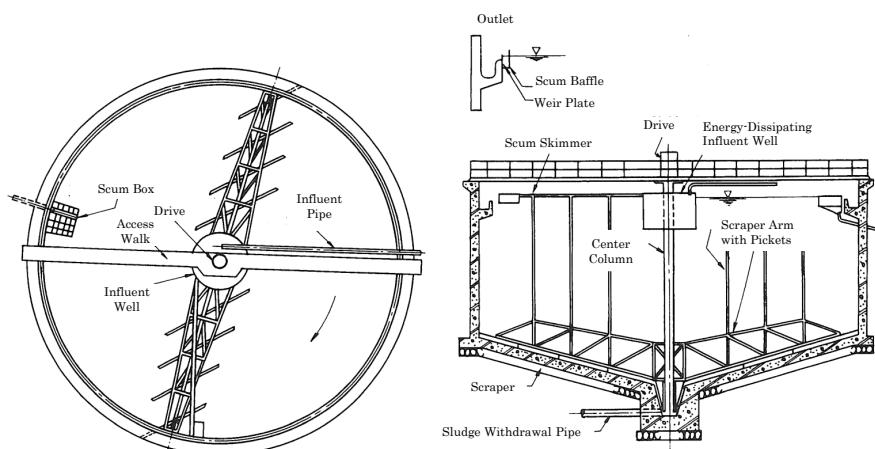
Figure 5.24.1 Circular Center-Feed and Rim Take-Off Sedimentation

*Example of design

In this example, the radial flow aerator is used.

Design Conditions

Maximum daily flow, Q=2,000m3/d for entire plant.

Influent

BOD, $C_{BOD, in}$=200mg/l

Soluble BOD, $C_{S\text{-}BOD, in}$ =100mg/l

SS, $C_{SS, in}$=200mg/l

Kj-N, $C_{KN, in}$ =35mg/l

Effluent BOD limit =10mg/l

Water temperature: 20℃ in winter

Setting HRT of reactor and overflow rate of final sedimentation

HRT: τ =1day

Overflow Rate=8m3/m2/d

Reactor volume per train: V

Two trains are supposed for Q, 2,000m3/d.

A train receives Qin=1,000m3/d=2,000m3/d÷2

V=Qin・τ =1,000・1=1,000m3

Actual Oxygen Requirement: AOR, kgO2/d

Mass of required oxygen is the sum of oxygen for BOD removal (DB, kgO2/d), nitrification (DN, kgO2/d), endogenous respiration (DE, kgO2/d), and keeping oxygen concentration in the reactor (DO, kgO2/d).

AOR=DB+DN+DE+DO

DB={($C_{BOD, in}$－$C_{BOD, eff}$)・Qin・10^-3－ ($L_{NOX,DN}$－$L_{NOX,A}$) ・K} ・A

Where,

$C_{BOD, in}$: Influent BOD=200mg/l

$C_{BOD, eff}$: Effluent BOD=10mg/l

Qin: =1,000m3/d

$L_{NOX,DN}$:

NOX-N load to reactor=($C_{K\text{-}N, in}$－$C_{K\text{-}N, out}$)・Qin・10^-3－$C_{SS, in}$・ς・Qin・10^-3・Nx(kgN/d)

$L_{NOX,A}$: NOX-N mass outflow from reactor=0kgN/d

K: BOD removal by denitrification=2.0(kgBOD/kgN)

A: Oxygen consumption per removed BOD=0.6(kgBOD/kgN)

$C_{K-N, in}$ =35mg/l

$C_{K-N, out}$ =1.0mg/l

$C_{SS, in}$=200mg/l

ς: Waste sludge generation ratio=0.75

Nx: Nitrogen concentration of waste sludge=8%

Hence,

DB=[(200－10)・Qin・10^-3－{(35－1)・Qin・10^-3－200・0.75・Qin・10^-3・0.08}・2.0]・0.6

   =0.0876・Qin=87.6 (kgO2/d)

DN=C・(mass of nitrified Kj-N)

   =C・{(inflow Kj-N mass)－(outflow Kj-N mass)－(Kj-N mass in waste sludge)}

Where,

C: Oxygen consumption by nitrification=4.57(kgO2/kgN)

Hence,

DN=4.57・(35－1－200・0.75・0.08) ・10^-3・Qin

   =0.1005・Qin＝100.5 kgO2/d

DE=B・V・MLVSS

   =B・ τ ・Qin・{X・10^-3・(MLVSS/MLSS)}

Where,

B: Oxygen consumption by endogenous respiration=0.10(kgO2/kgMLVSS/d)

MLVSS/MLSS=0.8

Hence,

DE=0.10・0.5・Qin・(3000・10^-3・0.8)=0.12・Qin=120 kgO2/d

DO=$C_{O.A}$・ τ_A ・(1+R)・Qin・10^-3

Where,

$C_{O.A}$: Dissolved oxygen concentration at reactor end=1.5mg/l

 τ_A: HRT of reactor=0.5d

R: Return sludge ratio=1

Hence,

DO=1.5・0.5・(1+1)・Qin・10^-3=0.0015・Qin=1.5 kgO2/d

AOR=DB+DN+DE+DO=(0.0876+0.1005+0.12+0.0015)・Qin≒0.310・Qin=310 kgO2/d

AOR／(Influent BOD mass)=0.310Qin／0.200Qin≒1.6 （kgO2/kgBOD）

SOR=(AOR・Cs1・γ)／{1.024^(T2-T1)・α・(β・Cs2・γ－C$_A$)}・101.3/P

Where,

SOR: Oxygen requirement under clean water condition at T1℃

AOR: Oxygen requirement under process water condition at T2℃=0.310・Qin

T1: Aerator performance is tested at this temp=20℃

T2: Reactor temp=20℃

Cs1: Saturated dissolved oxygen concentration under clean water condition at T1℃ =8.84mg/l

Cs2: Saturated dissolved oxygen concentration under clean water condition at T2℃ =8.84mg/l

C$_A$: DO con in reactor=1.5mg/l

α: Process water KLa / clean water KLa=0.93, α is 0.93 in low rate system and 0.83 in high rate. KLa is volumetric mass-transfer coefficient.

β: Process water DO saturation con. / clean water DO saturation con.=0.97, β is 0.97 in low rate system and 0.95 in high rate.

γ: correction factor on aerator depth, γ =1/2・{(10.332+h)/10.332+1}, where h is aerator depth=0m in case of radial flow type, γ =1

P: Barometric pressure at WWTP=101.3kPa

Hence,

SOR=0.310Qin・8.84・1/{1.024^(20-20)・0.93・(0.97・8.84・1－1.5)}・101.3/101.3

=0.417 Qin=417(kgO2/d)

SOR／(Influent BOD mass)=0.417Qin／0.200Qin≒2.1（kgO2/kgBOD）

Final sedimentation is designed as circular center-feed and rim take-off.

Necessary surface area (A,m2) per each train

A(m2)=1000m3/d／8m3/m2/d＝125m2

Tank diameter; D

125=(π/4)・D^2

D=12.6≒13m