TABLE 2 – SITE SELECTION – SCORING

General Objectives	*Weight*	*Characteristic Name*	*Max Score*	*13*	*16*	*30*	*4*
1. Public Health and Safety	1000.00	GWHZ	294.11	175.47	176.47	117.64	147.05
		GAS	235.29	235.29	211.76	164.70	188.23
		GWAT	235.29	47.05	70.53	47.05	47.05
		SWAT	176.47	141.17	141.17	158.82	105.88
		ODOR	29.41	29.41	23.53	23.53	23.53
		TRAF	29.41	23.53	23.53	23.53	23.53
		OBJECTIVE TOTAL	1000.00	652.94	647.06	535.29	535.29
2. Public Acceptability	800.00	ISOL	258.06	258.06	154.83	206.45	232.25
		TRAF	206.45	185.80	144.51	165.16	165.16
		ODOR	154.83	154.83	123.87	123.87	139.35
		SWAP	103.22	82.58	82.58	92.90	61.93
		FUTE	51.61	25.80	25.80	25.80	25.80
		IMPR	25.80	12.90	12.90	12.90	12.90
		OBJECTIVE TOTAL	800.00	720.00	544.51	627.10	637.42
3. Suitability for Operation & Development	600.00	COV	272.72	136.36	163.63	136.36	136.36
		DWAT	190.91	152.72	133.63	171.81	152.72
		TRAF	136.36	122.72	109.09	95.45	95.45
		OBJECTIVE TOTAL	600.00	411.82	406.36	403.63	384.54
4. Land Use	500.00	FUTE	333.33	166.66	166.66	166.66	166.68
		IMPR	166.66	150.00	100.00	150.00	100.00
		OBJECTIVE TOTAL	500.00	316.66	266.66	316.66	266.66
5. Ecology	300.00	VEGN	250.00	100.00	175.00	150.00	175.00
		DIST	50.00	20.00	25.00	25.00	25.00
		OBJECTIVE TOTAL	300.00	120.00	200.00	175.00	200.00
		TOTAL SCORE	3200.00	2221.43	2064.61	2057.70	2023.93
		POSITION		1	2	3	4

not be construed, however, as a measure of how much better one site is to another.

Having determined the better 6 or 8 sites by the scoring technique, one can select the best site on an economic basis. The first step is the determination of the cost to develop and eventually finish the sites. This task involves the preliminary design of each site to establish site capacities, drainage requirements, and natural site screening.

CONCLUSION

In small and large municipalities, site selection for a proposed sanitary landfill requires consideration of a number of important environmental factors : Site capacity, Site topography, Pollution potential, Isolation, Cover availability, Accessibility and haul distance and Future land use. These factors can be integrated and incorporated into a scoring system to select a small number of alternative sites for more detailed technical and economic assessment. In this way, public and regulation agency concerns can be addressed in the planning process.

The use of a scoring system for assessing sites is a rational paradigm for site evaluation. With minor alterations, the scoring techniques can be adapted to suit a multitude of investigative situations. Experience in using this scoring system has demonstrated that in spite of the initial impression of complexity, the principles are readily understood and the results are accepted as being meaningful.

References

1. Bolton KF and Curtis FA (1986). An Environmental Assessment Procedure for Siting Solid Waste Disposal Sites. *Impact Assessment Bulletin*, **4**, 111-124.

2. Sexsmith, DP; Wilson MA and Graham RG (1973). Selection Criteria, Methods and Scoring System for Sanitary Landf... Site Selection, *Proc. Internat Conf Land for W... Management*, (Ottawa).

3. Thompson MA (1990). Determining ... EIA : A Review of 24 Meth... **30**, 235-250.

4. Viraraghavan T (19... Methodology...

Journal of the Indian Associ...
Environmental Management,

DESIGN CONSIDERATIONS FOR HAND PUMP ATTACHABLE IRON REMOVAL PLANT

S.N. KAUL[1], T. NANDY[2], A.S. BAL[3] and A. GUPTA[4]

ABSTRACT : An attempt has been made to identify the major elements for design of hand pump attachable iron removal plant. The cause of presence of iron in ground water has also been highlighted along with some important considerations of hand pump.

Key Words : Ground Water, Iron Speciation, Kinetics, Aeration, Sedimentation, Filteration, Design, Iron removal, Removal Potential, Backwashing, Rejuvenation, Hand Pump, Maintenance.

Acknowledgement : Authors wish to thank Prof. P. Khanna, Director, NEERI, Nagpur for inspiration and encouragement provided during the course of writing this overview on iron removal and also thank him for permission to publish the same.

INTRODUCTION

Ferrous and manganous ions are often found in natural water with low oxygen content, such as ground waters and anaerobic regions of lakes. In the presence of an oxidizing atmosphere, insoluble ferric and manganic compounds may be formed which cause staining in fabric, paper and industrial processes. The most common oxidising agents are molecular oxygen (air), chlorine and potassium permanganate.

PRESENCE OF IRON IN GROUND WATERS

Iron is one of the most important and valuable of all the elements and is present in practically all soils, gravels, sands and rocks. Percolation of rain water through soils and rocks, dissolves iron in addition to other mineral constituents according to the character of geological formation. Iron in surface water is mostly in insoluble or low colloidal forms.

Iron can get accumulated in distribution mains resulting in reduced carrying capacity and growth of iron bacteria. The limits for iron are based on aesthetic and taste considerations. Ministry of Health, Government of India has suggested the following limits in relation to iron.

- Permissive 0.3mg/L
- Execessive 1.0 mg/L

It is therefore, essential to treat water containing ...on > 1.0 mg/L.

...aterite bearing iron can be overlying the entire ... There are two types of lime stone, *viz.* ... Stromatolitic. The former is older ... depth of hand pump is 55 m. The maximum section of lateritic can be 10-15 m. After the lateritic section, it is possible to get lime stone or shale porcellamite. Even in this formation, only lime stone is potential water bearing. It is possible that raw water, while passing through the laterite deposit, fixes up some iron and travels down to the lime stone layer. It is also possible that in presence of carbonates, iron gets precipitated. When hand pump is operated, the precipitated iron flushes out and shows higher concentration as usually is being encountered. As withdrawal continues, iron concentration decreases. This is particularly true for those hand punps which are unused for some time.

In case water is to be abstracted from the ground, the well should necessarily pierce the lime stone formation and if iron problem is to be avoided the lateritic depth should be sealed.

However, the geological formation in areas of lime stone type, also have the problem of soluble iron (Fe^{++}). It may be due to the aggressive nature of water because of the presence of carbon dioxide in high concentrations. The formation of carbon dioxide can result from two sources, *viz.*

- decomposition of bearing strata under heat and high pressure, and
- decay of animal and plant under heat and high pressure

It is difficult to surmise at this juncture about the formation of CO_2 in low strata of the Earth. However, most of the carbon dioxide must have resulted from first cause listed above over a very long period of time. The presence of carbon dioxide from second source cannot also be eliminated over a very long

...nvironmental Engineering Research Institute, NAGPUR-440 020

period. Carbon dioxide reduces the pH considerably and reacts with minerals particularly iron bearing rocks, etc., in the underground water resource and this leaching of iron from rocks, etc., is the main cause for presence of iron in underground water. Stabilization is the adjustment of pH and alkalinity of a water to its calcium carbonate saturation equilibrium value. At this point, the water will neither dissolve nor deposit calcium carbonate and protective coatings of this substance on the inner walls of the pipes are thereby stabilized. If the pH lies below the equilibrium values, no protective coatings are formed and the water has free access to metal. Natural waters of low alkaliniy and hardness or of high CO_2 content or demineralized waters fall into this category. If the pH lies above the equilibrium values, deposits of calcium carbonate accumulate in distribution mains, meters, hot water heaters and other equipment. This reduces their carrying capacity or it causes poor heat transfer or overheating of metals in boilers. Other problems, such as the incrustation of sand or gravel in filters are also created. Since the equilibrium point shifts with temperature, it is not possible to attain a perfect balance for both cold water and hot water systems at the same time. In order to provide a measure of stability of a ground water, Langelier's Law proposed naming the difference between the measured pH of water and its calculated or observed pHs, the saturation index (I)

$$I = pH - pHs$$

There are three possibilities for Langelier Index (I)

a. I > O (positive value) implies that the water is supersaturated with $CaCO_3$ (or lacking in excess CO_2) and will tend to deposit $CaCO_3$
b. I < O (negative value) implies that water is undersaturated (or possessed of excess CO_2) and will tend to dissolve any metal.
c. I = O indicates that the water is in equilibrium.

Excess or aggressive, CO_2 is the amount of free CO_2 in excess of that required to maintain $CaCO_3$ in solution. It has been observed that iron bearing waters are soft and contain high concentration of free dissolved CO_2 and may be the main reason for occurrence of Fe^{++} in the underground water reservoirs.

SPECIATION OF IRON

In natural waters, soluble bivalent iron consists of Fe^{++} and $Fe(OH)^{+}$. The solubility of ferrous iron in all carbonate bearing waters (total carbonic species, exceeding 0.001 M) within the pH range of 6 to 9 is governed by the solubility product of $FeCO_3$ ($Ksp = 10^{-15.1}$). The solubility product of $Fe(OH)_2$ governs the solubility of Fe^{++} only in waters that contain no carbonate or their pH is very high. Over the entire pH range of natural waters, Fe^{++} is thermodynamically unstable in the presence of O_2.

The solubility of Fe^{+++} in natural water is controlled by the solubility of ferric oxide and ferric hydroxide.

The solubility of iron in water can be influenced by complex formation. The complex formation of Fe^{++} with ligands other than $(OH)^-$ does not appear to be extensive or rather prevalent in natural waters. The stability constants of bicarbonate or sulphate complexes do not exceed 10 and thus neither bicarbonate nor sulphate, within common concentration range, affect the solubility relation markedly. Ferric ion has higher tendency to form complexes than ferrous ion.

The following oxidation reactions are indicated below

$$2\,H_2O = O_2\,(g) + 4\,H^{+}\,^{4e},\; E_1° = -1.23\ V$$
$$4\,Fe^{2+} = 4\,Fe^{3+} + 4e;\; E_2° = -0.77\ V$$

$$4\,Fe^{3+} + 2H_2O = O_2(g) + 4\,Fe^{2+} + 4\,H^{+}$$

and the redox potential is given by $E_3° = E_1° - E_2°$ $= -1.23 - (-0.77) \quad = -0.46\ V$

and the equilibrium constant for the overall reaction at 25°C can be found from

$$RT\ LnK = nFe_3°$$
$$= 4(96500)(-0.46)\ /\ 8.31\ (298)$$
$$K = 7.5 \times 10^{-32}$$
$$K = (Fe^{2+})^4 (H^{+})^4 (O_2)g \ /\ (Fe^{3+})^4 \quad \ldots\ldots\ldots\ldots (1)$$

Material balance for two species of iron is

$$Fe^{2+} + Fe^{3+} = Ct \quad \ldots\ldots\ldots\ldots\ldots (2)$$

It may be mentioned that H^{+} and $(O_2)g$ for any particular saturation is known. Therefore, it is theoretically possible to estimate Fe^{+2} and Fe^{+3} from the two algebraic Equations 1 and 2.

DESCRIPTION OF HAND PUMP OPERATED IRON REMOVAL PLANT

It will be an ideal situation if the iron removal plant requires no accessories, *viz.*, valves, etc., except those of pipe fittings. It should be compact and robust and can be easily covered so that the external contamination entering the iron removal plant can be minimised. All these considerations will result in less mechanical problems.

An iron plant generally has the following three components, *viz.*, *A. Aeration Chamber* : In this chamber, due to aeration of raw water, atmospheric oxygen gets dissolved in raw water and reacts with ferrous ion to form insoluble ferric ion according to the following chemical reaction,

$$4\,Fe^{2+} + O_2(g) + 10\,H_2O \rightarrow 4\,Fe(OH)_3 + 8\,H^+$$

and results in reduction of pH. Therefore, some buffering agent is required to keep pH around 7.0.

The CO_2 from supersaturated raw water gets removed because of the difference in partial pressure of CO_2 assisted by turbulence in aeration basin.

The exchange of gases in aeration process is proportional to the concentration deficit or excess in water and the equilibrium concentration with the adjacent air. The proportionality constant (K_La) is a governing factor expressing the efficiency of gas transfer in aeration unit. All these vary with temperature and pressure in a given saturation.

Ground water often requires aeration in order to :

1. Dissolve oxygen to ensure taste and aerobic conditions
2. Make it possible to oxidise iron and manganese and to oxidise organics and ammonia
3. Reduce the content of corrosive CO_2
4. Strip nasty volatile substances, e.g., H_2S

Aerators are constructed in numerous ways. Three principles are applied, *viz.*,

1. Water is spread into fine streams or small droplets through air, i.e., cascade, multiple tray and spray aerators
2. Air is spread into fine bubbles through water, i.e., bubble and mechanical aerators
3. Water is spread on an un-submerged, air exposed solid medium like stone, coke, marble or charcoal, i.e., trickling aeration or dry filters.

The important design criteria and obtainable efficiencies are listed in Table 1. A summary of effect of some important operating variables is given in Table 2.

The cascade and multiple tray aerators are mainly used to add oxygen to the water. To remove H_2S and CH_4 in amounts of more than 0.5 mg/L, it is necessary to use spray or bubble aeration. The trickling aeration may improve the aeration compared to open tray aeration and facilitate precipitation of iron and manganese. The maintenance of aeration units mainly consists of removal of precipitated matters as iron/manganese and scales from the units. Especially the units where water or air passes through small holes or nozzles require frequent maintenance to prevent clogging. The holes/nozzles may be cleaned by dissolving the precipitated matters with acid.

The oxygen transfer capacity decreases in the following order, *viz.*,

Spray > Bubble > Trickling > Multiple tray Cascade

However, it may be mentioned that :

Spray aerator : Loss due to unit formation and drift and associated mechanical problems

TABLE 1 – DESIGN CRITERIA AND AERATION EFFICIENCIES FOR DIFFERENT TYPES OF AERATORS

	Loading	*Falling height* *m*	*Number of steps/trays*	*Aeration efficiency %*
Cascade	15 – 20 $m^3/hr/m$ length of step	3–4	4–8	60–80
Multiple tray	100 – 200 $m^3/hr/m^2$ of tray	2–3	3–6	60–80
Spray	1 – 2 $m^3/hr/m$ length of spray pipe	5–10	–	90–99
		Depth of basin *m*	Air to water ratio	K_La-value hr^{-1}
Bubble	3 – 5 $m^3/hr/m^3$ of basin	2	4	5–10
		Depth of water/ air layer *m*	Air to water ratio	K-value
Shallow Depth bubble	5–12 $m^3/hr/m^2$ of perforated plate	0.10 – 0.20	30–200	0.9–0.99
		Depth of fixed medium *m*	Diameter of fixed medium *m*	K-value
Trickling	50–100 $m^3/hr/m^2$ of tray	0.1–0.5	10–50	0.8–0.9

Bubble aerator	: Capital intensive and associated mechanical problems
Trickling aerator	: Good for building DO but limiting to expel CO_2 beyond 20 mg/L
Multiple tray aerator	: Loss due to drift and other parameters similar to trickling aerator
Cascade aerator	: Good for building DO but limitation to expel CO_2 beyond 15 mg/L

Theoretical Background For Oxygen Transfer

The basis of aeration kinetics in batch system is given by Equation 3

$dC/dt = K_La(Cs–C)$ or

$Ct = Co + (Cs–Co)\ (1–\exp)\ (–K_Lat)$

For a well mixed system with steady flow (CSTR), Equation 4 can be used

$(Ce–Ci) = (Cs–Ce)\ K_L\ a\ \Theta$ ..... (4)

Table 2 – Effect of Some Operating Variables on Oxygenation

Increase in operating variable	*Resulting physical change*	*Effect on equation variable*	*Net effect on oxygenation capacity*
Temperature	Diffusivity, D increases but film thickness and Ca decreases	k_L a increases Cs –C decreases	Negligible if $C \leq 3$ mg/L decreases if $C > 3$ mg/L
Circulating Velocity	L-decreases, bubble size decreases hence interfacial area increases	K_L a increases	Increases
Aeration Rate	A–increases, L–decreases	K_L a increases	Increases
O_2 Partial Pressure	Cs–increase	(Cs–C) increases	Increases
O_2 Demand	O_2 is removed faster from solution, C decreases	(Cs–C) increases	Increases
Height of Water	Bubble size path is longer and Cs increases but there is proportionally less surface removal and surface formation	K_L a decreases but (Cs–C) increases	Decreases
Soluble inorganics	D and Cs both decrease	K_L a and (Cs–C) both decrease	Decreases

In case of submerged aerators like trickling, cascade, etc., Equation 3 can be used. It has been found that a steady state plug flow reactor is equivalent to a total system.

$Ln\ (Cs–Ct)\ /\ (Cs–Ce) = –\ K_La\ t$ or .... (5)

$K = (Ct–Ca)/Cs–Co)$

For a plug flow system, the K (transfer efficiency constant) can be written as :

$K = (Ce–Ci)/(Cs–Ci)$

where C, Ct, Ce, Ci, Co, Cs are DO concentrations at any time, effluent, influent, initial at t = O, saturation DO concentration respectively.

K_La – overall mass transfer coefficient

Θ – hydraulic retention time

2. *Sedimentation* : Sedimentation is the removal of solid particles from a suspension by gravitational settling. If the major concern is the production of a concentrated suspension, the vessel is normally called a thickener. Sedimentation is used to remove readily settleable particles, flocculated or coagulated impurities and precipitated impurities.

The aerated water is allowed to enter the sedimentation basin where precipitated ferric hydroxide flocs are settled. The ferric hydroxide flocs are flocculant in nature for a given clarification rate, Q where

Q = VcA

Only those particles with a velocity greater than terminal velocity will be completely removed. The remaining particles will be removed in the ratio of Vp/Vc for a given area A. The fraction of particles removed is given by Equation 6

Fraction removed = $(1–Xc) + \int_0^{x_c} Vp/Vc\ dx$ ... (6)

where (1-Xc), fraction of particles with velocity Vp > Vc; dx, fraction of particles removed with Vp < Vc. However, where flocculation, coagulation, etc., are occurring, the percent removal is given by

$\%\ removal = \Delta H_1 / H\ (R_1 + R_2) / 2 + \Delta H_2 / H\ (R_2 + R_3 / 2) + \text{---} + \Delta Hn / H\ (Rn–1 + Rn) / 2$ .... (7)

where $\Delta H_1, \Delta H_2$...... ΔHn – incremental depth size

H – total sedimentation depth

R_1, R_2......... Rn–1, Rn – % removal

3. *Filtration* : Filtration process removes suspended and colloidal particles by passage through porous media. The principal type of granular filters may be classified according to (i) direction of flow, (ii) type of filter bed, (iii) driving force, and (iv) the method of flow control.

The flow of water through the filter is closely related to the headloss, ΔH, cross sectional area, A; and total filter permeability, k/L

$$v = Q/A = k/L\ (\Delta H) \text{ .... (8)}$$

The total filter permeability is given by Equation

$$L/K = (L/K)_o + A\ t^n \quad \text{.........} \quad (9)$$

Where,

$(L/K)_o$, (L/K) – filter resistance at any time t = o and t , A & n

– constant depending upon filter media and material to be filtered

In the downflow filtration, choking problems and build-up of head loss is often encountered resulting in frequent backwash.

The upflow filtration is superior to downflow filtration because of

- Gradual build-up of head loss
- Negligible head loss and no cut walls
- Rate of filtration is double the downflow type
- Helps in flocculation of flocculant material

The only disadvantage being the loss of sand media and choking if only sand is used as a filtering media. Tables 3 and 4 indicate different characteristics in filter design.

TABLE 3 – FILTER CHARACTERISTICS FOR DESIGN

Flow Direction	*Force*	*Rate of flow*	*Media*	*Bed type*
Downflow	Gravity	Slow	Sand	Ungraded
Upflow	Pressure	Semi rapid	Gravel	Graded
Horizontal	Vacuum	Rapid	Chips	Multiple
		High rate	Diatomite	media
			Anthracite	
			Marble	
			Pumice	
			Coconut	
			shell Resins	

SOME DESIGN CONSIDERATIONS

For the design of iron removal plants, the following aspects must be considered :

(A) Flow Regime : The aeration system of hand pump attachable iron removal plant (IRPs) should act as a turbulent device. It will assist in removal of free dissolved CO_2 which interferes in the removal of iron. By and large, only plug flow type aerators can be used in hand pump operated IRPs. However, at each stage, there is the possibility of creating turbulence.

The sedimentation and the filtration unit must be free from any kind of turbulence and act like perfect plug flow devices. The entire IRP unit must approach to the steady state plug flow system.

In order to determine the flow regime, tracer studies must be carried out using NaCl or Rhodamin, etc, as tracers to determine mixing levels or flow type zone. The following experessions are used, *viz.*,

Table 4 – Typical Design Criteria For Different types of Filters

Characteristics	*Slow sand*	*Hand pump*	*Rapid gravity*	*High rate*
Filtration rate (Q/A), m/hr	0.1–0.5	1	5	15
Effective size (D_{10}), mm	0.25–0.35	U = 3 D = 0.6	0.45–0.55	G = 0.2 P = 0.5
Uniformity coefficient (D_{60}/D_{10})	2–3	1.5	1.5	1.3
Head above bed, m	0.9–1.6	0.7	0.9–1.6	0.4
Thickness of bed, m	1.0–1.5	U = 0.2 D = 0.6	0.8	1.2
Thickness bearing, medium,m	0.3–0.5	U = 0.4	0.6	0.6
Head loss, m	0.05–1	0.02–0.3	0.2–2	G = 0.3–1 P = 1–20
Maintenance process	Scraping	Scraping	Back wash	Back wash
Maintenance frequency	Per month	U = per month D = per week	per day	per day

P = Pressure filter; G = Gravity open filter; U = Upflow filter; D = Downflow filter

(a) Mixing Levels (Impulse Dose)

$$\bar{t} = \Sigma\ ti\ Ci\ /\ \Sigma\ Ci$$

$$o^2\ (\text{variance}) = 1\ /\ \bar{t}^2 \quad (\ \Sigma\ ti^2Ci \quad \Sigma\ Ci \quad - t^2\ )$$

$$\text{or} \quad 1\ /\ \bar{t}^2 \quad (\ \Sigma\ ti^2Ci \quad \Sigma\ Ci \quad (ti\ Ci)^2\ /\ Ci$$

$$\sigma^2 = 2(D/UL) - 2(D/UL)^2\ [1 - \exp\ (\ - UL\ /\ D\ )]$$

(b) Flow type zone (Step Decrease Dose)

$$C/Co = \exp\ [\ 1/\underline{a}\ (Qt\ /\ V) - (1\text{-}a\text{-}b)\ ]$$

$$V = aV \quad + \quad (1\text{-}a\text{-}b)\ V \quad + bV$$

[Complete mix] + (plug flow) + (stagnant zone)

where D/UL = dispersion co-efficient

Ci, ti = Concentration of the tracer at any time, ti

t = average detention time

a = fraction of total volume as CSTR

b = fraction of total volume as stagnant zone

C, Co = Effluent and influent tracer concentration

The mixing levels (D/UL) of the hand pump attachable IRPs is around 0.005. The plug flow zone volume (1-a-b) is about 95%. The remaining can be stagnant zone combined with complete mix zone (a & b)

(b) Aerator : Aerator has to perform two important functions, *viz.*,

- Addition of oxygen
- Expulsion of volatile matter particularly CO_2 in the present case; otherwise obnoxious gases are also to be removed.

The molecular DO is required for oxidation of unstable ferrous ion so that effective precipitation can be achieved within permissible pH range normally encountered. Beside this, some DO should always be maintained within the IRP and also in the treated water so that it is wholesome. If DO is nil within the iron removal plant, there is possibility of redissolution of ferric ion by CO_2 which is normally present. Therefore, aerator should be quite efficient, otherwise, the possibility of septic conditions will always affect the removal of iron from raw water.

It has been mentioned earlier that iron requires about 0.143 mg O_2/mg Fe^{++}. Therefore, iron removal plants with attachable hand pump can easily remove iron upto an iron concentration of 15 mg/L and also provide 2-3 mg/L DO in the treated water which is desirable. If the concentration of iron is upto 5 mg/L, there is no need for making special design of aerators.

The mass transfer co-efficient plays a significant role in absorption (dissolving O_2) and desorption (evolution of CO_2) from raw water. It has been found that liquid film resistance is the rate limiting step in exchange of gases. The liquid film mass transfer co-efficient is represented by the following expression, *viz.*,

$$k_La = D/L \cdot A/V$$

where

k_L = liquid film mass transfer co-efficient
a = specific area
A = total area
D = diffusivity of gases
L = liquid film thickness
V = volume of the liquid

The liquid film thickness is inversely related to Reynolds Number (N_{Re}), i.e.,

$$L \propto 1 / N_{Re}$$

In order to increase the exchange of gases, it is necessary to increase k_La (or indirectly K or k) and it can be achieved by adopting following means, *viz.*,

- Increase in Reynolds Number (N_{Re}) will reduce film thickness (L) which results in increase of k_La
- Increasing specific area (A/V) for contact
- By reducing surface tension with addition of chemicals to increase total surface (A)
- If temperature is somehow increased, it will result in increased diffusivity and total surface area (A). However, this is not in our control under field condition.

The turbulence can be increased by providing resistance in the flow of water. Contact media placed in the aerators tends to increase turbulence and specific area (A/V) for exchange of gases. It is equally necessary to increase the period of contact for exchange of gases into or out of raw water. Based on these criteria, the aeration can be grouped into three categories, *viz.*,

Type I $Fe \leq 5$ mg/L
Type II $Fe > 5$ mg/L but ≤ 15 mg/L
Type III $Fe > 15$ mg/L

The design and sophistication of aerators becomes more involved and complicated as the concentration of iron increases. Iron is invariably associated with free dissolved CO_2 and, therefore, the design of aerator becomes still complicated. The degree of sophistication of aeration is given below (increasing order)

Type I < Type II < Type III

Type I (Any known design can work without the use of contact media)

Type II (Use of contact media necessary, particularly for removal of CO_2. It would be preferable to use marble chips, etc., to shift the equilibrium towards higher pH values, i.e., make Langelier Index, I, negative)

Type III (Special type of aerator which provides contact period, specific area for exchange and high turbulence. The removal of CO_2 is a must and addition of chemicals, Na_2CO_3 or $CaCO_3$, may be necessary to make Langelier Index, I, positive)

Since the hand pump attachable IRPs behave as plug flow system under steady state conditions, the efficiency factor, K, can be determined and indicate the efficiency of oxygen transfer which should be around 0.7 for a good type of aerator, *viz.*,

$$K = (C_e - C_i)(C_s - C_i)$$

The time, t, of fall of water is equally important to determine the contact period which can be in the range of 60-600 seconds. Larger the time of contact, better is the removal of CO_2 and addition of oxygen.

$$t = (2nh/g \sin \Theta)^{0.5}$$

where n = number of stages

$g_{\bullet} \sin \Theta$ = accleration due to gravity
h = height of water fall

The CO_2 removal rate parameter, k, is given by

$$Cn = Co\ 10^{-kn}$$

A good aeration device should have k in the range of 0.1 – 0.21. The reduction in CO_2 level helps in increasing the pH of groundwater and thereby assisting in efficient removal of iron in the sedimentation basin.

For hand pump attachable IRPs and particularly in rural places, only plug flow type of aerators can be used, *viz.,*

- Multiple tray
- Cascade type
- Trickling type

All the above aerators require large space and cannot be covered to avoid external contamination. The simplest solution can be a 10–15 cm pipe closed at both ends with several punched holes (3 mm). These holes should be in lower portion of the pipe. The total height of the IRP should be in the range of 1.2 – 1.5 m. Care should be exercised to provide enough ventilation in the aeration chamber. In addition, it should be properly covered.

c. Sedimentation : The generalised equation for removal of iron is represented by the following expression, *viz.,*

$$dFe^{++} / dt = - k\ (Fe^{++})\ (O_2)\ (OH)^2$$

This is a fourth order chemical reaction. However, it reduces to pseudo first order considering concentrations of oxygen and OH as constant. A slight increase in the DO and OH concentration can result in high removal of iron from IRP. Therefore, an efficient aerator can do both the jobs simultaneously upto concentration levels of 15 mg/L. Beyond this value, addition of chemicals, Na_2CO_3, etc., may become mandatory, i.e., to make Langelier Index positive.

The steady state plug flow reactor behaviour is mathematically equivalent to a batch type of reactor. It has been found theoretically that a detention period of 33 min is sufficient to reduce iron concentration from 10 to 0.3 mg/L. The behaviour of the iron flocs comes under flocculant category of settling. The various types of settling characteristics are presented in Table 5.

By and large, the IRPs behave like plug flow system. Based on this information, it is possible to determine the removal rate parameter for iron which includes all mechanisms (oxidation, precipitation and filtration) by using the following expression for a continuously hand operated iron removal plant.

$$C_R = C_{RO} \exp(-K_r \bar{t})$$

where C_R, C_{RO} = effluent / influent iron concentration

K_r – removal rate parameter

The value of K_r for iron removal can be in the range of 1.2 to 2.5 hr^{-1}.

In order to avoid turbulence, the aerated water from the aeration chamber can be directed in such a way through a vertical pipe to reach the sedimentation basin. This pipe should be of at least 15 cm diameter and should never be full. This will aid in additional aeration. The placement of this vertical pipe is equally important. It can be placed in the centre to equally distribute the flow in the sedimentation basin.

Experience shows that sedimentation basin can easily remove 50-60% of the total oxidized iron. The colloidal and finer flocs cannot be removed in the sedimentation basin unless some coagulation chemicals are added which is not desirable in rural water schemes. If backwashing is not done periodically, there is a possibility that large concentration of a flocculating type flocs compress under its own weight and deposit at the bottom of the sedimentation basin. This may result in consolidation of iron and may pose problems relating to its removal.

TABLE 5 – TYPES OF SEDIMENTATION (SETTING)

Type	*Description*
Type I (Discrete)	Sedimentation of particles in suspension of low solids concentration. Particles settle as individual entities and there is no significant interaction with neighbouring particles.
Type II (Flocculant)	Refers to dilute suspension of particles that coalesce or flocculate during sedimentation. By coalescing, the particles increase in mass and settle at a faster rate.
Type III (Hindered)	Refers to intermediate concentration, in which the interparticle forces are sufficient to hinder settling. Particles tend to remain in fixed position with respect to each other. A solid liquid interface develops at the top of settling mass.
Type VI (Compression)	Refers to settling in which the particles are of such concentration that a structure is formed and further settling can occur only by compression of the structure. Compression takes place from the weight of the particles which are constantly being added to the structure by sedimentation from supernatant liquid.

D. Filtration : The principal mechanisms and the variables in the design of filters are given in Tables 6 and 7. The filtration can be upflow, downflow and biflow. A downflow filtration, particularly for hand pump operated IRP, may require additional system whereby backwashing can be achieved. It has been shown by experience that rate of filtration of hand pump operated IRP falls between slow and rapid gravity sand filtration. Therefore, scraping of the top sand layer can be practiced. But it is a tedious job in a rural setting. Biflow filtration cannot also be practiced in rural setting because of the skill required in operating the filter unit.

It appears that there is only one choice, i.e., using upflow filtration. The filter bed can be graded or of one media type. In order to increase the effectiveness of the filter in removal settling, a filter bed of pebbles can be more appropriate than sand bed.

In sand filter bed, straining mechanism is more important than other mechanisms listed in Table 6.

Table 6 – Principal Removal Mechanisms Occurring in Filtration

Type	*Description*
1. Straining Mechanical Chance contact	Particles larger than pore space of the medium are strained mechanically Particles smaller than pore space are trapped within the filter by chance contact
2. Sedimentation	Particles settle on the filtering medium within the filter
3. Impaction	Heavy particles will not follow stream lines
4. Interception	Many particles that move along the stream line are removed when they come in contact with the surface of the filtering medium
5. Adhesion	Flocculant particles become attached to the surface of the filtering medium as they pass by
6. Chemical adsorption Bonding Chemical interaction	Once particle has been brought in contact with the surface of the filtering medium or other particles, one or both may be responsible for holding it there
7. Physical adsorption Electrostatic Electrokinetic Van der Waal force	
8. Flocculation	Large particles overtake small particles, and form still larger particles. These are removed by mechanisms 1 to 5 above
9. Biological growth	Biological growth within filter will reduce the pore volume and may enhance removal of particles (mechanisms 1 to 5 above)

However, the most pronounced removal mechanisms in the pebble bed (3-6 mm) are :

- Sedimentation and
- Flocculation

It may be mentioned that other mechanisms do play some part but are not so pronounced considering the size of the filter bed media. In addition, upflow filtration has many other advantages.

It can be estimated that about 34-40% of total iron can be trapped in this filter bed containing pebbles. In order to increase the effectiveness of the filtration, two methods can be employed, *viz.*,

(a) Increasing the filter depth keeping the same filter media size. This will help in accommodating more flocs and thereby frequency of backwash is reduced. However, DO must be maintained to avoid septicity. Generally a filter depth of 0.30 m is sufficient.

(b) Decreasing the filter media size with or without increasing the filter media depth. This will tend to increase the frequency of backwashing.

To achieve a permissible limit of 0.3 mg/L, the following variables are important in an IRP (handpump attachable)

a. flow rates (5-20 L/min)

b. hydraulic loading rates (1.0–2.5 $m^3/m^2/hr$)

TABLE 7 – FILTER DESIGN VARIABLES

	Variables	*Remarks*
1.	Filter medium characteristics a. grain size b. grain size distribution c. grain shape, density, and d. medium charge	Affect particle removal efficiency and head loss build up
2.	Filter bed porosity	Determines the amount of solids that can be stored in the filter
3.	Filter bed depth	Affects head loss, length of run.
4.	Filtration rate	Used in association with variables 1,2,3, and 6 to compute clear head loss
5.	Allowable head loss	Design variables
6.	Influent characteristics a. Suspended solids concentration b. Floc or particle size distribution c. Floc strength and charge d. Fluid properties	Affect the removal characteristics of a given filter configuration

c. filter run ($\leq$ 15 days)

d. rejuvenation (1–4 months)

A qualitative filter performance is shown in Fig. 1. Considering the various variables for hand pump attachable IRP, it can be easily seen that upflow filtration is quite superior to downflow filtration. However, all the three units can be housed in one unit. The theoretical backwash period can be calculated by using the following expression.

$$C_d \; a \; V \; dt = -A dh$$

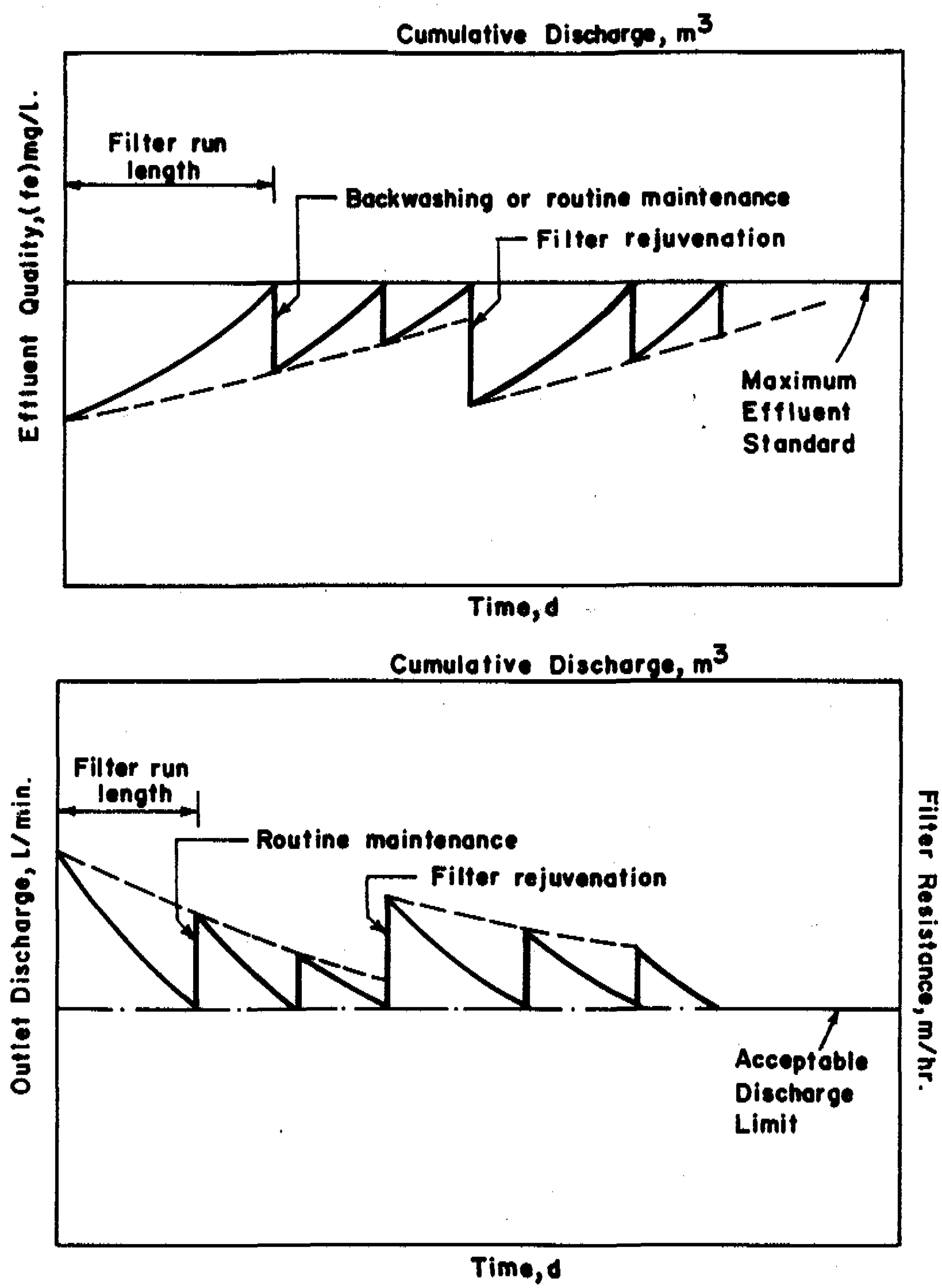

Fig. 1 – Filter Performance Curves

where

C_d = coefficient of discharge

a,A = cross-sectional area of outlet discharge point and filter

V = flow velocity

h = water head available for discharge (above filter bed)

The value can vary between 1 to 3 min. If the water head above filter media is greater than 0.4 m, the backwash rate can be estimated to vary between 0.50 - 0.75 m/s. This flow rate is sufficient to keep the iron flocs in suspension. However, some agitation of the filter bed is needed before backwash is carried out. This flow velocity also assists in removal of iron flocs from the sedimentation unit. To determine the frequency of backwash, three possible methods can be used, *viz.*,

a. Material balance (considering about 30-34% of total iron to be removed and can be accommodated in the voids of filter bed and 0.3 mg/L of iron coming out in the treated water). The total voidage available in the filter bed is known and, therefore, theoretical frequency of backwash can be estimated.

b. From field investigations, it has been observed that an IRP requires at least two washes in about 15 days. Mention must be made about the opening of the sludge drain outlet at the bottom of the sedimentation basin. It should be operated very fast and water should not tend to accumulate around it. If this frequency of backwashing is not maintained, there is a possibility of sludge being consolidated in the sedimentation basin which is difficult to remove subsequently and may also reduce the effective volume of the sedimentation basin resulting in reduction of detention period for settlement of flocs in the basin.

c. When treated effluent discharge level rises by 2 to 3 cm, it is mandatory that backwashing of the filter bed is necessary.

The dimension of discharge outlet or sludge outlet size is very important. A small diameter outlet may increase the backwashing period but the total quantity of flow rate of water will reduce. Moreover, from operation and maintenance point of view, neither large diameter outlet nor very small diameter outlet is desirable. In practice, it has been observed that the size of the drain which has to discharge concentrated sludge should be in the range of 100-150 mm. It may be emphasised that during backwashing, the velocity is nearly 70 cm/s which is sufficient to keep the floc in suspension and helps its removal from the sedimentation basin.

A clear water zone above the filter bed (0.1 m) may be kept. This will act as a polishing zone to remove any colloidal particle. Water can be tapped from this zone for use.

In order to avoid fittings like valves, check valves, non-return valves, etc., it is desirable that the spout of the hand pump should directly feed the horizontal aerator pipe. This can be achieved by two methods, *viz.*,

- Raising of the hand pump (if IRP is installed in level with the ground)
- Lowering of the IRP (keeping the hand pump spout at the optimum level)

It is preferable to have second option. However, some times a compromise can be made. In situations where these two options are not possible, only then the first option may be given considerations.

The sludge draw outlet should be placed in such a manner that it is possible to open/close it quite quickly and effectively. This is more important for second option.

The drains should be well laid and cleaned properly and led into fields or in soak pits. The water from IRP should not spill around and create unhealthy/aesthetic problems.

NON-CONVENTIONAL IRON REMOVAL PLANT

Keeping in view the fact that IRP is the need of rural population, the development of IRP warrants simple, efficient and cost effective technology for adequate quantity of safe potable water to the problem villages. Another constraint in villages is the shortage or non-availability of power.

In the non-conventional IRP, these factors form a basis. The technology is musclepowered, easy to operate, versatile with respect to varying sources and quality of water. The problems of water quality which the package resolves are removal of suspended solids, Iron, hardness, fluoride; and bacteriological quality with minimal maintenance.

Salient Features of the IRP

★ The system operates on the principle of floatation.

★ The rate of floatation being higher than that of sedimentation, as much as 500 litres of treated and disinfected water is produced in each batch taking about 25 minutes.

★ The package is useful for the treatment of surface and ground water.

★ The expenditure being that of essentially the chemicals used in the treatment, working cost is minimal.

★ Electrical power is not required.

Working Principle of the System

According to Henry's Law, solubility of a gas in liquid increases with pressure at a temperature. When water saturated with air at elevated pressure is exposed to atmosphere, excess air equivalent to the difference of solubility is released from the water. The gradually ascending micro-bubbles of air attach to the precipitate or floc produced during the process resulting in the bubble-solid agglomorate floating to the surface. The suspended particulates are thus removed resulting in an acceptable treated water quality.

Plant Operation

The plant comprising air saturator and floatation tank with filter can be made of MS, FRP or HDPE. No intricate structural design is involved and the system can be fabricated with local talent. The desired treatment of water is achieved through the following sequence of plant operation.

1. Air Saturator : Raw water is filled in the saturator to approximately three-fourths its volume and the screw-cap is tightened. The pneumatic hand pump is operated by stroking the handle to achieve 3.5 kg/cm^2 pressure. Water gets saturated with air at this pressure, which is then admitted into the floatation tank through a distributor, regulated by hand controlled shut-off valve, connected with flexible hose, to the distributor manifold.

2. Floatation Tank with Filter : The tank filled with raw water is dosed with requisite quantity of chemical and disinfectant and thoroughly mixed so that reaction is complete and floc is produced to entrap suspended matter. At this stage, air-water is admitted from saturator. The micro-fine air bubbles quiescently lift the floc formed to the surface along with the impurities. The air-water mix discharge from the saturator continues for nearly 20 minutes by which time the water in the floatation tank becomes clear and rid of impurities and bacterial contamination.

The treated water from the floatation tank then flows into a sand filter through a perforated tray. The filtrate collected through a manifold is stored in a treated water tank.

Advantages of the Package

★ The rate of floatation is faster than the rate of settling of the floc, hence the time required to remove the suspended impurities is shorter.

★ Since sufficient pressure is achieved by pneumatic hand pump to prepare air-water mix, need of an electrically operated pump is eliminated, this makes the system highly useful in remote and hilly areas.

★ The process in the treatment scheme is simple and does not require sophisticated machinery, hence easy to install and maintain.

★ The device has been tested for removal of turbidity, dissolved iron, fluorides, hardness and bacterial contamination from water. The results are very satisfactory compared to those with other conventional treatment systems in terms of time and cost.

★ The unit should be adapted to solve water quality problems with respect to the removal of iron, fluorides, hardness, and turbidity.

★ As the principle of treatment is floatation, the floc formed is light, hence the dose of chemicals is low as compared to any sedimentation based system.

HAND PUMPS FOR IRP's

Hand pump installation programme should use the rough guide line of at least one pump for every two hundred people, the pumps should preferably be situated at less than 1 km distance from the village centre. Of course, hand pump supplies must never be installed near open sewerage, nor primed with dirty water.

Common problems encountered in hand pump servicing are

- Difficulties in replacing plunger cap seals
- Failure to lubricate pins and connectors
- Rod coupling failure (in case of deep well pumps)
- Pilfering of parts
- Inferior tools
- Poor store-house facilities resulting in weathering or corrosion of spare parts
- Poor quality of hand pump design and manufacture
- The technology in use makes frequent lubrication mandatory. Iron and steel journals and bearings, poor and large clearances, lack of lubricant reservoirs, exposure to weather, etc.
- Lack of feed back from maintenance to engineering and procurement personnel (lack of record keeping)
- Poor maintenance skills, lack of training, inadequate tools, etc.

DISCHARGE ESTIMATION FOR RECIPROCATING PUMPS

The theoretical discharge capacity, Q, of a single action plunger pump is the product of volume swept, V, by the plunger during upstroke and number of strokes per unit time N,

$Q = \pi / 4 \, D^2 S \, N$

$V = A.S$

where A = cross-sectional area

S = stroke length

Actual discharge usually differs slightly from theoretical discharge because the valves do not close instantly when plunger changes direction and there is some leakage round the plunger when pumping. The difference between theoretical and actual discharge is known as slip.

$$\text{Slip} = Qt - Qa / Qt \times 100\%$$

Typically, there is a decrease in required pumping effort roughly proportional to the slip. Negative slip can also occur in some pump installation with a long suction pipe of large diameter suspended from the cylinder, the flow velocity may be sufficiently high to keep the foot valve open during down stroke, so that actual discharge exceeds theoretical rate.

Static Head : Head against which a hand pump operates is the vertical distance between standing water level in the well and the level of the water at which water is discharged (Fig. 2).

There are four possibilities for static head

1. W or D–S (when pump cylinder is submerged in water)
2. W or D+S (when water level is below the cylinder)
3. W + F or D–S+F (when feeding a tank and the cylinder submerged in water)
4. W+F or D+S+F (when feeding a tank and pump cylinder is above water level in the well)

where S – distance from free water surface to the pump cylinder

W – distance from free water surface to spout of pump

D – distance from pump cylinder to the spout

F – distance from spout to the tank

Dynamic Head (Draw down) : When water is pumped from a well, a drop in water level will occur. The extent of drop (draw down) will depend on rate of pumping and recharge of the pump. The pumping head under operating conditions, including draw down is often referred to as dynamic head and is the measure of pumping lift for which a hand pump needs to be designed. The rate of withdrawal for most hand pumps is of the order of 1 m^3/hr and draw down resulting from this small withdrawal is often very small.

Friction Head : Additional head losses are caused by hydraulic friction in the rising mains, by turbulence, pump rod and rising main connectors or spacers, and inertial energy losses caused by alternating acceleration and deceleration of water flow.

Suction Head : The cylinder of deep well pumps should be installed deep enough to ensure that it remains submerged when the water in the well is at its lowest level. In suction pump, where the cylinder is located above water level, the maximum allowable suction depends on the quality of the pump. It is about 2/3 rd of the theoretical possible suction head.

The power (P) required to operate a hand pump can be calculated using the following expression, *viz.,*

$P = Pw \; g \; QH / \eta$

The power requirement rises in pumping lift or discharge rate increases and falls with increasing pump efficiency. The force (F) required for operating a hand pump is given by the following expression, i.e.,

$F = Pw \; g \; H \; (\pi D^2/4)$

where

Pw = density of water

g = acceleration due to gravity

H = pumping head

η = pump efficiency

It has been estimated that hand pump requires a power level of about 60 watts and the efficiency is about 50%. The power equation can be simplified to the following expression, *viz.,*

Q.H. = 3 or

Q.H. = 180 (Q = L/min)

The hand pumps can be classified according to operating depths, i.e.

Depth Range	*Pump Type*
upto 7 m	Low lift pump (suction pump)
9–21 m	High lift pump (solid link pump)
24–45 m	High lift pump (India Mark II)
45–90	Very high lift pump (extra deep well pump)

A summary of common hand pump troubles and their remedies and schedule for maintenance of hand pumps are given in Tables 8 & 9 respectively.

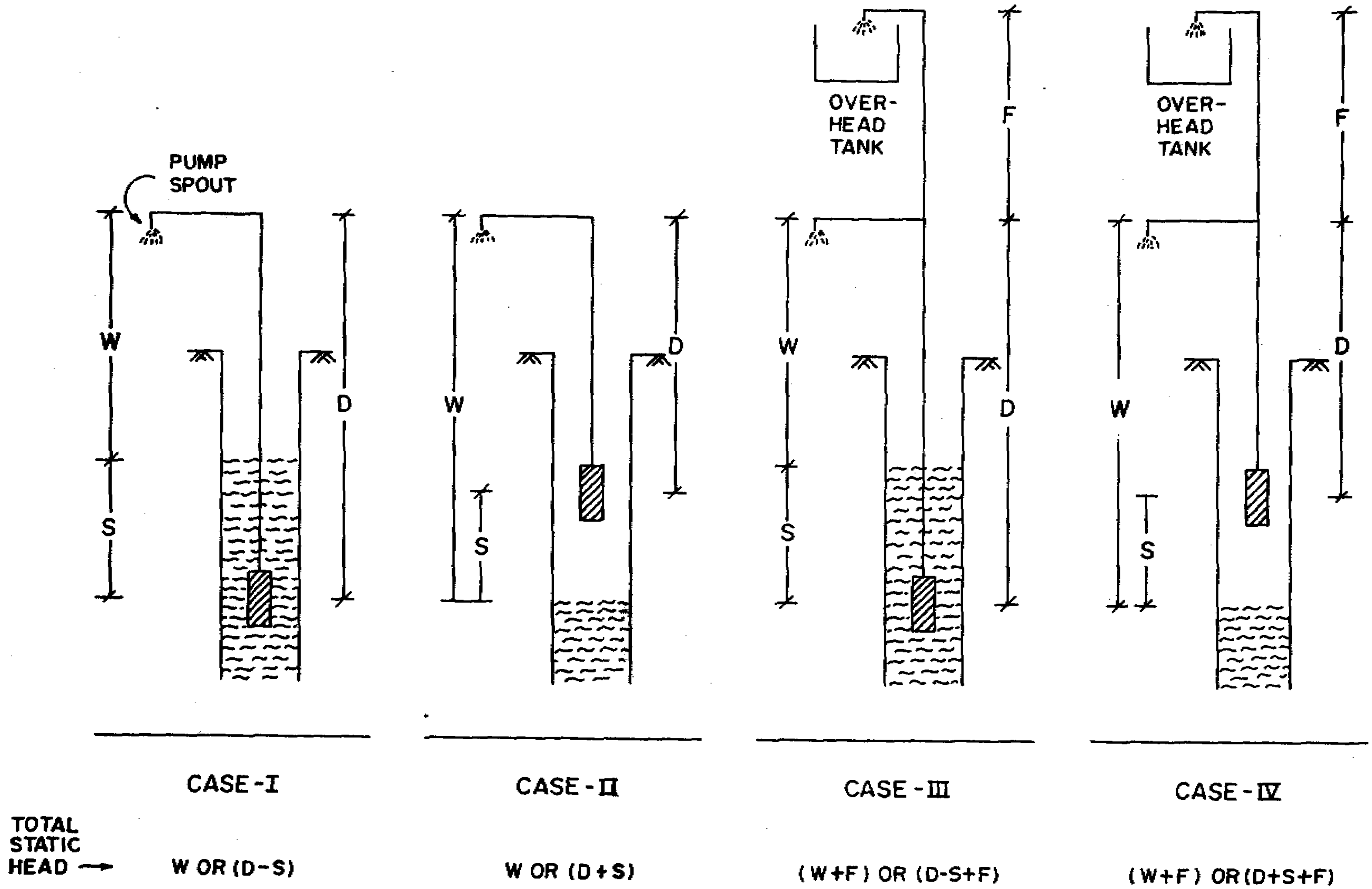

FIG. 2.—SCHEMATIC DIAGRAM SHOWING STATIC HEAD FOR DIFFERENT CASES.

Fig. 2 – Schematic Diagram Showing Static Head For Different Cases

Table 8 – Summary of Common Hand Pump Troubles and Remedy

Trouble	*Likely Cause*	*Remedy*
1. Pump handle works easily but no water delivered	a. No water at the source, well dry	Rehabilitate well or develop a new source or sources of water
	b. Level of water has dropped below suction distance of the pump	Can be checked with vacuum gauge or with weighted string. Reduce pumping rate or lower pump cylinder
	c. Pump has lost its priming	Prime the pump. If the pump repeatedly loses its priming, the suction line may be leaking, or suction valve or discharge valve may be leaking. Repair line or valve
	d. Cyclinder cup seals may be worn out	Renew the cylinder cup seals (leathers)
	e. The valve or valve seat may be worn or corroded	Renew valves and repair or renew seats
	f. With a deep well plunger pump, the plunger rod may be broken	Pumping running freer and preferably quieter. Broken rod must be renewed and this usually means pulling the drop pipe and cylinder out of the wellk
	g. Hole in the suction line	Renew suction pipe. Cylinder may be lowered below water level in well
	h. The suction pipe may be plugged with scale or iron bacteria growth or sediment	Can be checked with vacuum gauge. Remove suction pipe and clear or renew
	i. The pump cylinder may be cracked	Renew the cylinder
	j. Leak at the base of cylinder	Renew cylinder gasket
	k. One or more check valves held open by trash or scale	Remove valves and inspect for troubles. With deep well plunger pumps, this means pulling the pump cylinder or plunger and valve out of the well
2. Pump runs but delivers only a small amount of water	a. Plunger leathers badly worn	Renew leathers
	b. Well not yielding enough water	Decrease demand or establish new sources of water
	c. Cracked cylinder (piston/plunger pump)	Renew cylinder
	d. Check valve(s) leaking	Repair valves
	e. Screw or suction valve may be obstructed	Remove and clean
	f. Suction pipes are too small	Can be checked with vacuum gauge. Instal pipe with large diameter, or for deep well pump, lower pump cylinder below water level in well
	g. Suction valve(s) may be out of order	Repair valve(s)
	h. Cracked drop pipe or coupling	Renew drop pipe or coupling
3. Pump needs too many strokes to start	a. Pump has lost its priming	Renew valves and repair or renew seals
	b. Cylinder cup seals (leathers) may be worn out	Renew the cylinder cup seals
4. Handle springs up after down stroke	a. Suction pipe plugged up below pump cylinder	Remove pump and clean out suction pipe. If well has filled with dirt up to suction pipe, the well should be cleaned out or the pipe cut off
	b. Plunger check valve fails to open or to close	Repair check valve
	c. Suction pipe too small	Replace with large suction pipe
	d. Water too low below pump (suction pipe too long)	Place cylinder nearer to water
5. Leaks of stuffing box	a. Packing worn out or loose	Renew or tighten packing. Leave packing nut loose enough to allow a slow drop of water. The water serves as a lubricant
	b. Plunger rod badly scored	Renew plunger rod
6. Pump is noisy	a. Bearings or other working parts of the pump are loose	Tighten or renew parts
	b. Pump is loose on mountings	Tighten mountings
	c. With deep well plunger pumps having a steel plunger rod, the rod may be slapping against the drop line	Use a wooden rod or install guides for rod or straighten drop pipe if crooked

TABLE 9 – SCHEDULE FOR MAINTENANCE OF HAND PUMPS

Daily	1.	Lock and unlock the pump as agreed by villagers
	2.	Clean the well-head
Weekly	1.	Thorough clean up of pump, well head and surroundings
	2.	Oil or grease all hinge pins, bearings, and sliding parts, after checking that no rust has developed on them
	3.	Record any comments from users about irregularities (tightness of parts, leaks from stuffing box)
Monthly	1.	If necessary, adjust the stuffing box or gland
	2.	Check that all nuts and bolts are tight, and check that there is no evidence of loose connections on pump rods
	3.	Check for symptoms of wear at leathers. If pump fails to raise water when worked slowly (e.g., at 10 strokes per minute), replace the leathers.
	4.	Carry out all weekly maintenance tasks
Annually	1.	Paint all exposed parts to prevent development of rust
	2.	Repair any cracked concrete in the well-head and surroundings
	3.	Check wear at handle bearings and replace parts as necessary
	4.	Check plunger valve and foot valve. Replace if found leaking
	5.	Check the pump rod and replace any defective length or connectors
	6.	Replace packing at stuffing box or gland
	7.	Carry out all monthly tasks

Acknowledgement

Authors wish to thank Prof. P. Khanna, Director, NEERI Nagpur for inspiration and encouragement provided during the course of writing this overview on iron removal and also thank him for permission to published the same.

INDEX