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DEVELOPMENT OF FLOCCULATING PADDLES IN MOBILE WATER TREATMENT PLANTS

By

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This thesis was submitted to the Department of Mechanical Engineering of the University of Moratuwa in partial fulfillment of the requirements for the Degree of Master of Engineering in Manufacturing Systems Engineering

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ABSTRACT

Water is precious for every living being. It covers almost 75% of the earth's surface. Only about 3% of the water on earth exists as fresh-water and most of it is not easily available to men.

Freshwater sources are polluted by activities of men, animals and by natural disasters. Water pollution is dominated by industrial and domestic wastes through channels and drains. Treating this water to meet standards of drinking quality is a huge task and a costly process.

Many countries face the problem of providing safer drinking water rapidly when faced with disaster situations like thousands of refugees as a result of civil disturbances, or natural disasters such as tsunami-related events, earthquakes, landslides, droughts or in an event of floods. The main issue is to construct water treatment plants which are heavy concrete structures in a shorter period of time in a limited land space.

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The R & D section of the National Water Supply and Drainage Board (N.W.S.& D.B) has designed and fabricated a moveable water treatment plant using locally available materials and expertise within an affordable capital cost . Three of these mobile type water treatment plants have being installed in Pugoda, Mahiyangana and Allauwwa.

This type of water treatment plants can dismantle into separate sections. They are fabricated steel tanks as middle stages of water treatment plant array. These sections can be transported to another place, re-assembled and re-located.

The Pugoda plant has a mechanical flash mixer and three speed mechanical tapered flocculators. Flocculating is done by four paddle rotors rotated by geared motors in three speeds in three adjacent tanks. These paddle wheels (rotors) are mounted on a horizontal axis inside the tank. The two ends of axel are sealed and supported by two end bearings housed

beside the tank steel wall. This arrangement of the paddle wheels gives many operational and maintenance difficulties when dismantling the bearings and water seals.

Very frequently chemically mixed water leaks through the water seals and bearings. This leads to reduce productivity by reducing bearing life, equipment safety and increasing down time, power requirement and operational cost. It needs a substantial quantity of water to remove the sludge in the bottom bed by washing them out.

The objective of this special study is to study the ways and means of improving the present installation arrangements of flocculator paddle wheels and to propose an alternative arrangement eliminating above operational difficulties. Objective is to find an efficient alternative mechanical flocculator system to be used in package-type water treatment plants.

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This report discusses about conventional water treatment arrangement, a brief study of floc forming phenomena, specification of the mobile water treatment plant, flocculator types and other arrangement types of mechanical flocculators used elsewhere in the world. The report includes theoretical aspects of power requirement for rotating paddles.

The study also proposes a vertical arrangement of flocculating. This is by fabricating frame and a plate to mount the gear box and motor. This frame is fitted on to the top frame of the tank. The axes of the paddle wheel is supported by two bearings, one is top of the channel section and the other is submerged in the water. The housing shall be fixed to fabricated plate to bottom of tank. The bearing shall be water resistant type and fully water tight by seals.

The advantages expected from this arrangement are to prevent water leaks, long life of seals, bearings and couplings and to reduce operational and maintenance difficulties thus reducing operational costs and reducing the amount of sludge washing water.

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CHAPTER 1

1. INTRODUCTION

1.1 CRITICALITY OF FRESH WATER

Water is precious for every living being. It covers almost 75% of the earths surface and also includes in the atmosphere, geo-sphere and in the biosphere. Only about 3% of the water on earth exists as freshwater and most of it is not easily available to men. It includes 2% water locked in glaciers and ice-caps. About 0.5% water is beneath the earth surface. It is said rivers and lakes contain only 0.2% of earth's water and 0.001% as water vapor in the atmosphere.

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Water had been cheaper and people have been careless and wasteful. Freshwater resources over the world are shrinking today. They are polluted by activities of men, animals and by natural disasters. Water pollution is dominated by industrial wastes and domestic wastes through channels and drains. Men have dumped untreated sewage and the wastes into rivers and lakes spoiling the quality of water.

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Water treatment involves removal of undesirable inorganic and organic constituents from the water and then disposal of them in the easiest and safest manner. Selection of the correct treatment process is the key success of the treatment plant. Treating this water to the standard drinking quality is a huge task and a costly process.

These water treatment plants use rapid sand filters, slow sand filters and hydraulic flocculation tanks. Conventional hydraulic flocculators use cross-flow baffles or 180^0 turns to provide required turbulence. Criticality is to get gentle, uniform mixing that will not sheer floc. This type is efficient only if the flow is relatively constant and is more suitable for medium large treatment plants

1.2 CONSTRAINS OF CONVENTIONAL WATER TREATMENT PLANTS

Main weakness of conventional concrete water treatment plants is their **immovability.** All these are heavy concrete structures covering large land space and taking about two years to construct. They consume large amount of material and capital.

Many countries face the problem of providing safer drinking water quickly to an area where drinking water demand is very high, especially, when they faced with a disaster situation like tsunami, camping thousands of refugees rescued from a terrorist custody, flood situations, landslides, droughts, relocating or earthquake destruction. Main issue is to construct a medium-scale water treatment plant in these areas in a shorter period or in a limited land space.

In Srilanka , the National Water Supply and Drainage Board (N.W.S.&D.B.) bears the sole authority and responsibility to supply pipe borne drinking water to the nation with a standard quality at a reasonable price.

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1.3 SOLUTION

Facing these challenges, R & D center of the N.W.S. & D.B. has designed and fabricated a movable water treatment plant using locally available materials and expertise within an affordable capital cost. This type of water treatment plants are fabricated separately, section by section, (fabricated steel tanks) in one location as middle stages of water treatment process. These steel tanks are then transported to the location where land space is limited or to the place where the treated water demand is severe. The tanks are re-assembled and installed in a reasonably short period. A plant with a total plant capacity of 500 m^3 /day is built at a backyard area of 37.2 m^2 (400 sq ft). The settling tank tube setting method which occupies only one sixth of the plan area required for conventional sedimentation tank. It has been found that this is a viable solution instead of importing package water treatment plants of capacity ranging from 500 to 2000 cum/d.

Three of these movable type water treatment plants were built at Pugoda Water Supply Scheme (WSS), Allawuwa and Mahiyangana (WSSS). The Pugoda plant has a capacity of 500 m^3/d costing Rs 6 million, and Mahiyangana plant is of 2000 m^3/d with a cost of Rs: 21 millions. This is generally one fifth of the cost of an imported plant. [1](Research & Development News Vol: 1, Issue 1, Pg 1, Jan 2007 N.W.S. &D.B.)

1.4 PUGODA WATER TREATMENT PLANT

Pugoda mobile water treatment plant has a capacity of 500 m^3/day and costs about Rs: 6 million. Earlier Pugoda water supply plant had only pressure filters for filtering. Raw water is taken in from 'Kelani' river. This was not operating properly and not producing quality water with respect to turbidity. As mentioned in R & D News of N.W.S. & D.B (Volume: 1, Issue 1, Pg 1, Jan 2007) most treatment plants in N.W.S&D.B water supply schemes have neglected the flash mixing and flocculation. The objective of a flocculator in a treatment process is to produce particles big enough to form collides, and afterwards to be removed by gravity sedimentation or filtration. For this, different types of flocculators are used.

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Current package-type mobile plant at the Pugoda WSS (Water Supply Scheme) has a mechanical flash mixer and **three speed mechanical tapered flocculators** to reduce the size of the tanks. Flocculating is done by four pedal **mechanical rotors** rotating on horizontal shafts in three speeds in three adjacent tanks. Although this mobile plant saves space, it faces **operational and maintenance difficulties** as flocculation is done by mechanically driven paddle wheel.

1.5 PROBLEM BACKGROUND

The present arrangement of the paddle wheels gives many dismantling difficulties when replacing bearings and water seals. Paddle wheels are mounted in a horizontal axis inside the tank. One bearing end is fixed to outside the tank wall and fully sealed. The driven end of the shaft is taken out from the tank by piercing the tank metal sheet wall and shaft is sealed from water and supported on bearings fitted in a bearing housing fixed to tank frame.

This arrangement causes to frequent leaks of chemical mixed water, through the water seals , when they are worn out. The bearings and the gear couplings are exposed to water plash due to worn out seals. This leads to loose bearing life and seal life. Too much load acts on driving shaft of gear reducer due to this. Shafts have failed many times.

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It needs substantial quantity of water to remove the sludge in the bottom bed by washing out the sludge with water in the tank. This type of paddle wheel arrangement consumes more material, labour, power and costs more. This arrangement gives many maintenance difficulties and more down time and leads to low productivity.

1.6 THE STUDY

A brief study has been done on conventional water treatment processes adopted in the world and Sri Lanka to identify common strengths, weaknesses and constraints when applying them in different situations.

A detailed study has been done on the arrangements and steps of package type water treatment plant at Pugoda water treatment plant installed by N.W.S. &D.B. Then a detailed study has been done on the operational and maintenance difficulties of paddle wheel type rotating flocculators. A careful study has been done to identify the weaknesses for improving the arrangements of paddle wheels to eliminate the current operational difficulties.

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A brief literature study has been done on the phenomena of floc formation and principles of floc formation. Having done that a detailed literature survey has been done on other types of mechanical flocculators used in the world and their weaknesses, strengths and their suitability of applying in different situations. The study also includes restrictions and limitations of parameters and principles and how they are applied and governing the mechanical flocculation.

CHAPTER 2

2.0 OBJECTIVES

It is found that the mechanical flocculation is more suitable for reduced space flocculator tanks especially for package-type water treatment plants. Therefore, it is beneficial to develop the mechanical system of operation to improve productivity.

- The objective is to study alternative ways of mechanical systems of imparting energy to coagulate water while performing controlled flocculation.

- To study weaknesses and strengths of other systems used elsewhere to different situations and to find suitable arrangement for paddle wheels and to find solutions to avoid current maintenance difficulties in dismantling.

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- To conduct a brief study on the phenomena of floc formation. This is to observe the restrictions and limitations when doing mechanical flocculation. The specific objective is to study how they govern the parameters of mechanical equipments in controlled flocculation.

- To improve the sludge removal mechanism and to reduce the amount of sludge washing water.

- To find an efficient alternative mechanical flocculator system to be used in package type water treatment plants .Thus it will improve plant productivity by reducing power consumption, plant down time, material replacements, labour usage. Thus reducing overall operational costs thereby contributing the development of package type water treatment plants to the benefit of the community who enjoy the services .

2.1 HYPOTHESIS

There have been continuous experiences related to the weaknesses and disadvantages of present arrangement of paddle wheels both during operation and maintenance. Studying other ways of doing this, the best method applicable to the present situation is to arrange the wheels to rotate in a vertical axis inside the tank section. Top end of the wheel shaft is guided by a vertical bearing and the weight of the unit is rested on it. Wheel is driven by gear reducer shaft coupling. Lower end is guided by a suitable bearing or bush arrangement submerged in water installed on the tank bottom.

Wheel frames are to be fabricated by lighter but non-corrosive material. A transverse channel is arranged in the tank bottom to collect sludge swept by rubber strips.

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CHAPTER 3

3 METHODOLOGY

3.1 APPROACH

Studying any other alternative ways of mounting the peddle wheels is of concern here. Fabricating the paddles in a shaft and mount the shaft vertically. Top end is mounted on a bearing which is supported on a 'U' sectioned cold rolled mild steel section . This bracket is fixed on the vessel frame. Top end of the wheel shaft is guided by a vertical bearing and the weight of the unit is rested on it. Wheel is driven by gear reducer shaft coupling. Lower end is guided by a suitable bearing or bush arrangement submerged in water installed on the tank bottom .This bearing or bush is sealed by water seals. Or it is covered by a conical shape circular rubber sheet so that no sand particles will enter in to bush. Material for bottom end bearing or bush shall be used with polished carbon block, bronze or stainless.

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Paddle boards and frame materials are selected from lighter and non-corrosive materials. Appropriate dimensions are decided by design calculations using the study results. The frame and paddle boards are to be fabricated and fastened so that they can be easily dismantled for maintenance.

Gear box & drive motor arrangement is mounted on steel plate welded on to the fabricated frame. All bolts to be used with none corrosive material such as chrome plated or stainless steel. Power transmission is done by flange coupling from gear shaft to paddle wheel shaft vertically. Horizontal paddle wheels are thereby improved.

Sludge removal is improved by reducing the amount of sludge washing water by introducing rubber strips fitted to bottom segment of the paddle frame which will sweep the accumulated sludge in to a trench in the bottom of the tank connected to drain out valve.

3.2 IMPOSITION OF LIMITATIONS

1. Flocculation is to be done carefully by maintaining the paddle wheel rotational speeds in three stages as to specified ratios recommended in the literature. This is because blade linear velocity maintenance is important not to breakdown the bonded floc, as they are ready to settle down as sludge particles.

2. Not exceeding the present power consumption.

3. Not to fabricate any heavy mounting structures on the steel tank frame which may deform side wall plate or frame.

4. No any high cost or complex structures used to mount the driving mechanism.

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5. Submerged parts should be in non-corrosive light material.

CHAPTER 4

4 INTRODUCTION TO WATER TREATMENT

Water resources over the world are polluted by activities of men, animals and by natural disasters. Main pollutions are caused by industrial wastes and domestic waste through sewerage channels and drains.

Water treatment involves removing of undesirable inorganic and organic constituents from water and then disposal of them in the easiest and safest manner. Selection of the correct treatment process is the key success of the treatment plant. Treating this water to the standard drinking quality is a high task and costly process.

These water treatment plants use rapid sand filters, slow sand filters or pressure filters with hydraulic filters. All these are heavy concrete structures covering large land space

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TYPICAL WATER TREATMENT STAGES WITH FABRICATED MOBILE STEEL TANKS

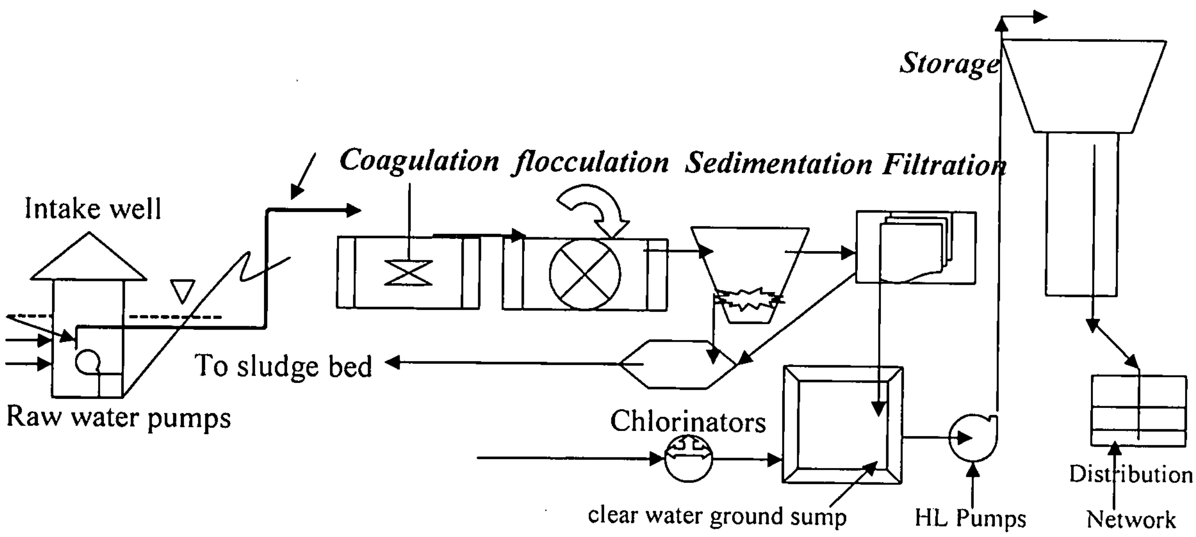

Fig. 4-1a Water treatment process train [2]

4.1 WATER TREATMENT PROCESS

The water treatment process consist of following major steps. They are screening, aeration, chemical adding (coagulation &flocculation), sedimentation, filtration, chlorination, storing and distribution.

Screening :

1. Trash rack: Provided at the intake gate for removal of floating debris .
2. Coarse screen: Mechanically clean screen before pumps. Removes fish and solids.
3. Micro strainer : Removes algae and plankton from the raw water.

Aeration :Oxidizes taste and odor causing volatile organics and gases .Removes bad smells.

Mixing : Rapid distribution of chemicals (lime & alum) and gases into water.

Coagulation: Rapid mixing of coagulant resulting chemicals to react with clay and micro organisms destabilization of colloidal particles of pin-head flock.

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Flocculation: Combining destabilized turbidity and color pin heads forming heavy flocks.

Sedimentation: Rapid gravity separation of big flocks resulting clear water at the top.

Filtration :Top water sent through sand filters, suspended solids and micro organisms stay

Disinfection : Injecting chlorine gas. Chlorine is a strong oxidizing agent destroying bacteria [3]

Steps of fabricated mobile steel tanks.

1. Mixing & coagulation
2. Mechanical flocculators
3. Sedimentation tank
4. Filtration tank

4.2 A STUDY FOR FLOC FORMATION

4.2.1 Solids Suspended

Suspended solids in the water include sand, soil, organic material, bacteria, viruses and other material. Particles at high end of spectrum greater than 1 micron will usually settle in quiescent water. A suspension of particles that will not settle is known as stable suspension.

4.2.2 Colloidal particles

Particles that make up these suspensions are known as colloids, but they do not readily settle. These can be removed by sedimentation and filtration only after chemical and physical conditioning.

4.2.3 Coagulation

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This is chemical conditioning. It is adding chemicals to modify the physical properties to either break down the stabilizing forces or promoting destabilizing forces or both. Chemicals used are aluminum sulfate (alum), ferric sulfate, ferric chloride or synthetic polymers. Recently coagulation has been used to remove organic and inorganic contaminants from water. This is done by using higher coagulant dosage. This is known as **enhanced** coagulation. Turbidity removal is seen as process efficiency.

4.2.4 Flocculation

Physical conditioning is known as flocculation. Energy input must be properly provided after rapid mixing. This is done by gently stirring the mixture to accelerate inter particle contact to promote the growth of the flock to a size of destabilizing and enhances to settle by sedimentation and by filtration. Typical flock size is 0.1mm to 2.0 mm. [4]

Table 4-1 Particle sizes found in water treatment

Material	Particle Diameter Micron μ [a,b]
Viruses	0.005-0.01
Bacteria	0.3-3.0
Small colloids	0.001-0.1
Large colloids	0.1-1
Soil	1-100
Sand	500
Flock Particle	100-2000

a μ = micron $=10^{-3}$ mm b m μ=mille micron$=10^{-6}$ mm [4]

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4.2.5 Characteristics of Colloids

Colloids in that range of 0.001 micron to 1 micron. Colloids dispersions have light- scattering properties measured turbidity units. These are **hydrophobic** (water–hating) when a weak affinity for water exists and **hydrophilic**, when it is strong affinity. Mass is very little compared to surface area. Gravity has little effect on settling. Main phenomena controlling the behavior are electrostatic forces.

Most solids are electrically charged. Charge type varies depending on the nature of colloid. Metallic oxide is generally positively charged and nonmetallic and metal sulfides are negatively charged. Similar charged colloids repels. Most colloids are negative. The forces that influences stability of colloids are 'Van der Waals 'force and Brownian motion. [4]

4.2.6 Layers on colloid surface.

Negative surface chargers attract cations like hydrogen in water molecules, thus forming a thicker layer surrounding the particle. This is named as *stern layer*. Next layer is the *diffused layer*. That is ions of both electrical charges attracted, opposite ions predominates. In the diffused layer water molecules bound to form a *shear layer,* and will behave as if attached to the colloid. Water molecules outside the shear surface are independent of colloid influence.

The electrical potential at the shear surface is known as the ***zeta-potential***. The potential often measured in water treatment, to give an indication of the stability of the colloidal system of the effectiveness of the coagulation process.

4.2.7 Van der Waals Forces & Brownian motion

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These forces attracting between any two masses, which is a function of the two masses. The repulsion due to the electrical charge will normally repel the colloids before they can move enough for **Van der Waal** forces to become significant.

Colloids have sufficiently small mass that collisions with molecular-size particle will cause movement of the colloid. Molecules in water in constant motion, with the intensity of this motion being dependent upon water temperature. This particle motion causes random collision with colloids. This phenomenon is known as ***Brownian motion.***

4.2.8 Particle movement

(a) Para kinetic : Growth of a particle as a result of inter-particle contacts due to 'Brownian motion'.

(b) Ortho kinetic: Particle growth as a result of inter-particle contacts due to fluid motion.

Para coagulation is typically inefficient for turbidity removal. Only extremely high solid concentration will a sufficient number of particle collision occur due to 'Brownian motion'. In most plants ortho-kinetic flocculation predominate as mechanism to promote particle growth. [4]

Distribution of electrostatic potential, shear plane ,and zeta potential

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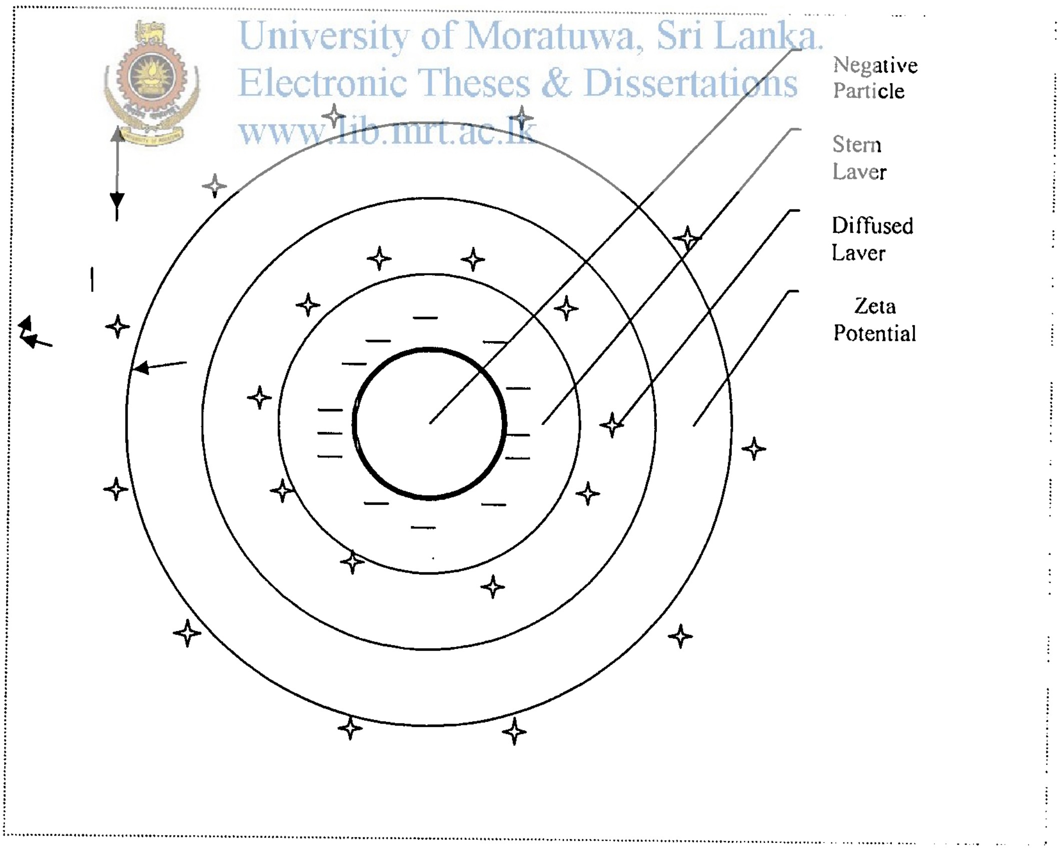

Fig 4-1b

SCHEMATIC REPRESENTATION OF THE DESTABILIZATION OF COLLOIDS

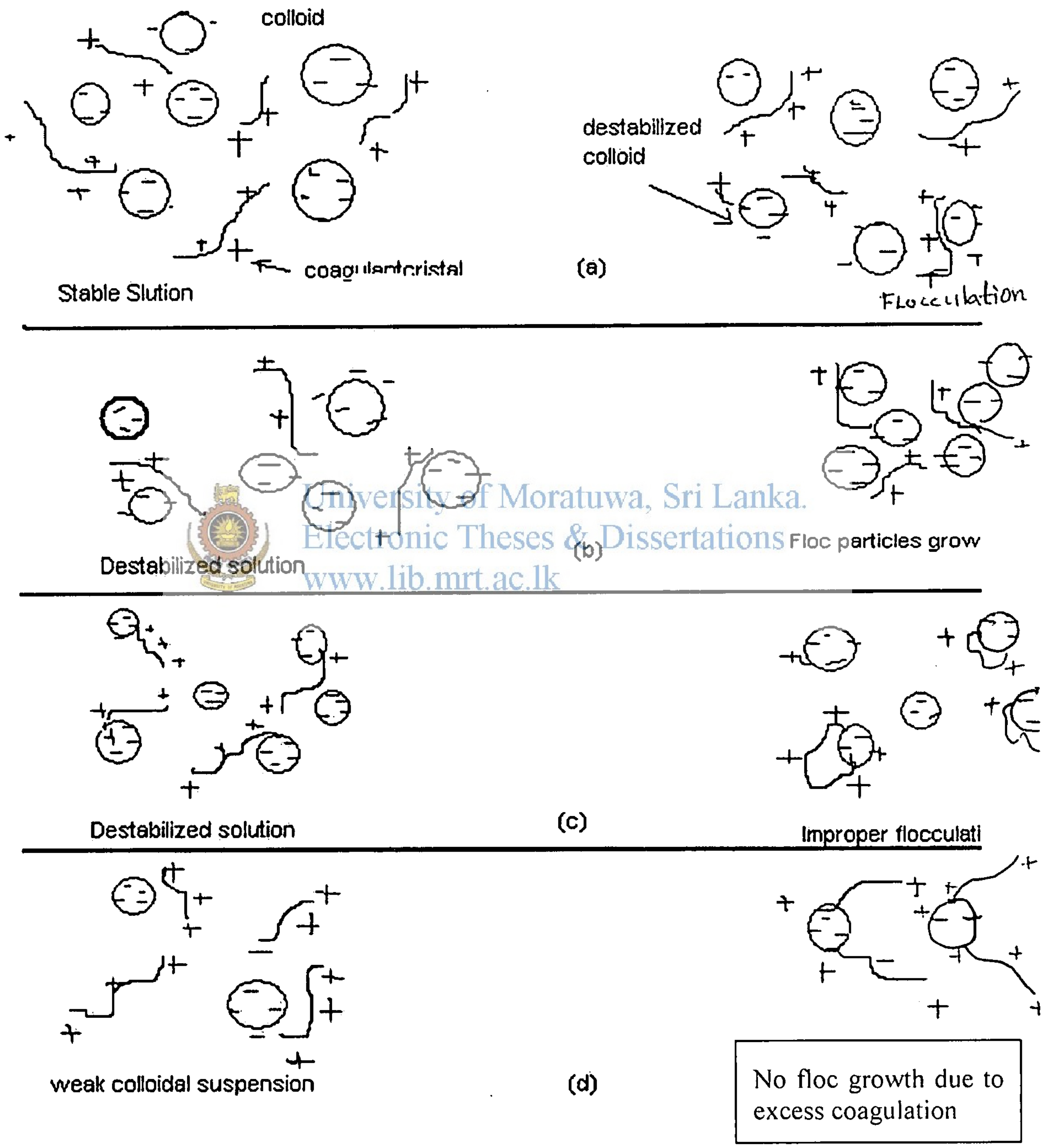

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Figure 4 - 2

CHAPTER 5

5 LITERATURE REVIEW ON FLOCCULATORS

5.1 Objectives of flocculators

Imparting energy to coagulated water with controlled flocculation without disturbing formation of large flocs . This is done by gently stirring the solution to accelerate inter particle contacts to promote the growth of the flock to a size of destabilizing and enhances to settle by sedimentation and by filtration. This stirring velocity gradient (three rotating speeds) should be maintained not to breakdown the already formed big flocs.

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5.2 Types of Flocculators

a). **Hydraulic flocculators**

Simply utilized cross-flow baffles or 180^0 turns to provide required turbidity and turbulence. Criticality is to get, gentle, uniform mixing that will not sheer flocs. This type is efficient only if the flow is relatively constant and is suitable for medium large treatment plants.

b). **Mechanical flocculators**

These are rotating in horizontal or vertical axis, oscillating or reciprocating types.

See figure **5 -1** for flocculator types (a) Paddle wheel (Vertical & Horizontal)

(b) Walking Beam

(c) Oscillating type

5.2.1 Walking beam flocculators

These have horizontal line shaft, drive units, "Walking beams", and paddle supports assemblies, and paddles. The paddles are moved up and down in a reciprocating movement by means of a drive motor. The gear reducer, torque arm assembly, connecting rod and riser beam converts the circular motion of the drive out put shaft in to linear motion. All the bearings drive mechanisms, line shafts and guide devices are located above the water level which allows for maintenance access at any time. See Fig 5-1 b I in page 19.

Walking beam flocculators can be designed to ensure the entire basing is effected by the flocculation process minimizing short circuiting. The flocculate line shaft and be installed either perpendicular to the direction of the water flow or parallel to the flow. Tapered flocculation can occur in either direction. [5 A]

5.2.2 Oscillating type flocculators.

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"Roberts Filter Group" has manufactured swinging paddle and reel type vertical flocculators. Swinging paddle flocculators are constructed entirely from coated steel with two rows of paddles set 90 degrees apart. Paddles swing freely from a horizontal arm bracket, thus eliminating jamming debris or sludge. Wood or fiber glass paddles are fitted to steel arms. See Figure 5 -1 9 (c) in page 19.

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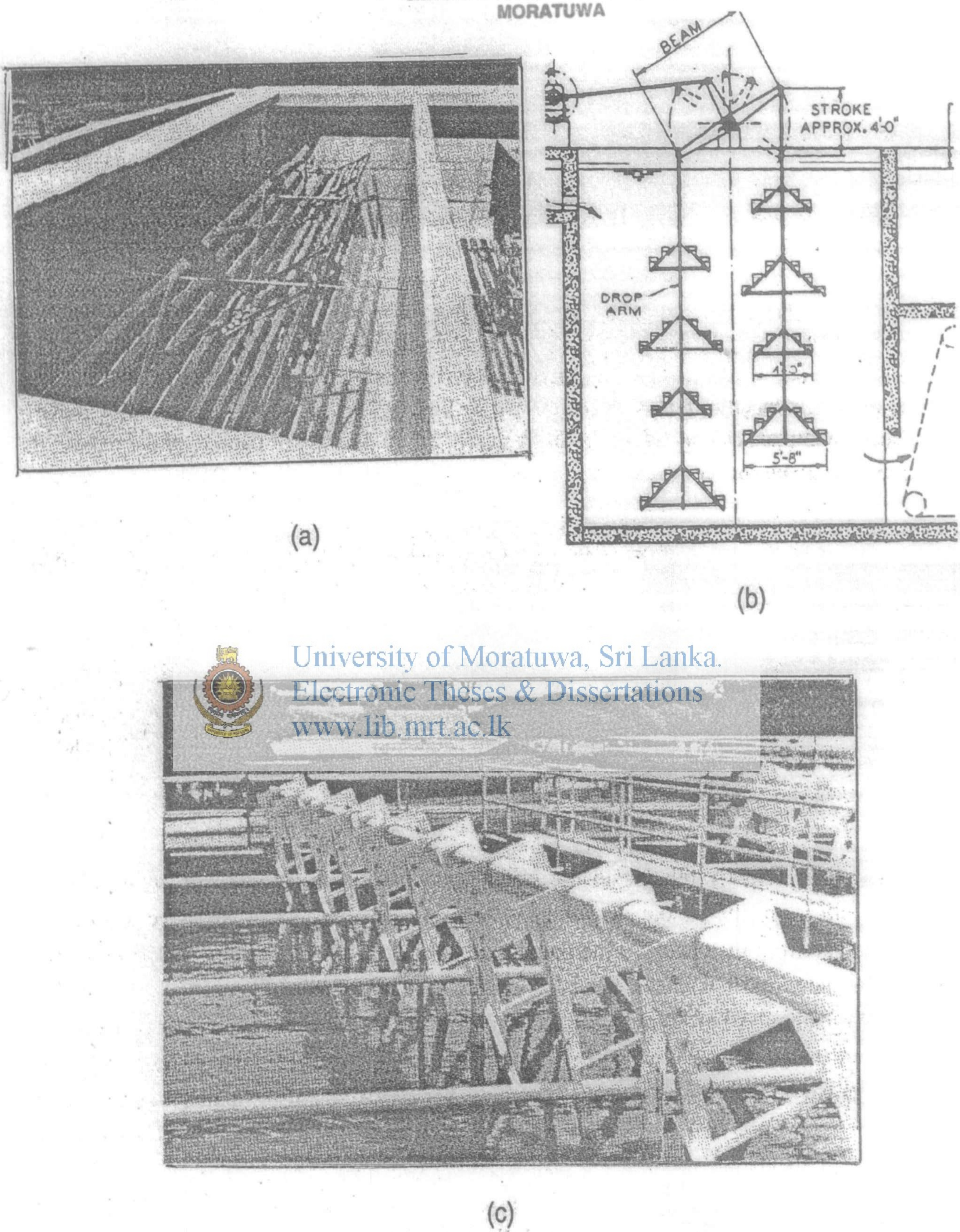

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Typical flocculators. (a) Paddle wheel. *(Courtesy of Envirex/U.S. Filter)* (b) Walking beam. *(Courtesy of JDV Equipment Corp.)* (c) Oscillating paddle. *(Courtesy of Baker Process)*

Fig5-1

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5.2.3 Rotating flocculators

The slow rotation of flocculate wheel virtually assures that every water flow laminate contacts a paddle surface since in there is substantially no water laminate which pass the wheel without contacting one of the paddles and further since the rotation of the paddles constantly cuts across the water flow laminates. See Fig5-2

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5.2.3.1 (a) Vertical Shaft Flocculators

These consist of vertical shafts, drive units and paddlewheel assemblies. Counter current or concurrent rotation to water flow can be provided based on the design rotation. See Fig 5 -2 in page 21.

Advantages: These allows for easier compartmentalization due to its vertical shaft, single reel design. In order to minimize short-circuiting in flocculation basins a **minimum of three** compartments are recommended. Compartmentalized flocculation basins also allow flexibility for varying velocity gradient and removing the units out from basin for maintenance easily. Bridge ways can be provided by concrete, thick duraluminum or steel to mount the unit and the driving unit. Bridges are to be fabricated to withstand the total load of the unit. [5B]

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Vertical type simple flocculator has been designed and fabricated by "AMWELL" a Division of McNISH corporation in US. It has three paddles rotating with a heavy duty constant or speed variable drive, with stainless steel or carbon steel construction. Driving mechanism is either shaft mounted or chain or sprocket or belt drive. Paddles are fiber glass.

Lower end rests by readily adaptable C/I pillow block precision roller bearings. Drive chains are non-metallic or stainless steel. Drive shaft is, solid or torque tube of carbon steel or stainless steel. [6]

Paddle Flocculators

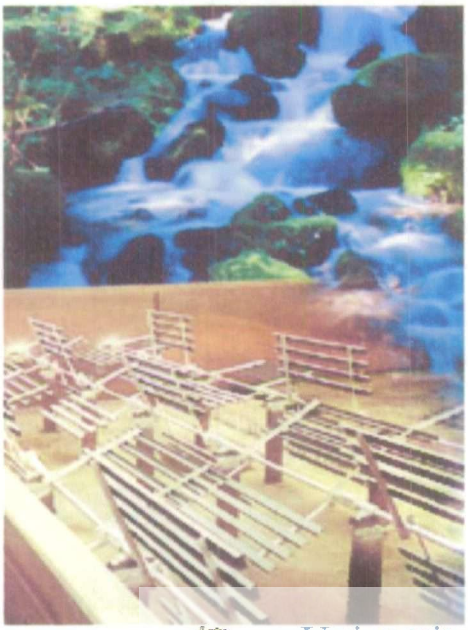

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Fig 5-2

5.2.3.1 (b) Vertical type flocculators from India.

Manufactured by Environ Engineering Company India (Environ Eng Com) [7] Picture shows flocculator wheel being rested horizontally before installing vertically.

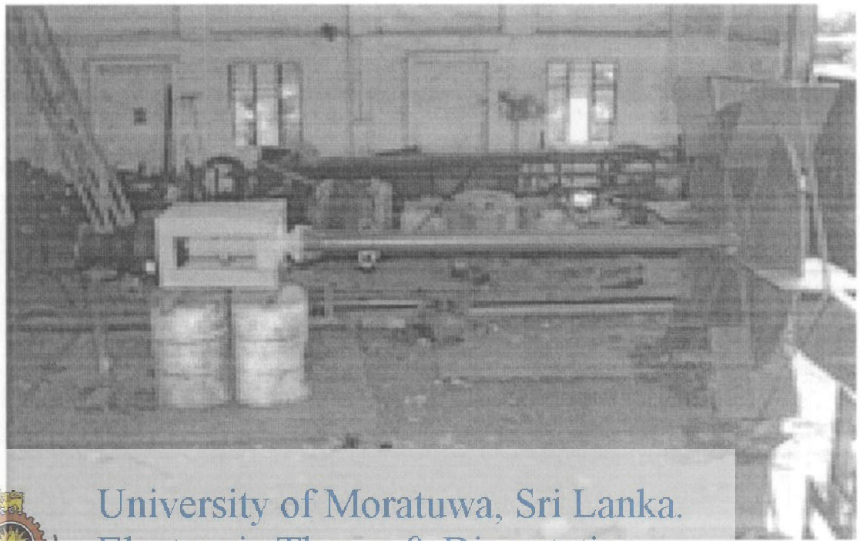

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Fig 5-3a

Specifications

Mounted vertically

Impeller: four blades pitched

Paddle type: r.p.m. 5 to15

Motor: HP, 4p, AC, Ph 50 Hz, 415 v

Gear box: Worm reduction gear box.

Base: Fabricated and machined

5.2.3.2 Horizontal Shaft Flocculators

The shaft can be installed either perpendicular to the flow or parallel to the flow. These can be designed to produce tapered flocculators by varying the size and spacing of the paddlewheel assemblies over the entire length of the shaft. They typically operates at different speeds with which each successive shaft operating at a lower speed than the previous one. The drive unit of the horizontal shaft flocculators is mounted outside the flocculator tank or on a platform above the water level. This type incorporates a stuffing box to eliminate water leakage from the tank to outside. Power transmission is done by a chain and sprocket wheel. These have rotating hubs from which radial arms extending. Paddles made by plates, fiberglass, wire mesh, flat board or planks. See Fig 5-1a of page 19 & fig 5-2 of page 21.

Advantage : Above mentioned types can be process greater volume of water.

Disadvantages: These leads to water leaks if the stuffing box or seals are not functioning properly. These are relatively large power consuming, it can be eliminated by reducing flow resisting area by using wire mesh or low weight boards. [5]

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This type of direct drive horizontal flocculators has been fabricated by 'The Roberts Filter Group' in 3-12 meter length. Each paddle section consists of fiberglass paddles mounted on steel arms attached to cast shaft plates. Plates are keyed to cold rolled steel shaft. A flexible coupling securely connects each flocculator section to a variable speed traction drive. [7]

(Roberts Filter group a company manufacturing flocculator related items.)

5.2.3.2. a) Horizontal paddle flocculator at Package Water Treatment Plant Pugoda, Sri Lanka.

The Arrangement

This plant has mechanical flash mixer and three speed tapered mechanical flocculator. Flocculating is done by four paddle rotors rotating on horizontal shafts in three speeds in three adjacent tank sections. The paddle rotors are fully submerged in the water. Motive power is given from out side shaft of the gear box which is mounted on a plate on a bracket fabricated firmly to the tank structure.

Specifications

Paddle: Horizontal mounted 4 arm wooden paddles. Load axel dia: 40 mm

Gear Reduction: Step 1 70:01; Step 2 125:01 ; Step 3 173:01

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Coupling type: flexible bolted coupling.

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Gear Box: Worm & Worm shaft. Carbon steel C 45

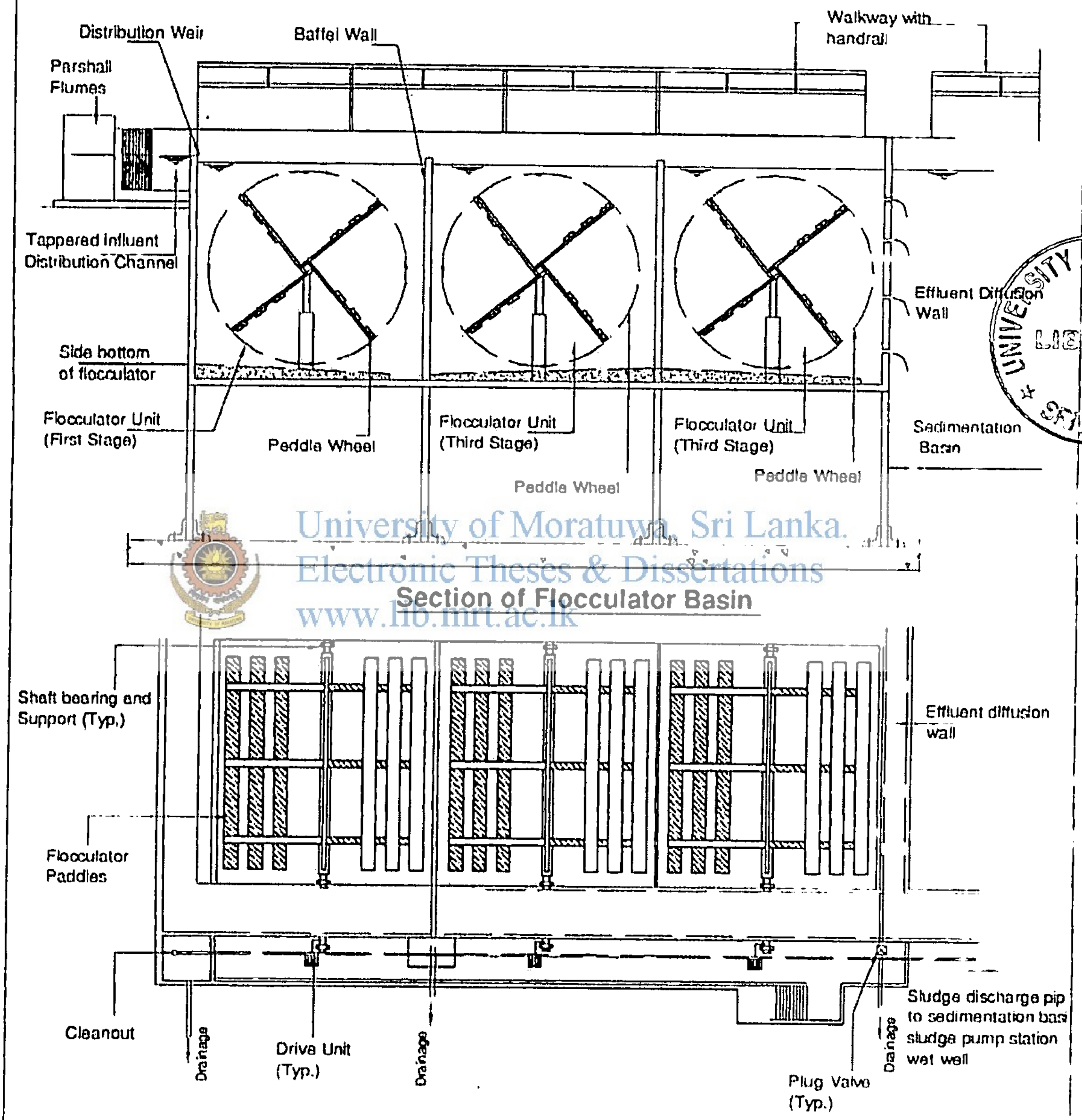
Input shaft dia: Step 1 30 mm; Step 2 25 mm ; Step 3 20mm Carbon steel

Output Shaft dia : Step 1 50 mm; Step 2 30 mm ; Step 3 25 mm SS or Shaft steel

Motor : 3 ph, AC 50 Hz, 400 v, 1400 r.p.m.

Step 1 2.2 kW ; Step 2 1.5 kW ; Step 0.75 kW

Horizontal paddle flocculators arrangement at Pugoda Water Treatment Plant



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Horizontal Flocculator Basin - Plan

Figure 5 - 3

5.3 Zero Energy Input Flocculator

(This is a US patent invention. **Inventors Harries, Leslie W. 1438** Yosemite Circle, Concord, CA, 94521 , publication date 03/02/1976) **[8]**

A paddle wheel flocculator used in a horizontal direction water flow. The wheel is fabricated by a plurality of equally spaced semi cylindrical (cup shaped) paddles , formed by relatively thin sheet material that is undulated in a direction perpendicular to the length of the paddles. The paddles are extended across the full width of the basin and they are fully secured to rotatable mounted hubs.

The paddles are at all times fully submerged in the water. The paddles arranged in such a way that transversely to the water flow. The water flow in the basin is diverted over relatively moving paddle surfaces to enhance the coagulation providing the sole source of motive power to rotate the wheel.

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These semi-cylindrical shape cups creating a concave trough and a convex back. The troughs of the paddles facing in the same direction of rotation of the hub, the plate including a multiplicity of undulations extending transversely to the length of the trough. The plate further having a projected width which at least about one-fourth the water depth. The water flow rotates the wheel at a speed compatible to the water speed while coagulants in the water effects on and are guided by the undulations of the plates.

Advantages of this design:

1. The thrust impeded on the elongated cup shaped paddle impose the sole motive power to drive the wheel. It saves the driving cost.

2. Undulated sheet members like - semi-circular sections of a corrugated culvert pipe, enhances strength and rigidity of paddles. This shape maximizes the surface area of the semi cylindrical cup and enhances the contacts between coagulated articles. Thus enhances the formation of the relatively large flocs and thereby shortens the floc settling time.

3. The paddles are oriented so that each trough faces upstream when it is adjacent to the floor of the basin. This slightly increases the water speed in the spaces between the outer most edge of such paddle and the basin floor. This helps prevent the accumulation of flocs, in the space immediately beneath the flocculator.

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4. The width of the paddles projecting onto a plane aligned with the axis of rotation. This is between about one-third to one-fourth of the total water depth. As they say, this avoids an excessive obstruction of the water path past the flocculator.

5. Paddle surface area over which the incoming water must flow is substantially greater than the "projected paddle surface". This is due to the semi-cylindrical configuration of the paddle and surface enlarging undulations. The ultimate flock size appears to be increase with the total surface area over which the water must flow. It has notified that larger surface area has a direct relation to the increase of flock size. [8]

5.4 Literature Summary and Discussion

Drinking clear water is a main need of consumers. Clarifying is done by removing turbidity. The literature describes how turbidity is removed and clearing water in treatment plants by employing mechanical flocculators. It also describes how suspended solid particles and colloids get together and form big floc separating from water and settling.

Flocculation process has to be done very carefully and sequentially. This is done by adding chemicals and controlled agitation to imparting energy to improve particle movement and contact colloids enhancing growth of flocks heavy enough to separate from water.

Many methods had been practiced to achieve this objective, without breaking already formed heavy flocks settling.

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Hydraulic flocculators simply utilized cross-flow baffles or 180^0 turns to provide required turbidity and turbulence. Criticality is to get ,gentle ,uniform mixing that will not sheer flocs. This type is efficient only if the flow is relatively constant. Type is suitable for medium large treatment plants.

Mechanical flocculators are rotating in horizontal or vertical axis, oscillating or reciprocating.

Walking Beam: Assembled paddles moving up and down in reciprocating motion. This minimizes short circuiting the water flow. This type can be installed either perpendicular or parallel to the flow directions. **Swinging paddles** sets 90 degrees apart. Peddles swing freely from a horizontal arm bracket, thus eliminating jamming debris or sludge. Wood or fiber glass paddles are fitted to steel arms.

Rotating flocculators: The slow rotation of wheel assures that every water flow laminate contacts a paddle surface. Can be used in tapered flocculators by varying velocity gradient .

Vertical rotating flocculators: These allow easier compartmentalization due to its vertical shaft, single reel design. In order to minimize short-circuiting a minimum of three compartments are recommended. These have flexibility for varying velocity gradient and removing the units out from basin for maintenance easily. No water leaks through basin walls. Driving mechanism is either shaft mounted or chain and sprocket or belt driven. Driving unit is mounted on concrete, aluminum or steel bridge over the basin. Lower end rests by readily adaptable C/I pillow block precision roller bearings in a water sealed housing.

Horizontal flocculators: Shafts are either perpendicular to the flow or parallel to the flow. These can be designed to produce tapered flocculators by varying the size and spacing of the paddle wheels can reduce the speed with each successive stage. Driving unit is mounted in out side the basing or on a platform above the water level. Disadvantage of this type is, water leaking through the stuffing box or seals and bearings and difficult to remove for maintenance. Advantage of this type is then can be process greater volume of water by coupling more wheels in a row in the same tank. See Fig 5-1a of pg 19 & fig 5-2 of page 21.

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Zero Energy flocculator: Horizontal wheel of equally spaced semi-cylindrical paddles, by thin sheet material that is undulated in a direction perpendicular to the length of the paddles. Paddles are across the full width of the basin and transverse to flow. Due to divergence of flow paddles enhance the flocculation providing the sole rotating power to the wheel. Corrugated semi cylindrical section increases contact area and improve rigidity of paddles.

CHAPTER 6

6. RESULTS AND RECOMMENDATIONS

Based on above literature review and special area studies, following recommendations and results were found.

6.1 Findings

1. As micro particle are negatively charged they are enlarged by combining with positively charged chemicals. Imparting energy to particle contact movement should be done in a reducing velocity gradient. It is practically recommended that velocity gradient is **60/s to 15/s.** [Ref - 9]

2. Hydraulic flocculators are efficient only if the flow is relatively constant. These are stationary concrete structures used in medium large water treatment plants and not suitable for mobile package plants.

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3. Mechanical swing and reciprocating flocculators have the fabricating and installation complexity on a steel tank that of our problem.

4. **In rotating flocculators,** slow rotation of wheel assures that every water flow laminate contacts a paddle surface. They can be used in tapered flocculators by varying rotating speeds in the recommended steps.

5. The ultimate flock size appears to be increase with the total surface area over which the water must flow. It has notified that larger surface area has a direct relation to the increase of flock size . But larger it should not break the ready to settle flocs.

6. **Vertical** rotating flocculators are easy to compartmentalization due to its vertical shaft, single reel design. Very suitable for mobile type flocculator tanks. Very easy to remove the units out from basin for maintenance. No water leaks through the stuffing boxes or rubber seals.

7. **Horizontal** flocculators can be designed to produce tapered flocculators by varying the size and spacing of the paddle wheels and reduce the speed in each

successive stage. Horizontal types more tends to water leaking through the stuffing box or seals and difficult to remove for maintenance

6.2 Recommendations

1. The peripheral speed of a paddle-wheel mixer should be limited to **0.40 m/s** for alum coagulation and **0.50 m/s** for lime softening flocculation. The ratio of maximum to minimum mixer rotational speeds normally varies between **2and 4 Ref[4] and [9]**
2. Paddle wheel diameter shall be **85%** of the water depth of basin. This ensures complete mixing. (For horizontal wheels)
3. Practically recommended velocity gradient **(G)** shall **successively** lowered in the next compartment from **60/s to 15/s . (G = 60/s ; 45/s ;30/s ; 15 /s)** [9]
4. Motors may have variable speed drives to enable to operator to vary the velocity gradients to match variations in the raw water turbidity conditions.

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6.3 Rational for choice

Based on my findings in the literature review, my aim is to modify, design and develop the present horizontal paddle arrangement to a vertical arrangement. Vertical flocculator is very suitable to mobile type flocculator tanks. Paddles wheel is easy to remove out from the basin for maintenance. No water leaks through the stuffing boxes or rubber seals. Paddle wheel ether can hang by a direct shaft coupled to gear box shaft or can supported at bottom thrust bearing.

It can improve the sludge removable by introducing strips of rubber flaps fitted to the bottom side horizontal frame of the wheel at the last stage ,which will sweep the deposited sludge in to a trench in the bottom of the tank. Final goal is to reduce maintenance and operational costs through labour, time, material and money.

CHAPTER 7

7. FLOCCULATOR PADDLE WHEEL DESIGN

7.1.1 Power Requirement & Paddle Wheel Design

Design of flocculator paddles requires followings.

a) Mixer speed (velocity gradients)

b) Paddle size

c) Power requirements

d) Number of paddles

e) Paddle wheel size

f) Layout

Flocculator wheels are rotated to give energy to move particle contact while not creating sufficient turbulence to break up the already grown up flocks.

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As literature mentions from practical experience typical **velocity gradients 'G'** in 1/s for flocculators ranges from **15/s to 60/s**. Flocculator basins are normally designed with multiple mixing compartments in a series, with velocity gradients successively lower in each stage. These are called "***Tapered flocculators***".

The ***G*** value in the first compartment causes a rapid transformation of the primary particles into higher-density floc. The lower ***G*** values in next compartments cause the building of progressively larger-size floc.

Water power for mechanical mixers is given by $P = G^2 V\mu$ **N-m/s** 7.1 {9A}.

Where *G*= velocity gradient V=Basin volume; μ=mixer viscosity in N-s/m^2 at 5^0 C.

Normally *G* values for stages 1, 2, 3 can be taken as $G_1=60$, $G_2=45$, $G_3=30$ or $G_1=45$, $G_2=30$, $G_3=15$ respectively for equal step down.

Water power requirement for mechanical paddle wheels is given by,

$$P = \frac{C_D A \rho v^3}{2} \quad \left(\text{or } \frac{C_D A \gamma v^3}{2g}\right) \qquad 7.2$$

Where, **P** = power imparted to water, in Watts.

C_D= Coefficient of drag, which varies with the length-to-width ratio *(L/W)* of the paddle blades. C_D values are given in the table 7-1

A= area of paddles, m^2 ρ = density of solution.

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Paddle imparts velocity to water. Therefore absolute velocity of paddle rotational velocity n_{abs} exceeds the relative velocity n_{rel}. Practical experience has shown that relative velocity of water is **75%** of the absolute peripheral velocity of the blade. [9B]

The peripheral speed of a paddle-wheel mixer should be limited to **0.40 m/s** for alum coagulation and **0.50 m/s** for lime softening flocculation. The ratio of maximum to minimum mixer rotational speeds normally varies between 2 and 4

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Table 7-1 Coefficient of Drag C_D for Paddle-Wheel flocculator, Based on Length to – Width ratio of the Paddle

Length –to-Width ratio (L/W)	C_D
5	1.20
20	1.50
∞	1.90

Table 7-1

Motor Power Required

The motor power required is calculated as follows.

$$\text{Motor Power } P_M = \frac{P}{E_{gears} \times E_{bearings}} \qquad 7.3$$

Where , $E_{bearings}$ = efficiency of the bearings, assumed 90 %

E_{gears}= Efficiency of bearings, assumed 70%

7.1.2 Determining Paddle wheel arrangement.

Paddle wheel diameter shall be 85% of the water depth of basin for horizontal axis wheels. In the case of vertical axis it will be the height of paddle blades. This ensures **complete mixing.** Determination includes paddle size, number of paddles and paddle wheel layout.

Each basin can have more than one paddle segments coupled together.

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A sample vertical paddle wheel is shown in Fig 7-1

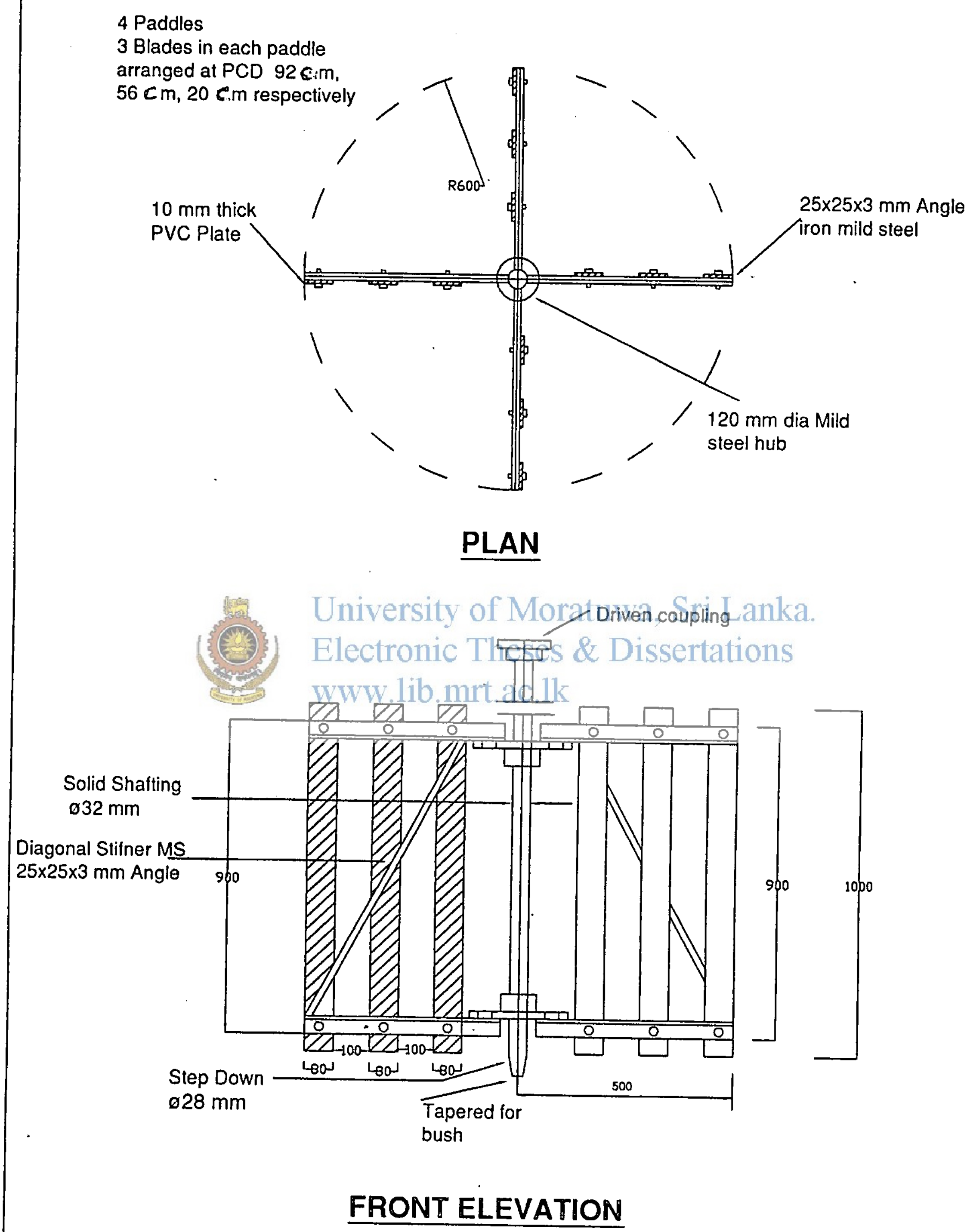
Diameter of wheel =1000 mm ; Height = 1000 mm

Blade width = 80 mm ; Blade spacing = 100 mm

03 blades in each paddle. 4 paddles placed at 90 ^{0} angle.

Blades located at center to center diametric distances of 920mm ; 560mm; and 200 mm. respectively.

VERTICAL PADDLE WHEEL ARRANGEMENT



All measurnments are in milli meters

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Fig 7 - 1

7.1.3 Rotational speed & Power required

From equation 6.2, ***Pw*** (Power imparted to the water) = $\frac{C_D A \rho v^3}{2}$

Then $Pw = (\frac{C_D \rho A_1 v_1^3}{2} + \frac{C_D \rho A_2 v_2^3}{2} + \frac{C_D \rho A_3 v_3^3}{2})N$ 7.4

C_D (Coefficient of drag) is calculated from the table blade length to width ratio *L/W*.

A_1 = *Total peddle blade area in the 1st* radius = *4× single blade area* ***W×L***

A_2 = *Total peddle blade area in the 2nd radius* = *4×single blade area* ***W×L***

A_3 = *Total peddle blade area in the 3nd radius* = *4×single blade area* ***W×L***

$A=A_1=A_2=A_3$ = 4×L(length of paddle)×W(width of paddle)

Say ***(Pn)*** = Number of paddles at each radius per wheel = 4 (normally *Pn*=2,3,4)

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Let *'N'= number of* segments (full wheel with 4-paddles. N= 1, 2, 3, ...)

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If Total area of paddles = A_T ,then $A_T = Pn \times A \times N$

Let,

v_1, v_2, v_3 = Average velocity of each paddle blade relative to the water in each radius

In practice paddle velocity relative to the water is approximately **75%** of the absolute peripheral velocity of the paddle. If n=paddle revolutions per seconds (r.p.s)

then $v=\pi n_{rel}d=0.75\pi n_{abs}d$ where, d =diameter from center to center of each blade.

Total power from all paddles , substituting these in *equation 7.4* we get,

$$Pw = \frac{C_D \rho\, (PnA_1v_1^3+PnA_2v_2^3+PnA_3v_3^3)N}{2} \qquad 7.4$$

That is $$Pw = \frac{C_D \rho PnNA}{2.}\{(0.75\pi n_{abs}d_1)^3+(0.75\pi n_{abs}d_2)^3+(0.75\pi n_{abs}d_3)^3\}$$

then, $$Pw = \frac{C_D \rho}{2} A_T(0.75\pi n_{abs})^3\,(d_1^3+d_2^3+d_3^3) \qquad 7.5 \quad [9\ D]$$

7.1.4 Sample calculation for vertical paddle wheel in fig: 7-1

Paddle wheel dimensions are selected to floculator tanks of mobile water treatment plants.

Considered three stage flocculating tanks each compartment with following dimensions.

Length 1.6m ; **height** 1.6m ; **width** 1.5m. Alum mixed water height **1.5 m.**

In the equation 7-1, water power for stage1 $P = G^2 V\mu$ **N-m/s** 7.1

Velocity gradient for first stage 1 $G=60/s$. and $\mu = 1.512 \times 10^{-3}$ N-s/m^2 at 30^{0}C

Flocculating volume V=1.6 x 1.5x 1.5 m^3 = **3.6 m^3**

Substituting these in equation 7.1,

water power for stage 1 paddle wheel

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$P = (60/s)^2 x 3.6 m^3 x 1.512 x 10^{-3}$ *N-m/s*

$P = 19.595$ *N-m/s*

Say ,P=20 W

Motor Power $P_M = \dfrac{P}{E_{gears} \times E_{bearings}}$ *7.3*

Where , $E_{bearings}$ = Efficiency of the bearing , assumed 90 %

E_{gears} = Efficiency of gears , assumed 70%

Then, from equation 7.3 Stage 1 $P_M = \dfrac{0.02}{(0.7x0.9)}$

$P_M = 0.0317$ *kW*

Say $P_M = 0.032$ *KW.*

In a similar manner power imparted to water and motor power wanted for 2nd and 3rd stages are calculated using *G=30/s and G=15/s,* respectively. Results tabulated in the **table 7-2.**

7.2.1 Rotating speed for paddle wheel configuration selected in Fig 7 -1.

L = length (Height) of blade = 120 cm =1.2 m and wheel diameter is 1.2 m.

W= width of blade = 10 cm = 0.1 m space between two adjacent blades 8 cm =0.08 m.

3 blades in each four paddles in the locations of 1.10 m; 0.74 m and 0.38 m. center to center.

Then, Total paddle area $A_T = A \times Pn \times N$

.Where $A = L \times W = 1.2 \times 0.1 = 0.12$ $Pn = 4$ *paddles,* $N = 1$ *(one segment)*

$A_T = 0.12 \times 4 \times 1$

$A_T = 0.48$

C_D=Drag coefficient . In table 7.1 ,this given as to L/W ratio.

Blade length to width ratio L/W=1.2/0.1=**12**

L/W	C_D
5	1.2
12	C_D
20	1.50

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Interpolating for C_D ,

$$\frac{12-5}{20-5} = \frac{C_D - 1.2}{1.5 - 1.2}$$

$C_D = 1.34$

When ρ=1000 , $P_w = 20.0$ *W (N-m/s)* substituting these values in the equation 7.5

$$20 \text{ N-m/s} = \frac{(1.34) \times 1000 \text{ N/m}^4 \times 0.48 \text{ m}^2 \times (0.75\, \pi \mathbf{n}_{abs}) \times [(1.1\text{m})^3 + (0.74\text{m})^3 + (0.38\text{ m})^3]}{2}$$

$\mathbf{n}_{abs} =$ 0.0147 rev/s

Say, $\mathbf{n}_{abs}$ **= 0.88 r.p.m.**

Recommended values for n_{abs} for first stage is **2 to 10 r.p.m.** Since above n_{abs} value is very low , suitable r.p.m. in the **recommended** range was obtained by trial and error by altering blade length and width and their placing distances in the arm.

7.2.2 Second trial for finding speed in the recommended range.

Trial dimensions selected L = length of blade =1m ; W= width =0.08 m ;wheel diameter= 1m

3 blades each four paddles in pitch circle diameter 0.92 m; 0.56 m and 0.02 m. center to center.

Using equation **7.5** , let **Pw** = Power imparted to the raw water

then, $\mathbf{Pw}=C_D\rho A_T(0.75\pi n_{abs})^3\ (d_1^3+d_2^3+d_3^3)$ **7.5**

where $A_T=APnN$

. $A=L\times W=1.0x0.08$ $Pn = 4$ *paddles,* $N=1$ *(one segment)*

$A_T=0.08\times4\times1$

$A_T=0.32$

C_D=Drag coefficient . In table 7.1, this given as to L/W ratio.

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Blade length to width ratio L/W=1.0/0.08=12.5

L/W	C_D
5	1.2
12.5	C_D
20	1.50

Interpolating for C_D ,

$$\frac{12.5-5}{20-5} = \frac{C_D - 1.2}{1.5 - 1.2}$$

$C_D=1.35$

When ρ=1000 , Pw= **20.0** ***W*** *(N-m/s)* substituting these values in the equation **7.5**

$$20\ \text{N-m/s} = \frac{(1.35)\times1000\ \text{N/m}^4\times0.32\ \text{m}^2\times(0.75\ \pi\mathbf{n_{abs}})\times[(0.92\text{m})^3+(0.56\text{m})^3+(0.20\ \text{m})^3]}{2}$$

$\mathbf{n_{abs}}$ = 0.0408 rev/s

Say, $\mathbf{n_{abs}}$ **= 0.041 rev/sec = 2.46 r.p.m.** lowest r.p.m .required for flocculation.

This is in the recommended r.p.m range of 2 – 10 .

In the similar manner $\mathbf{n_{abs}}$ for 2nd and 3rd stages were calculated using respective water powers.

Table 7-2 Sample design parameters for the selected *Paddle Wheels* in three stages .

Stage	Velocity Gradient, G,1/s	Motor power Required kW	Water Power kW	n_{rel} r.p.m.	n_{abs} r.p.m.	Actual speed 'n' rpm
1	**60**	**0.032**	0.02	1.84	**2.46**	2—10
2	***45***	**0.02**	0.011	1.01	**1.35**	1—6
3	***30***	**0.008**	0.005	0.46	**0.61**	0.5--4

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Table 7 -2

Absolute rotational speed n_{abs} is the lowest required speed for the wheel. Gear reduction shaft r.p.m.s were selected more than that as to market availability of gear reduction units, but in the respective recommended **r.p.m. range limits** for each stage.

It is selected **identical** motors for all three stages for interchanging ability with identical size spare motor. Motor capacity recommended is **0.37 KW** .

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8.1 CHAPTER 8 - DESIGN TREE & ANNALYSIS.

DEVELOPMENTS OF FOCULATING PADDLES IN MOBILE WATER TREATMENT PLANTS

USER NEEDS

- To improve the paddle wheel arrangement to improve the flocculation and productivity without increasing power consumption.
- To reduce fabricating and operational costs by easy removing with low labour, time, cost without any heavy mounting structures.
- To prevent any water leaks and to increase life time of bearings and parts. Not to harm the processing water and environment.. .

ENGINEER'S PERSPECTIVES

- Processing capacity & paddle type : 500 m3/day ; Vertical rotating
- Wheel Size : Diameter 1.m ; height 1.m Speed (r.p.m.) **step1**- 8, **step 2**- 5, **step 3** -3
- Gear ratio : **Step 1**- 175:1, **Step 2** -280:1, **Step 3**- 460:1
- Motor power : Max 0.37 Kw ,1400 r.p.m. 4 pole. A.C. 3 ph,50 Hh.
- Cost per unit : LKR 150,000.00 (with new motor & gear boxes ,paddle wheel and structure).

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Main Problem

- Flocculator Type
  - 1Rotate vertical
  - 2 Rotate Horizon
  - 3 Walking
  - 4 Swing
  - 5Vertical Impeller

Associate Problem

- Fabrication AP 1
  - 1Welding&Fastn
  - 2 Reverting
  - 3 Welding
  - 4 Adhesive
- Material AP 2
  - 1F.Glass/Al/Steel
  - 2 Stainless steel
  - 3 Wood / Steel
  - 4Aluminum/ Steel
  - 5 P.V.C.& Steel

Secondary Problems

- Power Source SP1
  - 1 Electric Motor
  - 2 I.C. Engine
  - 3 Manual Power
- Transmission SP2
  - 1Belt Drive
  - 2Chain& Sprocket
  - 3Gear Reduction

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8.2 Design tree analysis - problems to be addressed

1.0 Main Problems	2.0 Associated Problems	3.0 Secondary problems
1. Flocculator type	1. Fabrication method	1. Power source
	2. Materials	2. Power transmission modes

8.3 Solutions for main problem – Strengths and weaknesses

1 Rotating Vertically :

These allows easier compartmentalization due to its vertical shaft, single reel design. They have flexibility for varying velocity gradient and removing the units out from basin for maintenance easily. No water leaks through basin walls since no bearings fitted on side walls. Readily removable bearings on top. Installing submerged bearing is little complex and expensive. Since these are rotating in low r.p.m. a guide bush is enough at the submerged end of shaft. No tight gland or rubber seal friction. Can attach sludge sweeping rubber strips to bottom side of frame.

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2 Rotating Horizontally :

These can be produce tapered flocculators by varying the size and spacing of the paddle wheels. Driving unit is mounted in out side the basing or on a platform above the water level. Disadvantage of this type is, water leaking through the stuffing box seals and bearings and difficult to remove for bearing and seal replacements and cleaning work. Advantage is these types can be process greater volume of water by coupling more wheels in parallel in a row in a wider tank. At this situation only one wheel is used.

3. Walking Beam :

This mechanism needs more power and extra mechanical linkages such as torque arm assembly, connecting rod and riser beam and paddles. It also needs more strengthened structures. This is not suitable for our problem situation.

4. **Swing paddles assembly.**

A series of vertically swinging paddles are mounted on a long horizontal shaft. The tank should have a large length and breath. Structure is heavier. This type is not suitable for the limited space basing. Area is not so effective.

5. **Single vertical impeller**

This is a single large impeller mounted in the middle of a large basing. Flocculation effect is limited as only one impeller or fan type blade. Suitable for a large single basing. Short circuiting happens.

8.4 . Solution for Associated Problems. - Strengths and weaknesses

A.P.1Fabrication

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1. **Welding & Fastening :**

This paddle wheel needs to remove from the basing tank for cleaning and bearing replacements. The wheel frame must be stiff. Non metallic paddle blades shall be fastened by bolts. Driving unit and primover to be dismantled to remove the wheel, therefore welding and bolt fastening both needed. This solution is **recommended**.

2. **Reverting :**

This is not recommended as the wheel unit has to be removed when wanted. Reverting only is not enough for fabricate the parts and it is not enough for strength of the frame.

3. **Welding :**

Welding only is not permitted as some parts to be dismantled. Non-metallic parts cannot be welded.

4. **Adhesive :**

This is not suitable as most parts are metallic and unit is working under water.

8.4 Associated problem 2- Materials

1. **Fiberglass, Aluminum & Steel :**

This is recommended. Paddle blades can be made by applying 4 mm thick fiber glass layers on a 2mm thick longitudinally corrugated aluminum sheet. As frame, hub and mounting brackets needs rigidity, they are recommended to fabricate from mild steel sections and painted food grade marine paint.. Fiber glass surface to be smoothen by spraying a water resistant paint.

2. **Stainless steel :**

Stainless steel is very suitable , but it is expensive and much heavier.

3. **Wood & Steel :**

Tough water resistant wood and steel is recommended. Timber surface should seasoned and polished. (recommended timber is "*Redwood*", "*Hora* " and " *Kumbuk* ".)

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4. **Aluminum /Steel :**

Aluminum sheets alone are not suitable for blades. Coagulated water is mixed with aluminum sulfate and lime. Aluminum reacts in acidity and alkaline media and form cavities on the surface. Pure aluminum is **not suitable**. Therefore it is **rejected**.

5. **Thick P.V.C. curve section plates & Steel sections :**

A thick P.V.C. curve section plates can be obtained from splitting a thick 200 mm diameter 10 mm thick P.V.C. pipe. P.V.C. gives the chemical and water resistance and lightness. Thickness and the curvature gives the stiffness of blade. Frame is fabricated by mild steel . Thickness of section gives the strength and stability of assembly.

8.5.1 Secondary Problems 1- Power source

1. **Electric Motor :**

   Electric motor is **ideal** for this situation. It can be readily coupled with gear reducer and energy efficient than I.C. engine. Runs smoothly and very low noise. Not suitable for areas where no electricity. Can used with variable speed drives. Should be covered from bad weather.

2. **Internal Combustion engine:**

   These engines have extra maintenance aspects and they are heavy. They vibrates and noisy. Oil or fuel may spill on mounting brackets and to water basins. More suitable for areas where no electricity.

3. **Manual Power :**

   Very hard to use human power as rotating has to be done continuously at a constant speed for several hours. Therefore it is not recommended.

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8.5.2 Secondary Problems 2- Power transmission :

1. **Belt Drive :**

   Too much space required to placer with an electric motor. Difficult to get a large speed reduction. Slipping may occur. Operation is simple. Suitable for little power requirements. Low weight and easy maintenance. This wheel rotates in very low r.p.m. It requires large speed **reductions**. Therefore belt drives are **rejected**.

2. **Sprocket and chain :**

   Little more space requires with a motor on a flat-form. Noisy and requires little maintenance. Can transmit more power without slipping, Cannot obtain large speed reductions.

3 **Gear reduction box :**

Requires less space when directly coupling with the motor. Gear reduction unit is expensive and heavy. Can transmit high power and obtain **large speed reduction as our requirement**. Therefore **gear drive system selected** for power transmission.

Based on above disadvantages and advantages of above alternatives, some sub solutions were selected and some were rejected according to the suitability to present **problem** situation.

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8.6. New Sub Solutions

(01) 1.1.1.1.3. – Vertical/Welding & Fastening /F.glass, Alu&Steel / Electric Motor /Gear

(02) 1.1.2.1.3 --Vertical/Welding & Fastening / Stainless Steel / Electric Motor /Gear

(03) 1.1.3.1.3 --Vertical/Welding & Fastening / Wood & Steel / Electric Motor /Gear

(04) 1.1.5.1.3 --Vertical/Welding & Fastening / P.V.C. & Steel / Electric Motor /Gear

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Comparison of new sub solutions		
Sub solution	**Advantages**	**Disadvantages**
1.1.1.1.3	Conversion to vertical rotation is easy. No leaks through walls. Easily removable. Fiber glasses reinforced with rippled aluminum have good and adequate strength . Can bolted to mild steel frame. Can drive with electric motor and pulley- belt drive.	Belt may slip. Maintenance of bottom submerged bearing is much difficult. Fiber glass surface should be painted by a food quality paint.
1.1.2.1.3	Well suitable for muddy , chemically coagulated raw water. Can fabricate the paddles and frame for more strength and long lasting period. Suitable for vertical rotation . Requires little space for direct coupled gears. Can obtain large speed reductions and toque than other types of drives	Material is expensive and heavy, may require little more power. Gear box is heavy and expensive
1.1.3.1.3	Can fabricate the paddles using high water resistant variety of wood . Frame is done by mild steel sections. Can obtain good strength and fairly long life. Suitable for vertical rotation. Gear drives can obtain large speed reduction and power than to belts and chains. Need small space and low maintenance than to belt and chains.	Material is expensive and heavy, may require more power than a fiberglass or stainless steel. Not long lasting as stainless steel. Wood must protect by applying wood preservative painting. Wood preservatives may toxic to drinking water. Gear drives expensive and heavy and noisier..
1.1.5.1.3	Can fabricate the paddle boards with thick P.V.C. curve section plates split from thick P.V.C. pipe. Have good water and chemical resistant and light weight. Frame is done by mild steel sections. Can obtain good strength and fairly long life. Suitable for vertical rotation. Gear drives can obtain large speed reduction and power than to belts and chains. Need small space and low maintenance than to belt and chains.	P.V.C. pipe should be split evenly. Not strong and long lasting as stainless steel. Gear drives expensive and heavy and noisier than belts.

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8.7. Candidate Solution

Considering above mentioned strengths and weaknesses, following two candidate solutions were selected .

- **1.1.1.1.3**

  Type - Rotating vertically

  Fabrication - Welding and fastening

  Material - Fiber glass / Aluminum / mild steel

  Power source - Electric motor

  Speed reduction - Gear reduction box_

- **1.1.5.1.3.**

  Type - Rotating vertically

  Fabrication - Welding and fastening

  Material - Thick P.V.C. plates & Steel

  Power source - Electric motor

  Speed reduction - Gear reduction box

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Comparison of material combination

In the candidate solutions, flocculator type, fabrication of paddles, power sources and speed reducing methods are all identical. Conceptual solution is found by comparing material combination.

1. Candidate solution 1.1.1.1.3

Fiber glass /Aluminum /mild steel

Advantages

Wheel paddles are made by thin longitudinally corrugated aluminum sheets covered by fiber glass layers. These blades are fixed by stainless steel bolts to mild section fabricated frame. This is low weight and cheap.

Disadvantages

- Construction complexity. Takes time for fiber glassing the aluminum sheet blades. Fiber glass surface must coated by a paint to smoothen the surface.
- Somewhat low strength. If fiber glass layer damages, aluminum start to react with chemicals and starts decaying.

8.7.2 Candidate solution 1.1.5.1.3

P.V.C. paddle boards

Advantages

- Light weight and cheaper than fiber glassing. No paint coating requires.
- Good stiffness with curved wall and long lasting to chemicals and raw water.

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Disadvantages

Cutting P.V.C. pipe evenly is difficult. Not very strong as wood or stainless steel.

By considering the above strengths and weaknesses of the candidate solutions, most suitable final solution was selected for the main problems and secondary problems.

8.8 Conceptual Solution

- **1.1.5.1.3**

Type	- Rotating vertically
Fabrication	- Welding and fastening
Material	- P.V.C. Paddle boards with mild steel frames protection painted .
Power source	- Electric motor
Speed reduction	- Gear reduction box

CHAPTER 9

9.0 PADDLE WHEEL DESIGN DESCRIPTION.

1. **The paddle wheel**

The paddle wheel is mounted in vertical axis. Paddles are or bolted to a steel angle iron frame .The frame is strengthened by a diagonal bar. Frame is welded or bolted to hub plate welded with a steel bush. The bush is keyed to carbon steel shaft.

Top end is mounted on a radial roller bearing which bears the weight of the shaft and paddle wheel assembly. This bearing tight fitted in to a purpose machined bush welded to a mild steel plate. This plate is welded on to two channel sections. This cut sections are fixed on the tank top frame by bolting. Shaft top end has the driven side coupling half keyed to shaft.

2. **Gear box**

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Gear reducing unit & drive motor arrangement is mounted in a higher level to upper bearing plate on a steel bench fabricated on the same steel bridge way.

3. **Bottom end**

Bottom end is submerged in side the flocculating water tank guided by a purpose machined bronze or nylon bush. This prevents swinging of the wheel. This bush is tight fitted in to a steel bush which is welded on to a steel plate or cast iron plate which is firmly fixed to tank bottom plate by means of welding or fastening by non corrosive bolts. This bush can be replaced with a new one when worn out.

4. **Sludge sweeping**

The system introduces flexible rubber strip to bottom horizontal arm of the frame of rotor, so that it will sweep the accumulating sludge in to a transverse direction channel on the bottom plate. (This is optional).

5 **Discarding**

Items can be dismantled from bolts Mild steel decay by nature. P.V.C. recyclable

Non corrosive bolts can be re-used . Bronze bush can be re-melted.

9. 2 Design Specifications

1. **Flocculator Wheel :** Vertical axis , 4 paddles in 90^0 apart, 3 blades in each paddle.

   Diameter 1.0m height 1.0 m.

   Paddle blade : Length =100 cm; Width 8 cm; 10 mm thick quarter circle curve section P.V.C. plate. These are cut pieces of axially split P.V.C. blades from 10mm thick diameter 200mm P.V.C. pipe. Paddles are fastened to frame by 10mm stainless steel or chrome plated bolts.

   Blades fitted at center to center pitch circle diameters 920 cm ; 560 cm ; 20 cm.

2. **Frame arms :** Mild steel angle iron redially welded to hub. Diagonally stiffened up and down arms by M.S. angle piece. M.S. size 25 mm x 25 mm x 3 mm.

3. **Hub :** Mild Steel plate 10 mm thick & M.S. bush. Thickness 15mm :

   Outer ø=50mm ; inner ø=25mm.

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4. **Paddle shaft :** cold rolled solid shaft steel (carbon steel) . Bigger than power shaft

   Outer ø=20 mm

5. **Power shaft :** Dry well shafts cold rolled solid shafts (carbon steel) turned and polished.

6. **Shaft coupling :** Keyed cast iron flexible coupling, bored to slipover the shaft and babitted for accurate alignment.

7. **Top Bearing :** Top bearing is grease lubricated antifriction thrust ball bearing .

   (L 10 rating at least 100,000 hrs. with 10 r.p.m.). Housing shall be bolted to steel plate. This bearing shall be purpose design to carry shaft and wheel loads plus and additional of 25% load of the weight of the unit.

8. **Bottom end :** Guide bush is purpose machined bronze or nylon bush. This prevents swinging of the wheel and shaft corrosion.. The bush is tight fitted in to a steel bush which is welded on to a steel plate or cast iron plate .

9. **Bridge way :**M.S. channel section 37mm x 50mm x 37mm x 5mm .

Mounting structure; M.S. 90^0 angle section 37mmx37mmx5mm: 12mm M.S. plate

10. **Protective coating :** Metal surfaces painted with anticorrosive marine paints.

11. **Gearing ratio : stage 1**,175:1 ; **Stage 2**, 280:1 ; **Stage 3** ,460:1

Type :Worm & gear. with life factor 100 million cycles with service factor1.5 (continuous, transient, starting).

12. **Electric Motor :** Squirrel cage induction ,3 ph, AC 50 Hz ,1400 r.p.m.

All stages 0.37 KW identical motors.

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To get the calculated speeds from the 1400 r.p.m. electric motors it have to find very high gear ratios. Market availability of such speed reduction gear sets are **difficult** to find. Therefore Gear ratios were selected so that paddle wheel rotational speeds will **increased** within the recommended range as **table 9 – 1**

13. **Selected gear ratios and actual wheel speeds.**

Stage	Calculated n_{abs} r.p.m.	Motor power KW	Motor r.p.m.	Gear ratio	Actual Wheel speed rpm	Recommended range
1	2.46	0.37	1400	175 :1	8	2—10
2	1.35	0.37	1400	280:1	5	1—6
3	0.61	0.37	1400	460:1	3.0	0.5--4

Table 9 -1

CHAPTER 10

10 DESIGN EVALUATION

10.1 Motor power for drive.

Power required to rotate the fastest wheel at **8 r.p.m.**

using the equation 7.5 , $n_{abs}=8/60$

$$\text{Power} = \frac{(1.35)}{2} \times 1000\ \text{N/m}^4 \times 0.32\ \text{m}^2 \times (0.75\ \pi \mathbf{n}_{abs}) \times [(0.92\text{m})^3+(0.56\text{m})^3+(0.20\ \text{m})^3]$$

$$= 508.93 \times (8/60) \times [0.962]$$

Power = 65.278 watts

Power = 0.0653 KW.

Proposed power for motor 0.37 KW > 0.0653 KW

$$\text{Safety factor} = \frac{\text{Available power}}{\text{Required power}} = \frac{0.37}{0.0653} = 5.67$$

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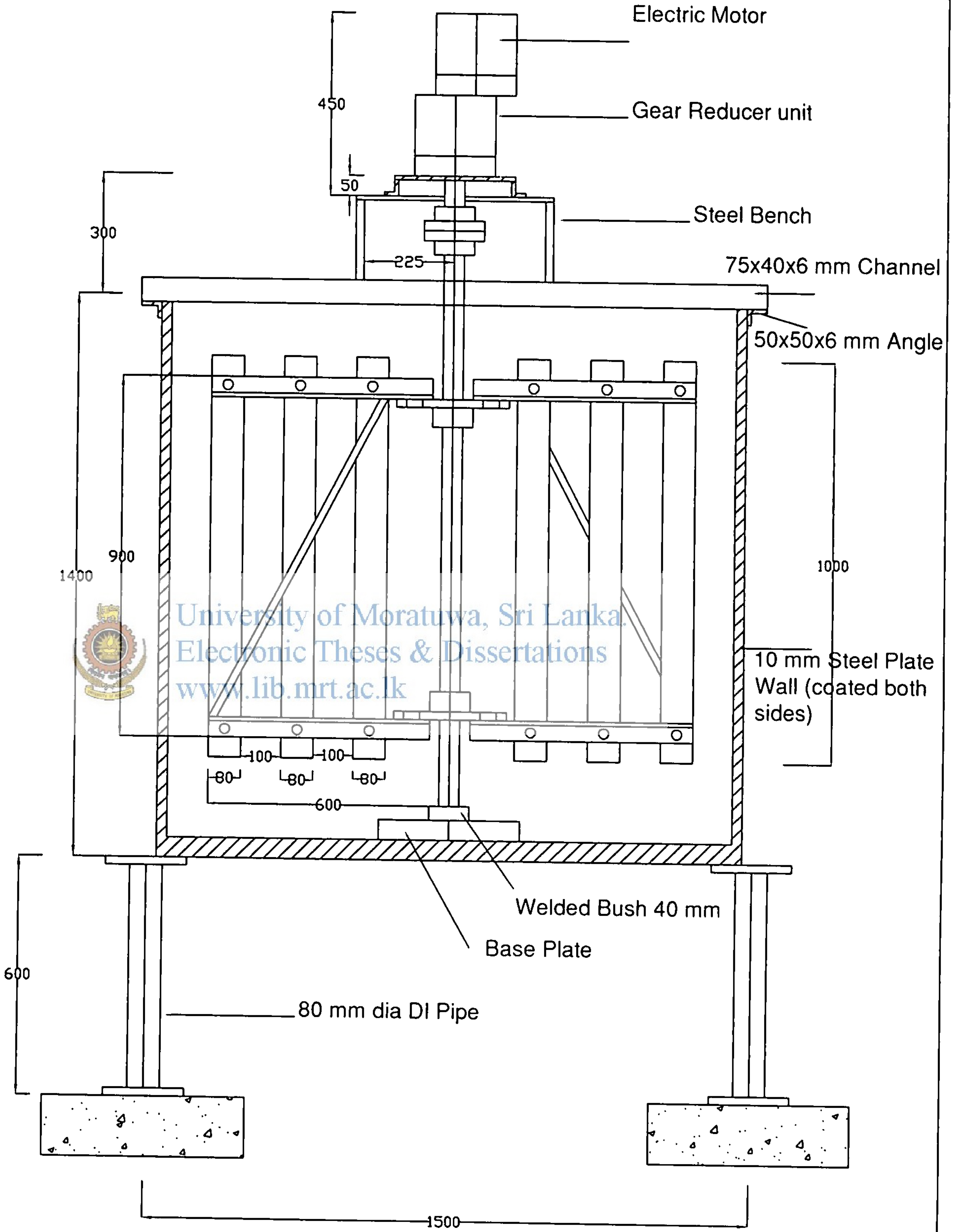
Therefore selected power **0.37 KW** for identical motor is suitable .

VERTICAL PADDLE WHEEL FLOCCULATOR FOR MOBILE PACKAGE TYPE WATER TREATMENT PLANT



FRONT ELEVATION

FLOCCULATOR PADDLE WHEEL & DRIVING UNIT ARRANGEMENT

FIG 10-1

All measurnments are in milli meters

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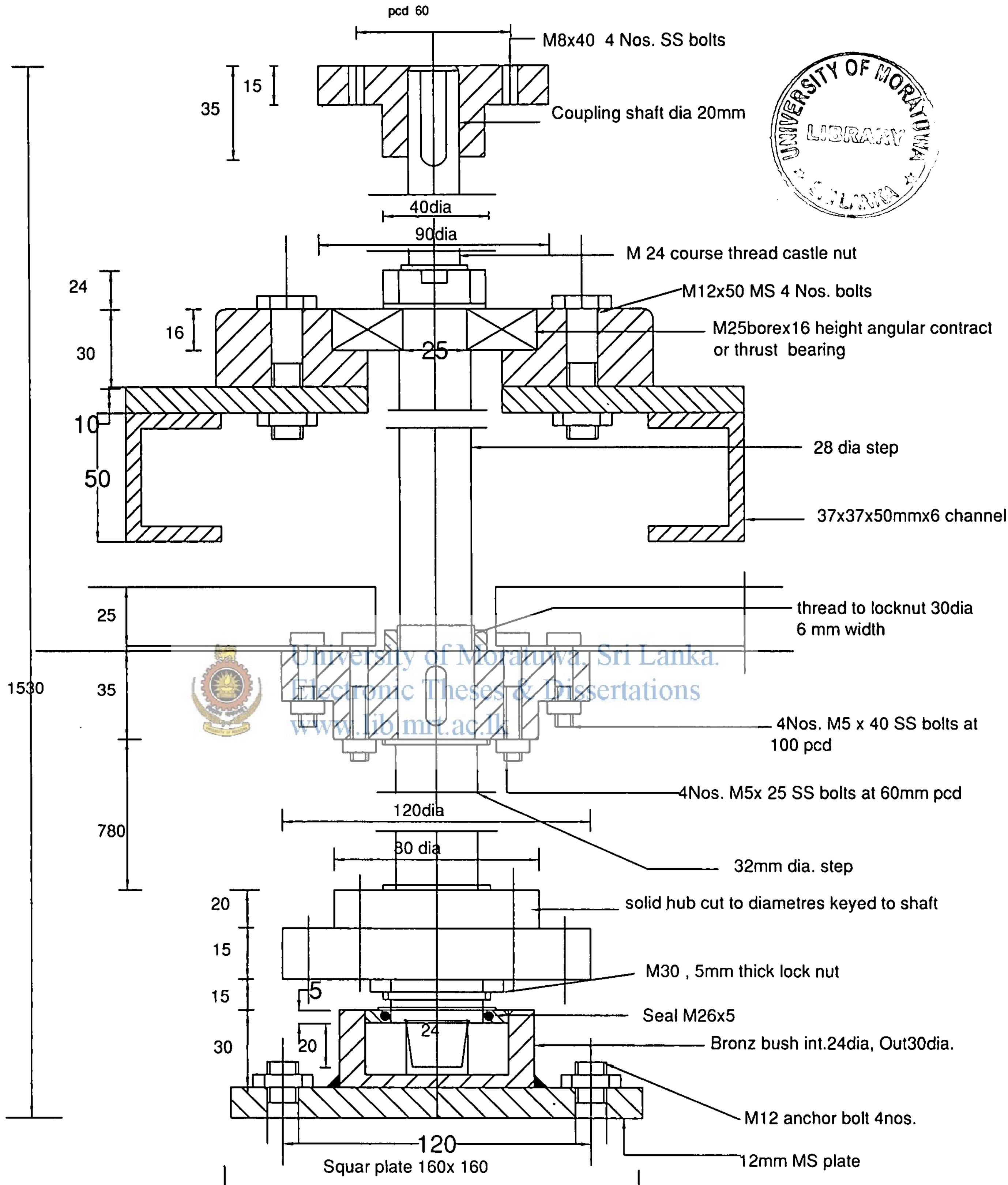

SECTIONAL ELEVATION

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FLOCCULATOR PADDLE WHEEL SHAFT & PARTS ASSEMBLY

FIG 10-2

ALL DIMENSIONS ARE IN MILIMETER

10.2 Evaluation of shaft sections ,bolts and sections for strength.

Least diameter of shaft is at driven coupling . Considering power required for fastest wheel, considered fastest r.p.m. is 10.

Power = Torque X angular velocity

65.3 = T *10 * 2 π/60

T = 62.357 Nm

From Torsion equation ,

$$\frac{T}{J} = \frac{\tau}{r}$$

where J= Polar moment of shaft section = $\pi d^4/32$

τ = torsional shear stress for shaft material

d/2= r

then , $d^3 = \frac{16\,T}{\pi\,\tau}$

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From theory , $M = \frac{I\sigma y}{y}$ where M = bending moment on shaft and $I = \frac{\pi d^4}{64}$, $y = \frac{d}{2}$

hence , $\sigma y = \frac{32M}{\pi d^3}$

Considering principal stresses acting on shaft,

Allowable least shaft diameter for maximum bending moment **'M'** and allowable maximum bending stress 'σd' is given as ;

$$d^3 > \frac{16}{\pi \sigma_d} \left\{ Mk_b + \sqrt{(Mk_b)^2 + (Tk_t)^2} \right\} \qquad 10.1$$

Allowable least shaft diameter for maximum torque **'T'** on and allowable maximum torsional shear stress 'τ_d' is given as

$$d^3 > \frac{16}{\pi \tau_d} \left\{ Mk_b + \sqrt{(Mk_b)^2 + (Tk_t)^2} \right\} \qquad 10.2$$

Where K_b and K_t factor for sudden minor shocks k_b =1.5 to 2.0 ; k_t =1 to 1.5

For sudden heavy shocks k_b = 2.0 to 3 ; k_t =1.5 to 3.0

The shaft paddle wheel assembly is suspended on a thrust bearing . It is guided in a bush at the bottom end.

No swinging at the bottom or lateral forces acting on shaft. Therefore it is assumed that the shaft is in tension and torsional shear only.

Then both equations 10.1 and 10.2 compiles to equation 10.3 as follows;

$$d^3 >= \frac{16}{\pi \tau d} \{Tk_t\} \qquad 10.3$$

Shaft material is low carbon S46 C Ni alloyed (0.8%) shafting material.

Practical recommendation for design purposes for most ductile materials ,

for bending stress σ_d =0.36*δut & σ_d=0.6*δy which ever lowest.

Like wise τ_s=0.2*δut & τ_s =0.3*δy which ever lowest.

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[10] Ref: Google serch Torsion: power transmission and stress concentrations design supplement. & Mechinery hand book (1996) 25^{th} ed., Industrial press Inc. New York. Pg280

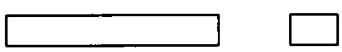
Ni steel shaft S45C (ASME) σy =504 N/mm^2 σ_{ut}=700 N/mm^2

[11] WWW.engineershandbook.com/tables/steelproperties G10500 (sited 12/14/2009)

Therefore τ_s=0.2 *700 = 140 N/mm^2 and τ_s =0.3*504 = 151.2 N/mm^2

Lowest is τ_s= 140 N/mm^2 .

Rectangular key dimensions from shaft diameter.

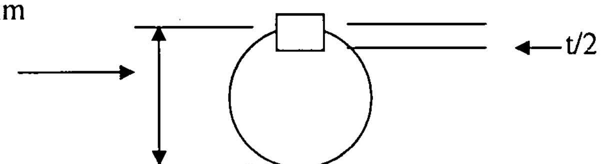


L=length 1.5d ; w=width = d/4 ; t/2=thicknes/2=d/12

Diameter at coupling step d=20 . **selected** L=30mm ; w=6 mm ; t/2=1.67 taken as t=5 mm. [12]

Shaft diameter at key cut = 20-t/2 mm

= 17.5 mm



From eqn; 3 , $d^3 >= \frac{16}{\pi\tau d}\{Tkt\}$ --------**eqn 3**

used K_t= 1.5 for sudden minor shocks. Then T x k_t= 62.357 * 1.5

$$\tau d >= \frac{16\, Tk_t}{d^3\, \pi}$$

$$\tau d >= \frac{16 \times 62.357 \times 1.5 \times 10^3}{\pi \times (17.5)^3} \quad N/mm^2$$

$$= 88.88 \ N/mm^2$$

88.88 N/mm^2 < Allowable shear stress for shaft 140 N/mm^2 140/88.88 = 1.57=S.F.

<u>This section diameter for shaft 20 mm is satisfied .</u>

[13] Material yield stresses are real material tested values . Therefore S.F. =1.3 is acceptable to ASME codes. (ASME = American Society of Mechanical Engineers)

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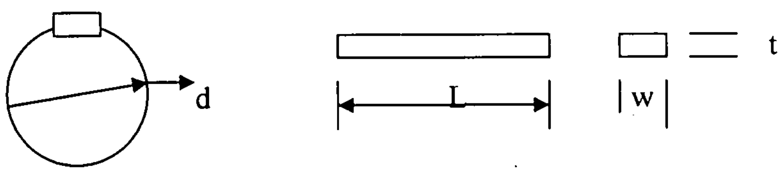
10.3 Strength for coupling keys



Key material is plain carbon (0.15%) mild steel. Ref: [14]

Material properties Tensile strength =430 N/mm^2

Yield stress = 230 N/mm^2

Most ductile material $\tau d= 0.6*\sigma y$ [10]

σ crushing =2 τ shear if the key is to fail both by crushing and shear at once.

<u>**τ shear** = 230 * 0.6 = 138 N/mm^2</u>

σcr =2*138

<u>= 276 n/mm^2</u>

Strength for crushing of key ;

Key dimensions selected. L= 30 mm ; W=6 mm ; t=5 mm.

Torque of shaft $T = \sigma cr * \frac{d}{2} * \frac{t}{2} * L$ Key crushing area 5/2 x 30

Crushing stress of key= σcr

$$62.357 * 1.5 * 10^3 = \sigma cr * \frac{20}{2} * \frac{5}{2} * 30 \ N/mm^2$$

σcr= 124.714< allowable shear stress 276 satisfied.

$$S.F. = \frac{276}{124.714}$$

S.F. = 2.2

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10.3.2 Strength for shearing of key

Torque of shaft $T = \tau \ shear * \frac{d}{2} * w * L$

$$62.357 * 1.5 * 10^3 = \tau \ shear * \frac{20}{2} * 6 * 30$$

τ shear =51.96 < Maximum allowable shear 138 N/mm^2 **satisfied.** S.F.= 138/51.96 =2.6

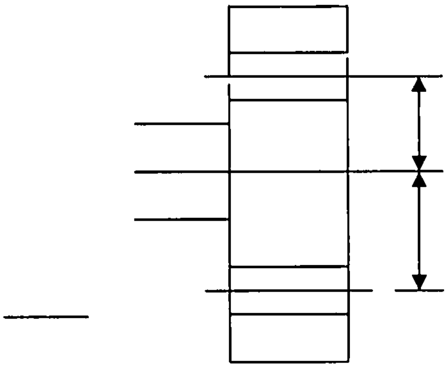
Selected key dimensions . **L= 30 mm ; W=6 mm ; t=5 mm**. satisfied.

10.4 Keys for hub

At hub shaft step diameter =30mm From key hand book rectangular keys for shaft **d=30**, table dimensions for key L=40 ; W=8 ; t=7. ref: [12]

Shaft d=30 > 20 mm. therefore no failure of keys at this section. **Key size is satisfied.**

10.5 Strength of coupling bolts.



30mm	**M8** A2 coupling bolts material S304 Stainless steel
	Typical values Tensile strength =700 N/mm^2
	Yield Strength =450 N/mm^2
30mm	minimum Values Tensile strength =500 N/mm^2
	Yield Strength = 210 N/mm^2
	Ref: [15] stainless steel alloy Ni% 8 – 13 ; Cr %18 -19

Torque =nFr n= number of bolts r= pitch circle radius Bolt diameter=8 mm as M8 bolt.

$$F= \frac{62.357 \times 1.5 \times 1000}{4 \times 30}$$

F= 779.46 N

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Shear stress in single bolt $= \frac{779.46}{\pi (8/2)^2}$

Shear stress in single bolt = 5.5 < Maximum σs= 63=210 x 0.3 **Satisfied.**

10.6 Safety at the castle lock nut.

Weight of paddle wheel assembly is suspended on a thrust bearing . The shaft is locked by a castle lock nut and friction at bearing inner bore.

Weight of the paddle wheel assembly .Unit weights by tables. Ref; [15] International ship builders association tables .

Weight of the paddle wheel assembly

	Item Description	Unit weight per meter	Item size or volume	Qty	Total weight KG
1	Driven coupling Ø 90 mm+ Ø 40 mm	50 Kg & 9Kg	0.015 &0.02	1+ 1	0.75 +0.18
2	Ø32 mm shaft assumed removed 15% volume	6.31	0.85	1.530	8.206
3	Solid hub Ø 80 mm+ Ø120 mm	35.5 & 88.8	0.02& 0.015	02	1.42 +2.664
4	M.S. Angle arms & cross bars 25x25x5mm	2.90x0.6	0.5 & 1.2	8 & 2	7+ 4.176
5	PVC plates 80mm x 100mm x 10mm	1.5per board		12	+18 Total =42.4 with bolts**44 Kg**

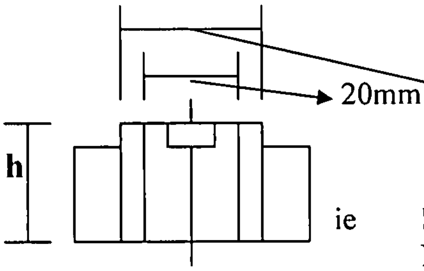


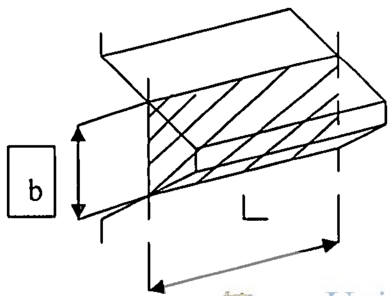
Table 10 - 1

$h = 0.9 \times$ shaft d_m shaft nominal diameter $= \frac{24+20}{2} = 22mm$

ie $h = 22 \times 0.9 = 19.8$ mm.

Nut material is hot forged and grooved .

Threads of nut will fail only by direct shear. Shaft is not compressed axially. Therefore threads do not have compression or bending forces.



rm=(24+20)/2=11mm mean thread height =(24-20)/2=2mm
M24 thread ,pitch =3mm ref:[16]
p=3mm b=breath at mean diameter = pitch/2 =1.5mm
$L = 2 \pi r_m n$ n = least numbers of threads not to shear
δ y=230 N/mm^2 σs=0.6 X δ y Ref [10]

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$\sigma s = \frac{W}{b \times 2 \pi r_m n}$ but σs=0.6 X 230=138 N/mm^2

Design stress of nut thread $\frac{\sigma s}{4} = \frac{W}{b \times 2 \pi r_m n}$ S.F.=4

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Then $\frac{138}{4} = \frac{44 \times 9.81}{1.5 \times 2 \pi \times 11 \times n}$

Required threads n = 0.12

But nut height h $= 0.9 \times d\,m$

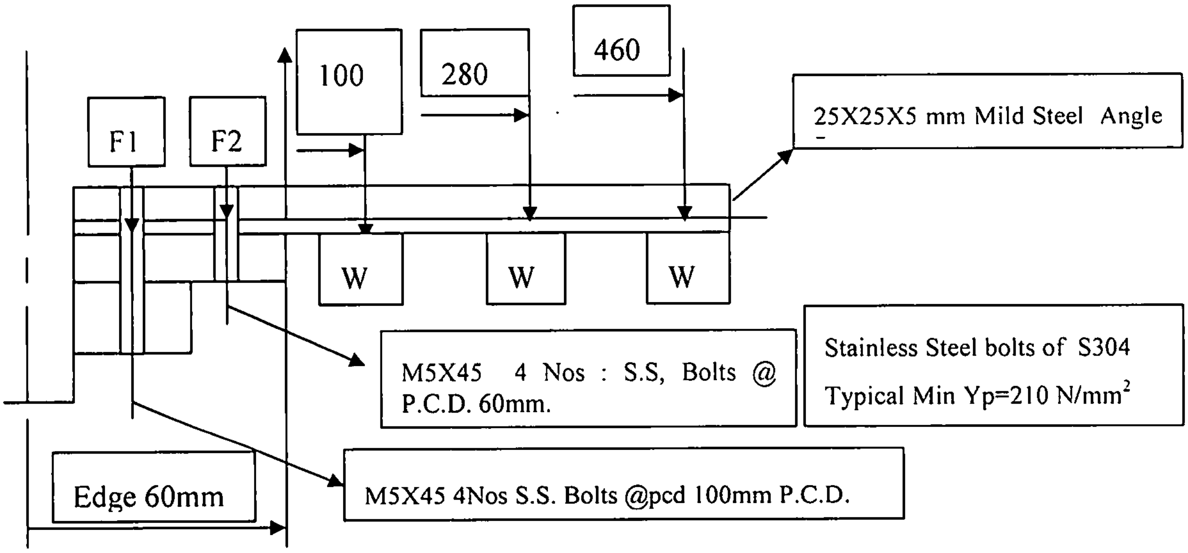
$= 0.9 \times \frac{(24 + 20)}{2}$

$= 19.8$ mm

Actual number of threads = 19.8/pitch =3

=6.6 > 0.12 required threads **satisfied.**

10.7.1 Design safety for hub bolts - See Fig 10-1 & Fig 10-2



Considering one arm of out of 4 paddles , weight of the three PVC paddle blades are shared by two mild steel frame arms at up and down.

Assumed that the frame is lifted and not touching the hub surface at the moment of bolts just starting to yield . Then the arm is simply supported at hub edge.

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F1 and F2 are the reactions by two bolts inner and outer on arm respectively.

W = weight shared by upper arm at 200/2 mm ; 560/2 mm ; 920/2 mm Pitch circle radii (PCR) from shaft axis respectively.

PVC blades are fastened to arms.

Let weights W= 1.5/2=0.75 kg.=0.75 x 9.851 N & Reaction at hub edge = R

Weight of one PVC blade = 1.5 Kg

↻ Rightwards moments about hub edge,

--F1(60-30)-- F2(60-50) + W(100-60) + W(280-60) + W(460-60)=0

3F1+F2=66W ----A

Vertical stability of arm assembly ↑ --F1--F2+R= 3W ----B

Please note that width of blade is 80mm, space between two adjacent blades is 100mm and arm length from shaft axis =500mm

↻ Moments about right free end of arm.

--40W--(40+100+80)W--(80+100+80+100+40)W--F2(500--50)--F1(500--30)+R(500--60)=0

Where 40R=66W+45F2+47F1 ----C

.

W=0.75x9.815 N

Substituting W and solving above A ,B ,C equations for F1 & F2,

F1= 55.18 N/mm^2 ,

F2=320.053 N/mm^2

Maximum tensile stress at bolt 2= $\frac{320.053}{\Pi d^2/4}$ Where d= 5 mm bolt diameter

Maximum stress 16.30< 500 N/mm^{2}tensile strength of bolt material therefore **satisfied.**

10.7.2 Torque on bolts

Total numbers of bolts sharing the torque = 2x4 in a hub x 2 (upper & down hubs) =16

Torque exerted on frames by drag on paddle boards = Torque on shaft

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Assuming only nearest 4 bolts to shaft is taking the torque , total of eight numbers of such bolts have in up and down .

Let shear force for each single bolt=F

$$\text{Then } T=8F \times r$$

$$62.357\text{x } 1.5\text{x}1000 = 8F\text{x } 30 \quad N/mm^2$$

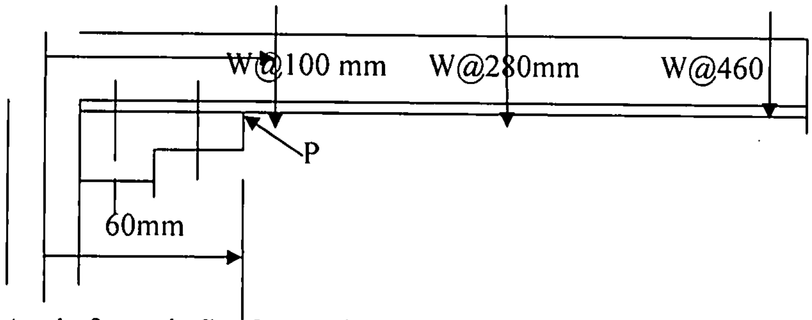
$$F= 103.92 \text{ N}$$

Working shear stress at single bolt = $\frac{103.92}{\Pi 5^2/4}$

$$=5.29 \text{ N/mm}^2$$

5.3 < 63. Nmm^2 minimum shear strength found in S.S. bolts. **Satisfied**

10.8 Bending of angle section arms



Angle frame is **fixed** on to hub by bolts. Frame maximum bending stress at P due to blade weights.

BM at P=Wg(100—60)+Wg(280—60)+ Wg(460—60) where W=0.75 g=9.81

P=4858.425 Nm.

Bending formula $M = \frac{(I x \sigma)}{Y}$ I_N= 2 nd Moment of plane section.

y= distance to neutral axis

σ = bending stress.

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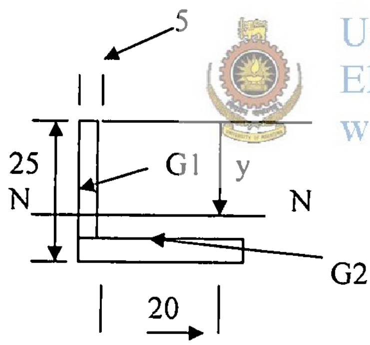
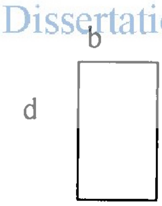




$I = \frac{bd^3}{12}$

Distance for neutral plane=y

{(5x25)+(20x5)}y=25/2(5x25)+(20+2.5)(20x5)

y=17 mm

In=In1+In2

In= $(IG + A1h1^2) + (IG2 + A2h2^2)$ by parallel axis theorem.

$= \frac{5x25^3}{12} + 25x5(17—12.5)^2 + \frac{20x5^3}{12} + 20x5(25—17—2.5)^2$

I_N= 12275 mm^4

$\sigma = \frac{4858.425x17}{12275}$ = 6.73 N/mm^2 bending stress . Axial tension of mild steel =0.6 σy=0.6x230

6.73<138 N/mm^2 Satisfies . Frame will not fail by bending

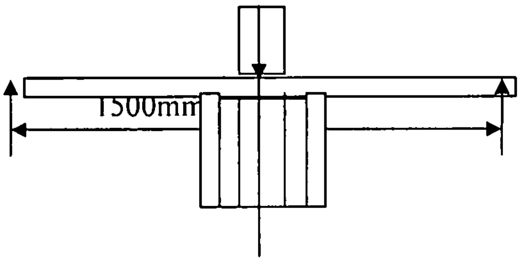
10.9 Strength of steel bridge girders

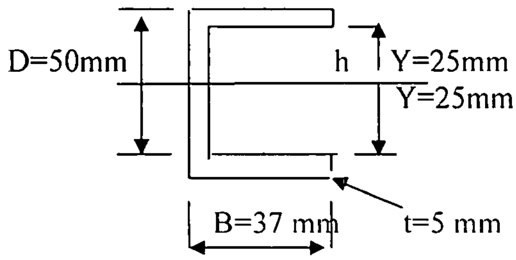
Bridge girder section material is grade 43A structural steel BS 4360.

OR ASTM A36 Structural steel having

Tensile strength=430 N/mm^2

Yield Strength =230 N/mm^2





Total weight of the Unit= Paddle wheel +Plates +gear motors

= 44 + 4 + 5 (assumed)

= 53 Kg

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Design load=58x1.3=68.9 taken 69 Kg

Assumed section beams are simply supported. Maximum bending moment is at middle.

Where Mx=WL/4

$$= \frac{69 \times 1500 \times 9.815}{4}$$

$$= 253963.125 \text{ N mm}$$

$$Mx = \frac{I\sigma}{y} \quad \sigma = \text{working stress.} \qquad \text{----D}$$

$$I = \frac{bd3 - h3(b-t)}{12} \qquad \text{-----Ref;[13]}$$

$$I = \frac{27 \times 50^3 - 40^3(37-5)}{12}$$

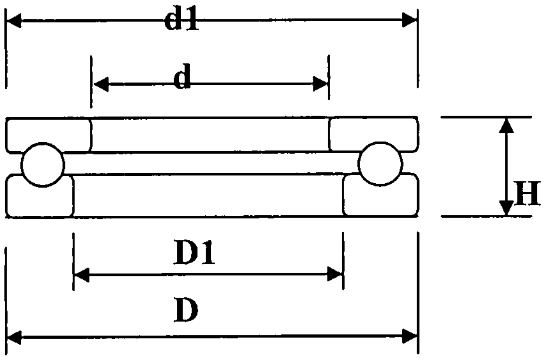
$$I = 110583.33 \text{ mm4}$$

Then from equation D, $\frac{253963.125 \times 25}{110583.33} = \sigma$ working stress.=57.41 N/mm^2 for two sections.

Stress for one channel section=57.41/2=28.70< 165 N/mm^2 **Satisfied.**

10.10 Bearing selection

The bearing shall be thrust ball bearing having Life rating= L_{10} with 100,000 cycles. RPM=10 and design to work 25% over safe load. Low clearance and metal seal. Shaft size =25 mm.



Axial load Fa= 44 x 9.815 x 1.25

= **539.325 N**

$F_{am}= A(n/1000)^2$ where A = minimum load factor in bearing table

N = rpm

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Equivalent dynamic load =P=Fa= 539.325 N

Equivalent static load =Po=Fa Ref.[17] SKF Bearing book Pg 317, 318.

From table A=4.2,

then $F_{am}=4.2\ (10/1000)^2$

$\underline{F_{am}=4.2\text{x}10^{-4} < 539.325\ \text{N}}$

From tables given bearing dimensions for selected shaft diameter =d=25

D=42 ; H=11 ; C= dynamic load factor =15,900 ; C=static load factor =22800

Given bearing designation (Number) =**51205**

Life rating L10h=$\dfrac{1\text{x } 10^6}{60n}$ x $(C/P)^p$ for ball bearings p=3

$= \dfrac{1 \times 10^6}{60 \times 10} \times \dfrac{(15900)^3}{(539.325)^3}$

$= 42.6 \times 10^6$ hrs.

Bearing = Thrust ball bearing with bore d=25 mm. No;51106 2Z C3 D=42, H=11 mm

10.11	**Cost estimate for fabricating paddle wheel assembly and driving unit**			
Item	**Description**	**Unit rate**	**Qty**	**Total cost Rs.cts**
1	Electrical Motor Induction O.37Kw 1500 rpm; 3 Ph	10,000.00	01	10,000.00
2	Gear reducing unit	20,000.00/item	01	20,000.00
3	PVC pipe Ø 200mm x 10mm thick (type 1000)	2800per meter	03	8,100.00
4	Machining driven coupling with material.	3000.00 per set	01	3000.00
5	Ø32mm Ni alloy steel shafting blank bar	8000.00/m	1.6	12,800.00
6	Machining shaft to step diameters, threads &key cuts.	12,000.00/item	01	12,000.00
7	Material for hubs	150/kg	4	600.00
8	Machining hubs	2000.00/item	02	4000.00
9	Angle iron frame 25mmx25mmx5mm	300/m	6.4	1920.00
10	Bolts stainless steel Ø8mmx40mm thread & Ø5mmx25mm thread (hub &coupling & blade)	30/-per bolt 25/-per bolt	04 52	120.00 1120.00
11	Channel section 50mm x 37 mm x 37mm x5 mm	850/m	4	3400.00
12	Bottom shaft base plate, guide bushes steel &bronze	3000.00/item	01	3000.00
13	Bottom anchor bolts	150.00/bolt	04	600.00
14	Shaft thrust bearing _No;51106 2Z C3	3000.00	01	3000.00
15	Shaft bearing plate and housing assembly	3000.00	01	3000.00
16	Gear motor unit mounting bench	2000.00	01	2000.00

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17	Aluminum chequred plate 8ftx 4ftx 1/8inch	15000.00/sheet	1/4	3750.00
18	Hand rail material GI Ø 1"x6m length	2000/length	6m	2000.00
19	Anticorrosive paint	2000.00/4 lit	4 lit	2000.00
	Total for material and equipments			***96410.00***
20	Electrical Wiring – 1/1.13 mm red & 7/0.67 Green	2000/100m 4000/100m	16m 6m	320.00 240.00
21	DOL starter	5000.00	01	5000.00
22	16A; 25 ka 3 pole MCCB	10,000.00	01	10,000.00
	Total for electrical work			***15560.00***
23	Man power cost Welder	800/day	03	2400.00
24	Electrician	800/day	02	2400.00
25	Helper	600.00/day	03	1800.00
	Total for man power			***6600.00***
	Total			115,570.00
26	**Measelanious expenses , Contingencies and transport OH**	**25% of TOTAL**	-	**29,642.50**
	Grand Total			**148,212.50**
	ESTIMATE COST Rupees & cents			**150,000.00**

Table 10-1

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CHAPTER 11

11 COST BENIFIT ANALYSIS

1. **Pugoda water treatment plant operational details from year 2009 reports.**

Pugoda mobile package plant design capacity = 500 m^3/day a day.

Storage pumps operating period =10 hrs a day with a capacity 50 m^3/h.

Pumping capacity = 50x10 = 500 m^3/day.

Water production, one unit = 1000 liters (1 cubic meter)

2. **Average water production cost and revenue.**

Average monthly production cost = SL Rs:500,000.00

(Including chemicals ,electricity ,maintenance, material, labour wages and over heads)

Average monthly water production = 17,000 m^3

Production cost per unit volume = **29.41 SL Rs: per m^3**

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By data water consumer data of the Water Supply Scheme average of 70% of production volume is consumed by domestic users . Other 30% is consumed by commercial users.

Average domestic user consumes 10 to 20 units per month .
Average water tariff for this rang = SL Rs:22.50
Commercial water tariff (flat rate) = SL Rs:65.00

$$\text{Average monthly revenue per unit} = \frac{17000 \times 0.70 \times 22.5 + 17000 \times 0.30 \times 65}{17000}$$

Average monthly revenue **per unit = 35.25 SL Rs: per m^3**

Profit from one unit of water production = 5.84 SL Rs:

3. **Daily profit**

Average daily production = $\frac{17000}{30}$ = 566.66

Say = 567 m^3

Therefore average daily profit = 567 x 5.84

Average daily profit = 3311.28 SL Rs

4 **Yearly operational cost for one existing flocculator**

Electrical cost :

Flocculators are working twelve hours a day . Motor power is 1.5 KW.(Middle speed unit)

Electrical power unit cost is 9.30 SL Rs: per Kwh (Industrial II Tariff)

Monthly electrical cost per one flocculator = 1.5x9.30x12x30

= **5022 Rs: ----A1**

Repair maintenance .

One unit is dismantled and repaired in every **two months time**.

Material cost for each repair (Bearing, seals, shaft repair) = 10,000.00

Repair time for dismantling replacing and refitting three days ,three skilled technicians.

Labour charges for one repair (@ 800/= per technician per day ,2 hours O.T, traveling) =3x(800+300+250)x3

=12150

Transport charges and other over head charges = 4000.0

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Total (Repair + Transport) per repair = 26150.00

Monthly repair cost = **13075.00 -----B1**

Average water leak cost

Measured average of water leak per minute = 0.75 liters

Water leak cost (@ 29.41 Rs: per m^3) = 0.75x(0.001)x60x29.41x12x30

Water leak cost per month = **476.44 Rs: ----C1**

Revenue loss in down time period

Water pass through all three flocculators in the plant

Daily revenue from one flocculator @ 35.25 per m^3 = $\frac{17000}{30} \times 35.25 \times \frac{1}{3}$

= 6658.33

Monthly revenue loss from one flocculator (1.5 day down time) =**9987.5 Rs -D1**

Total monthly operational cost for one flocculator (**A1+B1+C1+D1**)= Rs:28560.94

Total yearly operational cost for one flocculator = Rs: 342731.28

Say = **Rs: 343,000.00 ---X**

5. **Yearly operational cost for proposed flocculator**

Electrical cost :

Motor power is 0.37 KW.(**any** unit)

Monthly electrical cost per one flocculator = 0.37x9.30x12x30

= **1238.76 Rs: ----A2**

Repair maintenance .

Proposed to dismantle one unit for repairs **once in every six months time**.

Material cost for each repair (Bearings and minor adjustments) = 3000.00

Proposed repair time for dismantling replacing and refitting one day with two skilled technicians.

Labour charges for one repair (@ 800/= per technician per day ,1 hour O.T, traveling) =2x(800+150+250)x1

=2400

Transport charges and other over head charges = 3000.0

Total (Repair + Transport) per repair = 8400

Monthly repair cost = 1400 **----B2**

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Average water leak cost . No water leak = 0 **--- C2**

Revenue loss in down time period

Water pass through all three flocculators in the plant

Daily revenue from one flocculator @ 35.25 per m^3 = $\frac{17000}{30} \times 35.25 \times \frac{1}{3}$

= 6658.33

Monthly revenue loss from one flocculator (1/6 day down time) =**1109.72Rs -D1**

Total monthly operational cost for one flocculator (**A1+B1+C1+D1**) = 3748.48

Total yearly operational cost for one flocculator = Rs: 44981.76

Say = **Rs: 45000.00 -----Y**

6. **Annual saving** **X-Y = Rs 298,000.00**

7. Pay back period = $\frac{\text{New unit capital cost}}{\text{Annual saving}}$ = $\frac{150,000.00}{298,000.00}$ = 0.503

Pay back period = **Approximately six months**

CHAPTER 12

12 CONCLUSION

All process plants attempt to minimize the number of steps of processing so as to minimize the complexity and cost and to increase the plant productivity. In large scale district water treatment plants, flocculation process is done in many ways.

Large scale stationary water treatment plants commonly use hydraulic flocculators. Here they utilize cross-flow baffles or 180^0 turns to provide required turbidity and turbulence. Challenge is to get, gentle, uniform mixing that will not sheer flocks. This type is efficient only if the flow is relatively constant. These types are suitable for medium to large treatment plants and use the gravitational energy to run though the baffles.

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This report discusses many ways of flocculation process done using external energy input. Finally it proposes one of the cheapest and easier method to do flocculation in a small scale mobile water treatment package plant. This method is used in large scale stationary water treatment plants also.

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Limitations of the modifications.

Not to exceed the present power consumption and no any high cost or complex structures used to mount the driving mechanism. Sticking the paddle wheel r.p.m.s in the three stages as to specified ratios. The ratio of maximum to minimum mixer rotational speeds normally varies between **2 and 4**. Imparting energy to particle contact movement should be done in a reducing velocity gradient. It is practically recommended that velocity gradient is **60/s to 15/s.**

In some high tech automated water treatment plants , speed variable motors with gear reducers are used to compensate with the turbidity condition of raw water. Then the costs of the equipments are increased.

Unique advantage of vertical rotation is the unit can be removed easily for maintenance such as cleaning painting or replacing bearings. Small portion of sludge is accumulated at the bottom of each tank. If desired, this can be more quickly drained out through side drain valves. Accumulated sludge will swept by the rubber flaps fixed to bottom frame to bottom trenches which will guide the sludge to drain hole.

In previous studies it had been notified that larger surface area has a direct relation to the increase of flock size . Increasing the surface area should not lead to break the floccs which are ready to settle. Paddle wheel diameter shall be 85% of the water depth of basin. This ensures complete flocculation.

Further more, for further research it is recommended to employ another hypothetical system in flocculation. Electro magnetically vibration of charged plates in the flocculation tank to give the colloids the motive forces. Charged heavy particle will attract to charge plates. Attracted flocs on to charged plates can be dropped down by removing the charge by switching off power. Plate vibration is done according to required energy for particle movement.

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CHAPTER 13

13 REFERENCES

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[8] Harris, Leslie W. Zero energy input flocculator (1976) ,Website *http://www.freepatentsonline.com/3941695.html*

[9] Edward . Mothey, Gnang Z hu , (2000) Water Works engineering Planning Designing & operation Chapter 8 pp256-257 &278-283 : *pg 280 last para*

[10] Ref: Google serch Torsion: power transmission and stress concentrations design supplement. & Machinery hand book (1996) 25th ed., Industrial press Inc. New York. Pg280

[11] WWW.engineershandbook.com/tables/steelproperties G10500 (sited 12/14/2009)

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[12] Hand book for key ways; Hand book 18;1972 section 1. General (BS 4235: part **1)**

[13] Ref ; Load and stress analysis by Dr. U.P. Kahangamage 2006.12.13 .A course note on ' Mechanical engineering design' for IESL P:6 – 7.

[14]] WWW.engineershandbook.com/tables/steelproperties -steel properties for 0.25% 3.4.1. mild steel pg 1 of 1. section.

[15] WWW.boltdepot.com stainless A2 bolts Cr517 to 19 mechanical properties.

[16] Engineering Drawing by S. Bogolyubov.; A.voinov 1987 p216 table 11

[17] SKF Bearing book Pg 317, 318

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CHAPTER 14

14 APPENDIX

List of Appendices **Pg**

A Abstracted notes from references.

1. Ref [10] - Power transmission and stress concentrations design supplement. Relationship between allowable stress between axial and shear with σy yield stress .-- ---**A1**
2. Ref [14]- Properties of steels --**A2**
3. Ref [8] – Zero energy input flocculator (U.S. Patent 3941695)------------------**A3**

B Charts and tables – Steel properties

1. Reference tables – properties of Steel (Ref 11)--------------------------------------**B1a-B1b**
   (Cited 12/14/2009 WWW.engineershandbook.com/Tables/steeprop.htm p1,2)
2. Chemical composition and mechanical properties of steel (Indian Standard)-----**B2a-B2c**

C. Charts and tables - Information for design

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3. Table – Moments of Inertia, section modulii and Radii of gyration ----------------**C4**
4. Dimensions and tolerances of keyways for rectangular parallel keys---------------**C5-C6**
5. Thrust ball bearing – specification table & information (S.K.F. bearing book)---**C7**

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where r and d denote the radius and diameter of the shaft, respectively. Moreover in the absence of other factors, we would replace the shear stress by an allowable value found using a factor of safety together with material test data. (See the problems below.)

If a complication such as a stress concentrator exists, then a design problem may become iterative if initially we do not have the shaft geometry from which to determine the stress concentration factor. Then the design algorithm is, 1) solve the problem for dimensions, 2) use the stress concentration factor to check if allowables are violated, and 3) repeat until optimal dimensions which satisfy all requirements are found.

Ref [10]

In the case of power take-off applications which typically involve belts or chains wrapped around sheaves or gears, bending as well as torsion occurs. This is treated by Hibbeler (1997) in a section devoted to shaft design.

Interestingly, Machinery's Handbook (1996, p. 280) recommends for allowable stresses 60% of σ_Y for axial and 30% of σ_Y for shear where σ_Y is the yield stress in tension. This amounts to factors of safety FS (assume that yield in shear is 60% tensile yield) of

$$FS_{axial} = \sigma_Y / 0.6\sigma_Y = 1.7 \qquad FS_{shear} = 0.6\sigma_Y / 0.3\sigma_Y = 2.0 \tag{4}$$

which are rather high values indicating shaft design is viewed very conservatively. An official standard is not cited.

Examples

1D1. A solid SAE 1018 hot-rolled steel shaft is required to transmit 2 hp at 1725 rpm. Specify the minimum diameter shaft to the nearest 1/32 in if $\tau_{allow} = 18$ ksi.

Solution.

1. $\omega = 1725\text{rpm}\left(\frac{2\pi\text{rad}}{\text{rev}}\right)\left(\frac{\text{min}}{60\text{s}}\right) = 180.6 \text{ rad/s}$

2. $P = 2\text{hp}\left(550\frac{\text{ft}\cdot\text{lb}}{\text{s}\cdot\text{hp}}\right)12\frac{\text{in}}{\text{ft}} = 13200 \text{ in lb/s}$

3. $T = \frac{P}{\omega} = \frac{13200}{180.6} = 73.09$ in lb, or from (2) $T = \frac{5250(2)12}{1725} = 73.04$ in lb. O.K.

4. $d = \left(\frac{16T}{\pi\tau}\right)^{1/3} = 0.2745$ in . Hence choose d = 9/32 in. ◆

5. Check 1: $\tau = \frac{Tr}{J} = \frac{2T}{\pi r^3} = \frac{2(73.04)}{\pi(9/64)^3} = 16,730$ psi $< 18,000$ psi Hence O.K.

6. Check 2: $\tau = \frac{Tr}{J} = \frac{2T}{\pi r^3} = \frac{2(73.04)}{\pi(8/64)^3} = 23,800$ psi 1/4 in dia. shaft is too small.

7. Decision: Select SAE 1018 hot-rolled steel bar, 9/32 in dia. From step 5, the design is within 93% of the allowable stress.

16,730 / 18,000 → 92.9% ≃ 93%

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[14]

PROPERTIES OF STEELS,Steel Properties

(*) Steels properties

The second group of structural materials in the iron base category is steels. They have obtained an exclusive importance because of their strength, viscosity, and their ability to withstand dynamic loads. Also,
62 Materials Selection Deskbook
they are beneficial for producing castings, forgings, stamping, rolling, welding, machining and heat treatment works. Steels change their properties over a wide range depending on their composition, heat treatment and machining.
Most steels have a carbon content of 0.1-1%, but in structural steels this does not exceed 0.7%. With higher carbon contents, steel increases in strength but decreases in plasticity and weldability. In the carbon steels designed for welding, the carbon content must not exceed 0.3%, in the alloy steels it must not exceed 0.2%. When the carbon content in the steels exceeds the abovementioned value, they are susceptible to air hardening. Hence, high stresses may be created and hardening fractures in welding zones may be formed. The steels with low carbon content (below 0.2%) are well stamped and stretched, well cemented and nitrated, but badly machined. The physical properties of low-carbon, low-alloy steels are characterized by the following data:

[14] low alloy & low carbon steels

Translate to de es fr it pt ja

- density = 7.85 kg/dm3
- heat capacity Cp = dill kcal/m°C
- melting temperature tm = 1400-1500°C
- thermal conductivity \ = 40-50 kcal/m°C hr

mild steels

3.4.1 Low Carbon Steels (Mild Steel)
Mild steel (<0.25% carbon) is the most commonly used, readily welded construction material, and has the following typical mechanical properties (Grade 43A in BS4360: weldable structural steel):

- Tensile strength, 430 N/mm2
- Yield strength, 230 N/mm2
- Elongation, 20%
- Tensile modulus, 210 kN/mm2
- Hardness, 130 DPN

Bolts, Mild steel. / Angle Iron.

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No one steel exceeds the tensile modulus of mild steel. Therefore, in applications in which rigidity is a limiting factor for design (e.g., for storage tanks and distillation columns), high-strength steels have no advantage over mild steel. Stress concentrations in mild steel structures are relieved by plastic flow and are not as critical in other, less-ductile steels.
Low-carbon plate and sheet are made in three qualities: fully killed with silicon and aluminum, semikilled (or balanced), and rimmed steel. Fully killed steels are used for pressure vessels. Most general-purpose structural mild steels are semikilled steels. Rimming steels have minimum amounts of deoxidation and are used mainly as thin sheet for consumer applications.
The strength of mild steel can be improved by adding small amounts (not exceeding 0.1%) of niobium, which permits the manufacture of semikilled steels with yield points up to 280 N/mm2. By increasing the manganese content to about 1.5% the yield point can be increased up to 400 N/mm2. This provides better retention of strength at elevated temperatures and better toughness at low temperatures.

carbon +C ≤ 0.25C d steels

Corrosion Resistance

Corrosion

Equipment from mild steel usually is suitable for handling organic solvents, with the exception of those that are chlorinated, cold alkaline solutions (even when concentrated), sulfuric acid at concentrations greater than 88%, and nitric acid at concentrations greater than 65% at ambient temperatures [7].
Mild steels are rapidly corroded by mineral acids even when they are very dilute (pH less than 5). However, it is often more economical to use mild steel and include a considerable corrosion allowance on the thickness of the apparatus. Mild steel is not acceptable in situations in which metallic contamination of the product is not permissible.

corrosion allowance

corrosion alkaline solution used MS frame.

Ref [8]

SEARCH:

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Title:

Zero energy input flocculator

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Document Type and Number:

United States Patent 3941695

Abstract:

A flocculator for use in water treatment plants which comprises a paddle wheel disposed in a sedimentation basin. The wheel is defined by a plurality of equally spaced semicylindrical paddles which at all times are fully submerged in the water and which are constructed of a relatively thin sheet material that is undulated in a direction perpendicular to the length of the paddles. The paddles extend across the full width of the basin and they are secured to rotatably mounted hubs. The water flow in the basin provides the sole source of motive power for rotating the wheel.

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Oil Skimmer Inc.
Oil skimmer for every industry to remove oil, fat, grease and sludge.
www.oilskim.com

Inventors:

Harris, Leslie W. (1438 Yosemite Circle, Concord, CA, 94521)

Application Number:

05/427771

Publication Date:

03/02/1976

A → A-3

Ref [1] A

Engineer's Handbook

Reference Tables -- Properties of Steel

Back to References
Homepage

Properties of Steel

Mechanical Properties
of soft tissues
biaxial planar
testing
www.wpi-europe.com

(Tabulated in accordance with the Unified Numbering System for Metals and Alloys (UNS). Soci Automotive Engineers, Warrendale, Pa., 1975. This reference contains the cross reference number ASTM. FED, MIL SPEC, and SAE specifications. The values shown for hot-rolled (HR) and cold steels are estimated minimum values which can usually be expected in the size range of 3/4 to 1-1 minimum value is roughly several standard deviations below the arithmetic mean. The values sho treated steels are so-called typical values. A typical value is neither the mean nor the minimum. It by careful control of the purchase specifications and the heat-treatment, together with continuous testing. The properties shown in this table are from a variety of sources and are believed to be repr There are so many variables which affect these properties, however, that their approximate nature recognized. Multiply strength in kpsi by 6.89 to get strength in MPa.)

6.89

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Stainless, Inconel,
Monel, Aluminum
and other metals
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Properties of Steel

UNS Number	Processing Method	Yield Strength kpsi	Tensile Strength kpsi	Yield Strength MPa	Tensile Strength MPa	Elongation in 2 in. %	Reduction in Area %
G10100	Hot Rolled	26	47	179	324	28	50
G10100	Cold Drawn	44	53	303	365	20	40
G10150	Hot Rolled	27	50	186	345	28	50
G10150	Cold Drawn	47	56	324	386	18	40
G10180	Hot Rolled	32	58	220	400	25	50
G10180	Cold Drawn	54	64	372	441	15	40
G10350	Hot Rolled	39	72	269	496	18	40
G10350	Cold Drawn	67	80	462	551	12	35
G10350	Drawn 800 F	81	110	558	758	18	51
G10350	Drawn 1000 F	72	103	496	710	23	59
G10350	Drawn 1200 F	62	91	427	627	27	66
G10400	Hot Rolled	42	76	289	521	18	40
G10400	Cold Drawn	71	85	489	586	12	35

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datasheets
www.matweb.com

Federal Steel Supply, Inc
Carbon and
chrome-moly steel
pipe Heavy wall
tubular goods from
stock
www.FedSteel.com

1 MPa = 1 Newton / mm²
1 Pa = 1 Newton / m²

B1-a

Ref[1]B

Selected ←

				Ys	UTS		
G10400	Drawn 1000 F	86	113	593	779	23	62
G10500	Hot Rolled	49	90	338	620	15	35
G10500	Cold Drawn	84	100	579	689	10	30
G10500	Drawn 600 F	180	220	1240	1516	10	30
G10500	Drawn 900 F	130	155	896	1068	18	55
G10500	Drawn 1200 F	80	105	551	723	28	65
G15216	Hot Rolled, Annealed	81	100	558	689	25	57
G41300	Hot Rolled, Annealed	60	90	413	620	30	45
G41300	Cold Drawn, Annealed	87	98	599	675	21	52
G41300	Drawn 1000 F	133	146	916	1006	17	60
G41400	Hot Rolled, Annealed	63	90	434	620	27	58
G41400	Cold Drawn, Annealed	90	102	620	703	18	50
G41400	Drawn 1000 F	131	153	903	1054	16	45
G43400	Hot Rolled, Annealed	69	101	475	696	21	45
G43400	Cold Drawn, Annealed	99	111	682	765	16	42
G43400	Drawn 600 F	234	260	1612	1791	12	43
G43400	Drawn 1000 F	162	182	1116	1254	15	40
G46200	Case Hardened	89	120	613	827	22	55
G46200	Drawn 800 F	94	130	648	896	23	66
G61500	Hot Rolled, Annealed	58	91	400	627	22	53
G61500	Drawn 1000 F	132	155	909	1068	15	44
G87400	Hot Rolled, Annealed	64	95	441	655	25	55
G87400	Cold Drawn, Annealed	[illegible]	107	661	737	17	48
G87400	Drawn 1000 F	129	152	889	1047	15	44
G92550	Hot Rolled, Annealed	78	115	537	792	22	45
G92550	Drawn 1000 F	160	180	1102	1240	15	32

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Ref

Ref [15]

MARYLAND METRICS
phones: (410) 358-3130 (800) 638-1830
faxes: (410) 358-3142 (800) 872-9329
P.O. Box 261 Owings Mills, MD 21117 USA
6119 Oakleaf Avenue Baltimore, MD 21215 USA

Chemical Composition And Mechanical Properties of Steel (Indian Standard

IS : 10748 - Specification Of Hot Rolling Steel Strips For Welded Tubes & Pipe

CHEMICAL COMPOSITION

Grade	C% Max	Mn % Max.	S% Max.	P% Max.
I	0.10	0.50	0.05	0.05
II	0.12	0.60	0.05	0.05
III	0.16	1.20	0.05	0.05
IV	0.20	1.30	0.05	0.05
V	0.25	1.30	0.05	0.05

MECHANICAL PROPERTIES

Grade	UTS (Min) Mpa	YS (Min) Mpa	El % (Min) 5.65 Sqrt (So)
I	290	170	30
II	330	210	28
III	410	240	25
IV	430	275	20
V	490	310	15

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IS : 6240 HR - Steel Plate, Sheet and Coil for LP

CHEMICAL COMPOSITION

Constituent	Percent
Carbon, Max.	0.16
Manganese, Min	0.30
Silicon, Max.	0.25
Sulphur, Max.	0.030
Phosphorous, Max.	0.030
Aluminium Min	0.02

MECHANICAL PROPERTIES

Property	Grade *
Tensile Strength Mpa (kgf/mm²)	350 to 450 (36 to 46)
Yield Strength, Mpa (Kg/mm²) Min	240 (25)
Elongation, Min percent on guage length 5.65 OSo	25
Bend	t
EC v (for 2.80-3.15 mm thickness) min	13.5

* Both longitudinal and transverse directions.

TOLERANCE AS PER IS : 513

Tolerance on Thickness of Sheets

Tolerance on the thickness for different w d

Nominal Thickness	Upto 1250 mm	Above 1250 upto 1600	Above 1600
Upto 0.25	+/- 0.03	-	-
Above 0.25-0.40	+/- 0.04	-	-
Above 0.40-0.60	+/- 0.05	+/- 0.06	-
Above 0.60-0.80	+/- 0.06	+/- 0.07	+/- 0.08
Above 0.80-1.00	+/- 0.08	+/- 0.09	+/- 0.10
Above 1.00-1.25	+/- 0.09	+/- 0.10	+/- 0.12
Above 1.25-1.50	+/- 0.11	+/- 0.12	+/- 0.14
Above 1.50-2.00	+/- 0.12	+/- 0.14	+/- 0.16

B2a

Ref [15]2

Tolerance on Width Of Sheets		
Width of Sheets	Tolerance	
Upto 1250 mm	+7	-0
Above 1250 mm	+10	0

Tolerance on Length of Sheets		
Length	Tolerance	
Upto 2000 mm	+15	-0
Above 2000 mm	+0.75 % of the length	-0

Chamfer Tolerance For Coils and Cut Length	
Form	Tolerance
Coil	20 mm in any 5000 mm length
Cut Length	0.4% X length

Standard Flatness Tolerance for cut lengths			
Thickness	Tolerance on specified width		
	Upto 1200	Above 1200 - Upto 1500	Above 1500
Upto 0.63	15	18	22
Above 0.63-1.25	12	15	19
Above 1.25	10	12	17

Special Flatness Tolerance for Cut lengths Roller Levelled and Stretcher Levelled			
Thickness	Tolerance on specified width		
	Upto 1200	Above 1200 Upto 1500	Above 1500
Upto 0.63	6	7	8
Above 0.63-1.25	5	6	7
Above 1.25	4	5	6

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IS : 2062 - Specification of Steel for General Structural Purposes

CHEMICAL COMPOSITION

Grade	C% Max.	Mn% Max.	S% Max.	P% Max.	Si% Max.	C.E.% Max.
A	0.23	1.50	0.050	0.050	0.40	0.42
B	0.22	1.50	0.045	0.045	0.40	0.41
C	0.20	1.50	0.040	0.040	0.40	0.39

MECHANICAL PROPORTIES

Grade	UTS(MPa) Min.	Y.S.(MPa) Min.			El.% Min. 5.65 Sqrt(So)	Bend Test
A	410	250	240	230	23	3T
B	410	250	240	230	23	2T & 3T *
C	410	250	240	230	23	2T

* 2T - <= 25mm
* 3T - > 25mm

general sections

IS : 3039 - Specification of Structural Steel for Ship Building

CHEMICAL COMPOSITION

Grade	C% Max.	Mn%	S% Max.	P% Max.	Si% Max.	Al% Min.
I	0.23	*	0.040	0.040	**	0.01
II	0.21	0.70-1.4	0.040	0.040	0.10-0.35	-
III	0.18	0.70-1.5	0.040	0.040	0.19-0.50	0.015

MECHANICAL PROPERTIES

Grade	UTS (MPa)	Y.S. (MPa) Min.		El.% Min.

B2b

Ref [15]3

		< 25 mm.	> 25 < 50 mm.	5.65 Sqrt (So)
I	400-490	230	220	22
II	400-900	235	235	22
III	400-490	235	235	22

IS 1786 - High Strength Deformed Steel Bars and Wires for Concrete Reinforcement

CHEMICAL COMPOSITION

Constituent	Percent, Maximum						SAIL-TMT(Fe 415/FE 500/Fe 550)
	SAIL TMT 415	Fe 415	SAIL TMT 500	Fe 500	SAIL TMT 550	Fe 500	
Carbon	0.25	0.30	0.25	0.30	0.25	0.30	0.20
Sulphur	0.05	0.06	0.05	0.055	0.05	0.055	0.045
Phosphorus	0.05	0.06	0.05	0.055	0.05	0.050	0.045
Sulphur and Phosphorus	0.10	0.11	0.10	0.105	0.10	0.10	0.09
Corrosion Resistant Elements	-	-	-	-	-	-	0.75 min
Carbon Equivalent	-	-	-	-	-	-	0.53 max

MECHANICAL PROPERTIES

Property	Grade					
	Fe 415	SAIL TMT 415	Fe 500	SAIL TMT 500	Fe 550	SAIL TMT 550
0.2 percent proof stress/yield stress Min N/mm.sq.	415	415	500	500	550	550
Elongation,percent ,Min.on gauge length 5.65.Square Root(A) where A is the cross-sectional area of the test piece	14.5	22(Up to 28mm dia) 20 (Above 28 mm dia)	12	20(Up to 28mm dia) 18 (Above 26 mm dia)	8	18(Upto 25 mm dia) 16(Above 28 mm dia)
Tensile Strength,Min.	10% more than the actual 0.2% proof stress but not less than 48.5 N/mm.sq.	10% more than the actual 0.2% proof stress but not less than 500 N/mm.sq.	8% more than actual 0.2% proof stress but not less than 545 N/mm.sq.	8% more than the actual 0.2% proof stress but not less than 580 N/mm.sq. (Upto 28mm dia) & 560 N/mm.sq.) (above 28 mm dia)	6% more than the actual 0.2% proof stress but not less than 585 N/mm.sq. (Upto 28mm dia) & 560 N/mm.sq.) (above 28 mm dia)	6% more than the actual 0.2% proof stress but not less than 630 N/mm.sq. (Upto 28mm dia) & 610 N/mm.sq. (above 28 mm dia) Upto 28mm dia) & 560 N/mm.sq.) (above 28 mm dia)

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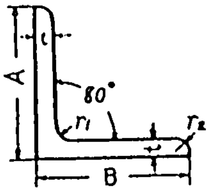
SPECIFICATION FOR WIRE RODS

Specifications	Grade	Chemical Composition				Mechanical Properties		
		%C	%Mn	%S	%P	Yield Mpa	Tensile Mpa	Elongation %
Structure Quality	IS2062	0.23 max	1.50 max	0.05 max	0.50 max	250 min	410 min	23 min

Wire Rods

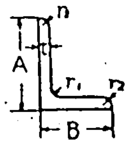
B2C

Weight Table of Steel



Equal Angle

Size (mm) A = B	t	r_1	r_2	Sect. Dim. (cm^2)	Weight (kg/m)
40	3	4.5	2	2.336	1.83
40	5	4.5	3	3.755	2.95
45	4	6.5	3	3.492	2.74
50	4	6.5	3	3.892	3.06
50	6	6.5	4.5	5.644	4.43
60	4	6.5	3	4.692	3.68
60	5	6.5	3	5.802	4.55
65	6	8.5	4	7.527	5.91
65	8	8.5	6	9.761	7.66
70	6	8.5	4	8.127	6.38
75	6	8.5	4	8.727	6.85
75	9	8.5	6	12.69	9.96
75	12	8.5	6	16.56	13.0
75	14	8.5	6	19.04	14.9
80	6	8.5	4	9.327	7.32
90	6	10	5	10.55	8.28
90	7	10	5	12.22	9.59
90	10	10	7	17.00	13.3
90	13	10	7	21.71	17.0
100	7	10	5	13.62	10.7
100	10	10	7	19.00	14.9
100	13	10	7	24.31	19.1
120	8	12	5	18.76	14.7
130	9	12	6	22.74	17.9
130	12	12	8.5	29.76	23.4
130	15	12	8.5	36.75	28.8
150	12	14	7	34.77	27.3
150	15	14	10	42.74	33.6
150	19	14	10	53.38	41.9
175	12	15	11	40.52	31.8
175	15	15	11	50.21	39.4
200	15	17	12	57.75	45.3
200	20	17	12	76.00	59.7
200	25	17	12	93.75	73.6
250	25	24	12	119.4	93.7
250	35	24	18	162.6	128



Unequal Angle

Size (mm) A	B	t	r_1	r_2	Sect. Dim. (cm^2)	Weight (kg/m)
90	75	9	8.5	6	14.04	11.0
100	75	7	10	5	11.87	9.32
100	75	10	10	7	16.50	13.0
125	75	7	10	5	13.62	10.7
125	75	10	10	7	19.00	14.9
125	75	3	10	7	24.31	19.1
125	90	10	10	7	20.50	16.1
125	90	13	10	7	26.26	20.6
150	90	9	12	6	20.94	16.4
150	90	12	12	8.5	27.36	21.5
150	100	9	12	6	21.84	17.1
150	100	12	12	8.5	28.56	22.4
150	100	15	12	8.5	35.25	27.7

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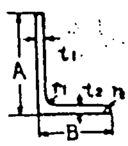
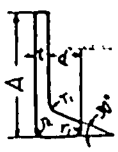
Half Round

Size (mm)	Weight (kg) 1m	4.5m	5.0m	5.5m	6.0m	6.5m
7×26	1.01	4.54	5.05	5.56	6.06	6.56
8.5×30	1.41	6.34	7.05	7.76	8.46	9.16
10×34	1.90	8.55	9.50	10.4	11.4	12.4
11×36	2.21	9.94	11.0	12.2	13.3	14.4
30.0×60	11.1	50.0	55.5	61.0	66.6	72.2
37.5×75	17.3	77.3	86.5	95.2	104	112



Unequal Leg and Unequal Thickness Angle

Size (mm) A	B	t_1	t_2	r_1	r_2	Sect. Dim. (cm^2)	Weight (kg/m)
200	90	9	14	14	7	29.66	23.3
250	90	10	15	17	8.5	37.47	29.4
250	90	12	16	17	8.5	42.95	33.7
300	90	11	16	19	9.5	46.22	36.3
300	90	13	17	19	9.5	52.67	41.3
400	100	13	18	24	12	68.59	53.8



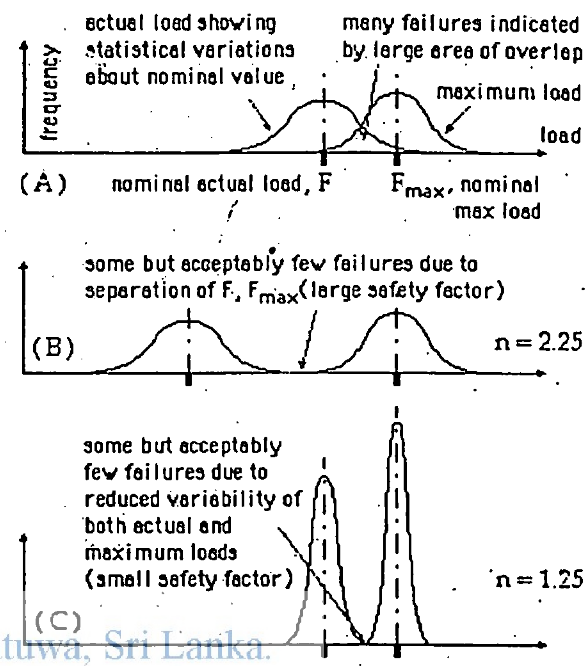
Bulb Plate

Size (mm) A	t	d	r_1	r_2	Sect. Dim. (cm^2)	Unit Weight (kg/m)
180	9.5	23	7	2	21.06	16.5
200	10	26.5	8	2	25.23	19.8
230	11	30	9	2	31.98	25.1
250	12	33	10	2	38.13	29.9

Margin of safety:
Margin of safety = n – 1, *where n = factor of safety*
e.g.: when factor of safety = 1.75, *Margin of safety = 0.75 (or 75%)*
When margin of safety is reduced to zero or less, the machine element (presumably) will fail.

Selection of Factor of Safety

After going as far as practical in determining the strength of machine components and the details of the loading to which it will be subjected, there always remains some margin of uncertainty that must be covered by a safety factor. The part must be designed to withstand a 'design overload' somewhat larger than the normally expected load. In the last analysis, selection of safety factor comes down to engineering judgement based on experience. Sometimes these selections are formalised into design codes covering specific situations – for example, the ASME Pressure Vessel Codes.



Factors to be considered in selecting a safety factor:

1. Degree of uncertainty about loading
2. Degree of uncertainty about material strength
3. Uncertainties in relating applied loads to material strength via stress analysis
4. Consequence of failure – human safety and economics
5. Cost of providing a large safety factor

When an assemblage of components is subjected to a single load, the assembly's safety factor is the smallest of the component safety factors - *'a chain is only as strong as its weakest link'*. If a component or an assemblage is subjected to a number of different simultaneous loads, then the concept of a single safety factor may be inappropriate - but nevertheless all potential failure mechanisms must be investigated when deciding whether an implement is safe to use or not.

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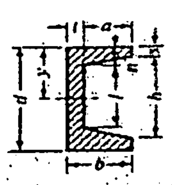
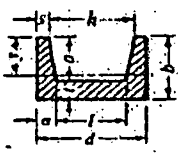
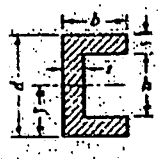
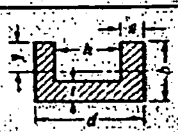
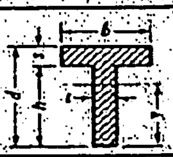
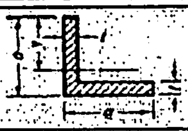
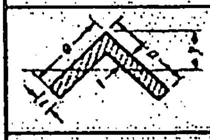
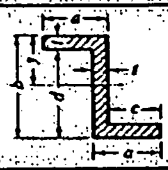
Table 1 Factors used to determine a safety factor for ductile materials

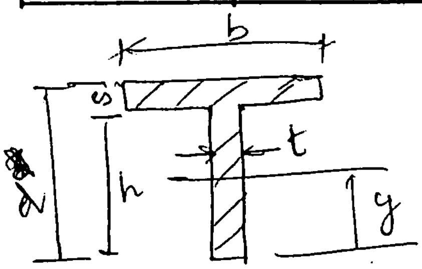
Information	Quality of Information	Factor
Material-property data available from tests	The actual material used was tested	1.3
	Representative material test data are available	2
	Fairly representative material test data are available	3
	Poorly representative material test data are available	5+
Environmental conditions in which it will be used	Are identical o material test conditions	1.3
	Essentially room-ambient environment	2
	Moderately challenging environment	3
	Extremely challenging environment	5+
Analytical models for loading and stress	Models have been tested against experiments	1.3
	Models accurately represent system	2
	Models approximately represent system	3
	Models are crude approximations	5+

Allowable Stress (Working Stress)

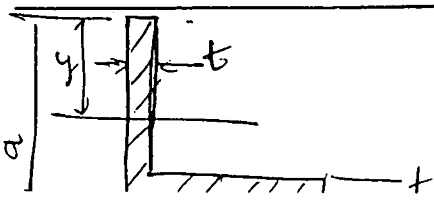
It is very rare that in practice, machine elements are subjected to direct stress alone. Very often we get the situation of direct stresses combined with shear stress. These situations are considered as follows:

Ref [13]   copy.

Section	Area of Section, A	Distance from Neutral Axis to Extreme Fiber, y	Moment of Inertia, I	Section Modulus, $Z = I/y$	Radius of Gyration, $k = \sqrt{I/A}$
		C-Sections			
	$dt + a(s+n)$	$\frac{d}{2}$	$\frac{1}{12}\left[bd^3 - \frac{1}{8g}(h^4 - l^4)\right]$ g = slope of flange $= \frac{h-l}{2(b-t)} = \frac{1}{6}$ for standard channels.	$\frac{1}{6d}\left[bd^3 - \frac{1}{8g}(h^4 - l^4)\right]$	$\sqrt{\frac{\frac{1}{12}\left[bd^3 - \frac{1}{8g}(h^4 - l^4)\right]}{dt + a(s+n)}}$
	$dt + 2a(s+n)$	$b - \left[b^2 s + \frac{ht^2}{2} + \frac{g}{3}(b-t)^2 \times (b+2t)\right] \div A$ g = slope of flange $= \frac{h-l}{2(b-t)}$	$\frac{1}{3}\left[2sb^3 + lt^3 + \frac{g}{2}(b^4 - t^4)\right] - A(b-y)^2$ g = slope of flange $= \frac{h-l}{2(b-t)} = \frac{1}{6}$ for standard channels.	$\frac{I}{y}$	$\sqrt{\frac{I}{A}}$
	$bd - h(b-t)$	$\frac{d}{2}$	$\frac{bd^3 - h^3(b-t)}{12}$	$\frac{bd^3 - h^3(b-t)}{6d}$	$\sqrt{\frac{bd^3 - h^3(b-t)}{12[bd - h(b-t)]}}$
	$bd - h(b-t)$	$b - \frac{2b^2 s + ht^2}{2bd - 2h(b-t)}$	$\frac{2sb^3 + ht^3}{3} - A(b-y)^2$	$\frac{I}{y}$	$\sqrt{\frac{I}{A}}$
		T-Sections			
	$bs + ht$	$d - \frac{d^2 t + s^2(b-t)}{2(bs+ht)}$	$\frac{1}{3}[ty^3 + b(d-y)^3 - (b-t)(d-y-s)^3]$	$\frac{I}{y}$	$\sqrt{\frac{1}{3(bs+ht)}[ty^3 + b(d-y)^3 - (b-t)(d-y-s)^3]}$
	$t(2a-t)$	$a - \frac{a^2 + at - t^2}{2(2a-t)}$	$\frac{1}{3}[ty^3 + a(a-y)^3 - (a-t)(a-y-t)^3]$	$\frac{I}{y}$	$\sqrt{\frac{I}{A}}$
	$t(2a-t)$	$\frac{a^2 + at - t^2}{2(2a-t)\cos 45°}$	$\frac{A}{12}[7(a^2+b^2) - 12y^2] - 2ab^2(a-b)$ in which $b = (a-t)$	$\frac{I}{y}$	$\sqrt{\frac{I}{A}}$
	$t[b + 2(a-t)]$	$\frac{b}{2}$	$\frac{ab^3 - c(b-2t)^3}{12}$	$\frac{ab^3 - c(b-2t)^3}{6b}$	$\sqrt{\frac{ab^3 - c(b-2t)^3}{12t[b+2(a-t)]}}$



$$I = \frac{1}{3}\left[ty^3 + b(d-y)^3 - b(b-t)(d-y-s)^3\right]$$



$$I = \frac{1}{3}\left[ty^3 + a(a-y)^3 - (a-t)(a-y-t)^3\right]$$

C-4

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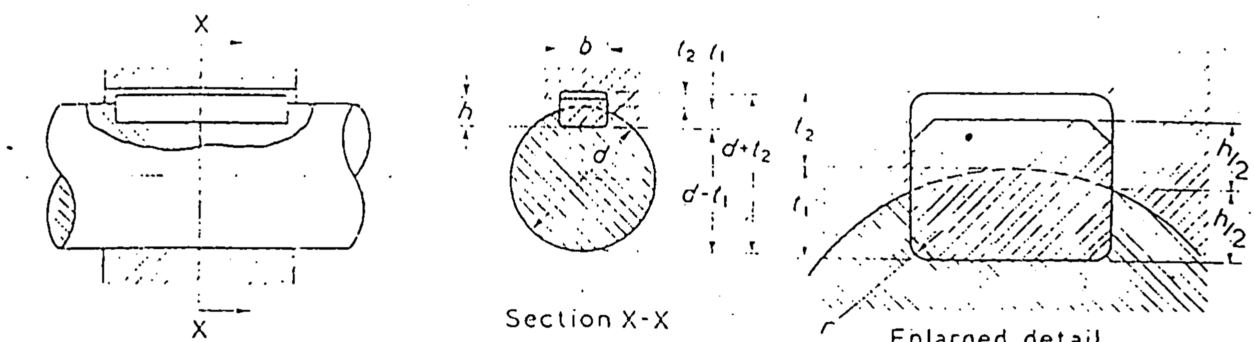
Handbook 18 : 1972

Section 1. General (BS 4235 : Part 1)

Table 1. Dimensions and tolerances of keyways for square parallel keys



Section X-X

Enlarged detail of key and keyways

All dimensions are in millimetres.

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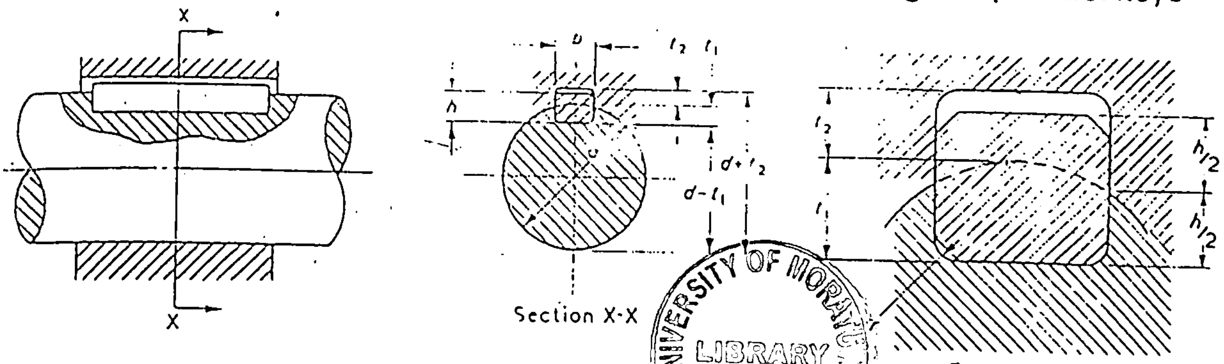
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shaft		Key (see Note)	Keyway											
nominal diameter (see Note) d		section $b \times h$ width × thickness	width b						depth				radius r	
				tolerance for class of fit										
			nom.	free		normal		close	shaft t_1		hub t_2			
over	incl.			shaft (H9)	hub (D10)	shaft (N9)	hub (J,9)*	shaft and hub (P9)	nom.	tol.	nom.	tol.	max.	min.
6	8	2×2	2	+0.025	+0.060	−0.004	+0.012	−0.006	1.2		1		0.16	0.08
8	10	3×3	3	0	+0.020	−0.029	−0.012	−0.031	1.8		1.4		0.16	0.08
10	12	4×4	4						2.5	+0.1 0	1.8	+0.1 0	0.16	0.08
12	17	5×5	5	+0.030 0	+0.078 +0.030	0 −0.030	+0.015 −0.015	−0.012 −0.042	3		2.3		0.25	0.16
17	22	6×6	6						3.5		2.8		0.52	0.16

* The limits for tolerance J,9 are quoted from BS 4500, 'ISO limits and fits' (see Section 2), to three significant figures.

NOTE. The relations between shaft diameter and key section given above are for general applications. The use of smaller key sections is permitted if suitable for the torque transmitted. In cases such as stepped shafts when larger diameters are required, for example to resist bending, and when fans, gears and impellers are fitted with a smaller key than normal, an unequal disposition of key in shaft with relation to the hub results. Therefore, dimensions $d - t_1$ and $d + t_2$ should be recalculated to maintain the $h/2$ relationship.

The use of larger key sections is not permitted.

Table 3. Dimensions and tolerances of keyways for rectangular parallel keys



Section X-X

Enlarged detail of key and keyways

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All dimensions are in millimetres.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shaft		Key (see Note)	Keyway											
nominal diameter *d* (see Note)		section *b* × *h* width × thickness	width *b*						depth				radius *r*	
			nom.	tolerance for class of fit					shaft t_1		hub t_2			
				free		normal		close						
over	incl.			shaft (H9)	hub (D10)	shaft (N9)	hub (J,9)*	shaft and hub (P9)	nom.	tol.	nom.	tol.	max.	min.
22	30	8 × 7	8	+0.036	+0.098	0	+0.018	−0.015	4		3.3		0.25	0.16
30	38	10 × 8	10	0	+0.040	−0.036	−0.018	−0.051	5		3.3		0.40	0.25
38	44	12 × 8	12						5		3.3		0.40	0.25
44	50	14 × 9	14	+0.043	+0.120	0	+0.021	−0.018	5.5		3.8		0.40	0.25
50	58	16 × 10	16	0	+0.050	−0.043	−0.021	−0.061	6	+0.2	4.3	+0.2	0.40	0.25
58	65	18 × 11	18						7	0	4.4	0	0.40	0.25
65	75	20 × 12	20						7.5		4.9		0.60	0.40
75	85	22 × 14	22	+0.052	+0.149	0	+0.026	−0.022	9		5.4		0.60	0.40
85	95	25 × 14	25	0	+0.065	−0.052	−0.026	−0.074	9		5.4		0.60	0.40
95	110	28 × 16	28						10		6.4		0.60	0.40
110	130	32 × 18	32						11		7.4		0.60	0.40
130	150	36 × 20	36	+0.062	+0.180	0	+0.031	−0.026	12		8.4		1.00	0.70
150	170	40 × 22	40	0	+0.080	−0.062	−0.031	−0.088	13		9.4		1.00	0.70
170	200	45 × 25	45						15		10.4		1.00	0.70
200	230	50 × 28	50						17		11.4		1.00	0.70
230	260	56 × 32	56						20	+0.3	12.4	+0.3	1.60	1.20
260	290	63 × 32	63	+0.074	+0.220	0	+0.037	−0.032	20	0	12.4	0	1.60	1.20
290	330	70 × 36	70	0	+0.100	−0.074	−0.037	−0.106			14.4		1.60	1.20
330	380	80 × 40	80						25		15.4		2.50	2.00
380	440	90 × 45	90	+0.087	+0.260	0	+0.043	−0.037	28		17.4		2.50	2.00
440	500	100 × 50	100	0	+0.120	−0.087	−0.043	−0.124	31		19.5		2.50	2.00

* The limits for tolerance J,9 are quoted from BS 4500 to three significant figures.

NOTE. The relations between shaft diameter and key section given above are for general applications. The use of sm sections is permitted if suitable for the torque transmitted. In cases such as stepped shafts when larger diameters a for example to resist bending, and when fans, gears and impellers are fitted with a smaller key than normal, an un tion of key in shaft with relation to the hub results. Therefore, dimensions $d - t_1$ and $d + t_2$ should be recalc the $h/2$ relationship.

The use of larger key sections is not permitted.

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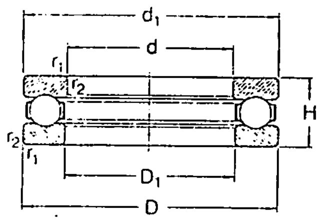
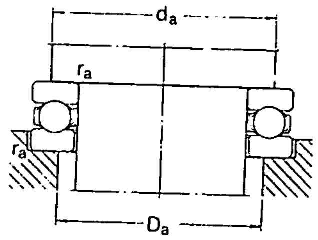
Thrust ball bearings
single direction
d 10–45 mm





Principal dimensions d	D	H	Basic load ratings dynamic C	static C_0	Minimum load factor A	Limiting speeds Lubrication grease	oil	Mass	Designation
mm			N		–	r/min		kg	
10	24	9	8 710	8 800	0,63	7 000	9 500	0,020	51100
	26	11	10 800	10 600	0,92	6 000	8 000	0,028	51200
12	26	9	9 040	10 000	0,82	6 700	9 000	0,022	51101
	28	11	11 200	12 200	1,2	6 000	8 000	0,032	51201
15	28	9	9 360	11 200	1	6 300	8 500	0,023	51102
	32	12	13 800	16 000	2,1	5 300	7 000	0,044	51202
17	30	9	9 750	12 200	1,2	6 300	8 500	0,025	51103
	35	12	14 300	17 600	2,5	5 000	6 700	0,051	51203
20	35	10	12 700	16 600	2,2	5 600	7 500	0,038	51104
	40	14	19 900	25 000	5,1	4 500	6 000	0,078	51204
25	42	11	15 900	22 800	4,2	4 800	6 300	0,056	51105
	47	15	24 700	34 000	9,4	4 000	5 300	0,11	51205
	52	18	33 800	44 000	16	3 400	4 500	0,17	51305
	60	24	55 300	71 000	41	2 600	3 600	0,34	51405
30	47	11	16 800	26 500	5,7	4 500	6 000	0,063	51106
	52	16	25 500	37 500	11	3 600	4 800	0,14	51206
	60	21	40 300	57 000	27	2 800	3 800	0,26	51306
	70	28	67 600	90 000	66	2 000	3 000	0,52	51406
35	52	12	17 400	30 000	7,3	4 300	5 600	0,080	51107
	62	18	35 100	53 000	23	3 000	4 000	0,22	51207
	68	24	49 400	69 500	39	2 400	3 400	0,38	51307
	80	32	80 600	112 000	100	1 800	2 600	0,76	51407
40	60	13	23 400	40 000	13	3 800	5 000	0,12	51108
	68	19	39 700	64 000	33	2 800	3 800	0,26	51208
	78	26	65 000	98 000	78	2 000	3 000	0,53	51308
	90	36	104 000	146 000	170	1 700	2 400	1,10	51408
45	65	14	24 200	45 000	17	3 400	4 500	0,14	51109
	73	20	41 000	68 000	38	2 600	3 600	0,31	51209
	85	28	71 500	110 000	99	1 900	2 800	0,67	51309
	100	39	121 000	173 000	240	1 600	2 200	1,40	51409

Dimensions d	d_1	D_1	$r_{1,2}$ min	Abutment and fillet dimensions d_a min	D_a max	r_a max
mm				mm		
10	24	11	0,3	19	15	0,3
	26	12	0,6	20	16	0,6
12	26	13	0,3	21	17	0,3
	28	14	0,6	22	18	0,6
15	28	16	0,3	23	20	0,3
	32	17	0,6	25	22	0,6
17	30	18	0,3	25	22	0,3
	35	19	0,6	28	24	0,6
20	35	21	0,3	29	26	0,3
	40	22	0,6	32	28	0,6
25	42	26	0,6	35	32	0,6
	47	27	0,6	38	34	0,6
	52	27	1	41	36	1
	60	27	1	46	39	1
30	47	32	0,6	40	37	0,6
	52	32	0,6	43	39	0,6
	60	32	1	48	42	1
	70	32	1	54	46	1
35	52	37	0,6	45	42	0,6
	62	37	1	51	46	1
	68	37	1	55	48	1
	80	37	1,1	62	53	1
40	60	42	0,6	52	48	0,6
	68	42	1	57	51	1
	78	42	1	63	55	1
	90	42	1,1	70	60	1
45	65	47	0,6	57	53	0,6
	73	47	1	62	56	1
	85	47	1	69	61	1
	100	47	1,1	76	67	1

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Thrus
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