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DEVELOPMENT OF A COMPUTER PROGRAMME FOR THE DESIGN OF MUNICIPAL WASTEWATER TREATMENT FACILITIES
Part 6: Sludge Thickening and Blending Facility

by

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ABSTRACT

The first sludge processing unit in a municipal wastewater treatment plant is sludge blending tank and sludge thickener before the sludge flow into sludge stabilization unit. A computer programme was developed using FORTRAN to design sludge blending tank and sludge thickening facility. The design include determining the size and hydraulic profile in the sludge thickener and in sludge blending tank. The influent and effluent structure is also designed using the same method in the secondary clarifier. The input data to this computer programme is mainly the quantity of sludge effluent from the primary sedimentation basins and from the secondary or final clarifiers. These values are computed in a separate subroutine which analyze the material mass balance in the treatment plant. The thickened sludge withdrawal rate and the effluent quality from the sludge thickener are also computed. The results are easy to interpret and automatically appear on the computer screen or in an output file.

INTRODUCTION

The settled solids (sludge) from the primary sedimentation basins and from the secondary or final clarifiers contain organic and inorganic solids and some of them are highly offensive. Thus sludge must be treated before it can be safely disposed. Primary sludge is the settled solids from the primary sedimentation basins while secondary sludge is the settled solids from the secondary clarifiers. Secondary sludge is also termed as waste activated sludge because the sludge was biologically activated in the aeration basins prior to secondary clarifiers. Primary sludge contains solids in raw wastewater while the secondary sludge contains mainly biological solids which are produced during the treatment process in the aeration basins.

The combined sludge contains large amount of water and will be treated in sludge processing units. The first unit a municipal sludge processing facility is sludge blending tank. It is then followed by sludge thickener, sludge digester or stabilizer and sludge dewatering unit. The design of sludge blending unit and thickener using computer programme will be discussed in this paper. Although sludge blending tank is the first sludge processing unit before sludge thickener, the design process is done by first designing the sludge thickener then the sludge blending tank because some data from the design of sludge thickener is used to design sludge blending tank. Figure 1 shows the arrangement and piping in the blending tank and the sludge thickener.

SLUDGE THICKENING TANK

General Overview

The purpose of sludge thickener is to capture the suspended solids in the sludge as much as possible. Coagulant chemicals may be added into the combined sludge to increase the capture of suspended solids and increase the density of the thickened sludge. Sludge entering the sludge processing unit contains large volume of water. Sludge thickening unit is used to separate solids and water and thus reducing the volume of sludge before it can be stabilized in an anaerobic digesting unit. The overflow liquid will be flowing back to the aeration basins for retreatment. Well designed and operated sludge thickener should be able to reduce the total incoming mass volume up to 50% or more [3]. This volume reduction will certainly require smaller size and thus reduce the cost of downstream sludge processing units. The computer programme is written to design two identical circular gravity sludge thickening tanks equipped with sludge scrapers to collect thickened sludge at the bottom.

The sludge which contains a large amount of liquid will enter the sludge thickening tank through a well located at the center of the circular tank. Sludge blanket is settled at the bottom of the tank where the mass of sludge is self-compressed by sludge continually added from the top of the tank due to gravitational action. The liquid will stay at the top of the tank and the supernatant will be returned to the aeration basins for retreatment. The thickened and concentrated sludge will be collected from the bottom of the tank and then flow to sludge digesting unit.

Characteristics of Sludge Entering Sludge Thickener

The combined primary sludge and waste activated sludge is thickened in two identical circular gravity thickening tanks. Solids loading is not to exceed 46.9 *$kg/m^2.day$* while the hydraulic loading is designed to be greater than 9.0 *$m^3/m^2.day$* [4]. The size of the sludge thickening tanks is determined from the flow rate and the combined sludge quantities. At average design flow conditions, the liquid flow (in m^3/day) and the dry solids (in kg/day) of the primary sludge and the waste activated sludge is obtained from the material mass balance analysis for the whole treatment plant. In the computer programme, the values produced in the material mass balance analysis are obtained from SUBROUTINE AERAT. Table 1 shows the symbol used in the computer programme for the parameter mentioned.

TABLE 1: Symbols Used for Various Parameters

Flow Condition/Sludge Type	Flow (m^3/day)	Dry Solids(kg/day)
(A) AVERAGE DESIGN FLOW		
1. Primary Sludge	*PAF*	*TSSR*
2. Waste Activated Sludge	*WAF*	*TS*
3. Combined Sludge	*CSAF=PAF+WAF*	*CSAV=TSSR+TS*
(B) PEAK DESIGN FLOW		
1. Primary Sludge	*PSFL*	*PSPK*
2. Waste Activated Sludge	*SWR*	*TSW*
3. Combined Sludge	*CSFL=PSFL +SWR*	*CSPK=PSPK+TSW*

The values of *PAF, WAF, TSSR* and *TS* are obtained from the material mass balance analysis in SUBROUTINE AERAT. At peak design flow condition, the dry solids of primary sludge is increased by 8% of the quantity at average flow condition ($PSPK = 1.08*TSSR$). The value of dry solids of waste activated sludge at peak flow condition is also obtained from SUBROUTINE AERAT in the material mass balance analysis.

Dimensions of Sludge Thickener

The surface area of the two identical thickening tanks is calculated from equation

$$TSA = \frac{CSPF}{SL} \qquad (1)$$

where *SL* is the maximum allowable solids loading taken to be 45 $kg/m^2.day$ which is about 4.05 % less than that mentioned in the design criteria. Hence the actual hydraulic loading can be calculated as

$$HL = \frac{CSFL}{TSA} \qquad (2)$$

The hydraulic loading rate for the gravity thickener for the combined sludge must not be less than the value in the design criteria of 9.0 $m^3/m^2.day$. If the calculated value of the hydraulic loading (*HL*) is less than the value in the mentioned design criteria, dilution water must be added to the sludge blending tank and not to the thickening tank, with the incoming combined sludge so that the value of *CSFL* in Equation 2 is increased. The surface area of the thickening tank cannot be reduced to increase the hydraulic loading because the solids loading calculated by Equation 1 tend to exceed the design criteria. The volume of the dilution water needed (*DWN*) to be added in the sludge blending tank in m^3/day is computed using equation

$$DWN = (HLN * TSA) - CSFL \tag{3}$$

where *HLN* is the new value of hydraulic loading taken to be 9.8 $m^3/m^2.day$ which is about 9% higher than that in the mentioned design criteria. The total flow to both sludge thickening tanks after the addition of the dilution water to the blending tank is *TFT* = *HLN***TSA*. The sludge thickening tanks surface area is maintained as *TSA*. The diameter of each sludge thickening tank can be determined based on the value of *TSA*. The computer programme also computes the solids loading and the hydraulic loading at average design flow for the case when one thickening tank is taken out of service for routine maintenance.

The depth of the sludge thickening tank varies from the circular tank side wall to the tank center. The bottom slope of the thickening tank is taken to be 17 *cm* drop to 1 *m* horizontal length. The purpose of the slope is to allow thickened sludge to be easily collected at the center of the tank at the sludge hopper. The total depth of the tank at the side wall consists of 0.6 *m* freeboard, 1.0 *m* deep for clear liquid zone, 1.5 *m* deep for settling zone and *h meter* deep for sludge thickening zone. The depth of the sludge thickening zone for one day retention time and for 3.58% solids in the zone is computed using equation,

$$h = 1.5\left(\frac{CSPK/2}{(TSA/2)(3.58\%)(sg)}\right) \tag{4}$$

where *sg* is the specific gravity of the blended sludge, assumed as 1.01 [4]. The depth of the sludge thickening zone at the side wall is increased by 15% to allow unusual flow condition. Based on the slope of the tank bottom, the depth of the tank at the centre can be determined. Since the tank bottom is sloping downward to the tank centre, the extra depth at the tank centre will provide extra storage for the thickened sludge in order to handle any unusual flow condition. Figure 2 and 3 show the details of the sludge thickening tank.

Influent Structure

The influent structure of the sludge thickening tank is designed to distribute the blended sludge evenly under quiescent condition throughout the tank. The influent well is located at the centre of each circular tank termed as central feed well. An influent pipe is installed across the tank at the top side under a crossing bridge which discharge the combined sludge plus the dilution water from the sludge blending tank to the sludge thickener. The diameter of the central feed well is taken to be 17.5 percent of the diameter of the sludge thickener. The influent structure is illustrated in Figure 3.

Quantity of Thickened Sludge Withdrawal

Before designing the effluent structure of the sludge thickener, the thickened sludge withdrawal rate must be determined because the effluent overflow is equal to the incoming flow to the thickener minus the sludge withdrawal rate. The thickened sludge quantity or the solids capture value is about 85% of the combined mass quantity reaching both sludge thickeners [1,4] which is equal to $QSW = 0.85*TFT$. The volume of thickened sludge withdrawal rate (SPR) in m^3/day from each sludge thickener is calculated using equation:-

$$SPR = \frac{(QSW / 2)}{(c\%)(sg^*)(1000 kg / m^3)} \qquad (5)$$

where sg^* is the thickened sludge specific gravity taken as 1.03 [4]. The value of solids concentration in gravity sludge thickener ($c\%$) is in the range of 2% to 6% [1] and in this study taken as 6% [2,4].

Effluent Structure

The effluent structure of the sludge thickener is similar to that of the secondary clarifier which consists of an effluent baffle, weir plate containing V-notch weirs, effluent launder, effluent box and an outlet pipe. The width of the effluent launder is designed to be 0.5 *m*. This effluent launder is located at the top of the tank around the circumference of each circular sludge thickening tank. The effluent launder must be designed to withstand buoyant force from the bottom. The length of the weir plate containing the V-notches can be calculated based on the diameter of the thickening tank and the width of the effluent launder. The 90° V-notch is 8 *cm* deep at 39.5 *cm* center-to center horizontal length. From the dimensions of the V-notches and the length of the weir plate, the total number of V-notches can be computed. The head over V-notch is computed using equation:-

$$H = \left[\frac{15}{8} \frac{Q_i}{c_d \sqrt{2g} \tan 45^o} \right]^{2/5} \quad (6)$$

where c_d is the weir coefficient, equal to 0.584. Q_i is equal to the flow rate in m^3/s through each single V-notch given by

$$Q_i = \frac{Q}{nju} \quad (7)$$

where Q is the effluent flow in m^3/day flowing out from the sludge thickener which is equal to the total flow to the sludge thickener (*TFT*) minus the thickened sludge withdrawal rate (*SPR*) from the two thickeners ($Q = TFT - 2*SPR$). The value of n in Equation 7 is the number of circular sludge thickener while j is the total number of V-notches in the weir plate and u is the unit conversion factor from m^3/day to m^3/s. The head over weir must not be greater than the notch height of 8 *cm*. The weir loading in $m^3/m.day$ is computed by dividing the flow through each sludge thickener by the length of the weir plate. The computer programme also calculate the liquid depth in the effluent launder. The circular sludge thickening tank is equipped with a central pier that supports trussed rake arm equipped with sludge scraper blades at the bottom to scrape the thickened sludge so that sludge can be collected to the sludge hopper at the bottom located at the center of the tank. Figure 4 shows the detail of the effluent structure.

SLUDGE BLENDING TANK

To maintain consistent feed to the sludge thickening tanks, primary and waste activated sludge from primary sedimentation basins and from secondary clarifiers respectively, must be blended thoroughly with some amount of dilution water in the sludge blending tank before entering the sludge thickening tanks. The designed dimensions of a single circular blending tank is based on the value of the total combined sludge flow plus the dilution water for the combined mass storage and blending period of 2 *hours* under peak mass loading. The volume of mass entering the sludge blending tank which is equal to the volume of sludge blending tank is equal to the quantity of the combined sludge plus the dilution water multiplied by 2 *hour* blending period. The depth of the circular blending tank is taken to be 3 *m* plus a 0.6 *m* freeboard. Based on the volume and the total depth of the sludge blending tank, the single circular tank diameter can be determined. The blending mechanism is not included in the computer programme and must be designed separately by mechanical engineers.

THE PROGRAMME STRUCTURE

The computer programme for the design of blending and thickening tanks was written using FORTRAN programming language utilizing IBM-PC compatible microcomputers. The structure of the programme for the design of this particular sludge treatment facility is outlined in a flowchart shown in Figure 5. The programme was written separately in a subroutine named SUBROUTINE THICK. This subroutine is called from the main programme which also be able to call other subroutines to design other units in a municipal wastewater treatment plant. SUBROUTINE THICK must be run after SUBROUTINE AERAT is run because some output data especially from the material mass balance analysis from the subroutine are needed to run SUBROUTINE THICK. The data are include the value of total suspended solids removed from the primary sedimentation basins (which is calculated in the material mass balance analysis), the value of solid wasted from the mixed liquor suspended solids (MLSS) collection box below the aeration basins, and the value of sludge wasting rate from the MLSS collection box.

The design results can either appear on the computer screen or in an output file. The results are easy to interpret and are ready to be included in design report. Appendix 1 shows the output file for the design of sludge thickener and sludge blending tank for a municipal wastewater treatment plant which serves a population of 170.45 thousand people.

CONCLUSION

The computer programme was written for fast and convenient in designing sludge thickener and sludge blending tank. The most time consuming part in the design of this particular facility is to determine the input data to the computer programme which is based on the material mass balance analysis. Trial and error procedure is involved in the material mass balance analysis in which if it is done manually it might consume much time and some error might be introduced. The computer programme is guaranteed to be convenient, accurate and faster compared to manually calculation. It is more versatile and easy to use and the results are easy to interpret and are ready to be printed and included in any municipal wastewater treatment plant design report.

REFERENCES

[1] Anderson, J.K. (1997). Workshop on The Design of Wastewater Treatment Plants., 5-7 August 1997 organized by Dept. of Civil Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia.

[2] Hammer, M.J. (1977). Water and Waste-Water Technology. John Willey and Sons. New York.

[3] Peavy, H.S. et al (1985). Environmental Engineering. McGraw-Hill, Inc. USA.

[4] Qasim, R.S. (1985). Wastewater Treatment Plant - Planning, Design and Operation. CBS Publishing, Tokyo, Japan.

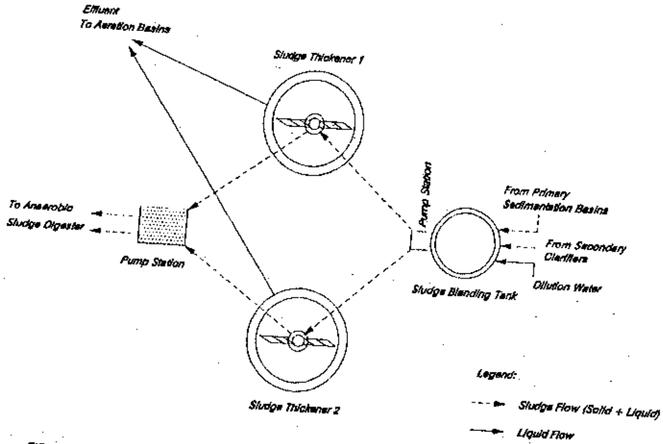


FIGURE 1: SCHEMATIC DIAGRAM OF SLUDGE BLENDING TANK AND GRAVITY THICKENER

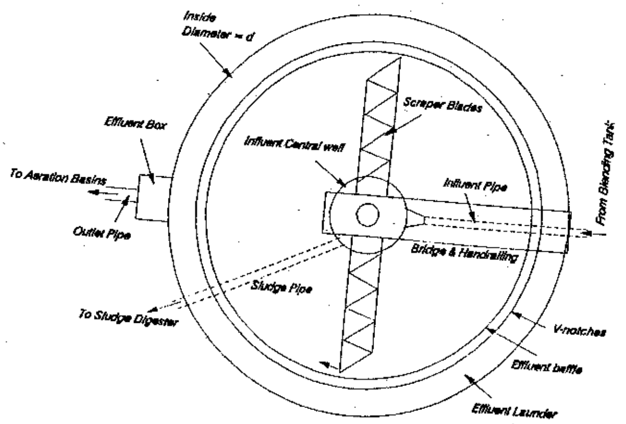


FIGURE 2 : PLAN VIEW OF A SLUDGE THICKENING TANK

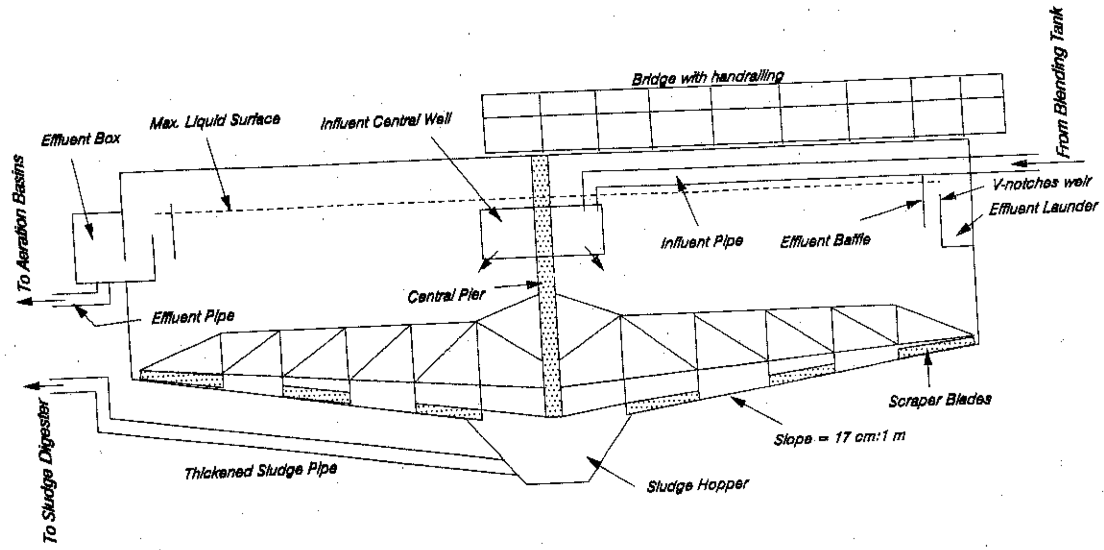
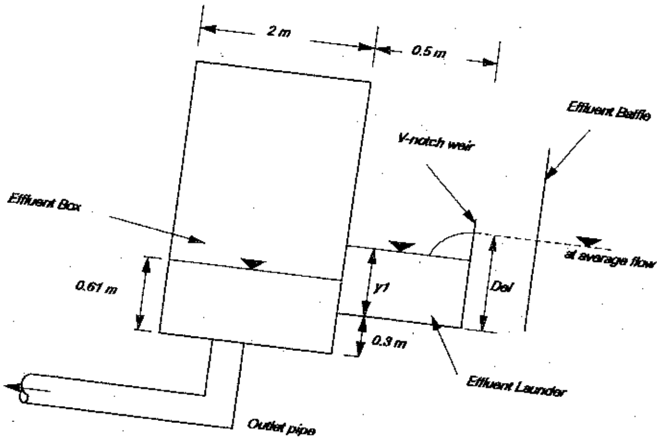
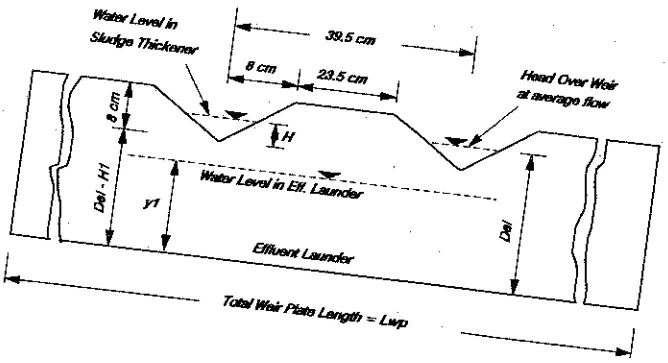


FIGURE 3 : ELEVATION VIEW OF SLUDGE THICKENER



(a) Detail of Effluent Structure and Hydraulic Profile



(b) Detail of Weir Plate and V-notches

FIGURE 4 : DETAIL OF EFFLUENT STRUCTURE
(Length Symbols = See
Programme Output File)

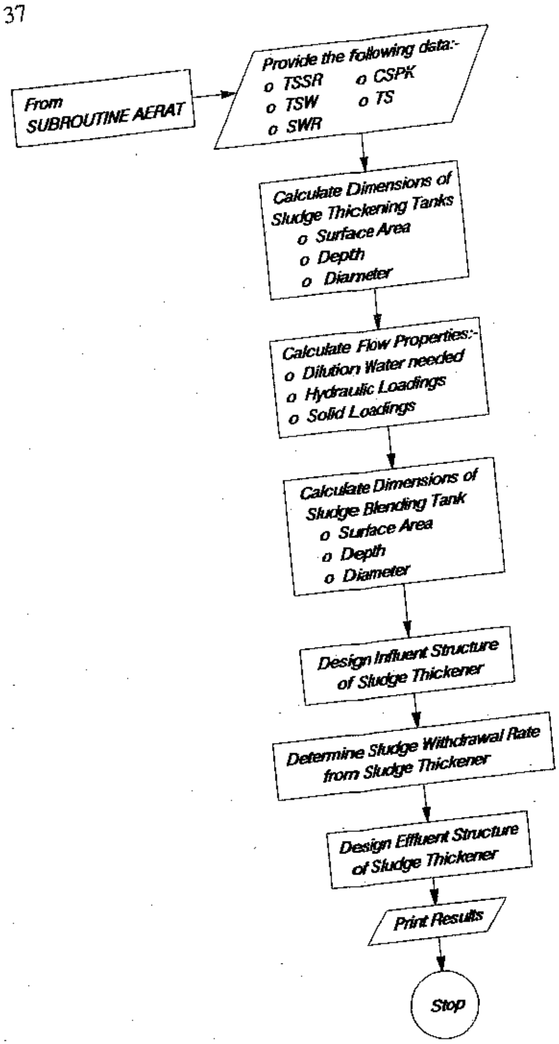


FIGURE 5 : FLOWCHART FOR THE DESIGN OF SLUDGE THICKENER AND SLUDGE BLENDING TANK (SUBROUTINE THICK)

APPENDIX 1

-- OUTPUT FILE --

```
W     W   W     W  TTTTT  RRRR   EEEEE    A    TTTTT
W  W  W   W  W  W    T    R   R  E       A A     T
W  W  W   W  W  W    T    RRRR   EEE    A   A    T
 WW WW     WW WW     T    R R    E      AAAAA    T
  W W       W W      T    R   R  EEEEE  A   A    T

*>>>>>>  DESIGN OF MUNICIPAL WASTEWATER      <<<<<<*
*          TREATMENT PLANT FACILITIES               *
*                                                   *
*              programmed by                        *
*            AMAT SAIRIN DEMUN                      *
*        Universiti Teknologi Malaysia              *
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Project Name : Pusat Pengolahan Airsisa Bandar XYZ
Program run by : Amat Sairin Demun
Organization : Universiti Teknologi Malaysia
Date : 9 th October 1997
Output Filename : OUTPUT.OUT

DESIGN INFORMATION
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1. Number of Population Served, P = 170.450 thousand
2. Peak Design Wastewater Flow, Qpk = 1.185 m3/s
3. Average Design Wastewater Flow, Qav = .444 m3/s
4. Minimum Design Wastewater Flow, Qmn = .200 m3/s

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    **********************************
8.0 SLUDGE THICKENING & BLENDING TANK
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Purpose: 1. Sludge Thickening Tank : To concentrate solids and reduce the total volume.
2. Blending Tank : The sludge must be blended thoroughly to achieve a consistent feed to the sludge thickener.

APPENDIX 1 continued

8.1 DESIGN CRITERIA FOR THE THICKENER

1. Provide two circular gravity sludge thickeners for thickening of combined primary and waste activated sludge.
2. Solids loading not exceed 46.9 kg/m2.day
3. Hydraulic loading not less than 9.0 m3/m2.day
4. Specific gravity of combined sludge = 1.01
5. The overflow liquid must go to aeration basins.

8.2 DIMENSION OF THE THICKENER

1.	Total surface area of thickener at solid loading of 46.9 kg/m2.d	= 214.1 m2
2.	Hydraulic Loading	= 4.74 m3/m2.d
	This is lower than design criteria. A decrease in surface area will increase the solids loading. Therefore dilution water must be blended with the incoming sludge.	
3.	Total flow to thickener	= 2098.2 m3/day
4.	Dilution water needed	= 1083.3 m3/day
5.	Total solids concentration in the blended sludge (s.g. = 1.01)	= .47 %
6.	New hydraulic loading(both operates)	= 9.8 m3/m2.d
7.	Solids loading (both unit operate)	= 46.9 kg/m2.d
8.	Solids loading (one unit operates)	= 73.7 kg/m2.d
9.	Hydraulic loading (one unit operates)	= 15.4 m3/m2.d
10.	Diameter of each thickener, d	= 11.7 m
11.	Depth of thickener at end, d1	= 4.4 m
12.	Depth of thickener at central well, d2	= 5.4 m
13.	Bottom slope of thickener well	= 17 cm/m

8.3 SLUDGE BLENDING TANK

1. The blending tank unit also provides a convenient place to meter the dilution water, pH adjusters, thickening aids, flocculants and other chemicals.
2. Provide sludge storage and blending period of 2 hr under peak design sludge loading.

3. Quantity of sludge loading = 2098.2 m3/day
4. Volume of blending tank = 174.9 m3
5. Provide depth of sludge storage = 3 m
6. Provide freeboard = 0.6 m
7. Diameter of the blending tank, Dbt = 8.6 m
8. The design of sludge-mixing and blending system, power requirement, paddles and pumping units are not included in this program.

8.4 INFLUENT STRUCTURE TO THICKENER
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The influent structure to the sludge thickener consists of a central well similar to that of the final/secondary clarifier - central feed well.
Diameter of the central feed well = 2.0 m

8.5 THICKENED SLUDGE WITHDRAWAL
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1. Quantity of solids withdrawn from both thickeners = 8535.3 kg/d
2. Volume of thickened sludge withdrawal rate from each thickener at 6% solids (thickened sludge pumping rate) = 69.1 m3/d
3. Provide one plunger-type pump for each thickener to transfer thickened sludge to the digester.
4. Volume of sludge blanket held in each thickener (thickening zone) = 149.9 m3
5. Sludge volume ratio, SVR = 2.2 day

8.6 EFFLUENT STRUCTURE
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1. The effluent will be discharged under gravity into a sump and then to aeration basins.
2. The effluent structure of the thickener consists of:-
   - o effluent baffle
   - o V notches
   - o effluent launder

APPENDIX 1 continued

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   o  effluent box
   o  an outlet pipe
3. Provide 90 deg V notches on the weir plate on one side
   of the effluent launder.
4. Provide width of effluent launder          =  0.5 m
5. Provide 8 cm deep notches at 39.5 cm centre to centre.
6. Length of effluent weir plate, Lwp         =   33.5 m
7. Total number of V notches                  =   84
8. Eff. Flow from each thickener              =  .0113 m3/s
9. Head over V-notch, H                       =    1.9 cm
10. Weir Loading at average flow              =  29.22 m3/m.d
11. Water depth in effluent launder, y1       =   .333 m
12. Effluent Launder & Effluent Box:-
    o  Provide effluent box of 2 m by 2 m
    o  Provide at least 0.8 m diameter outlet pipe
    o  Liquid level in the effluent box is kept 0.61 m
    o  Provide invert of the effluent launder 0.3 m above
       the invert of the effluent box.
    o  Provide depth of effluent launder,Del =    .637 m


8.7 SUPERNATANT QUALITY FROM THE THICKENER FLOW
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 1. Average volume of thickener overflow      =  1960.1 m3/d
    o This value is greater than that in the material mass
      balance analysis due to dilution water  added in the
      blending tank.
 2. Amount of solids lost in the               =  1506.2 kg/d
    thickener overflow
    o This value is larger than  that in the material mass
      balance analysis  due  to  higher value of overflow.
 3. TSS concentration                          =   768.4 mg/l
 4. BOD5 concentration in thickener overflow=     415.7 mg/l
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END OF OUTPUT FILE
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