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Design of a water treatment Mechanical Mixer for a pre-chlorination tank as an effective algae control, aeration and coagulation processing.

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ABSTRACT : *In any water treatment plant particularly in the rural communities, the provision of potable water supply system is a difficult task due to unavailability of sustainable power supply system. A mechanically operated mixer for pre-chlorination tank is a major pre-requisite in such a system. The design of a mechanically operated mixer has been successfully carried out leading to an efficient control of algae, aeration and coagulation process which is capable of storing potable water for a period of 3.7 hour for small rural community in Borno State, Nigeria in the event of failure of the pumping system.*

KEY WORDS: *Mixer, Pre-chlorination, algae, aeration, coagulation*

I. INTRODUCTION

A treatment plant consists of many processes, which can generally be subdivided into pre-treatment, and treatment. Some of these include screening, coagulation, flocculation, filtration etc. The impurities are removed in order of size, the bigger ones being eliminated first. Since, not every water requires all the treatment process (Smsrthurst G.:1979). The impurities are mainly removed by the following process: Floating objects by screening; Algae (if possible) by straining; Excessive iron, Manganese and hardness in solution by precipitation in basins after the addition of chemicals; This can generally be outlined as; screening; raw-water storage; pre-chlorination; aeration; algae control; straining; preliminary setting; mixing; coagulations; flocculation; settlement, filtration and sterilization. our interest here is to come up with an optimum design for a mechanical control mixer for effective algae control, aeration and coagulation process

II. PRE-CHLORINATION

Pre-chlorination refers to the practice of injecting chlorine into the raw water soon after it is obstructed from the river. This is usually omitted on water of reasonable quality (low bacteria count). Usually 2-5mg/1 are commonly used. This oxidizes and precipitates such as irons and manganese and kills algae and bacteria.A drawback to using pre-chlorination is that raw water has a high chlorine demand and much greater quantities of chlorine are observed than in later chlorination to affect the same degree of sterilization. It should be regarded as a substitute for post chlorination however; it is essentially an additional safeguard to be adopted only when extremely polluted (but clear) raw water has to be used. (Smsrthurst G.:1979)

AERATION : This treatment process provides oxygen from the atmosphere to effect beneficial changes in the raw water. At the same time it may liberate undesirable gases such as carbon dioxide, hydrogen sulphide. The principle behind this is mixing the raw water with normal air from the atmosphere to replenish or add to the raw water quality. This trend generally improves the water taste, odor, and color and may also affect the killing of some pathogens. This is usually done by splashing the water over trays to break up the stream into countless droplets or by reversing the effect and blowing air bubbles through the water.Gases are absorbed or liberated from, water until equilibrium is reached between the natural content of each gas in there and its content in the water. (Smsrthurst G.:1979) Aerators are commonly found to be necessary if any of the following conditions are present in the raw water.

a. Hydrogen sulphide (tests, odor etc.);
b. Carbon dioxide (corrosive tendencies);
c. Test due to algal growth (caused by volatile oils release);
d. Iron and Manganese in solution;
e. De-aeration
f. Above increase oxygen content, while (a) – (b) liberate excess gas (Smsrthurst G.:1979).

Mechanical Aerators: There are many kinds of mechanical aerators, but the most commonly used, are those which employ the use of submerged paddles that circulate water in aerator chamber and renew its air water interface. Surface paddles or brushes that dip lightly into aeration chambers, but far enough to circulate their water release air bubbles and throw spray of droplets onto their water surfaces. Propeller blades that whirl at the bottom of a central down draft tube in an aeration chamber and aspirate air into the water.

ALGAE CONTROL : Algae are minute organisms which are usually classified as plants and proliferate in Rivers and reservoirs. This occurs, whenever water is exposed to air and sunshine, the algae will gain entry and develop profusely unless inhibited, which can be costly. They cause deterioration in the quality of the water, increase the organic matter and are productive of color, odor and taste. They cause increased difficulty in purification, rapid clogging of sand filters, deficient filtration, additional expense in frequent cleaning of filters, added difficulty of chlorination, and may also produce blockage of pipes, channels and meters. Conditions favorable to luxuriant growth of algae occur in uncovered storage reservoirs and on open sand filters, aided by impurities in water such as bacteria and organic matter. The problem could be reduced by covering reservoirs. Alum treatment by liberating free carbon dioxide in the water is favorable to algae, but lime treatment prevents it. Covering prevents pollution by birds and animals and helps to avoid marked variations in temperature. Temperature changes bring water at the bottom deficient in oxygen and loaded with organic matter to the top and by the stimulus of light and sun profuse it algae development occurs. Avoidance of stagnation is an important preventive measures being affected by speedy delivery to the consumer. This can also be achieved by provision of large storage tanks after treatment (James G. V, 1971)

The use of upward-flow tanks also helps in the control of algae and this is achieved by the incorporation of the sludge blanket principle which is done by having the water to flow upwards in the tank while a sort of sludge blanket in the form of a sack or• other porous material to be at the top thereby preventing the algae from floating on the surface of the water. The blanket thus acting as a form of rapid filter.The algae can also be controlled by applying small doses (about 1mg/1) of chlorine. Also, the use of small concentrations of copper sulphate (about 0.3mg/1) helps in inhibiting the growth of algae. It is usual to scatter this chemical on the surface of the water, particularly in shallow places, at a dressing of 5kg/ha, but this is not too easy to practice. (Smsrthurst G.:1979)

III. COAGULATION

Coagulation can be said to be the addition of chemical substances to water in order to aid settlement of the dissolved particles, by forming large floes. (Gelatinous precipitates). There are many substances which react suitably with water to produce such an effect and these are known collectively as coagulants, examples of these are $A1_2\ (SO_4)_3$. 18 H_2O known as alum (Aluminum sulphate), ferrous sulphate or Fe SO_4. 7H_2O sodium Aluminates etc. (Smsrthurst G.:1979). Use of additional chemicals, which while not themselves true coagulants, intensify and improve floe formation otherwise called coagulant aids.Coagulants should be added immediately downstream of any re-setting basin which may have been considered necessary. Their primary purpose is to assist in the removal of the more finely divided sediment and colloids. Most of the larger and heavier particles settle unaided in the pre-settling basin thus permitting the coagulants to work more efficiently on the finer particles (Smsrthurst G.:1979).Where floe formation is poor, or for reasons of overall economy, coagulant aids may be added. By producing a heavier faster-setting floe, this allows small basins to be used, and smaller doses of the main coagulants may also be possible.

This choice of the best coagulant for any particular water is determined by experiment (Smsrthurst G.1979).Immediately coagulants are introduced into the water, rapid mixing is essential. Floe starts to form and if immediately after this, the water is stirred very gently the fine particle adhere to each other and grow into settle able floe. This gentle stirring action occurs to some degree naturally in all basins but can be greatly accentuated by methods designed to encourage the rolling action required. (Smsrthurst G.:1979)Certain designs of basins are multi-chambered and therefore flocculation does not in fact proceed more separately than might appear to be the case at first glance. The pH of water is very vital in coagulation because, it indicates the right type of coagulation and dosage required to form the heaviest flock at the water characteristic pH value, which can also be determined using the jar test. Acid waters i.e. those having a pH of 5-6.5 are often difficult to clarify, due to the high dosage of coagulants and alkalis is required. Waters of pH between 6.2 - 7 with a reasonable degree of alkalinity react well with aluminum sulphate. Alkaline, use of 7 - 7.8 may again be difficult and absorb high doses of alum. (Smsrthurst G.:1979)

MIXING : A combination of mixing and stirring or agitation that produces aggregation is called flocculation: Mixing is specific blending, mingling, or commingling of coagulating chemicals with water in order' to create a more or less homogeneous single or multiple phase systems. The sources of power for mixing devices are gravitational, pneumatic or mechanical. Generally speaking, mechanical and pneumatic devices are relatively flexible in power input; gravitational devices are relatively inflexible and are seldom used in large plants, even though they may possess quite useful (M. Fair, et-al, 1968). If coagulants are fed into an inlet pipe or chemical, some mixing is bound to take place due to turbulence. When the dosed water carrying floc finally passes into the flocculators through the inlet ports, a certain rolling motion are inevitable, which can be accentuated by baffles in a horizontal flow basin or in an upward flow basin by the sludge blanket (Smsrthurst G.:1979). There are therefore many existing basins working quite well without special mixing or flocculation chambers because the movement of the incoming water provides naturally for a certain amount of action to take place (Smsrthurst G.:1979).

FLOCCULATION : The use of gentle stirring of water, which flock has formed to induce the particles to coalesce and grow is known as flocculation. The bigger and denser the floc particles, the quicker are the rate of settlement. However, in many basins there is ample evidence that better results can be obtained if mixing and flocculation can be intensified. In recent years much research has been done on both and sound theoretical rules have been laid down. There are methods of theoretical approach, the mixing and flocculation can be carried out either by mechanical means in specially built chambers or in suitable baffled channel or interconnected chambers. The latter methods requires no mechanical equipment but lacks flexibility, because the system can be designed for maximum efficiency only at one rate of flow and at one temperature, where-as the speed of mechanical paddles can be adjusted to suit the variations of flow, temperature and silt conditions. However, the cost added to the complexity of mechanical equipment introduces additional complications to be avoided in a developing country, and in practice a sinuous inlet channel preceded by violent mixing generally provides a reasonable effective solution (Smsrthurst G.:1979)..

If the pipe or channel through WHICH the incoming water enters the basin is so dimensioned as to ensure a velocity > 1m/s ,and if the channel is directed at an end wall so that the flow is forced to reverse abruptly through 180^o, any coagulant introduced into the water before that sudden reversal will be adequately mixed and floc will form almost instantaneously. Unlike the absolute necessity for thorough mixing, the need for flocculation as a separate process may or may not be essential, much depends on the nature of the suspended solids, for rivers carrying a coarse and heavy sediment the main problem is to prevent the silt settling and blocking the inlet channels before it reaches the basin (Smsrthurst G.:1979). Shallow depth settling may present operational difficulties in developing countries, so separate flocculators are mostly found before conventional horizontal flow basins where colloids are a problem and the complication of additional machinery may be avoided by having the flocculating action imparted to the water by the gently rolling motion resulting from passing water along a sinuous channel. In practice a channel providing a velocity of flow of about 0.3m/s with cross-walls ensuring 12-20 changes of direction though 180^o (with well rounded corners), has often proved to be very effective. The emphasis must be placed on the comparative smoothness of flow required. Under no circumstances should velocity or turbulence be such as to break up the floc.

SINOUS FLOW CHANNEL : The nominal loss of head in such a channel is 0.5 - 1.5m (Smsrthurst G.:1979). Where flocculating chamber are provided with paddles to induce the rolling motion, typical basins show a 20-45 minutes nominal retention capacity. As a matter of structural convenience, the basins are generally built with the same width and depth as the setting basin they precede. This gives them the appearance of being preliminary chambers of the main basins. The paddles may revolve on vertical or horizontal shafts, or oscillate. In some designs, the peddles may revolve in the direction contrary to the one upstream to induce a rolling motion (Smsrthurst G.:1979)..

The total area of the paddles is about 20% of the cross-sectional area of the chamber and their maximum tip speed should not exceed 0.6m/s and the variable downwards to as little is 0.15m/s. the total horsepower of the driving motors is generally about 0.1hp for $1000m^3$/day, but if the paddles are of oscillating type the motors have to be a little bigger to overcome stalling point as the paddles reverse (Smsrthurst G.:1979)..

THEORETICAL APPROACH : The stirring of water creates difference of velocity and therefore velocity gradients. The average temporal mean velocity gradient in a shearing fluid is denoted by G. For mechanical agitation, the velocity gradient relation G is given by :-

$$G = \left(\frac{P}{\mu V}\right)^{1/2} \text{……………………..} \quad (1.0)$$

Where,

P is the power consumption, Watts (w)

v is the volume of fluid, m^3

The total number of particle oscillations is proportional to GT where T is the detention time, and is greater when there is a degree of turbulence as opposed to general rotation. It has been observed that in many of the more successful mixing and flocculating basins which are mechanically stirred the GT values are as shown in table 1.0 below.

TABLE 1.0 RECOMMENDED GT VALUES FOR FLOCCULATION (Smsrthurst G.:1979).

Type	Velocity Gradient G,s^{-1}	GT
Turbidity or color removal without solids recirculation	20-100	20,000-150,000
Turbidity or color removal (with solids recirculation)	75-75	25,000-200,000
Softeners (solid contact reactors)	30-200	200,000-250,000
Softener (ultra-high solid)	250-300	300,000-400,000

Increase in contact time above 120 s achieves little, and excessive G values can be harmful (Smsrthurst G.:1979).

For baffled basins with mechanical mixing design of a powered paddle operated flocculation basin the following formula may be used.

$P=1/2\ C_D e\ AV^3$ .... (2.0)

Where,

P is the power, watts

C_D is the coefficient of drag of the paddle

e is the mass of water per unit volume (1.00 x 10^3 kg/m^3 at 10°C, 0.998 x 10^3 kg/m^3 at 20°C).

A is the area of the paddle, m^2

v is the relative velocity between paddle and water, m/s

DESIGN STAGE: The cone shaped vortex mixer serves the purpose of mixing the water from the storage tank with the coagulant in the coagulant container. This is the coagulant mixing stage, and uses Alum as the coagulant ($A1_2$ (So_4) .18 H_20).The flocculation stage is achieved by the use of the baffled channel flocculators .

MIXER DESIGN : The cone shaped vortex mixer, performs the function of mixing the raw water with the coagulant, in a manner which makes floc formation easily obtainable. The fluid in the cone-shaped vortex mixer, behaves as a free spiral vortex.

The necessary equations relating to the vortex are, those relating velocity and radius. The fundamental equations are;

vr=constant ....………………...……(3)

p = eg (A $-Br^2$} ……………..……......(4)

Where A and B are arbitrary constants.

thus, from equation 4

$\frac{P}{eg}$= A-Br^2

but, at the free surface, p/eg = 0.

Hence, 0 = A-Br^2

Or A =Br^2

Also, V $=\sqrt{ve^2+vr^2}$ ……………………….. (5)

Where V = Resultant velocity

V_θ = Tangential velocity component = A/r,

And Vr = Radial velocity component = B/r

Hence, V $=\frac{1}{r}\sqrt{A^2+B^2}$…………………....................…(6)

And tan $\propto=\frac{V\theta}{Vr}=\frac{A}{B}$ =constant ………………...………… (7)

Hence, the inlet velocity v_1 at entry = l.0m/s and the outlet velocity v_2, at exit = 0.36 m/s (for proper floc formation).

Thus, the discharge from the vortex mixer is equal to the sum of the discharges from the storage tank and coagulant container.
i.e. Q storage tank + Q coagulant tank = Q out of vortex
mixer.
or
$Q_s + Q_t = Q_v$... .(8)
From the graph of solution flow rate V_s Raw water system flow rate (Appendix 1.0), the solution flow rate for 10% Alum (a) 60 ppm, usually used for gravity dosers was found to be $0.0018x10^{-3}$ m^3/s

For most mixers, the entry velocity should not be more than 1m/s, to facilitates proper mixing of the coagulant and water.

Thus, from the continuity equation,

$Q = a^1v^1 = a_2v_2$ = constant …………… (9)

i.e. Q_t = $\underline{0.0018 \times 10^{-3}} m^3/s$
Hence, from equation (8) $Q_v = 0.003 + 0.0018 \times 10^{-3}$
$Q_v = 0.003002 m^3/s$
It can be seen that, the discharge from the coagulant is very small compared to the raw water discharge.
Hence, at the outlet, from the continuity equation (9)
Q = aV
∴ a = Q/v
Or $= \frac{\pi d^2}{4} = Q/v$
∴ $d = \sqrt{\frac{4Q}{\pi v}}$
$d = \sqrt{\frac{4x\ 0.003002}{\pi \times 0.36}} = 0.013m$
Hence, the diameter of pipe at outlet should be 100mm, to be joined to a standard 100mm diameter pipe.
From equations (6) and (7) i.e.
$v = \frac{1}{r}\sqrt{A^2 + B^2}\ \propto\ = \frac{A}{B}$ constant
For most design purposes the angle ∝ is between 2^o and 8^o thus, assuming ∝ to be 2.5^o.
We have,
$\tan\propto = \tan 2.5^o = \frac{A}{B}$ = constant
but, from equation (4) $A = Br^2$
hence
$\tan 2.5^o = \frac{A}{B} = \frac{Br^2}{B} = r^2$
thus, $r = \sqrt{\tan 2.5^o} = 0.209m$
This gives a diameter d = 2r= 2 x 0.209 = 0.418m
Hence standard value .of 400mm will be used.
Thus, from equation (6)
$v = \frac{1}{r}\sqrt{A^2 + B^2}$
on substituting we have
$1 = \frac{1}{0.209}\sqrt{A^2 + B^2}$
$= B\sqrt{B^2r^4 + B^2}$ where $A = Br^2$
$= B\sqrt{(0.209)^4 + 1} = \frac{0.209}{1.001} = 0.209,$
and
$A = 0.209x\ (0.209)^2 = 0.009$
Thus, A = 0.009 and B = 0.209, which are constants of the equation (6)
An appropriate value for the height of the vortex mixer is chosen to be 0.8m. A cylindrical top of 0.15m (150mm) is made to facilitate easy fixing of the mixer cover, which also acts as a support for the coagulant tank and inlet pipe entry.

The volume of the mixer is thus,

volume of mixer = volume of frustums + volume of cylindrical top
Or
$V = 1/3 \pi H (R^2 + Rr + r^2) + \pi R^2 h$ ....(10)
$V = 1/3 \pi_x 0.65 (0.2^2 + (0.2)(0.05) + Q.05-^2) + \pi \times 0 \times 0.2^2 \times 0.15 = 0.0545 m^3$
i.e. the volume of the mixer = $0.055m^3$ ($5.5 \times 10^7 mm^3$)
Material Selection For Mixer And Its Accessories : The material to be used for the mixer is mild steel (0.03-0.50% carbon). And the mixer should be painted white to prevent rusting of the mixer and to reflect ultra violet light so that the temperature of the water does not increase appreciably. A 45 elbow of 100m diameter should be fitted to the smaller end of the mixer and welded at suitable points around it's circumference. Four pieces of mild steel slabs 60mm high should be weld to the cover as shown in the drawing appendix 2.0. Two vent holes diameter 20mm and a central delivery hole 10mm diameter are drilled on the cover. The inlet pipe should be tacked along its circumference, to the inlet of the mixer. See drawing for necessary details.

COAGULATION TANK DESIGN : From the volume flow rates equation, which gives the volume of fluid discharged over a given time, -

$$Q = \frac{\text{volume discharged}}{\text{time}}$$

$Q = \frac{V}{T} (m^3/s)$ …………………. (11)

Thus, volume v = QT.

The retention time T is taken to be 5hrs and it is flow rate of coagulant which was previously determine in equation (8), the volume of the tank is thus,
$V = 0.0018 \times 10-^3 \times 3600 \times 5 = 0.0324m^3 = 3.24 \times I0^7 mm^3$
Also assuming the tank to be cylindrical, with a diameter of
300mm,
V = cross-sectional area x height
Or $V = \frac{\pi^2}{4} \times h$.................................... (12)
Thus , $h = \frac{4v}{\pi d^2}$
$\frac{4v}{\pi d^2} = \underline{0.458m}$
h = 458mm. Hence a height of 500mm, will be a good value for ease of construction.
Also the discharge of the coagulant is assumed to pass through an orifice, in the bottom of the tank. Thus, the relationship between the orifice size and discharge is given as;
$Q = C_d a \sqrt{2gH}$ .... (13)
Where C_d = coefficient of discharge through the orifice ($C_d < 1$).
Q, a, g, and H are as earlier defined, hence assuming a coefficient of discharge of 0.5.

$Q = 0.5 a\sqrt{2 \times 9.81 \times 0.5}$
Or $0.0018 \times 10^{-3} = 0.5 \times a \times\sqrt{9.81}$
Thus, $= \frac{\pi d^2}{4} = \frac{0.0018 \times 10^{-2}}{0.5 \times \sqrt{9.81}}$
d = 0.0012m
d = 1.2mrn
Hence, a standard size of 1.5mm was chosen, since drilling this small hole in a tank of 300mm diameter will not be practically suitable, due to settlement of silt and debris etc, which may tend to block the hole. A larger size of hole 12mm diameter is better, the bottom of the tank is connected with the same size of pipe, which is later jointed with a flexible rubber tube of 2.0mm diameter with a clip to hold fast to it. A small gate valve is attached to the 12mm pipe. A handle was provided for easy removal of the coagulation tank which was then welded to the mixer cover to form a single unit.

Material Selection : Material to be used are the same with that of the vortex mixer, and also the painting should be the same. The flexible tubing to be used should be transparent, and made of polyethylene plastic tube 2mm diameter in size.

STORAGE TANK SELECTION AND SPECIFICATIONS : A standard $40m^3$ (8,800 gallons) tank is selected for this purpose, which is a 5m x 4m x 2m, tank. Thus for the calculated discharge of $0.003m^3/s$ (57,024 gallons per day) which is the daily water demand. The storage life of the tank neglecting any incoming water is;

Storage life = $\frac{\text{Volume}}{\text{discharge per day}}$ x 24

= $\frac{8,800}{57,024}$ x 24

= 3.7hrs

Thus if the pump is shut, there would be a 3.7hr supply of water from the storage tank. This will suffice for a small rural community. An overflow pipe should be fitted on the 2 x 4m side, which is a 20mm diameter galvanized steel pipe, 150mm long. Petitioners should be provided to stabilize flow, and improve the strength of the tank at the same time reducing bulging effects.

IV. CONCLUSION.

The mixer used for this design was adopted to ease the cost of constructing a separate mixing chamber sophisticated mechanical or flash mixer used in high tech water treatment processes which require a great deal of power.Both baffled channel flocculators and the storage tank were both designed to the required standard and made of materials appropriate for their efficient performance. The simplified processes made it easily operational in terms of maintenance and processing in a rural environment.

The use of virtually no external power to assist the flocculation process can be seen by the adoption of the sinous flow channel basin.

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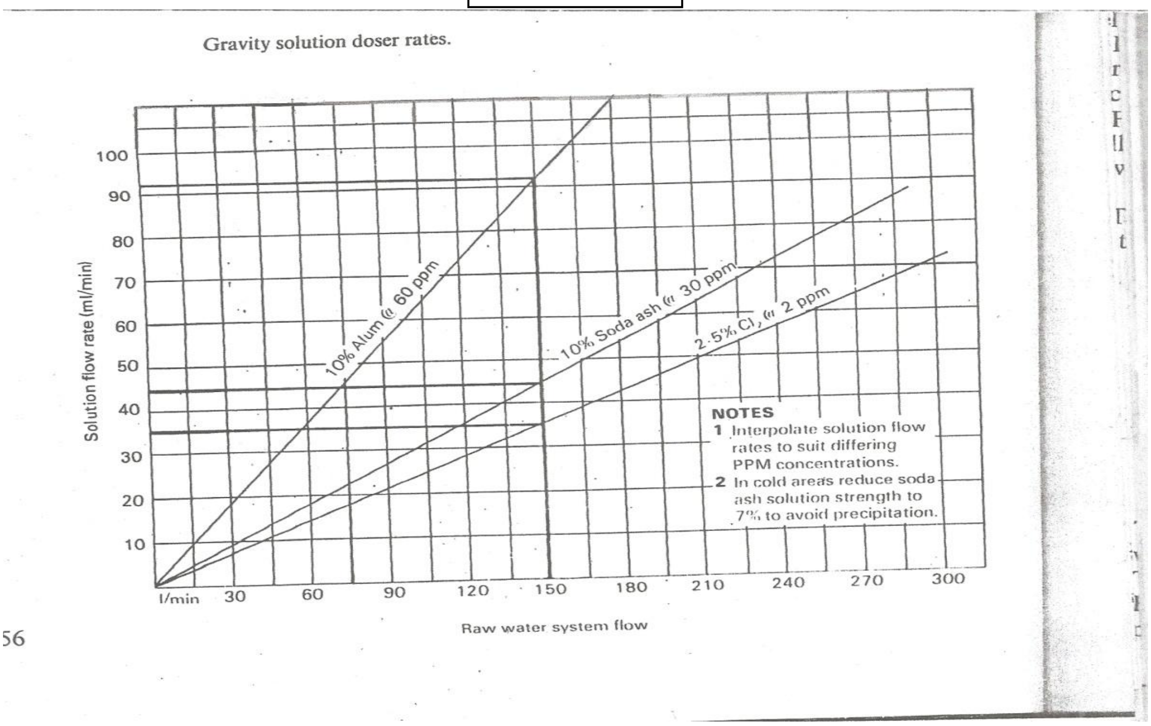
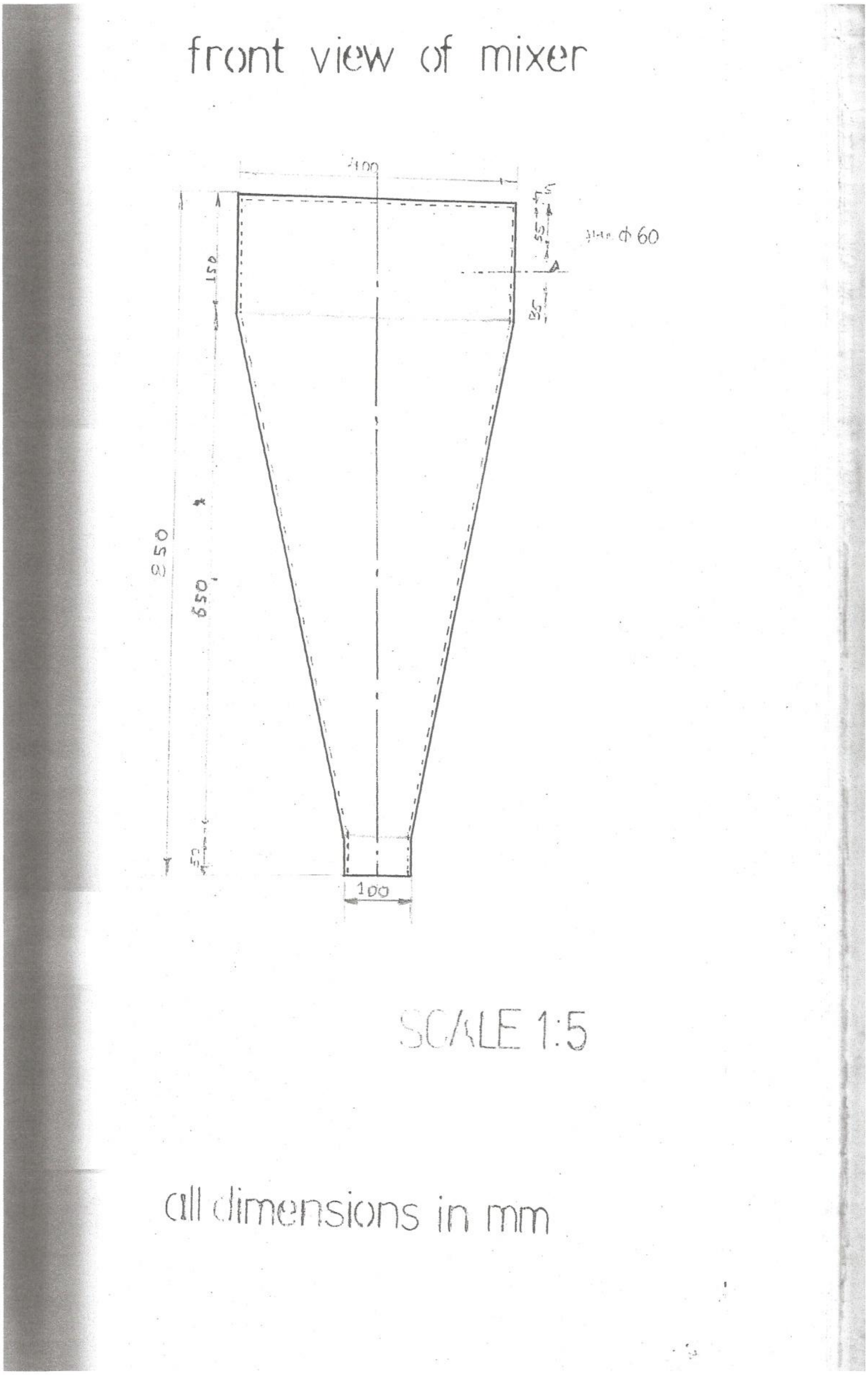
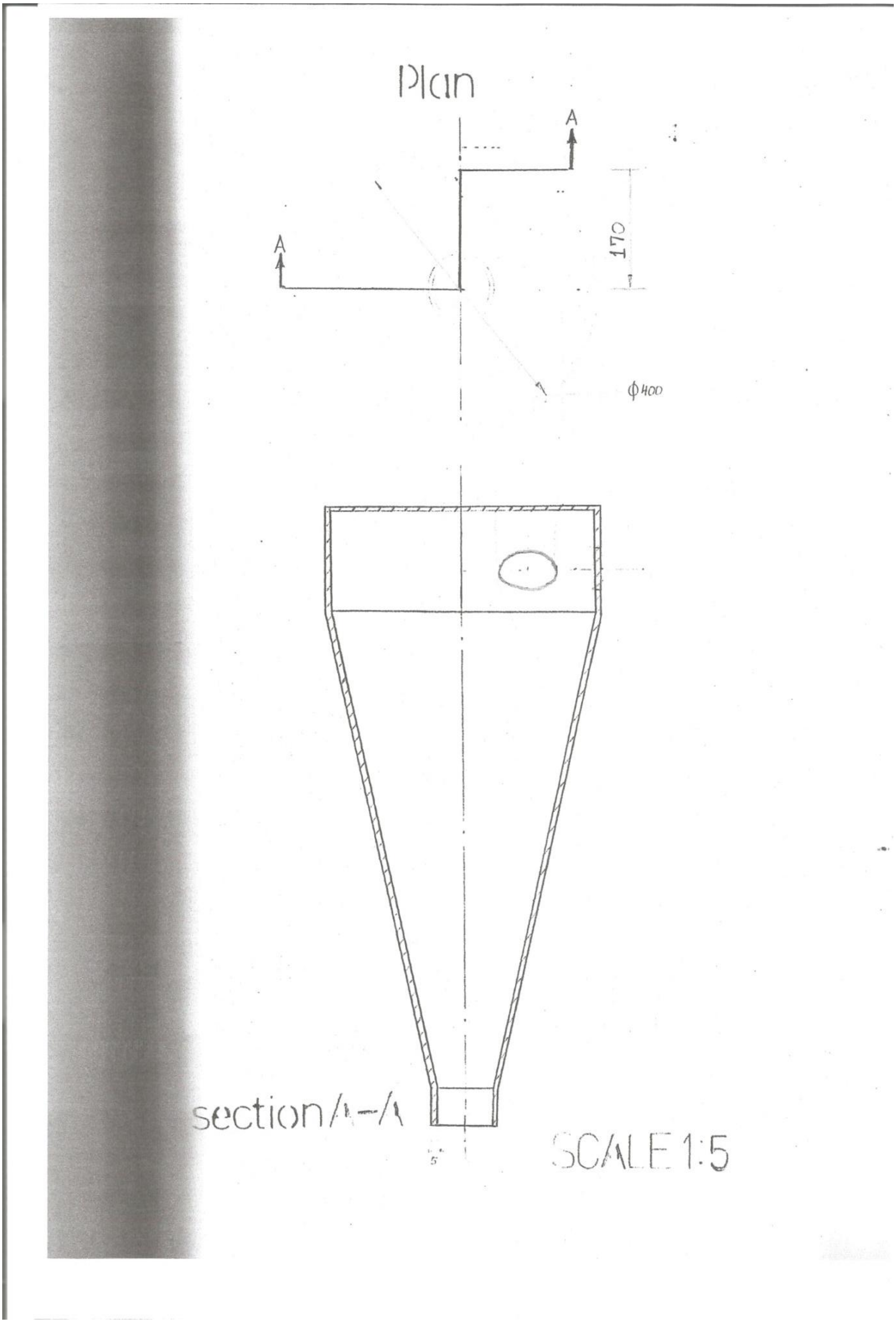
APPENDIX 1.0




front view of mixer
400
150
55
Φ 60
850
650
100
SCALE 1:5
all dimensions in mm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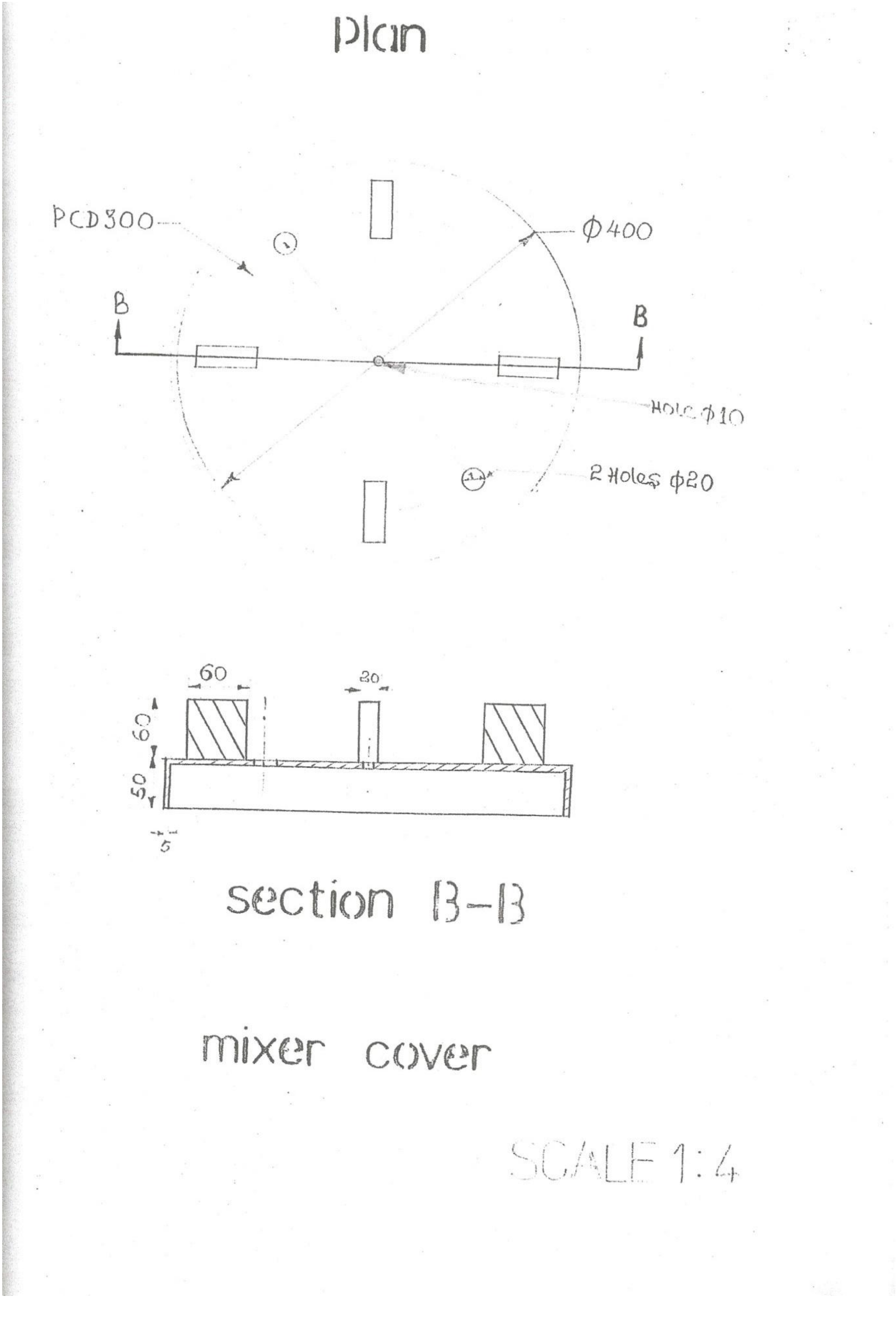
A
A
170
ϕ400
section A-A
SCALE 1:5


Plan
PCD300
Φ400
B
B
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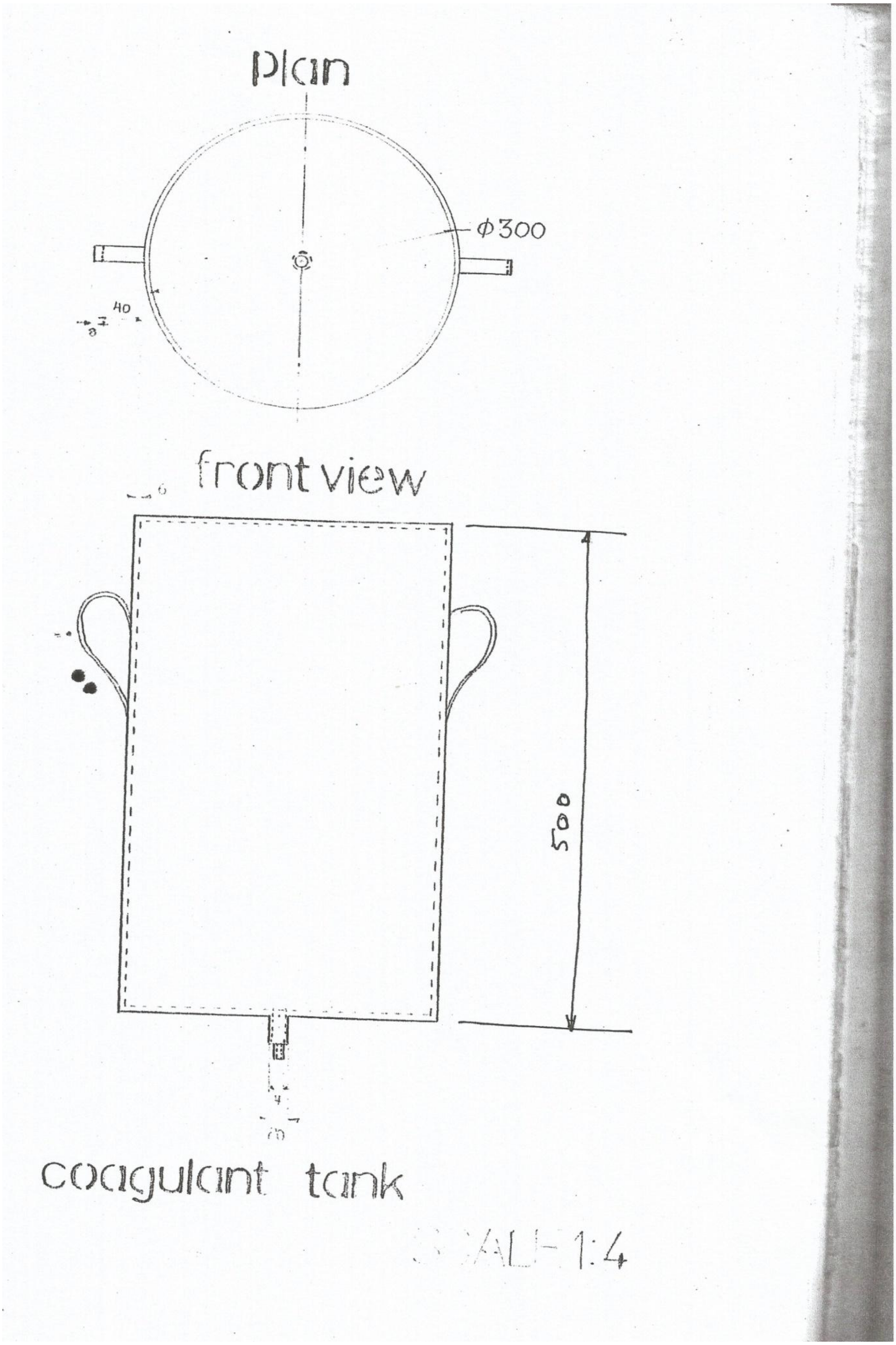
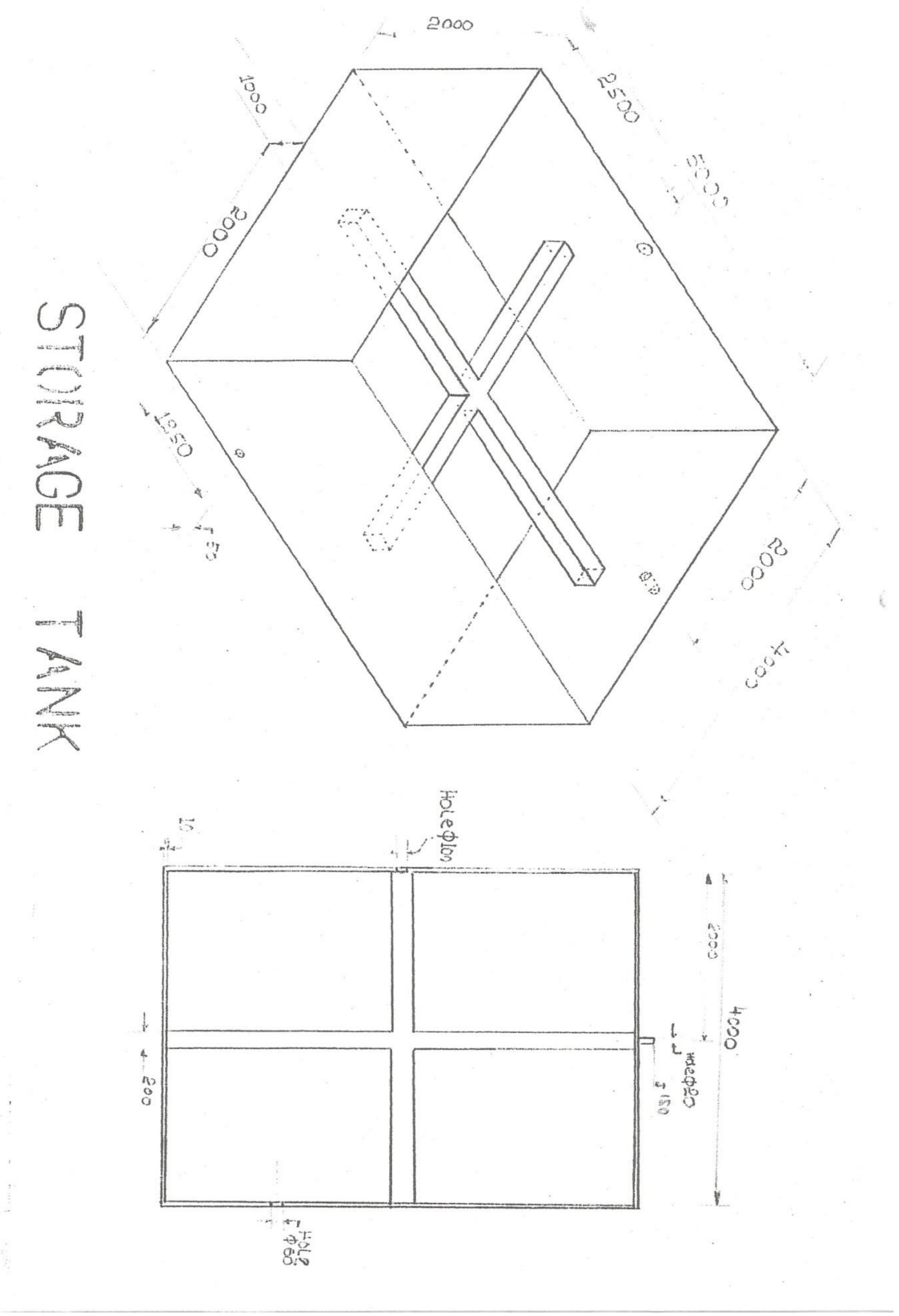
2 Holes Φ20
60
20
60
50
5
section B-B
mixer cover
SCALE 1:4


Plan
Ф300
40
front view
500
coagulant tank
SCALE 1:4


STORAGE TANK