POTENTIAL APPLICATION OF VORTEX SEPARATOR

by

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POTENTIAL APPLICATION OF VORTEX SEPARATOR

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A C K N O W L E D G E M E N T

I feel grateful to all Civil Engineering Faculty who were guiding me while writing my thesis, especially my advisor. He was the one to choose of the references that I have used for my thesis. He read all the draft and he gave his invaluable advice in every single detail that I think was very useful as well as helpful.

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O K T A Y Y A V U Z

ABSTRACT

It has been proposed that the type of separator be used as a primary or intermediate unit in wastewater treatment processes.

Following positive laboratory studies using synthetic material, the vortex type separator was tested using domestic sewage. Twenty experiments were conducted in eleven untreated sewage was used, in the remaining nine chemicals were added.

The parameters used to determine the efficiency of the unit were BOD_5, total solids, suspended solids and settleable solids.

Using flows lower than the ones recommended in the laboratory, orifice one (1.27 cm) gave best results. The efficiency for the removal of the two most important parameters, namely BOD_5, and suspended solids, were 11% and 30% respectively for untreated sewage discharge, w here as for sewage treated with coagulants and polyelectrolyte it was 10% and 36%.

N O T A T I O N

Symbol	Meaning	Dimensions
Q_{inlet}	Discharges through inlet channel	LT^{-3}
$Q_{orifice}$	Discharges through orifice	LT^{-3}
Q_{outlet}	Discharges through outlet channel	LT^{-3}
BOD_{inlet}	BOD_5 at the inlet channel	ML^{-3}
$BOD_{orifice}$	BOD_5 at the orifice	ML^{-3}
BOD_{outlet}	BOD_5 at the outlet channel	ML^{-3}
$S.S._{inlet}$	suspended solids at the inlet channel	ML^{-3}
$S.S._{orifice}$	suspended solids at the orifice	ML^{-3}
$S.S._{outlet}$	suspended solids at the outlet channel	ML^{-3}
$T.S._{inlet}$	total solids at the inlet channel	ML^{-3}
$T.S._{orifice}$	total solids at the orifice	ML^{-3}
$T.S._{outlet}$	total solids at the outlet channel	ML^{-3}
$Set.S._{inlet}$	settleable solids at the outlet channel	[illegible]
$Set.S._{orifice}$	settleable solids at the orifice	
$Set.S._{outlet}$	settleable solids at the outlet channel	
e	efficiency	

1. INTRODUCTION

The sedimentation process has long been used in water and wastewater treatment. Sedimentation is the separation, by gravitational settling of suspended particles that have a specific gravity greater than that of water. The process, one of the most widely used operation in wastewater treatment, is used to remove grit, inorganic material with a specific gravity of 2.65 and a diameter of $2x10^{-2}$ cm, particulate matter and chemical floc. It can also be used for the concentration of solids for the sludge thickening. The primary purpose of the sedimentation process is the produced aclarified effluent and a sludge that can be aesily treated. The primary purpose of sludge is to concentrate the sludge and reduce the quality that has to be treated.

Sedimentation processes have some importance among other treatment unite (See Fig. 1). Efficiencies of sewage treatment operations and processes as percent removals are depicted in Table 1.

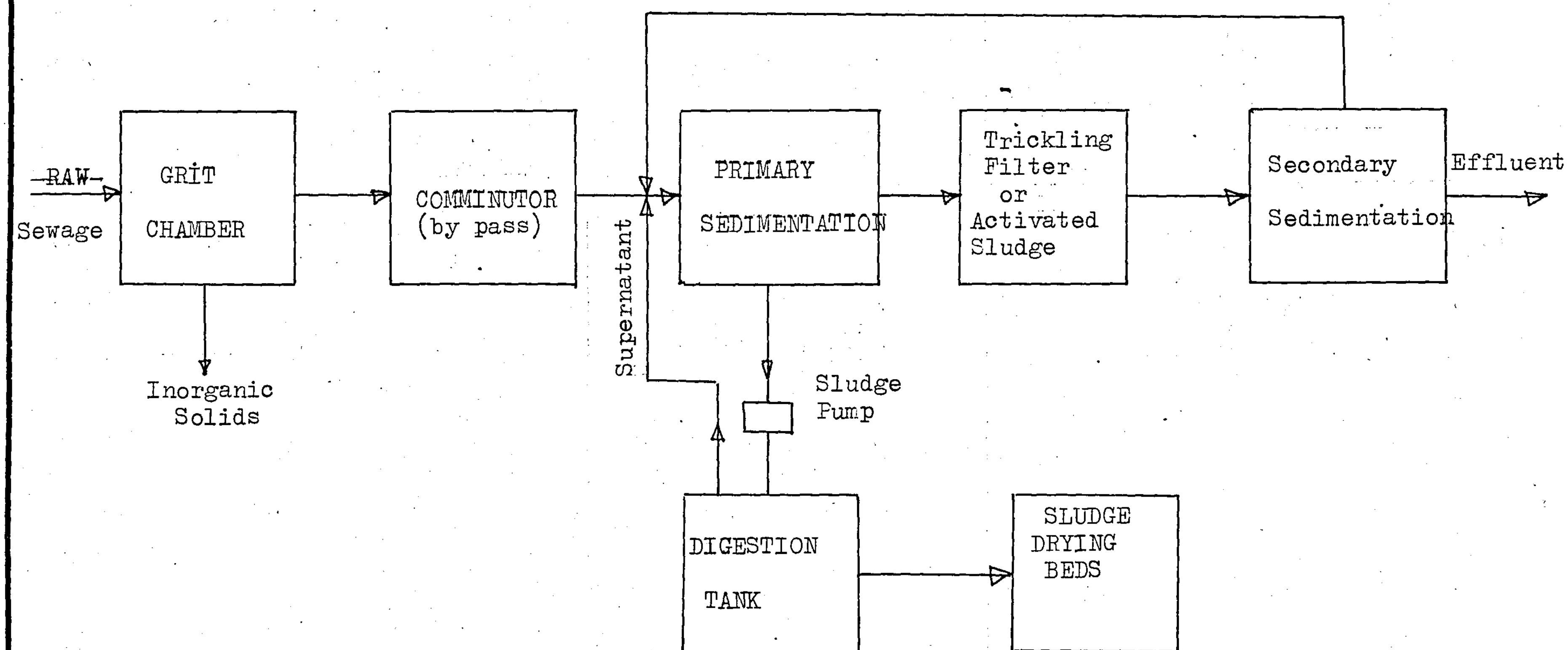


FIGURE I Typical sewage treatment plant

Table 1

Removal Efficiencies of Wastewater Treatment Plants

Treatment Operation or Process	BOD_5	Suspended Solids
Fine Screening	5–10	2–20
Plain Sedimentation	25–40	40–70
Chemical Precipitation	50–85	70–90
Trickling filter preceeded and followed by plain sedimentation	50–95	50–92
Activated sludge treatment preceeded and followed by plain sedimentation	55–95	55–95

(Fair and Geyer, 1971)

The general form of an ideal sedimentation basin is shown in Fig. 2. Water enters the sedimentation basin at the left and it is assumed that it spreads out uniformly over a verticle plane A–A in such a way that the concentration of suspended particles of all sizes and densities is constant throughout the incremental volume of the tank of length (L). The incremental volume of water moves from inlet to outlet through the settling zone at a uniform velocity "v" and arrives at a position "A'–A' " without a change in shape.

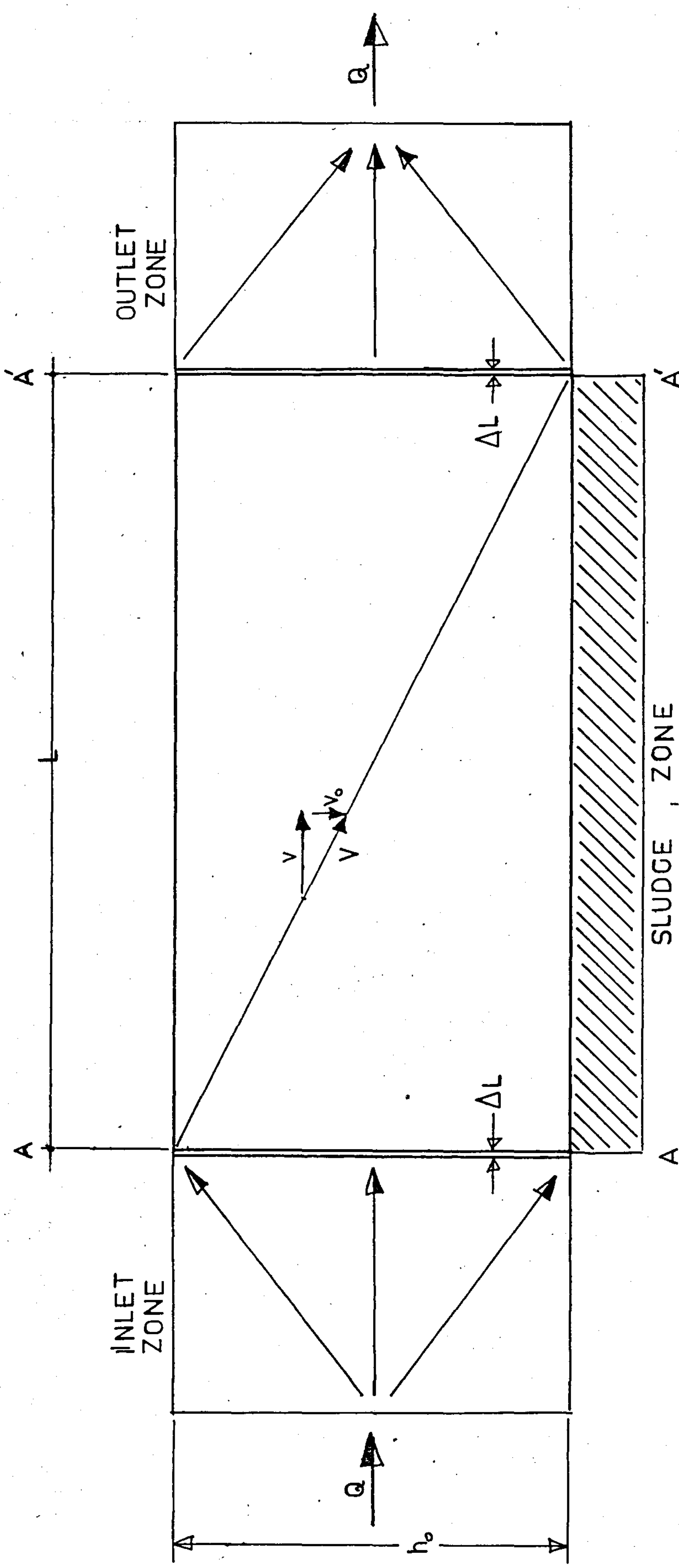


Figure - (2) IDEAL SEDIMENTATION BASIN (Fair and Geyer, 1971)

This velocity could be calculated by dividing the flow rate "Q" by the cross-sectional area of the basin "h.w." where "h" is the depth and "w" is the width. Then the increased amounts of water will flow through the outlet zone carrying along all the particles that did not settle. Those particles which strike the bottom are considered removed. Then the path "V" representing the maximum elevation at which particles of the smallest settling velocity "v" and experiencing 100% removal may be found. That is to say, if a particle with a settling velocity "v" enters the basin at height "h" above the bottom, will travel along the path "V" and will be removed near the outlet zone.

Another form of sedimentation basin is the vortex type of sedimentation basin. The advantage in the latter is that the detention time is short (7-28 sec). In the primary sedimentation basin, detention time varies with the percent removal desired as shown in Fig. 3.

The vortex type of sedimentation can be potentially treat water, wastewater, storm sewers, and industrial waste efficiently. It separates the solid phase from the liquid at the lower unit cost than other methods employed.

The purpose of the experiment is to find the efficiency of the vortex separator in the field and to see if it can be used in place of primary sedimentation tanks.

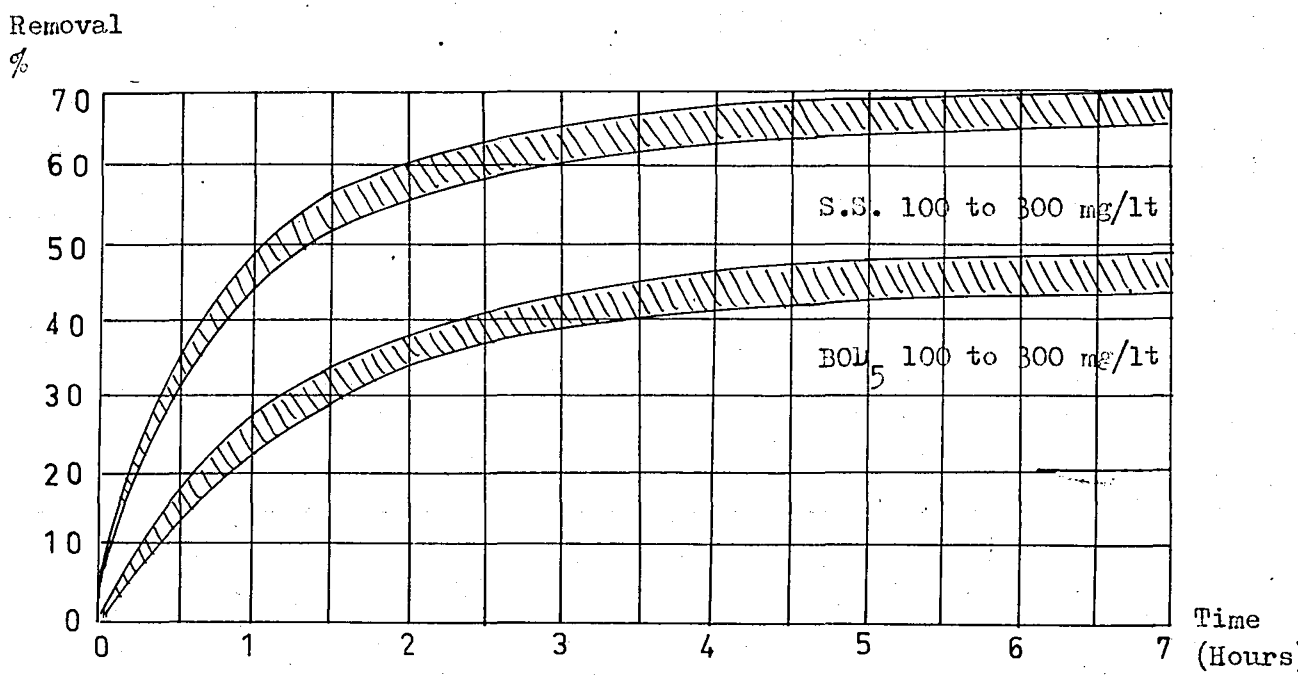


Figure 3

% Removal of Solids and BOD_5 versus time in a sedimentation Basin (Fair and Geyer 1971)

2. LITERATURE SURVEY

2.1. Operational Theory

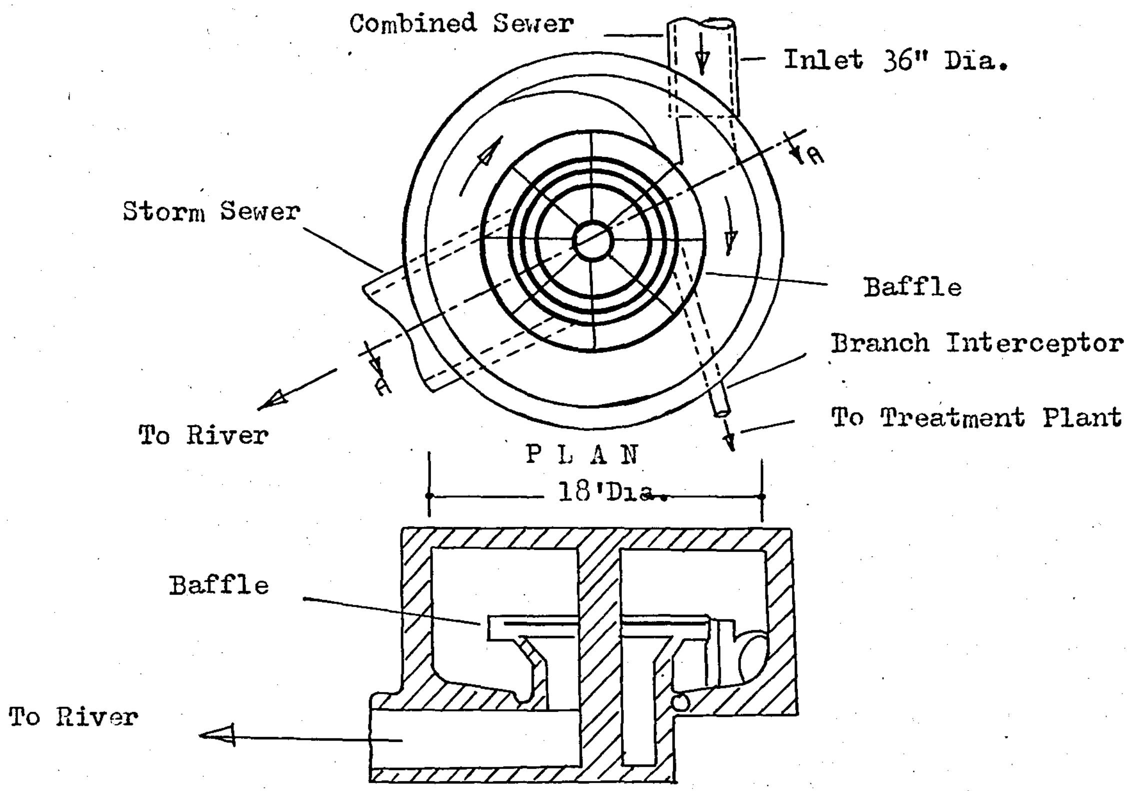
The vortex type sedimentation tank seperates solids from liquids. The vortex type separator concentrates the solid phase in a dilute slurry by accelerating the velocity of flow of the solid particles rather than by reducing their horizontal velocity. The mathematical theory for vortex motion and for the vortex separator was developed by Valantine (1965) and Velioğlu (1972) to confirm laboratory observations that particles in a moving fluid, subject to a non-linear flow pattern, tend to rotate, and that this rotational motion causes the particles to move into the stream lines of the highest velocity. The factors that determine the direction and rate of movement of a particle in a fluid are the particle dimensions effective diameter, shape, drag coefficient, weight, fluid viscosity, unit weight of the fluid, velocity of the fluid, and its flow pattern.

In this device, an orifice is used to generate a relatively high-velocity rotational field of flow. Particles of sufficient size are trapped in the non-linear flow field of the vortex induced by the flow from the orifice, causing them to rotate and accelerate as they move into the higher velocity flow. Particles thus seperated from the effluent, are concentrated in a significantly smaller volume of liquid and flow through the orifice. A larger volume of the fluid flows through another outlet with a much lower velocity.

Chemical and physical techniques cause particle nucleation to generate particles of an appropriate size for trapping in the vortex flow-field of the orifice. The various processes used to **create larger particles are those** now in common use industrial processes and in water and waste-water treatment. It is the combination of particle growth and particle concentration in a vortex flow-field to obtain efficient, low cost solid-liquid separation that constitutes the unique process, (Curi et.al.,1973).

2.2. Previous Work Done

Smisson (1964) used the first circular vortex device in the city Of Bristol, England, to increase the efficiency of existing regulator facilities for the purpose of minimizing overflow quantities and maximizing the quality of wastes discharged into receiving waters. This circular chamber concept was used to obtain adequate weir length for overflow discharge without the expense of constructing a long side-spill weir for this purpose. At Bristol Laboratory, studies were carried out on this configuration to determine its hydraulic characteristics and performance, prior to construction of the facilities in 1964. Smisson (1967) published a report about the research work at Bristol and the actual details of vortex chamber installed at White Ladies Road. The White Ladies Road device as shown in Fig. 4, provided an 18 ft diameter chamber, an overflow weir , a scum ring for retention of the floating material



S E C T I O N "A" _ "A"

W H I T E L A D I E S R O A D

FIGURE (4)

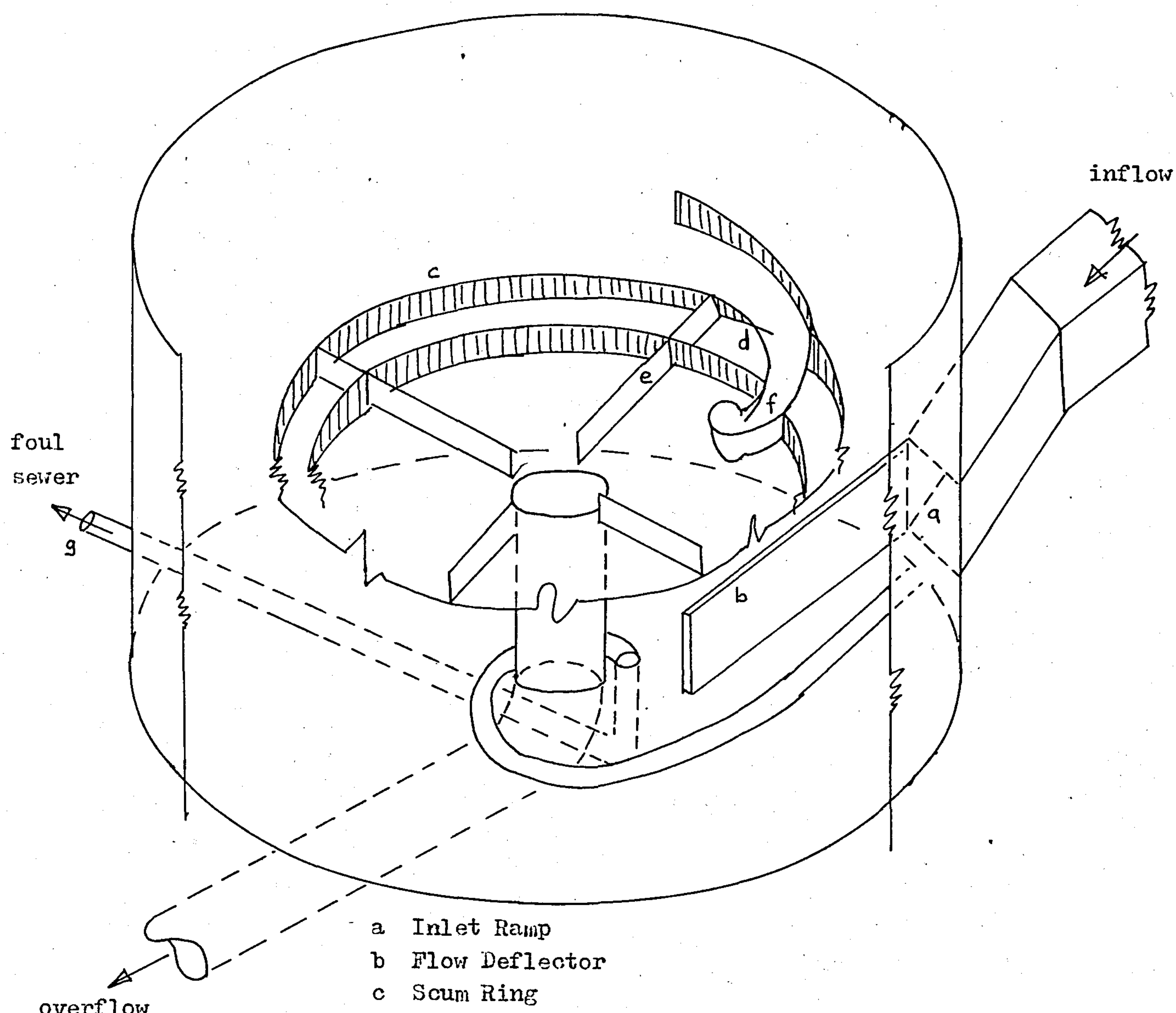
WHITE LADIES ROAD _ VORTEX REGULATOR (Field, et.al., 1972) mounted on the central column, and a sewer outlet for the concentrated solids. Flow entered the circular chamber tangentially at the floor level. The foul sewer outlet was located on the floor of the chamber, near the central column, at a point where it would collect the solids deposited on the floor of the chamber. The supernatant clarified liquid overflowed the weir and was discharged into receiving waters (walk up 1972). Tests done by Smisson were first carried out without any deflectors in the chamber. Galsonite with specific gravity of 1.06 and particle sizes between one and three millimeters was used. Very few galsonite particles settled to the bottom to be drawn off through the foul sewer outlet, the rest remained in suspension in the rotating water mass for several turns before overflowing. After installing a flow deflector into the chamber adjacent to the inlet, the flow conditions changed, so that the water entering the chamber from the inlet pipe was slowed down and diffused with very little turbulance. When the galsonite particles entered the chamber, they spread over the larger cross section of the chamber and settled rapidly. Particles were entrained along the bottom around the chamber and were concentrated by two secondary vortices located under the lip of the weir approximately 200° and 290° from the inlet point. Foul sewer outlets at each of these positions didnot draw off all the gilsonite: the greater part remained in deposits on the chamber floor, away from the central shaft. Volumetric measurements of the total galsonite recovers from both the foul outlet and the floor deposit, for three tests yielded the following results. (Walk up, 1972).

Table 2

Storm Discharge	Galsonite Removal efficiency
50 cfs	97%
100 "	87%
162 "	65%

Smisson (1967) found that large diameter weirs, with horizontal undersides but with no deflector walls, removed small solids better than that provided by smaller diameter weir having a sloping underside and a deflector wall. Smisson (1967) also suggested that a smaller diameter storm water down shaft would improve efficiency.

After 1967, Smisson kept on working with Sullivan, Cohn, and Coombes on this device and developed its design criteria in 1971. From the work of Smisson, a swirl concentrator was developed which offers a high degree of performance in reducing the amount of settleable solids in combined sewer overflows. This new type of vortex device was called a swirl concentrator. Some tests were conducted on the device by American Public Works Association APWA in the U.S.A. (See Fig. 5). The APWA tests, using a swirl concentrator, showed that it was possible to remove significant amounts of settleable



a Inlet Ramp
b Flow Deflector
c Scum Ring
d Overflow Weir and Weir Plate
e Spoilers
f Floatables Trap
g Foul Sewer Outlet
h Floor Gutters

FIGURE 5

ISOMETRIC VIEW OF SWIRL CONCENTRATOR (Field et.al., 1972) and floatable solids from combined sewer overflows.

This device has the advantege of low capital cost because of its simple structure. The absence of primary mechanical parts should also reduce maintenance problems. The motion is automatically induced by the inflowing combined sewage so that operating problems normal to dynamic regulators, such as clogging, would be very infrequent.

The swirl consentrator has a circular channel in which rotary motion of the sewage is induced by the kinetic energy of the sewage entering the chamber. Flow is deflected and discharged, through an orifice called the foul sewer outlet. This orifice is located near the center of the chamber. The rotary motion causes the sewage to follow a long spiral path through the circular-chamber. A flow deflector prevents the flow in the chamber from merging with inlet flow. A free surface vortex was also eliminated by this deflector. Some rotational movement in the form of a gentle swirl remains, so that water coming from the inlet pipe is slowed down and diffused with very little turbulence. The particles entering the basin spread over the full cross section of the channel and settle rapidly. Solids are entrapped along the bottom and around the chamber, then they are concentrated at the foul sewer outlet.

The study by American Public Works Association (APWA) in 1971-72 showed that the swirl concentrator was very efficient in separating both grit and settleable solids for the middle 0,2 mm and larger grain sizes ranges. By weight, these fractions represent about two-thirds of the respective materials in combined sewage. Separation of smaller grain sizes was less efficient.

A different type of vortex seperator for the removal of solids was constructed and tested at the Hydraulic Laboratory of the State Water Works, a Directorate of the Ministry of Energy and Natural Resources in Ankara by Akmandor (1972). The unit at the Ankara laboratory was designed for removal of heavy particles from water, such as sand and silt. The vortex seperator which was used by Akmandor is very similar to the one that is used in this study. Akmandor used five different types of materials in his work. These materials had a D_{50} (particle size corresponding to particles 50% finer) which ranged from 1.72 mm to 3.20 mm, and their specific gravities ranged from 1.047 gm/cm^3 to 1.425 gm/cm^3.

A vortex-assisted oil removal unit was reported in the American literature, by Walkup, et.al. (1972). This unit, however, used the surface phenomena of a vortex to draw an oil film to appoint over the vortex where it could be drawn off in an upward direction by an airlift. The vortex-assisted nozzle system is shown in Fig. 6. In this figure the main conponents are identified. As an additional aid, operational capabilities such as air flow and water flow are also given in Fig. 6.

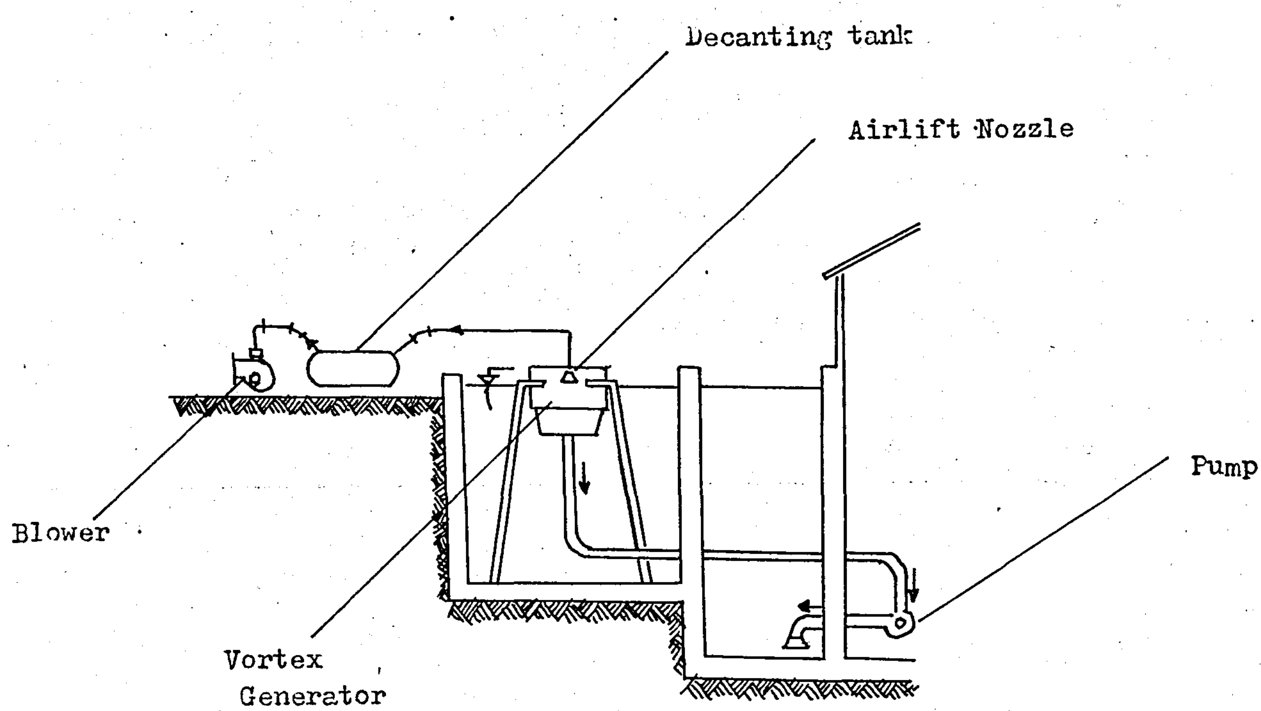


Figure 6
VORTEX SEPARATOR with AIRLIFT for OIL REMOVAL

(Walk up et.al. 1972)

Flow controlled was accomplished by adjusting the gate valve on the discharge side of the pump.The water level was controlled by pumping water into or out of the basin.The lower part of vortex generator was moved down or up manually to change the quantity of water entering the vortex from the side,thus controlling the vortex from the side,thus controlling the vortex size.P.C.Walkup, J.D.Smith,andE.R.Siminson have worked on this marine oil spill recovery by vortex-assisted airlift in 1972.(Walkup 1972).

Another vortex type solid-liquid seperator study was carried out in the laboratories of Boğaziçi University in Istanbul, Turkey, In 1972 by Velioğlu. This work was done to check whether a vortex type sedimentation unit could be used in water and wastewater treat-met processes. A measure of applicability was sought through finding the ratio of the amount of removed particles with the amount initially present. A design formula was developed for a vortex type sedimentation tank. The design of this separator is given in part 3.1.

Velioğlu (1972), in the laboratory evaluated the vortex separator using five different materials having a wide of unit weight and particle diameter. The removal efficiency in the laboratory at different inlet flow-rates, orifice discharge rates, orifice diameters, and depths of flow in the tank was measured. Table 3 is a summary of the variables and the solid liquid separation efficiencies obtained by Velioğlu (1972).

Observations of Velioğlu (1972) showed that the vortex type sedimentation tank was efficient for medium discharges of 4.5 - 9.0 lt/sec of total discharges. As the discharge was increased, the strength of vortex was more due to increased, velocity, and thus a highly turbulent flow was generated, resulting in a decrease in efficiency. On the other hand, to prevent the settling of particles in the inlet channel necessitates a minimum discharge, but this minimum might cause some difficulties in the generation of the vortex, especially for small orifice sizes. The particles used were of various shapes. Velioğlu did not take into consideration the

Table 3

Summary of Laboratory for Vortex Separator

(Velioğlu, 1972)

VARIABLES	UNIT	MINIMUM	MAXIMUM
Specific gravity of particle	g/cm^3	0.45	1.42
D_{50} media particle diameter	mm	0.80	3.40
Orifice size	cm	1.27	5.08
Inlet flow, Q	lt/sec	4.46	12.73
Efficiency	—	30.00	100.00
Orifice discharge, Q_o	lt/sec	0.22	1.68
Ratio of Q_o to Q	—	0.03	0.35
Detention time	sec	7	28

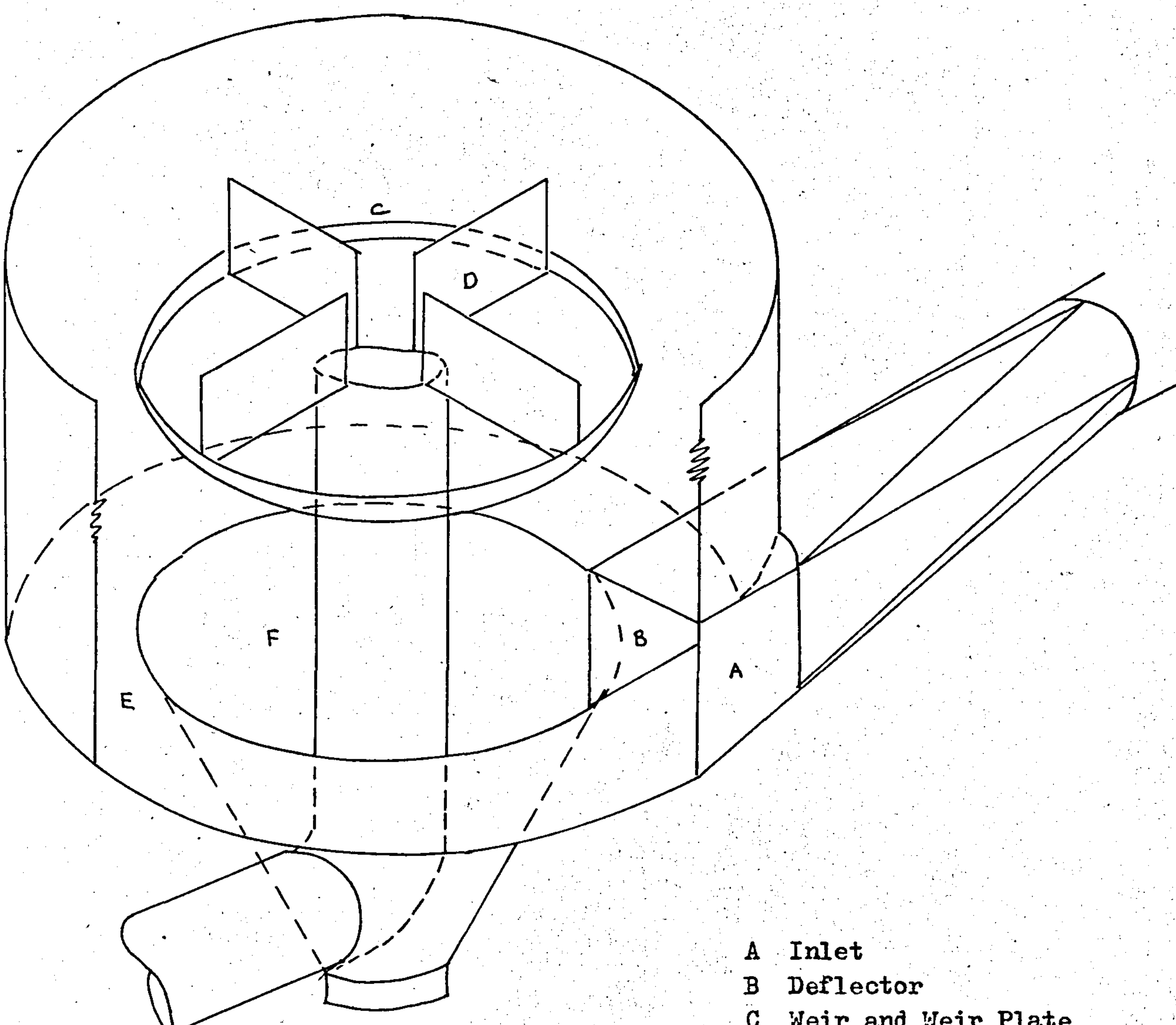
difference in shapes, although the particle size was thought to be an important parameter in sedimentation theory. Due to short detention times (7-28 sec.) in the trial runs, headloss between the inflow and the outflow was neglected.

Velioğlu noted that efficiencies ranged from 32% to 100% and that the median efficiency was 89%. These results were the subject of multi-variate analysisis and an appropriate relationship between the variables and the removal efficiency was obtained. This relationship is used as a design guide in prototype units.

An inspection of the obtained efficiencies allowed Velioğlu to think that the vortex type sedimentation tank could be used as a unit in water and wastewater treatment processes instead of sedimentation tanks.

A study was conducted by the American Public Work Association to determine the efficiency of the swirl concentrator chamber to perform the functions of a grit separation and removal facility in 1974. Sullivan, Cohn, Ure, Fred Parkinson had worked on the swirl concentrator as a grit separator device. (See Fig. 7).

Grit chambers are designed to remove grit, consisting of sand, gravel, cinders, or other heavy solid materials that have specific gravities greater than the organic solids in wastewater. It is one of the conventional pretreatment unit in sewage or industrial wastes treatment plants. The removal of inorganic grit prevents excessive wear on subsequent handling operations such as



A Inlet
B Deflector
C Weir and Weir Plate
D Spoiler
E Floor
F Conical Hopper

FIGURE 7

ISOMETRIC VIEW, SWIRL CONCENTRATOR AS A GRIT SEPARATOR (Sullivan et.al., 1974) pumping, comminuting and screening of sewage and pumping of sludge. Elimination of inert solids prevents deposition of such material in settling tanks, sludge hoppers, sludge digestion chambers, aeration chambers, pipelines and other locations. (Sullivan, 1974)

The removal of grit material involves separation or classification by means of flow rate-control, thus utilizing the difference in settling rates, or buoyancy, between the different specific gravities of the two types of waste solid (organic and inorganic). Design is based on the principle that average sewage solids - organic and inorganic in character - can be held in suspension in a so called self-scouring sewer line at flow velocities over 0.61 m (2 ft) per second. Similarly, grit chamber design is based on the principle that heavier grit will settle at velocities of flow of 0.3 m (1 ft) per second, while lighter organics will be held in suspension under these hydraulic conditions until they reach settling chambers where flow velocities are reduced to rates in the general range is the basic criterion for the separation of solids-from-liquid in clarification or settling chambers.

The application of the swirl concentrator phenomenon for the grit removal is dependent upon flow conditions and internal hydraulic patterns which will separate heavier as well as larger solids particles from lighter and smaller ones. Then it will allow the two separated classifcations to be collected and removed at separate points. Sullivan (1974) found out that the swirl concentrator could only be used for large materilas.

The swirl concentrator principle involves the development of a flow chamber utilizing circular, long-path kinetic energy to separate the solid particles and let them settle. The settling is achieved by having optimum hydraulic conditions without the use of mechanical accessories.

3. EXPERIMENTAL PROCEDURE

3.1. Experimental Set_Up

The vortex separator was constructed as a circular tank of 2 mm galvanized steel, about 30 cm deep. At the center of the separator there is an orifice from which the solid particles are to pass. (More details can be obtained from Velioğlu's thesis, 1972) In the experiment a series of different orifices were used to evaluate the most efficient orifice dimension for the sewer used.

The wastewater source used to feed the separator was a 40 cm sewer in Levend. The wastewater was diverted into a galvanized pipe which was connected to the main sewer. The pipe was supported on a wooden frame. The separator itself was installed on a wooden table. (See Fig. 8) Under the wooden table there was a barrel which was supposed to collect the flow from the orifice. The barrel was not used because of the small quantity of sample. When the sampling period was one hour, grab samples were taken every ten minutes, when the sampling period was half an hour, grab samples were taken every five minutes.

The wastewater was diverted into the galvanized pipe inlet by blocking the sewer outfall. Initial twelve runs, the channel was blocked with stones and soil to divert the flow to the separator. During the initial runs, it was noticed that the soil from the dike was eroded and carried to the separator, thereby increasing the

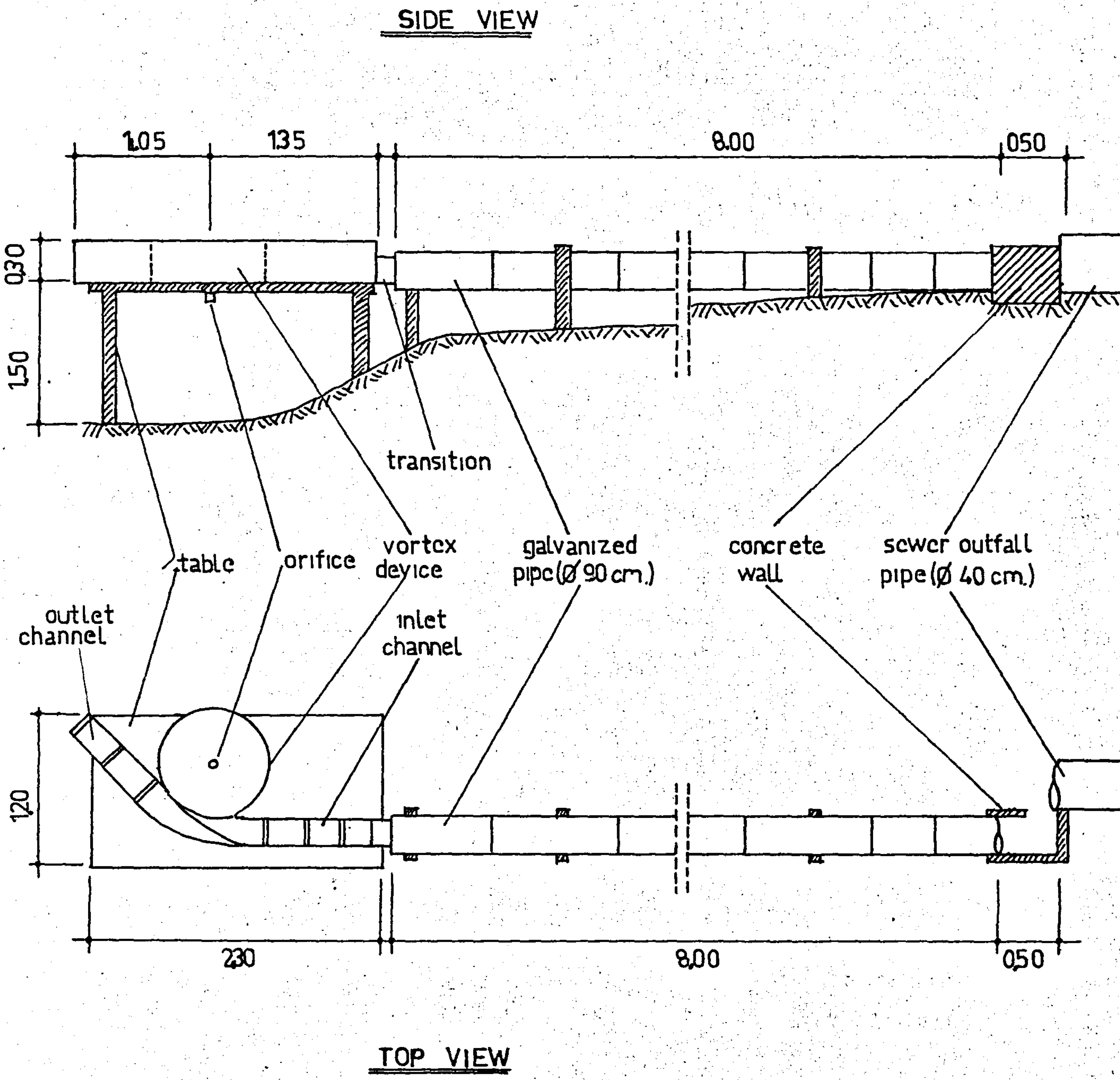


FIGURE 8

FIELD SET-UP OF VORTEX SEPARATOR

total solids. For the later runs, sand bags were used to reduce the erosion and the solids in the separator. At the end of the galvanized pipe there was a transition section from the circular to the rectangular inlet channel of the separator. At that section, the bottom was filled with concrete to supply a smooth transition. To reduce the seepage, the concrete was covered with a very thin layer of tar.

After passing the transition section, the wastewater entered the separator through the inlet and depending on the size of the orifice used, a classified portion of the liquid was discharged through the outlet to the field. According to the theory of the unit, the solid particles and a portion of the liquid flowed through the orifice. (See Fig, 9).

Both polyelectrolyte and alum were fed into a manhole 12 m from the main sewer outlet to give time for mixing and flocculating to take place. The chemicals were fed by a 6 lt. bottle which had two tubes, one for discharging the solution, the other for supplying pressure (See Fig. 10).

Experiments were conducted to check the rate of feeding. It was noticed that the rate differed depending upon whether the bottle was full, half-full or almost empty. The three points were plotted on a graph (Fig. 11.)

They came out to be on a straight line. For practical reasons the average discharge rate was accepted to be the rate when the bottle was half full.

Dimensions in mm.

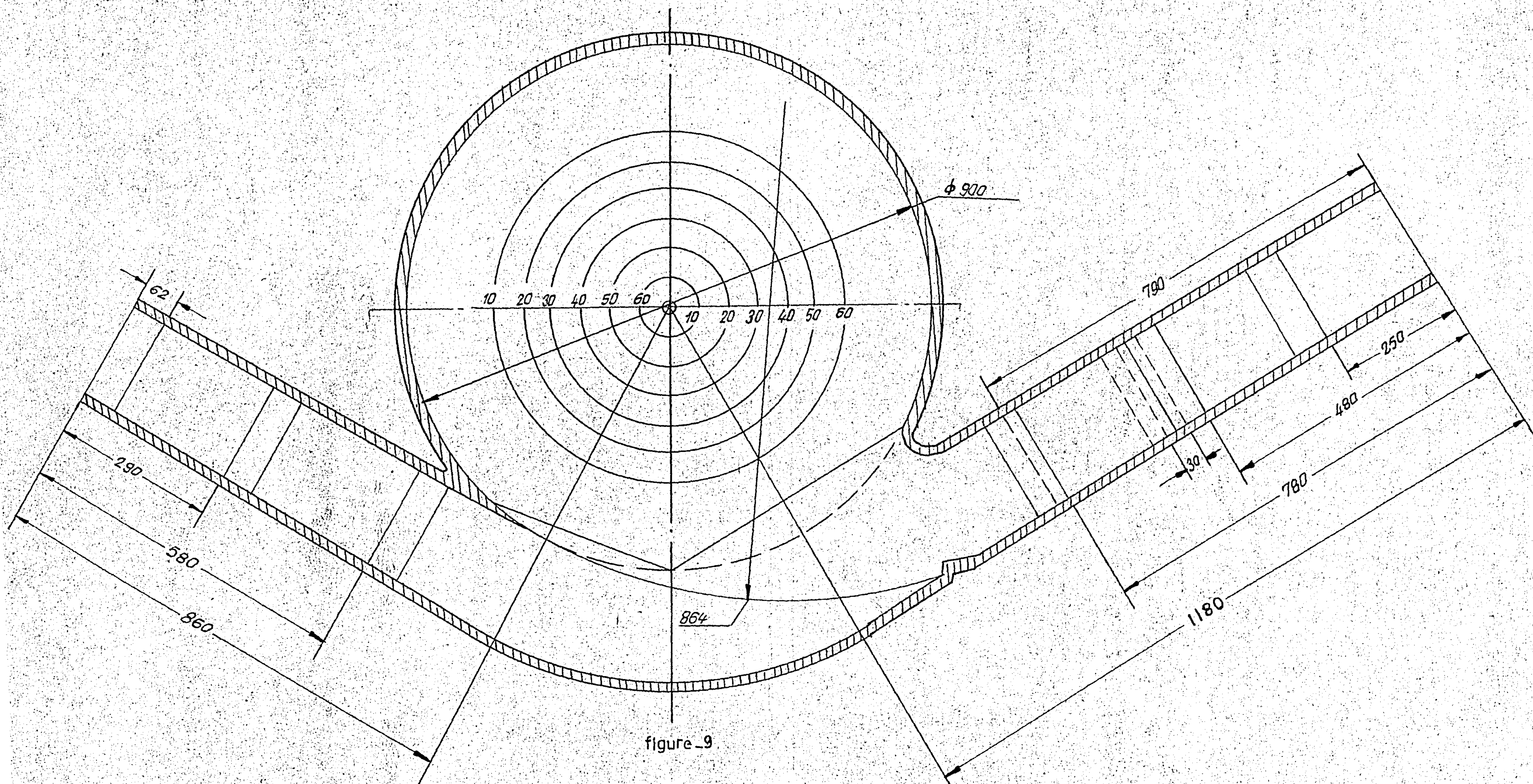


figure_9

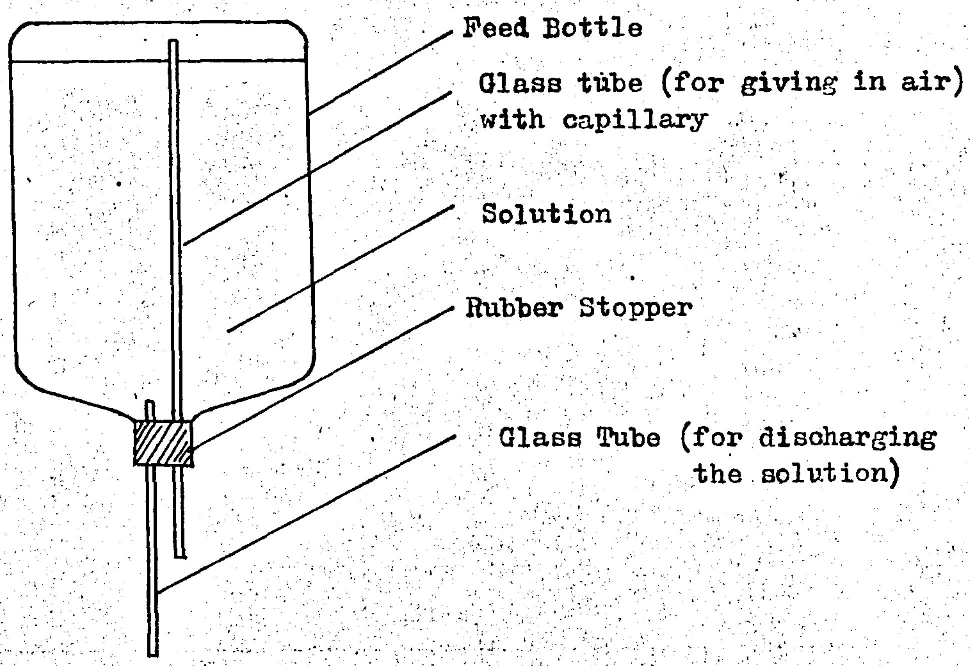


figure 10 FEED BOTTLES

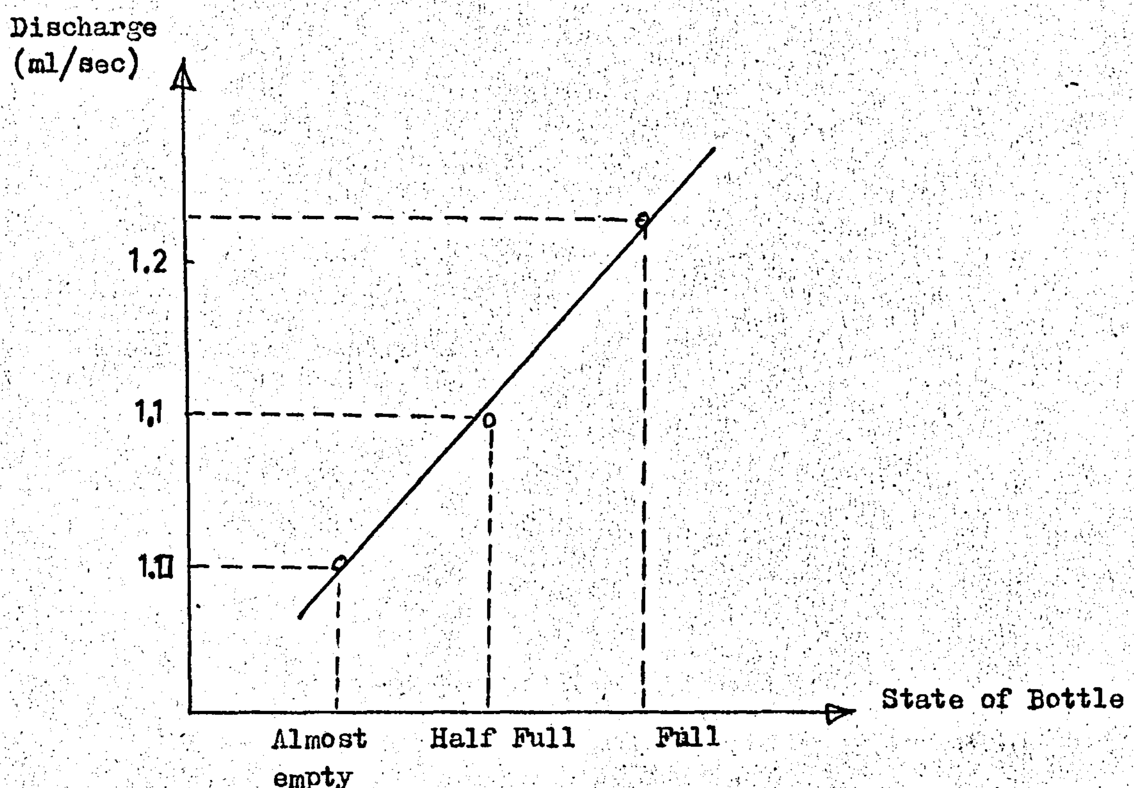


figure 11

DISCHARGE VERSUS DEPTH FOR FEED BOTTLE

3.2. Procedure

3.2.1. Field Work:_

After the wastewater discharge was diverted to the vortex separator, three different samples were taken every ten minutes for one hour. Grab samples were taken with a one liter beaker from the inlet channel. The samples may not be representative since some of the solids were carried along the bottom and the wastewater was not well mixed. No other alternative for sampling of the inlet was found, Another sample was taken from the orifice by means of a graduated cylinder. This was quite a representative sample since all the discharge was collected in the cylinder. Using a stop watch and the graduated cylinder, the rate of flow through the orifice was measured. The third sample was taken from the outlet by means of a graduated container. This sample was also a representative one because in this case, all of the discharge was also collected into the graduated container. The discharge was measured in the same way as the orifice sample. Since there was only one man taking the samples, they were collected in the sequence, inlet, orifices and outlet.

After eleven runs using only untreated wastewater, coagulants were added at the manhole for the rest of the runs. The quantity of coagulant added depended on the flow. Samples were taken either every ten minutes for one hour, when the feeding rate of coagulant was low, or every five minutes for half an hour when the feeding rate was high.

After the grab samples had been collected, composite samples were made combining the individual samples proportional to the flow rate. These three composite samples were used in the laboratory tests.

3.2.2. Laboratory Work:-

After the composite samples taken from the field were transfered to the laboratory and throughly mixed, the following tests were conducted.

Solid tests:- Settleable solids, total solids were determined according to The Standard Methods for the examination of Water and Wastewater. (Standard Methods)

The suspended solids that were modified because glass fiber filters were not available. An attempt was made to use the gooch crucibles with asbestos filter, but another problem occured. The asbestos available in Turkey is very fine and in spite of numerous washing, fine particles were lost while filtering the sample. This loss of fine caused a loss of weight in the sample plus crucible. In order to overcome this problem, No. 40 Whatman filter paper was placed on the bottom of the gooch crucibles and over it an asbestos layer was put. The fine particles blocked the pores of the filter paper. Finally glass crucibles were used with a dish of No. 40 Whatman filter paper. Everything else in the test was done according to the Standard Methods.

BOD_5 : The BOD_5 tests were done according to Azide Modification Wrinkler explained in Standard Methods for the water and wastewater.

4. EVALUATION OF EXPERIMENTAL DATA

In the experiments, three sizes of orifices were used, 1.27 cm (1/2 in), 2.54 cm (1 in) and 5.08 cm (2 in). Only one experiment was conducted with the third orifice (5.08 cm). Since the flow was small and the orifice was large, all the sewage flowed out of the orifice. The second orifice (2.54 cm) was used five times in the experiments, and the first orifice (1.27 cm) was used fifteen times in the experiments.

Table 4

Experiments Conducted

ORIFICE No.	Diameter	No. of Exp. without chemicals	No. of Exp. with chemicals
1	1.27 cm	9	9
2	2.54 cm	2	3
3	5.08 cm	1	-

The efficiency was defined to be the ratio of the amount of material removed of an item to the total amount of material in the item which can be expressed as:-

$$e = \frac{A_{in} - A_{out}}{A_{in}} x\ 100$$

where:- e : efficiency

A_{in} : Amount incoming through inlet channel.

A_{out} : Amount outgoing through outlet channel.

The efficiency of total solids, suspended solids, settleable solids and BOD are calculated for each run and given in the appendix.

Material balances were determined using the equation below:-

$$Q_{inlet} \times A_{inlet} = Q_{outlet} \times A_{outlet} + Q_{orifice} \times A_{orifice}$$

amount incoming Amount outgoing

Q_{outlet} : Total discharge incoming (lt/sec)

Q_{outlet} : Discharge from outlet channel (lt/sec)

$Q_{orifice}$: Discharge through orifice (lt/sec)

A_{inlet} : Amount of solids or BOD_5 in the inlet channel (mg/lt)$^+$

A_{outlet} : Amount of solids or BOD_5 from the outlet channel (mg/lt)$^+$

$A_{orifice}$: Amount of solids or BOD_5 through the orifice (mg/lt)$^+$

In most of the experiments the amount of solids did not balance as (discussed in Chapter 5).

Since suspended solids and BOD_5 are considered two of the most important parameters in wastewater treatment, a multi-linear regression program of Prof. Mehmet Tümay at Boğaziçi University was used to check whether these parameters are a function of the

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$^+$ With the exceptions of settleable solids (ml/lt) other parameters. Suspended solids out Q_{inlet}, $Q_{orifice}$, $S.S._{in}$, TS_{in} were considered as dependent variables and BOD_{out}, Q_{inlet}, $Q_{orifice}$, BOD_{in}, $S.S._{in}$, and TS_{in} were considered as dependent variables. (See Table 5).

A computer program was used to find a relationship for $S.S._{out}$, and BOD_{out} in terms of the other parameters for treated and untreated discharge.

T a b l e 5

Variables used in Computer Program

Type of run	Dependent Variable	Independent Variable
1	BOD_{out}	Q_{inlet}, $Q_{orifice}$, BOD_{inlet}, $S.S._{inlet}$, $T.S._{inlet}$
2	$S.S._{out}$	Q_{inlet}, $Q_{orifice}$, BOD_{inlet}, $S.S._{inlet}$, $T.S._{inlet}$

Out of the twenty experiments, data for fifteen experiments were used for the computer run. As it was discussed in section 3.2.2. in the first five runs, it was impossible to obtain suspended solids values since the fine asbestos used in the Gooch crucibles were lost. Since no reliable results were obtained for S.S. from the first five experiments, and since S.S. was used as a parameter for all types of computer runs, the first five experiments were not used for the computer program. Among these fifteen experiments, there were six chemicals runs for the first orifice and three chemical runs for the second orifice. Since the number of data of the second orifice was not sufficient, it was impossible to find any mathematical relationship for the second orifice. Table-5 above shows the types of the run and the parameters used in the computer program.

The data used for the program is given in the following Table 6.

The equations below were obtained from the computer output.

$$BOD_{out} = (Q_{inlet})^{-0,17}(Q_{orifice})^{0,90}(BOD_{in})^{1,33} \quad ...... \; 1\,a$$

(free)

99.68% correlation+

$$BOD_{out} = e^{-4,45} \cdot (BOD_{in})^{1,70} \cdot (T.S._{in})^{0,14} \quad .... \; 1\,b$$

(chemical)

99.47% correlation+

$$S.S._{out} = e^{3.09} \cdot (Q_{inlet})^{0.44} \cdot (Q_{orifice})^{2,10} \cdot (S.S._{inlet})^{1,01} \quad .. \; 2a$$

(free)

99.81% correlation+

$$S.S.^{out} = e^{-2.20} (Q_{orifice})^{-1,01} \cdot (S.S._{inlet})^{1.00} \quad ..... \; 2\,b$$

(chemical)

99.26% correlation+

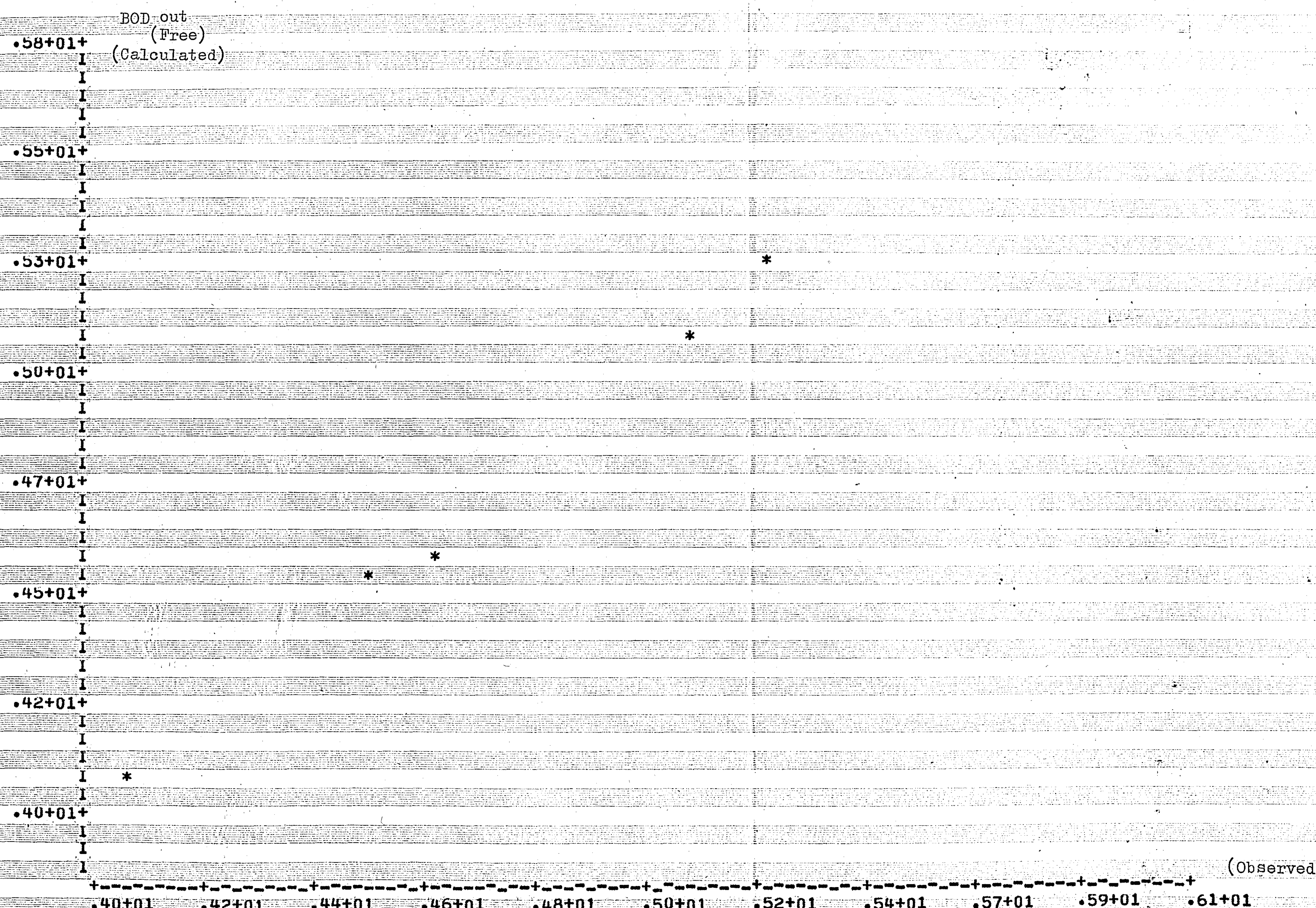
Table VI

Data Used For Computer Program

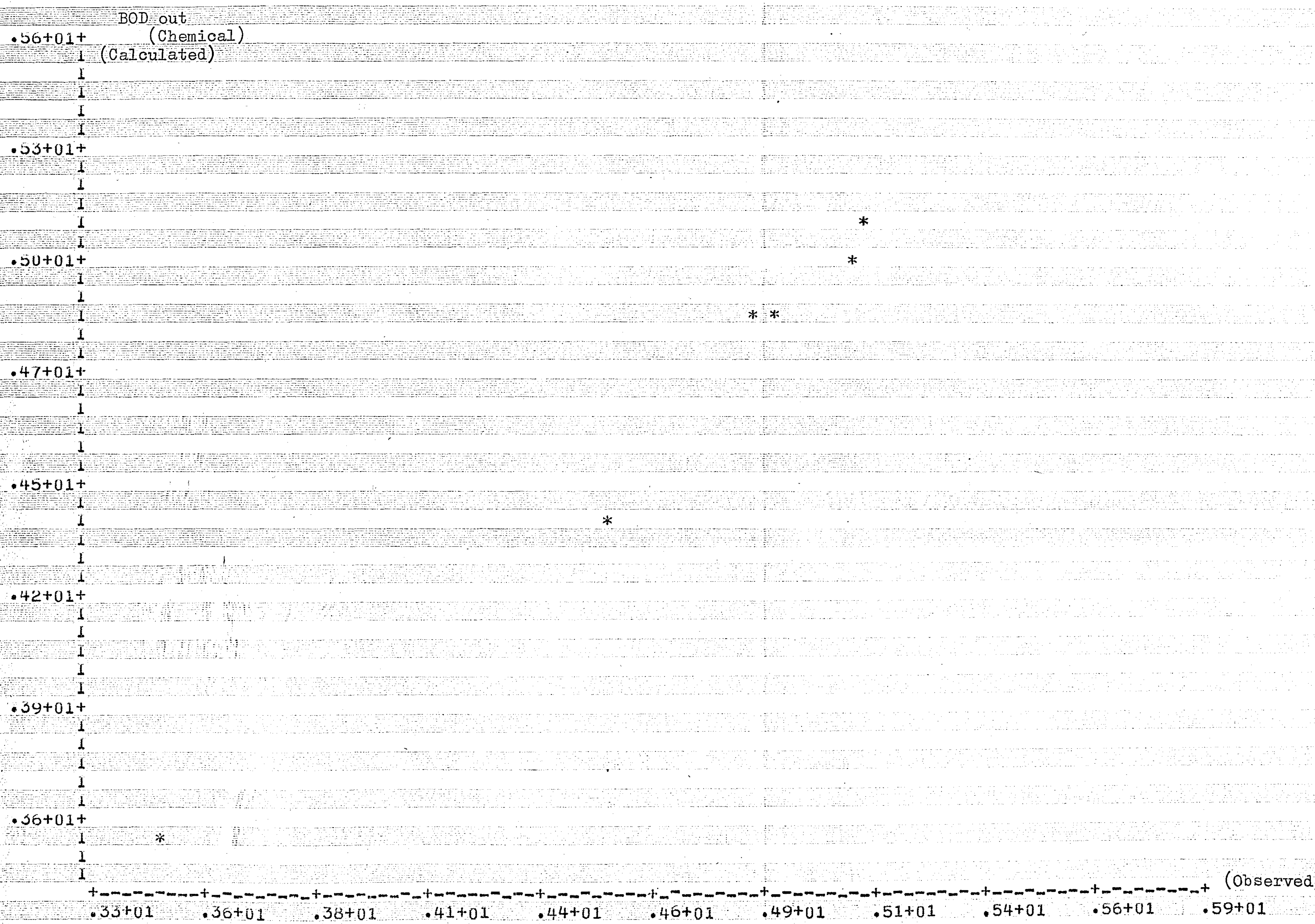
	DEPENDENT VARIABLES		INDEPENDENT VARIABLES				
	BOD_{out}	$S.S_{out}$	Q_{inlet}	$O_{orifice}$	BOD_{inlet}	$S.S_{inlet}$	$T.S_{inlet}$
FREE RUNS	90.00	23.00	I.I5	0.I6	I05.60	48.30	597.00
	I89.60	44.50	I.78	0.I7	I83.60	6I.83	8I5.00
	I02.00	37.00	I.04	0.I8	99.00	5I.50	747.00
	I64.00	40.00	0.93	0.2I	I32.00	52.00	649.00
	90.00	53.00	I.08	0.I9	94.30	69.50	580.00
	57.00	850.00	2.55	0.I6	8I.00	II24.00	2305.00
CHEMICAL RUNS	I26.00	578.00	3.0I	0.I6	I38.00	I089.00	I599.00
	I65.00	I0.40	0.69	0.23	I62.00	24.00	952.00
	I32.00	24.00	0.64	0.I7	I38.00	36.00	903.00
	33.00	835.00	3.85	0.2I	58.20	I763.00	2207.00
	I59.00	I06.50	I.86	0.I9	I50.00	I20.00	9I2.00
	90.00	3092.00	I.28	0.I8	96.00	3656.00	4048.00

Also the following graphs were given in the output where computed values versus calculated values.

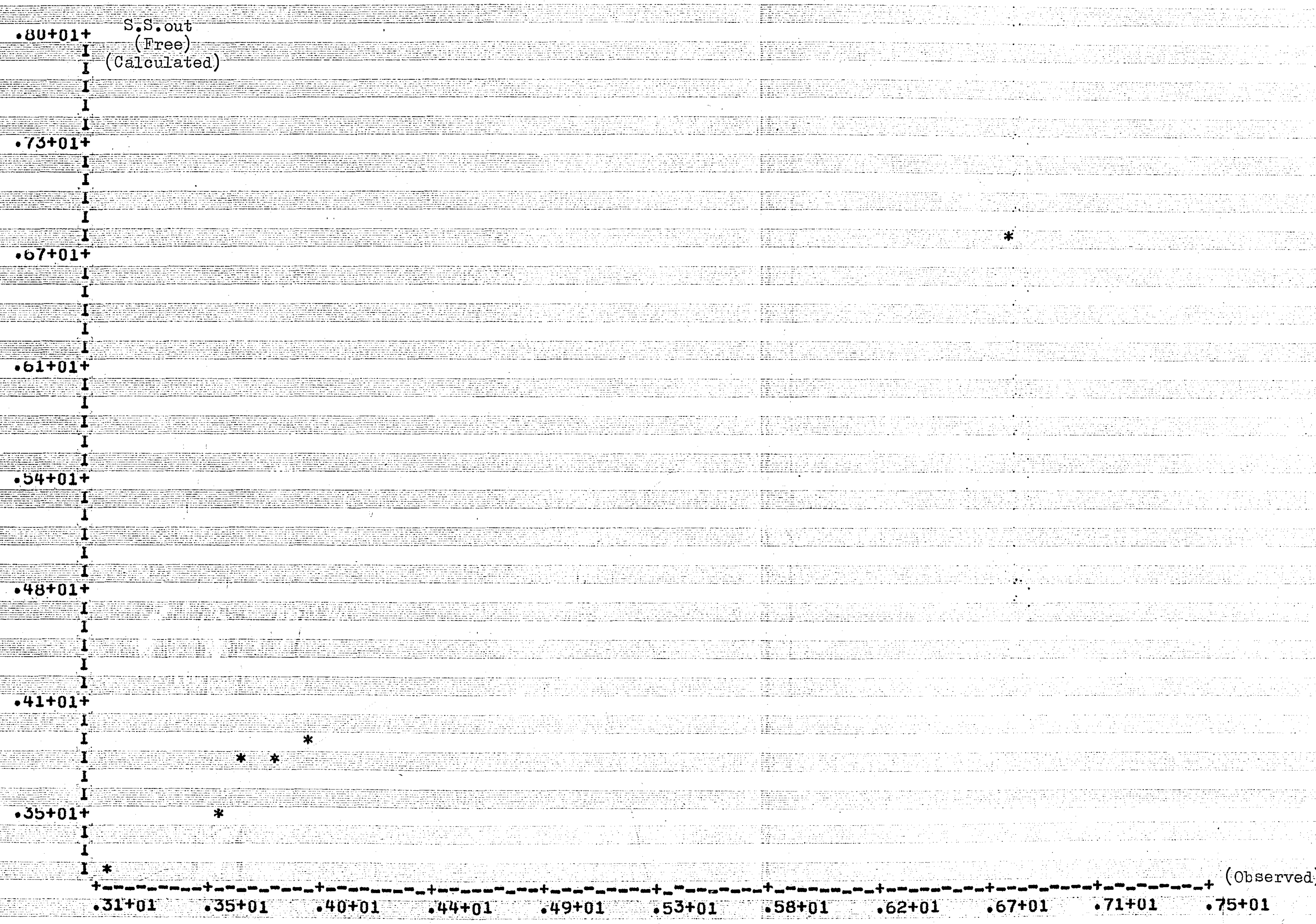
+ Correlation refers to degree of association between one variable and several others, so correlation coefficent is a measure of the amount of relation between these variables. (Volk, 1958)


BOD out
(Free)
(Calculated)
.58+01
.55+01
.53+01
.50+01
.47+01
.45+01
.42+01
.40+01
(Observed)
.40+01
.42+01
.44+01
.46+01
.48+01
.50+01
.52+01
.54+01
.57+01
.59+01
.61+01

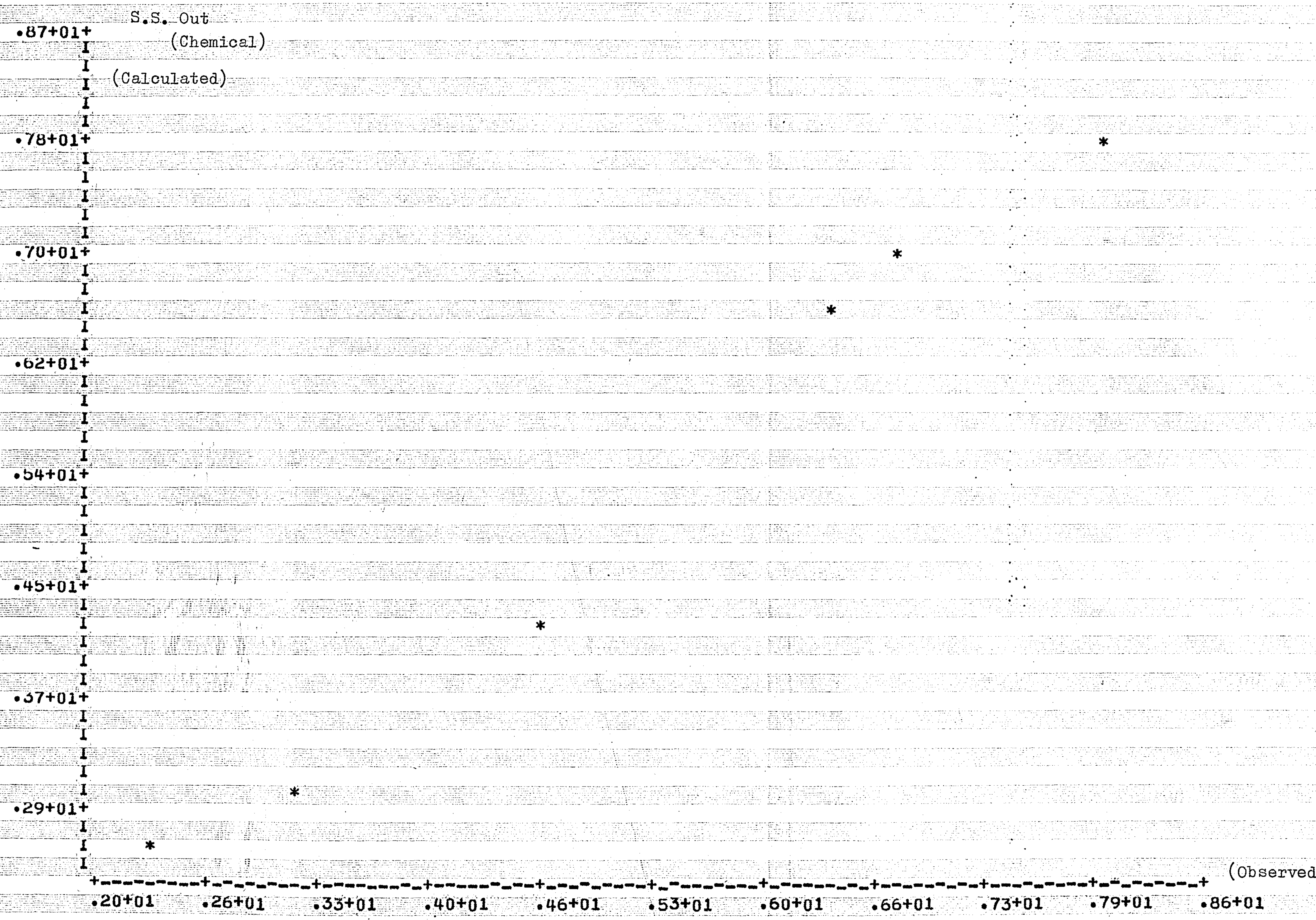
EQUATION I-a


BOD out
(Chemical)
(Calculated)
.56+01
.53+01
.50+01
.47+01
.45+01
.42+01
.39+01
.36+01
.33+01
.36+01
.38+01
.41+01
.44+01
.46+01
.49+01
.51+01
.54+01
.56+01
.59+01
(Observed)

EQUATION I-b


S.S.out
(Free)
(Calculated)
.80+01+
.73+01+
.67+01+
.61+01+
.54+01+
.48+01+
.41+01+
.35+01+
(Observed)
.31+01
.35+01
.40+01
.44+01
.49+01
.53+01
.58+01
.62+01
.67+01
.71+01
.75+01

EQUATION-2-a


S.S. Out
(Chemical)
(Calculated)
.87+01
.78+01
.70+01
.62+01
.54+01
.45+01
.37+01
.29+01
(Observed)
.20+01
.26+01
.33+01
.40+01
.46+01
.53+01
.60+01
.66+01
.73+01
.79+01
.86+01

EQUATION 2-b

5. DISCUSSION

If a comparasion is to be made between the results of the laboratory studies and the field application on the solid removal, a great difference can be noticed. Velioğlu in 1972 conducted a laboratory study on the vortex separator and obtained efficiencies as high as 100% (See table 3). In this field application the efficiency of suspended solid removal was about 30% for untreated sewage and about 36% for treated sewage considering both orifices. (See tables 7 and 8). Lower efficiencies can be attributed to difference in the discharge. In the laboratory study the discharge was much higher than in the field application. The discharge varied from 3.52 lt/sec. to 12 lt/sec, while in the field application it varied from 0.64 lt/sec to 3.85 lt/sec. So, higher velocities in the laboratory prevented settling of the particles at the bottom of the tank. Another reason for the higher efficiencies obtained in the laboratory study may have been due to the fact that the particles used as S.S. were uniform while in the field application different sizes of S.S. were present, and may therefore have affected the settling of the solids. In addition in every laboratory experiment the flow was constant but in the field, the flow varied from minute to minute.

In the field application two types of runs were made, one using untreated sewage and another using sewage treated with coagulants. The coagulants almost doubled the efficiency of solid removal. In untreated samples 20% to 25% of S.S. were removed and for treated samples 30% to 50%

of S.S. were removed. But in the BOD_5 removal a small change was noticed. In untreated sewage an average of 11% of BOD_5 was removed and for treated sewage an average of 10% of BOD_5 was removed. Tables 7 and 8 give the efficiencies for treated and untreated sewage. Comparing the efficiencies with a sedimentation tank a very big difference can be noticed after the addition of coagulants and polyelectrolytes. For untreated sewage, 50% – 65% of S.S. and 25% – 40% of BOD_5 are removed while in treated sewage 85% to 90% of S.S. and 50% to 60% of BOD_5 are removed. The reason is that in the primary sedimentation tank the movement of the flocs is so negligible that there will be no shearing of the flocs while in the vortex separator due to relatively high velocities in the inlet discharge shearing occured.

Also if we compare the solid content of the orifice discharge in the field application with the solid content of the sludge collected from the primary sedimentation tank we see that in the latter it is about 5% while in the orifice discharge it is about 0.01%. So in the case of the primary sedimentation tank the solid particles are taken to be digested directly but in the case of the vortex separator the orifice discharge cannot be taken directly to be digested unless it is treated further.

At the location used the flow was generally very low, except when it rained. The third orifice (5.08 cm) was used only once because all the flow went through the orifice. The orifice which showed best results was the first orifice (1.27 cm) since the second orifice was fairly large (2.54 cm), high percentage of discharge flowed through it. (See Tables 7 and 8).

Difficulties were encountered trying to obtain material balances for the suspended solids, settleable solids, total solids and BOD_5. As an example the solids found in the outlet discharge plus the orifice discharge were lower than the amount of solids found in the inlet discharge when the flow was in the range of 0.64 lt/sec. This was due to the fact that the solids settled at the bottom of the flat tank. The solids found in the outlet discharge were lower than the amount of solids found in the inlet discharge. One experiment was conducted at flow in which the solids on the flat bottom were removed, dried and weighed. When these solids are added to the solids found in the outlet and orifice, the solids balanced.

As for the equations mentioned in the evaluation of experimental data they could be stated as follows:

$$BOD_{out(free)} = Q_{in}^{-0.17} \cdot Q_{orifice}^{0.90} \cdot BOD_{in}^{1.33} \quad \text{........... 1a}$$

$$BOD_{out(chemical)} = e^{-4.45} (BOD_{in})^{1.70} (T.S._{in})^{0.14} \quad \text{......... 1b}$$

$$S.S._{out\ (free)} = e^{3.09} (Q_{in})^{0.44} \cdot (Q_{orifice})^{2.10} \cdot (S.S._{in})^{1.01} \quad \text{.. 2a}$$

$$S.S._{out(chemical)} = e^{-2.20} \cdot (Q_{orifice})^{-1.01} (S.S._{in})^{1.00} \quad \text{..... 2b}$$

Equation 1a is used for untreated discharge. The equation gives reliable results since the variables, namely BOD_{in}, Q_{in}, can

Table 7
First Orifice Efficiencies

	FIRST ORIFICE (1.27 cm.)							
	T.S. Efficiencies and % removal of Discharges from orifice		S.S. Efficiencies and % removal of Discharges from orifice		Settleable Solid Efficiencies and % removal of Discharges from orifice		BOD Efficiencies and % removal of Discharges from orifice	
	Free Runs	Chemical Runs	Free Runs	Chemical Runs	Free Runs	Chemical Runs	Free Runs	Chemical Runs
	13.50 14.26	5.32 29.52	13.50 - **	5.32 46.92	13.50 19.26	5.32 51.28	13.50 24.01	5.32 8.70
	15.15 20.00	34.78 26.47	15.15 -**	34.78 56.67	15.15 31.03	34.78 - (*)	15.15 18.32	34.78 -
	10.13 11.70	26.56 24.90	10.13 - **	26.56 33.33	10.13 46.00	26.56 - (*)	10.13 14.22	26.56 5.80
	13.91 6.31	5.46 27.19	13.91 52.38	5.46 52.64	13.91 73.80	5.46 21.20	13.91 14.77	5.46 43.30
	9.55 -	10.22 1.85	9.55 28.03	10.22 11.67	9.55 60.00	10.22 2.20	9.55 -	10.22 -
	17.31 7.97	13.28 10.35	17.31 28.16	13.28 15.43	17.31 77.94	13.28 51.43	17.31 -	13.28 6.25
	22.58 5.13		22.58 23.08		22.58 20.69		22.58 -	
	17.59 1.26		17.59 23.74		17.59 69.92		17.59 4.56	
	6.28 21.52		6.28 24.38		6.28 33.33		6.28 29.63	
TOTAL	126.00 88.15	95.62 120.28	126.00 179.77	95.62 216.66	126.00 431.97	95.62 126.11	126.00 105.51	95.62 64.05
AVG.	14.00 9.79	15.94 20.05	14.00 29.96	15.94 36.11	14.00 48.00	15.94 31.53	14.00 11.72	15.94 10.68

(First figures : % removal of discharges from orifice.)
(Second figures: Solids or BOD Efficiencies.)

(*) There were not settleable solids in the sample.
(**) In the first few runs no results were obtained. (Explained in 3.2)

Table 8
Second Orifice efficiencies

	SECOND ORIFICE (2.54 cm.)							
	T.S.Efficiencies and % removal of Discharges from orifice		S.S. Efficiencies and % removal of Discharges from orifice		Settleable Solid Efficiencies and % removal of Discharges from orifice		BOD Efficiencies and % removal of Discharges from orifice	
	Free Runs	Chemical Runs	Free Runs	Chemical Runs	Free Runs	Chemical Runs	Free Runs	Chemical Runs
	26.12 3.00	26.71 3.55	26.12 - (*)	26.71 -	26.12 31.47	26.71 10.00	26.12 -	26.71 -
	16.13 6.44	12.19 17.89	16.13 14.58	12.19 29.62	16.13 41.43	12.19 6.00	16.13 -	12.19 -
		15.91 36.05		15.91 40.38		15.91 50.79		15.91 8.33
TOTAL	42.25 9.44	38.90 57.49	42.25 14.58	38.90 70.00	42.25 72.90	38.90 66.79	42.25 -	38.90 8.33
AVG.	21.13 4.72	12.97 19.16	21.13 14.58	12.97 23.33	21.13 36.45	12.97 22.26	21.13 -	12.97 2.78

(First figures : % removal of discharges from orifice.)
(Second figures : Solids or BOD Efficiencies.)

(*) In the first few runs no results were obtained. (Explained in 3.2) be determined easily and $Q_{orifice}$ can only be assumed based on past experience. Equation 1b is used for treated discharge. The result it gives is fairly accurate since BOD_{in} and $T.S._{in}$ could be detrmined easily.

Equation 2a is used for untreated discharge while eq. 2b is used for treated discharge. Also here reliable results could be found since Q_{in} and $S.S._{in}$ could be measured and $Q_{orifice}$ could be assumed.

6. CONCLUSIONS

1. If a comparasion is to be made between the efficiencies of a primary sedimentation tank and the efficiencies obtained for the vortex separator in this field application, the following results are obtained:-

a) In the primary sedimentation time for a detention time of about two hours using untreated sewage, 50% to 65% of suspended solids are removed while in the vortex separator with a detention time of about two seconds 20% to 25% of S.S. were removed.

b) For BOD_5 with the same detention time using also untreated sewage 25% to 40% of BOD_5 is removed in the primary sedimentation tank while in the vortex separator 10% to 20% of BOD_5 was removed.

c) In the case of sewage trated with coagulants and polyelectrolyte, the removal of S.S. from the primary sedimentation tank for a detention time of 2 hours was 85% to 90%. While in the vortex separation using a D-4100 polyelectrolyte and a detention time of about 2 sec. 30% to 50% of S.S. were removed.

d) The BOD_5 removal for a sewage treated with coagulants and polyelectrolyte in a primary sedimentation tank is about 50% to 60%. In the vortex separator using the D-4100 polyelectrolyte 5% to 15% of BOD_5 was removed.

2.

$$BOD_{out(free)} = Q_{in}^{-0.17} \cdot Q_{orifice}^{0.90} \cdot BOD_{in}^{1.33} \ldots\ldots\ 1a$$

$$BOD_{out(chemical)} = e^{-4.45}\ (BOD_{in})^{1.70} (T.S._{in})^{0.14} \ldots\ 1b$$

$$S.S._{out(free)} = e^{3.09}\ (Q_{in})^{0.44} \cdot (Q_{orifice})^{2.10}\ (S.S._{in})^{1.01} \ldots\ 2a$$

$$S.S._{out(chemical)} = e^{-2.20} \cdot (Q_{orifice})^{-1.01}\ (S.S._{in})^{1.00} \ldots\ 2b$$

Equations above were found when using a linear regression computer program to calculate BOD_{out} and $S.S._{out}$ for treated and untreated discharges prior to installation of the device. This will give a rough estimation of what will be the BOD_{out} and the $S.S._{out}$ before setting up the the apparatus. These equations are applicable only when Q_{inlet} is in the limit of 0.64 to 3.85.

3. Based on the above results, a vortex separator unless improved and tested for higher discharges in this field application proved to be inefficient to use for a primary sedimentation tank.

7.RECOMENDATION FOR FUTURE WORK

-The vortex separator should be redesigned to have the bottom sloping towards the orifice in order to try to reduce the settling of solids at the bottom.

-A difficulty was faced while feeding the coagulant into the sewage discharge.Since the flow varies,the concentration of the coagulant must be kept constant with time by trying to control the dosage.

-A settling coloumn should be used to evaluate the removal of suspended solids and BOD to correlate these results with those of the vortex separator.

-The glass fiber disks should be used rather than the glass crucibles for suspended solids.

-In the laboratory study the discharge was much higher than in the field application.It will be better to use larger discharges or to use a still smaller orifice to see the efficiencies whether they are close to laboratory results.

-A study should be made for a number of vortex separators to see whether their efficiencies approximately match the efficency of a primary sedimentation tank.Also some kind of a cost analysis should be done concerning both to see which one is cheaper to use.

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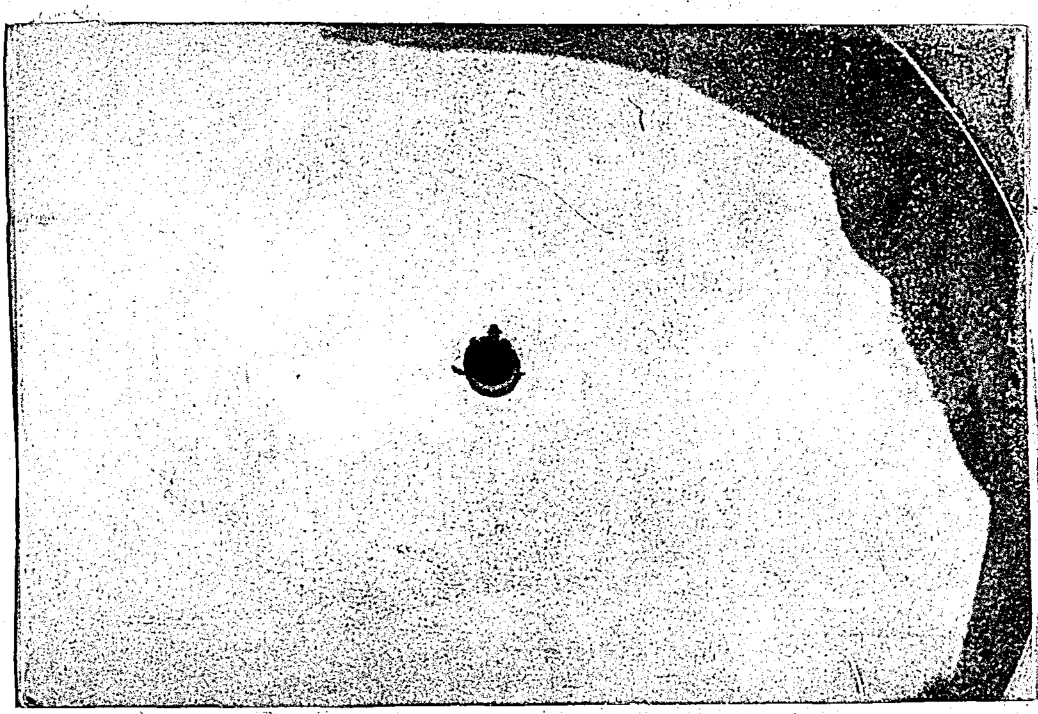
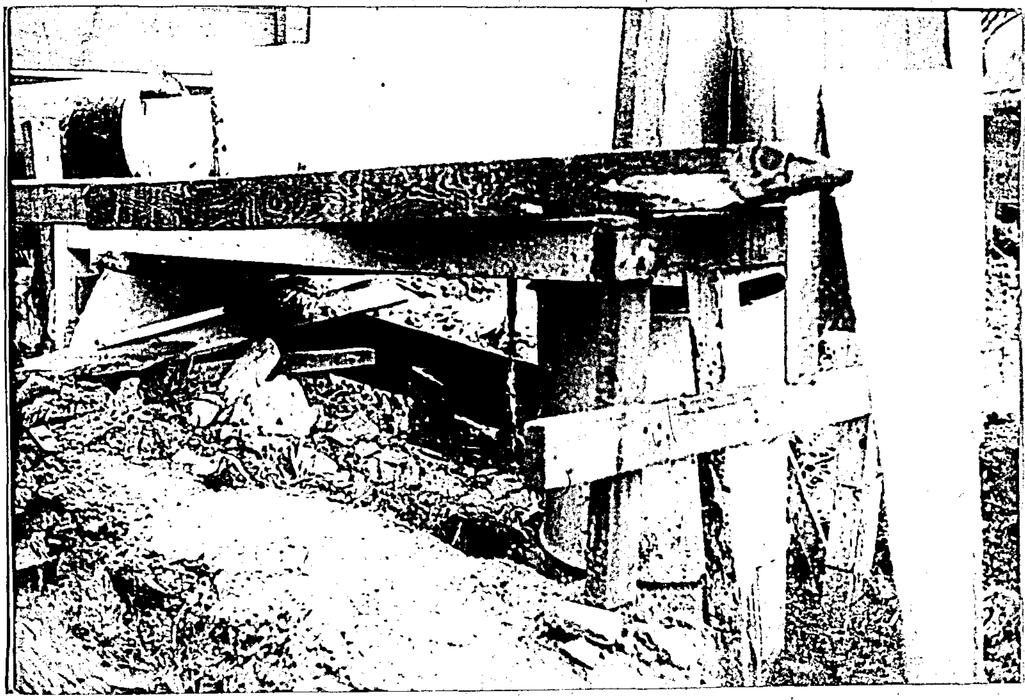
APPENDIX

1_Sewer entrance of the galvanized pipe to the vortex seperator

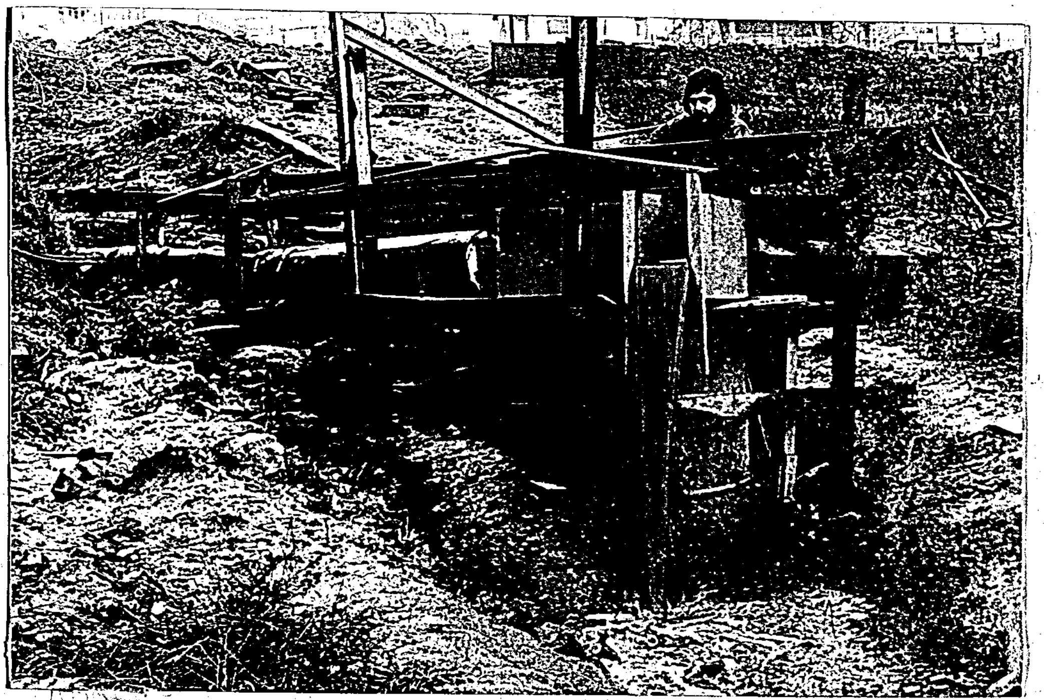
2_Discharge from the outlet channel.



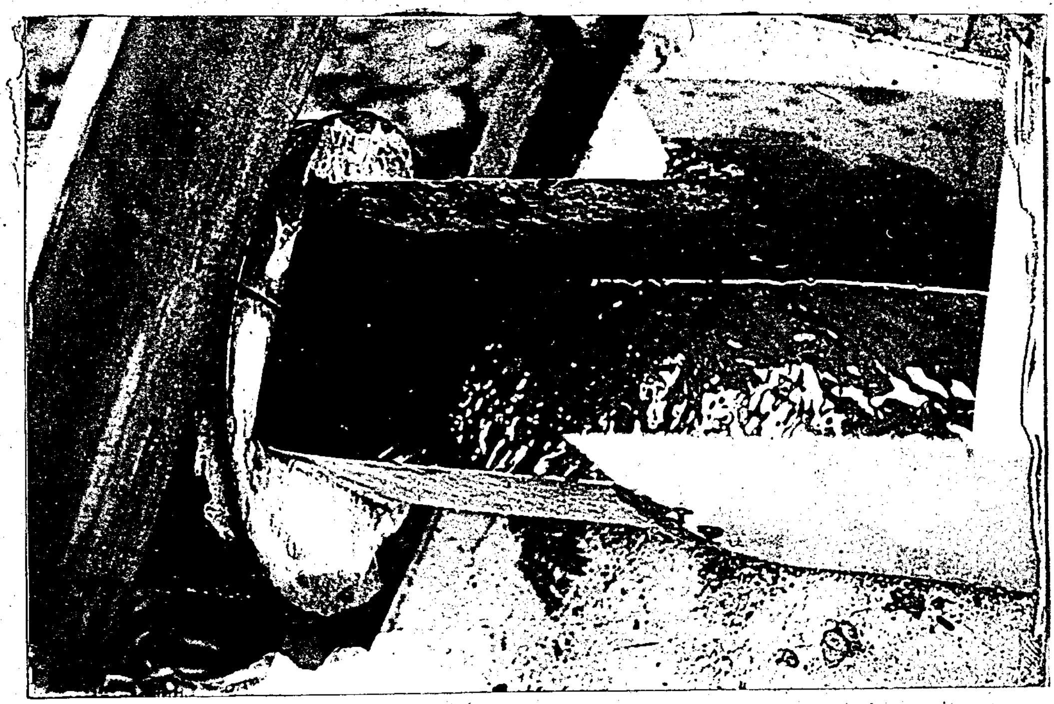
3_ A top view of circular chamber and vortex.



4_ Discharges from orifice and discharge from outlet channel.



5_The incoming galvanized pipe , vortex seperator and discharge from the outlet channel.



6_Transition: From circular to rectangular channel.

7- Blocking the sewer outfall by sand-bags and diverting the sewer into the galvanized pipe.

8 _Diverted sewer into the galvanized pipe.

Table 9

Discharges, BOD_5 and efficiencies

EXP. NO.	CHEMICALS ADDED (mg/l)	DISCHARGES AND BOD_5 (**) INLET	OUTLET	ORIFICE	REMOVAL (***)
1	–	3.II	2.69	0.42	I3.50
		242.40	I84.20	264.00	24.0I
2	–	I.32	I.I2	0.20	I5.I5
		I63.80	I33.80	I5I.80	I8.32
3 *	–	I.34	0.99	0.35	26.I2
		342.00	44I.40	3I8.70	–
4 *	–	2.I7	I.82	0.35	I6.I3
		I50.00	I59.60	I89.60	–
5	–	I.58	I.42	0.I6	I0.I3
		I22.40	I05.00	I35.00	I4.22
6	–	I.I5	0.99	0.I6	I3.9I
		I05.60	90.00	I27.80	I4.77
7	–	I.78	I.6I	0.I7	9.55
		I83.60	I89.60	23I.60	–
8	–	I.04	0.86	0.I8	I7.3I
		99.00	I02.00	96.00	–
9		0.93	0.72	0.2I	22.58
		I32.00	I64.00	I32.00	–
10	–	I.08	0.89	0.I9	I7.59
		94.30	90.00	I32.00	4.56
11	–	2.55	2.39	0.I6	6.28
		8I.00	57.00	II4.00	29.63
12	Alum-I20	3.0I	2.85	0.I6	5.32
	Poly-8.3	I38.00	I26.00	I44.00	8.70
13	Alum-I50	0.69	0.45	0.23	34.78
	Poly-I0	I62.00	I65.00	I92.00	–
14	Alum-I65	0.64	0.47	0.I7	26.56
	Poly-I2	I38.00	I32.00	I32.00	5.80
15	FeCl-25	3.85	3.64	0.2I	5.46
	Poly-5	58.20	33.00	94.20	43.30
16	Alum-70	I.86	I.67	0.I9	I0.22
	Poly-5	I50.00	I59.00	I50.00	–
17 *	Alum-70	I.6I	I.I8	0.43	26.7I
	Poly-5	84.00	84.00	93.00	–
18 *	Alum-I00	2.79	2.45	0.34	I2.I9
	Poly-I0	I26.00	I26.00	I32.00	–
19 *	Alum-I00	2.20	I.85	0.35	I5.9I
	Poly-I0	I44.00	I32.00	I74.00	8.33
20	Alum-I00	I.28	I.II	0.I8	I3.28
	Poly-I0	96.00	90.00	I92.00	6.25

(*) Experiments with the second orifice. (**) First figures: Discharges (lps), Second figures: BOD_5 (mg/l) (***) $\frac{\text{inlet} - \text{outlet}}{\text{inlet}} \times 100 = \text{removal}$

Table 10
Discharges, Settleable Solids and efficiencies

EXP. NO.	CHEMICALS ADDED(mg/l)	DISCHARGES AND SETTLEABLE SOLIDS (**)			
		INLET	OUTLET	ORIFICE	REMOVAL (***)
1	-	3.II	2.69	0.42	I3.50
		8.67	7.00	I6.67	I9.26
2	-	I.32	I.I2	0.20	I5.I5
		0.87	0.60	2.32	3I.03
3 *	-	I.34	0.99	0.35	26.I2
		I.97	I.35	I.97	3I.47
4 *	-	2.I7	I.82	0.35	I6.I3
		6.83	4.00	II.I6	4I.43
5	-	I.58	I.42	0.I6	I0.I3
		0.87	0.47	4.I7	46.00
6	-	I.I5	0.99	0.I6	I3.9I
		I.53	0.40	6.75	73.80
7	-	I.78	I.6I	0.I7	9.55
		4.50	I.80	II.00	60.00
8	-	I.04	0.86	0.I8	I7.3I
		0.68	0.I5	I.70	77.94
9	-	0.93	0.72	0.2I	22.58
		I.45	I.I5	3.83	20.69
10	-	I.08	0.89	0.I9	I7.59
		I.23	0.37	9.50	69.92
11	-	2.55	2.39	0.I6	6.28
		3.00	2.00	6.00	33.33
12	Alum-I20	3.0I	2.85	0.I6	5.32
	Poly-8.3	7.80	3.80	II.70	5I.28
13	Alum-I50	0.69	0.45	0.23	34.78
	Poly-I0	0.00	0.00	0.00	-
14	Alum-I65	0.64	0.47	0.I7	26.56
	Poly-I2	0.00	0.00	0.00	-
15	FeCl-25	3.85	3.64	0.2I	5.46
	Poly-5	I6.50	I3.00	34.00	2I.20
16	Alum-70	I.86	I.67	0.I9	I0.22
	Poly-5	2.73	2.67	4.67	2.20
17 *	Alum-70	I.6I	I.I8	0.43	26.7I
	Poly-5	I.00	0.90	I.50	I0.00
18 *	Alum-I00	2.79	2.45	0.34	I2.I9
	Poly-I0	25.00	23.50	38.I0	6.00
19 *	Alum-I00	2.20	I.85	0.35	I5.9I
	Poly-I0	3I.50	I5.50	65.00	50.79
20	Alum-I00	I.28	I.II	0.I8	I3.28
	Poly-I0	70.00	34.00	83.00	5I.43

(*) Experiments with the second orifice (**)First figures: Discharges (lps)
Second figures: Sett.S.(ml/l) (***) $\frac{\text{Inlet - Outlet}}{\text{Inlet}}$ x 100 = Removal

Table 11
Discharges, Total slids and efficiencies

EXP. NO.	CHEMICALS ADDED (mg/l)	DISCHARGES AND TOTAL SOLIDS (**)			REMOVAL (***)
		INLET	OUTLET	ORIFICE	
1	-	3.11	2.69	0.42	13.50
		933.00	800.00	1012.00	14.26
2	-	1.32	1.12	0.20	15.15
		950.00	760.00	825.00	20.00
3 *	-	1.34	0.99	0.35	26.12
		1000.00	970.00	975.00	3.00
4 *	-	2.17	1.82	0.35	16.13
		885.00	828.00	964.00	6.44
5	-	1.58	1.42	0.16	10.13
		823.00	726.00	901.00	11.70
6	-	1.15	0.99	0.16	13.91
		597.00	559.00	549.00	6.31
7	-	1.78	1.61	0.17	9.55
		815.00	821.00	1032.00	-
8	-	1.04	0.86	0.18	17.31
		747.00	688.00	783.00	7.97
9	-	0.93	0.72	0.21	22.58
		649.00	616.00	693.00	5.13
10	-	1.08	0.89	0.19	17.59
		580.00	573.00	652.00	1.26
11	-	2.55	2.39	0.16	6.28
		2305.00	1809.00	1949.00	21.52
12	Alum-120	3.01	2.85	0.16	5.32
	Poly-8.3	1599.00	1127.00	1976.00	29.52
13	Alum-150	0.69	0.45	0.23	34.78
	Poly-10	952.00	700.00	926.00	26.47
14	Alum-165	0.64	0.47	0.17	26.56
	Poly-12	903.00	678.00	880.00	24.90
15	FeCl-25	3.85	3.64	0.21	5.46
	Poly-5	2207.00	1607.00	3786.00	27.19
16	Alum-70	1.86	1.67	0.19	10.22
	Poly-5	912.00	895.00	1048.00	1.85
17 *	Alum-70	1.61	1.18	0.43	26.71
	Poly-5	760.00	723.00	784.00	3.55
18 *	Alum-100	2.79	2.45	0.34	12.19
	Poly-10	3080.00	2529.00	4532.00	17.89
19 *	Alum-100	2.20	1.85	0.35	15.91
	Poly-10	3293.00	2106.00	7000.00	36.05
20	Alum-100	1.28	1.11	0.18	13.28
	Poly-10	4048.00	3629.00	12068.00	10.35

(*) Experiments with the second orifice (**) First figures: Discharges (lps)
Second figures : T.S. (mg/l) (***) $\frac{\text{Inlet} - \text{Outlet}}{\text{Inlet}} \times 100 = \text{Removal}$

Table 12
Discharges, suspended solids and efficiencies

EXP. NO.	CHEMICALS ADDED (mg/1	DISCHARGES AND SUSPENDED SOLIDS (**)			
		INLET	OUTLET	ORIFICE	REMOVAL (***)
1	-	3.II	2.69	0.42	I3.50
		-	-	-	-
2	-	I.32	I.I2	0.20	I5.I5
		-	-	-	-
3 *	-	I.34	0.99	0.35	26.I2
		-	-	-	-
4 *	-	2.I7	I.82	0.35	I6.I3
		336.00	287.00	378.00	I4.58
5	-	I.58	I.42	0.I6	I0.I3
		94.00	240.00	32I.00	-
6	-	I.I5	0.99	0.I6	I3.9I
		48.30	23.00	57.50	52.38
7	-	I.78	I.6I	0.I7	9.55
		6I.83	44.50	III.67	28.03
8	-	I.04	0.86	0.I8	I7.3I
		5I.50	37.00	59.50	28.I6
9	-	0.93	0.72	0.2I	22.58
		52.00	40.00	I30.00	23.08
10	-	I.08	0.89	0.I9	I7.59
		69.50	53.00	I05.50	23.74
11	-	2.55	2.39	0.I6	6.28
		II24.00	850.00	I37I.00	24.38
12	Alum-I20	3.0I	2.85	0.I6	5.32
	Poly-8.3	I089.00	578.00	94I.00	46.92
13	Alum-I50	0.69	0.45	0.23	34.78
	Poly-I0	24.00	I0.40	38.50	56.67
14	Alum-I65	0.64	0.47	0.I7	26.56
	Poly-I2	36.00	24.00	58.00	33.33
15	FeCl-25	3.85	3.64	0.2I	5.46
	Poly-5	I763.00	835.00	3249.00	52.64
16	Alum-70	I.86	I.67	0.I9	I0.22
	Poly-5	I20.00	I06.50	370.00	II.67
17 *	Alum-70	I.6I	I.I8	0.43	26.7I
	Poly-5	90.50	II6.00	I20.00	-
18 *	Alum-I00	2.79	2.45	0.34	I2.I9
	Poly-I0	2296.00	I576.00	3448.00	29.62
19 *	Alum-I00	2.20	I.85	0.35	I5.9I
	Poly-I0	2I20.00	I264.00	2772.00	40.38
20	Alum-I00	I.28	I.II	0.I8	I3.28
	Poly-I0	3656.00	3092.00	I0660.00	I5.43

(*) Experiments with the second orifice. (**) First figures: Discharges(lps)
Second figures : S.S (mg/l) (***) $\frac{\text{Inlet} - \text{Outlet}}{\text{Inlet}} \times 100$ = Removal